Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Electric Power Engineering

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Excess solar, wind, and hydro power to charge heat storage for cooking

Master's thesis in Energy and Environmental Engineering
Supervisor: Ole Jørgen Nydal
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Abstract

The objective of this project was to test the viability of using oil for heat storage in a dump load system built for cooking applications. This is a continuation of the work conducted in the report "Dump loading to high temperature heat storage", which is used as a starting point.

A new prototype based on the previous work was built in Arusha, Tanzania, to test the concept under the intended conditions. The main problem encountered was the pistons inability to work as a thermostatic valve. The lack of equipment available in Tanzania, lead to the implementation of a bimetallic spring as an alternative. The prototype made in Tanzania used solar power from an off-grid system, in combination with a load controller. This successfully diverted power to one or two heating elements based on the magnitude of the voltage. Testing showed that it was possible to cook rice on the system.

As a result of the field work, the bimetallic spring was further tested at NTNU. The spring worked well as a thermostatic valve, regulating the heat storage at a temperature of 165 °C. However, the spring setup resulted in an unpredictable movement, which could cause it to get stuck at higher temperatures. Combined with the difficulties of finding the right initial settings, further changes are required.

Sammendrag

Hensikten med dette prosjektet var å teste om olje kan brukes til varmelagring i et kjøkkensystem basert på overskuddsenergi. Dette er en fortsettelse av prosjektoppgaven "Dump loading to high temperature heat storage", som dermed vil være utgangspunktet.

En ny prototype basert på den tidligere versjonen ble bygget i Arusha, Tanzania, for å kunne teste konseptet i de tenkte omgivelsene. Det ble oppdaget at stemplene ikke fungerte optimalt til å regulere temperaturen i varmelageret. I Tanzania er det begrenset med utstyr, og på bakgrunn av dette ble det bestemt å bruke en bimetallfjær som termostatventil. Prototypen i Tanzania var koblet opp til et off-grid system sammen med en lastkontroller som vellykket styrte effekten til varmeelementene, avhengig av størrelsen på spenningen.

Som et resultat av feltarbeidet, ble det valgt å teste bimetallfjæra videre på NTNU. Fjæra fungerte godt som en termostatventil og regulerte temperaturen i varmelageret til 165 °C. Oppsettet derimot, resulterte i en uforutsigbar bevegelse som igjen kan ha ført til at fjæra kilte seg fast under høye temperaturer. Kombinert med problematikken ved å finne de riktige startinnstillingene, understreker dette behovet for videre utvikling og testing av konseptet.

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Nomenclature

$\Delta_p T$	Phase change temperature, C
ΔV	Volume change
T	Temperature, C
r	Radius, m
D	Diameter, m
V	Volume, m^3 or L
L	Length, m
α_v	Volumetric thermal expansion coefficient, $\frac{\%}{K}$
ΔT	Temperature change, C
R	Resistance, Ω
I	Current, A
P	Power, W
A	Area, m^2
h	Height, m
m	Mass, kg
ρ	Density, $\frac{kg}{m^3}$
C_p	Specific heat capacity, $\frac{J}{Kg \cdot K}$
Q	Heat, J

Abbreviations

PV	Photo voltaic
DC	Direct current
AC	Alternating current
LHTES	Latent heat thermal energy storage
SHTES	Sensible heat thermal energy storage
TES	Thermal energy storage
PCM	Phase change material
NOCT	Nominal operating cell temperature
VCC	Voltage common collector
SD	Secure digital
IDE	Integrated development environment
SPI	Serial peripheral interface

1 Introduction

1.1 Objective

The motivation for this project is to contribute to a better indoor environment for the rural areas of Africa, to mitigate deforestation and provide a sustainable heat storage combined with a cooking application. More on motivation and background is found in section 2.1.

The content of this thesis is based on the previous work "Dump loading to high temperature heat storage", which was conducted fall 2018. The conclusion of that report will serve as a starting point for the work carried out. Several parts of this thesis overlaps to ensure that both reports can be read separately.

One of the main objectives of this project will be to modify the prototype from the previous project. A prototype will also be built in Tanzania, to prove the concept under design conditions with the materials available.

1.2 Project description

According to the project description, the following tasks are to be considered in this work:

- Demonstrate the use of oil for heat storage and for cooking, based on the previous work with a fully mechanical solution
- Demonstrate heating of the oil from excess PV power. After the electrical battery is full, a charge controller will divert the power (DC directly or AC after inverter) to the heating elements in the oil
- Demonstrate heating of the oil using excess electricity from a small scale hydro power generator
- Demonstrate a battery less PV heating of the oil by developing a load controller
- A system will also be constructed in Tanzania (with NTNU Discovery support). The project team will provide instrumentation for logging the performance of the system (temperature and power) and participate in the testing on site
- Reporting

1.3 Collaborations

A range of methods for collecting and storing heat for cooking has been explored through different projects between NTNU and developing countries in Africa. This particular project is a collaboration between the EnPe2 Capacity5 project (NTNU and the universities of Ethiopia, Uganda, Tanzania and Mozambique), NTNU Discovery, Norpart and IUG (Ingeniører Uten Grenser).

These projects aim to contribute to a decrease in the deforestation problem and to improve the indoor air quality by offering a sustainable and viable alternative to biomass used for cooking. There will be large rural areas off grid in Africa in the future, and the vision for these projects is that providers of energy systems can offer cooking applications as a part of more complete energy systems. Over time this can lead to a reduction in biomass based cooking, with the use of renewable energy sources becoming common practice.

The field work was conducted in Arusha, Tanzania, together with Per Bjerre from Technix Tanzania as a collaborative with NTNU Discovery.

A collaboration was also engaged with Ingeniører Uten Grenser (IUG) Norway, which are connected with Engineers Without Borders globally. In Norway, their aim is to offer engineering competence and help to Norwegian aid organizations [1]. This thesis is a "Master med mening", and IUG supported the field work in Arusha, Tanzania, to develop the solar cooker with heat storage.

1.4 Requirement specifications

For the resulting system to function in the desired manner, requirement specifications need to be established. To be able to follow these requirements during the building process, they need to be specific and developed prior to the construction work. In order to function in accordance with the applications, the system needs to fulfill the following requirements:

- The oil has to enter the heat storage at a consistent temperature
- The heat storage temperature has to be between 200 °C and 250 °C
- The temperature has to be sufficient for cooking applications
- The system has to be driven by gravity exclusively
- Limited maintenance required on the system during operation
- The system has to be equally user friendly as a regular cooking application
- The system has to be compatible as a dump load with renewable energy sources

During the construction process, these requirement specifications will be the basis for the choices made related to building the system. This includes choice of materials, dimensions, power supply and design. To prove that these requirement specifications are fulfilled will be the main goal of the testing.

1.5 Structure of report

The structure of this report is based on the timeline of the project. First, a literature review will be conducted to frame the project and to get an overview of the field based on research, experiments and development. Secondly comes a theory part where all the necessary concepts are introduced and explained, to easily follow the methodology. Thirdly, the field work will be presented, both with preparations done before travelling, and an overview of the system built including electronics, methodology, challenges, experiments and results.

Last, the work done at the laboratory at NTNU is presented. Methodology gives an overview of the preparations done before experiments, modifications, tests and analysis of results. At the very end, there is a discussion, conclusion and also recommendations for further work.

2 Literature review

In the following sections, the introduction and background of the thesis, and what work has been done on the subject previously will be explored. Concept of off-grid energy systems, solar cookers and storage solutions will be explained. The solutions available in the research field will be presented, as well as an elaboration on future predicaments.

2.1 Background

In the world today, the number of countries and areas getting access to electricity and energy is increasing, but especially the rural areas of the African continent are not experiencing the same development pace [2][3]. The slow electrification rate is generally due to remoteness of locations, lack of infrastructure and non-economical grid expansions [4]. These areas rely on biomass for cooking, heating and lighting [2][5]. Wood and charcoal are the most commonly used fuels for cooking purposes, and the number of people depending on biomass for cooking is estimated to increase over the next 25 years [6][7].

The World Health Organization states that the use of biomass for cooking is a significant cause to mortality and morbidity in developing countries due to pollution [8][9]. In rural households in developing countries, it is common to use inefficient, traditional stoves or open fires with either kerosene, charcoal or wood as fuel [3]. Because these buildings usually have poor or no ventilation, the indoor environment is far from optimal. This exposure to indoor, as well as outdoor pollution is an increasing factor for incidences of respiratory infections and mortality [8][10][11][12]. The estimation of premature deaths linked to household air pollution is estimated to approximately 2.8 millions [3][9].

From an environmental point of view, deforestation is causing loss of wildlife, biodiversity and ecosystems [13][14]. The forest and vegetation are considered to hold almost half of the global terrestrial carbon pool, contributing to massive CO_2 emissions when removed and used [15][16][12]. Deforestation, which is a consequence of increasing crop growths, raising livestock and harvesting for wood and charcoal, is contributing to the greenhouse effect and climate change [17]. In developing countries, deforestation is one of the biggest contributors to the global greenhouse effect [13].

To cope with the increasing demand for energy and at the same time provide it at a sustainable, environmental friendly and non-hazardous way, the use of renewable energy systems is of high importance. Africa, together with several other developing areas, have a large potential for solar energy which is a promising source for electrical and thermal energy [18][2][19].

2.2 Off-grid systems

The International Energy Agency have reported in a forecast, that over half of the additional electricity demand needed to meet the target of universal energy access, is expected to be provided through off-grid systems [20]. Brivio et.al (2016) emphasizes the importance of using renewable energy to meet the demand for rural electrification, and believes that $\frac{2}{3}$ of those gaining access in these areas will do so through an off-grid system powered by either hydro, wind, solar or a hybrid system [21].

An off-grid system is defined as a system that is generating and distributing electricity independently of a national connected distribution grid. Simply put, it is every energy system that is not connected to the national grid [22]. An off-grid system may either be powered through a renewable energy system or conventional fossil fuels, and it can also be a hybrid between the two. When the system is based on renewable energy, it is often equipped with a battery storage. If the off-grid system is meant to supply connected AC loads directly, an inverter is necessary, see figure 1 for layout. The production from renewable energy sources is not constant because of the intermittent nature of wind, solar and rainfall [19]. Batteries holds the purpose of increasing the reliability and efficiency of the system, and should be as big as the maximum capacity of the production [19].

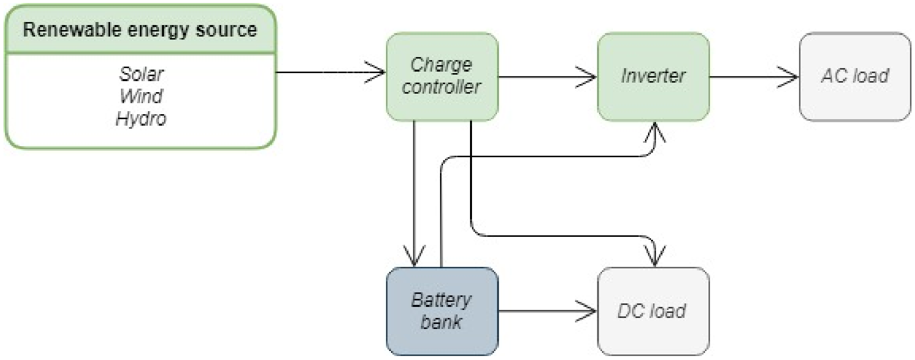


Figure 1: Simple example setup of an off-grid system

2.3 Dump load

In an off-grid system, when the demand is low and the batteries are full, the excess energy is dumped, usually as heat to the ambient air through a resistor bank or heating element [23][24]. This is done to prevent the batteries from over charging and to not stress them more than necessary [25]. A dump load can also work as the needed constant load connected to wind turbines and hydro electrical generators off-grid if the demand is low [23]. Having a constant load prevents the turbine and the generator from unwanted uncontrollable rotation and self-destruction [26]. For solar power, dump load is not crucial for the operation but in combination with batteries, the excess power that occurs when fully charged should be directed away and removed from the batteries.

Brivio et.al (2016) have looked at a school in Northern Tanzania which can be used as a general example of an off-grid system, equipped with a run-of-the-river hydro power system [21]. The turbine in the system is always working at the maximum capacity, and there is an integrated dump load which releases the excess power when the demand is low [21]. Similarly, described by Sandwell et.al (2016), the excess energy appearing in a PV based off-grid system is also dumped and wasted when the batteries are fully charged, and this energy is then of no use to the end consumer [27]. Exploration and utilization of this concept, though limited in literature and research, has potential.

As a result of the unexploited energy being dumped in off-grid systems, and the lack of clean cooking facilities in developing countries, this master thesis will try to contribute to insight in storing this excess energy. The approach will be a system based on solar energy, heat storage and cooking facilities combined.

2.4 Solar cooking

When it comes to utilizing the sun for cooking purposes, this can be dated back as far as the year 1767, thus the concept has been known for a long time [6]. From the literature review done by Aramesh et.al (2019), there are several ways to divide and classify solar cookers, see figure 2 below for the suggestion [28].

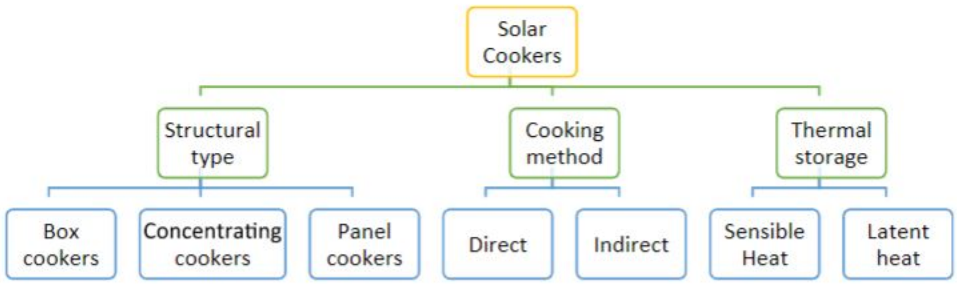


Figure 2: Classification of solar cookers

Starting from the left, the structural types of solar cookers are divided into three sub groups depending on the configuration of the unit; box cookers, concentrating cookers or panel cookers [6]. The concentrating cooker is also referred to as a direct focused cooker for the reason of focusing and concentrating the sunlight directly to a cooking application [29]. The box cooker has a simpler structure than the concentrating one, and consists roughly of an insulated box with transparent covers which directs the sunlight into the box. The food is then cooked based on the greenhouse effect that occurs in the box [29]. The panel cooker is considered having the simplest structure of the three, where the sun is concentrated onto a cooking vessel using reflecting equipment. See figure 3 for the basic differences of the structural types of cookers [6].

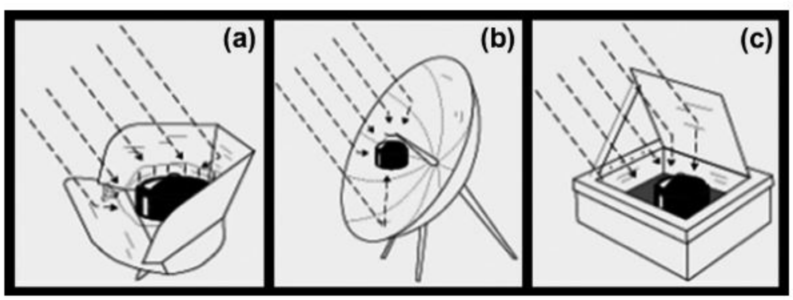


Figure 3: a) Panel cooker b) Concentrating cooker c) Box cooker

It is worth mentioning that within these categories of structural solar cookers, the design and material used can vary, but it is the way the sunlight is taken advantage of that unites them.

The group in the middle of figure 3, classified by cooking method, is divided into two sub groups depending on how the thermal energy of the sun is transferred into the cooking application; direct or indirect [30]. Lastly, there is a group classified by thermal storage, either through a sensible heat thermal energy storage, called SHTES, or a latent heat thermal energy storage, called LHTES [31]. LHTES units exploits the heat energy tied up in phase changes in materials, while the SHTES unit uses the temperature change of a material. All kinds of solar cookers can have these types of storage possibilities.

One of the major drawbacks when using a solar cooker is the ability to cook during cloudy conditions or at late afternoons and evenings due to the intermittent nature of the sun. By implementing a storage unit in combination with the solar cooker, this drawback will be decreased [29].

Bello-Ochende, King'ondu, Nkhonjera and John (2017) requests for the further development of a high temperature thermal energy storage (TES) unit for solar cookers, and defines these as 4-stage cookers [32]. In a 4-stage cooker, the first stage includes the heat transfer from the absorber to the heat transfer fluid, and the second stage is the heat transfer from the heat transfer fluid to the storage medium. The two latter stages involves again heat transfer from storage medium to heat transfer fluid. At last, the resulting heat transfer ends up in the cooking load [32]. A 4-stage cooker can achieve a higher temperature, thus a more efficient storage, than the 3-stage and 2-stage cookers [32]. Figure 4 shows the setups of 2-stage cookers, 3-stage cookers and 4-stage cookers as described by Bello-Ochende et.al (2017) [32].

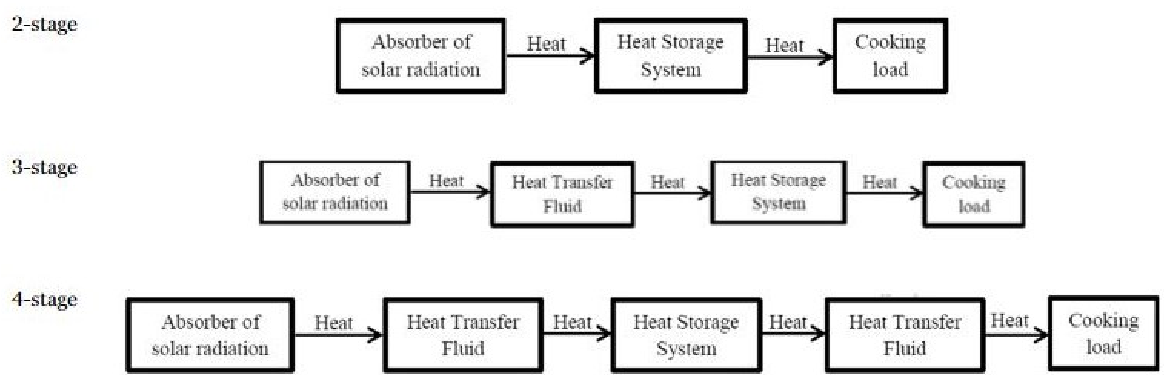


Figure 4: Explanation of 2-stage, 3-stage and 4-stage cookers

The main focus for the next section will be on the high temperature way of storing heat in either LHTES units or SHTES units, due to the relevance to this master thesis.

Phase change materials (PCM) are the most common and documented way of storing thermal energy in a LHTES unit [33]. PCM exploits the released energy from the material during a phase change from a phase of high energy density to a phase of low energy density [34]. PCM are materials that change phase at a temperature which is desirable, for instance the correct cooking temperature. Experiments have showed that a suitable cooking temperature is just below 100 °C for solar cookers [33]. Bello-Ochende et.al (2017) stresses the importance of a high $\Delta_p T$ of the PCM to efficiently exploit the latent heat [32]. It requires a lot of energy melting the material and in the same way it releases a lot of energy when it solidifies again. Because of this property, it is possible to use LHTES units with PCM for cooking after sunset since the energy is tied up in the phase change and not in the high temperature.

There is a smaller selection of literature and experiments on SHTES solar cookers. The concept of SHTES units are different than LHTES units because it exploits the energy needed to change the temperature of a substance with no phase changing process [29]. Commonly used materials are metals, oils, rocks or water [28]. The energy needed to change the temperature of the material can be utilized by direct heat transfer with oils or water. Alternatively, by letting a secondary fluid flow past a heated material, raise the temperature in the fluid and then exploit the energy by heat transfer. The heat capacity of the given material and the temperature during the heating cycle, determines the amount of heat that can be stored at a specific volume [29]. It is the density, specific heat, volume and variation of temperature that determines the amount of heat stored in a material, and the relationship is proportional [35].

When it comes to the choice between either a LHTES unit or a SHTES unit, it depends on the specifications of the user, the budget and the location. The latent heat energy that can be utilized from the melting of PCM is higher than the specific heat coefficient obtained in the SHTES unit, which leads to a higher heat storage capacity in the phase change process [36]. This property gives LHTES an advantage over SHTES, but according to Bello-Ochende et.al (2017), experiments shows that there is no significant difference between the cooking powers of cookers equipped with sensible or latent heat storage units [32]. It is also worth mentioning that a LHTES unit needs a more complex setup, which again will lead to higher fabrication- and implementation costs, thus the volume required for a PCM storage is less than for a SHTES unit [37][33]. For the purpose of being implemented and used in developing countries, the cooking application and storage unit should be as cheap and easily available as possible [37]. Another drawback with the PCM unit, as Sharma et.al (2009) pointed out, is that no PCM yet found in the literature have a suitable melting temperature between 95 °C and 105 °C [33]. This is the temperature range foods are cooked in experiments using solar cookers [33]. Mawire (2015) arguments that for the systems to be successfully used and implemented in the developing world, a SHTES unit is more suitable because it is more affordable, requires less maintenance and is easier to fabricate compared to LHTES [37].

2.5 Comparison of SHTES storage materials

For the selection of heat transfer fluid, storage material or both combined, rocks, metals, oils or water are commonly used [28]. For the case of solids, there is no limitation to boiling point or freezing point [35]. They do on the other hand need a heat transfer fluid to store the thermal energy when the case is a high temperature system, where fluids contrarily works as both the heat storage medium and the heat transfer itself [36]. Salts are corrosive, such that a system with this type of storage will require more maintenance, to avoid degradation over time [38].

Water has good properties for heat storage due to its high heat capacity, and because of availability and affordability it is a viable alternative [38]. On the other hand, water has a relatively low boiling point and because of this, water is not suited for storing temperatures above 100 °C [39][36][35]. For cooking purposes, the storage medium should hold a temperature between 100 °C - 250 °C [36]. Thermal oils and edible oils do have higher boiling points, making them more suitable for high temperature storage compared to water. The most crucial drawback for using thermal oil as the storage fluid is the cost, and it might not be as easily available [37]. Mawire (2015) analyzed the performance of used and filtered sunflower oil as the storage medium in a SHTES unit, and concluded that sunflower oil worked well under high temperature conditions [37]. In the same paper, the possibility of using other edible oils which have low viscosity at 25 °C is mentioned [37]. A comparison between the three thermal energy storage oils, sunflower oil, Shell Thermia B and Shell Thermia C, was conducted by Mawire, Phori and Taole (2014) [36]. The results showed that the three oils were comparable under low temperature conditions, and the sunflower oil outperformed the two other oils during high temperature conditions [36]. Since the focus lies in affordability and little maintenance, oils like sunflower oil are emphasized as suitable options for SHTES units in developing countries.

3 Theory

3.1 Length of coil

When deciding the length of the coil, there were two main factors. Firstly, the maximum expansion of the oil should not be too high such that the pistons could not handle it. Secondly, the total volume needs to be small enough that the expansion is reached within a small temperature change from when the valve starts opening. The volume change of the oil needed for the small piston to start moving, is the interesting feature in this calculation. By using the dimension of the previous piston, this can be found as shown below [40].

$$\Delta V_{oil} = \pi \cdot r_{cylinder}^2 \cdot D_{valve} = 3.9 \cdot 10^{-7} m^3$$

From this the corresponding volume of the coil can be expressed as:

$$V_{coil} = \frac{\Delta V_{oil}}{\frac{\alpha}{100} \cdot \Delta T}$$

Further, the length of the coil can then be expressed by:

$$L_{coil} = \frac{\Delta V_{oil}}{\frac{\alpha}{100} \cdot \Delta T \cdot \pi \cdot r^2}$$

$$\alpha = 0.1011 \frac{\%}{K}$$

$$r = 0.0021m$$

The unknowns are thus temperature change to fully open the valve and length of coil. The relationship is plotted below.

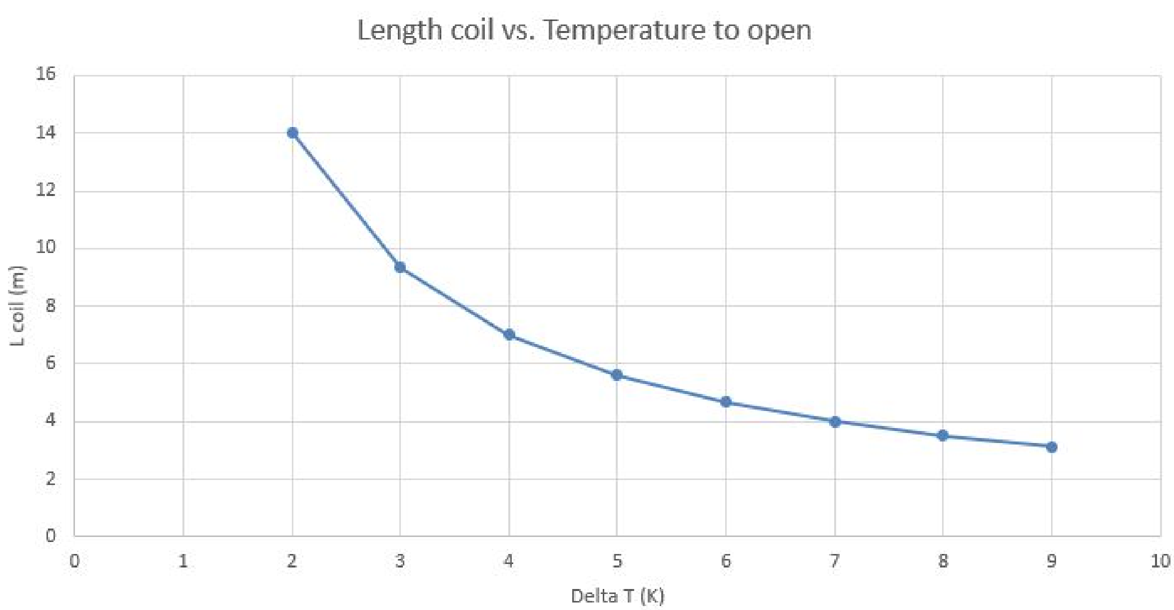


Figure 5: The length of the coil as a function of the temperature change

Figure 5 was used in the preface of the field work, where the copper coil was made and installed in advance, and then later removed due to another thermostatic valve concept. More information about the valve, see section 4.3.

3.2 Thermostatic bimetal

Thermostatic bimetal consists of two metal strips joined together, and it can be shaped as a strip, a spring, a bend, or any other desirable shape to fit the industrial application it is meant for [41]. When exposed to a change in temperature, the two metals will expand differently and create a movement resulting in a curvature [42]. See figure 6 further down for the design of a bimetallic spring.

The two metals have different thermal expansion coefficients, making the spring or the band bend in the direction of the highest coefficient, and this can be used in several applications. The bend is predictable because it is proportional to the temperature change it is exposed to [41]. The composition of the metals gives different mechanical properties to the bimetal [43].

Figure 6: Bimetallic spring from the producer HWAM A/S, used in fireplaces

The thermostatic bimetal is used in the industry, ranging from thermostats to regulating air flow in fireplaces [42][44]. For this project, the bimetallic spring, identical to the one in figure 6 is used as the temperature regulator in the thermostatic valve, see figure 19b in section 4.3 for more insight.

3.3 Loss in PV panels

The amount of output power a PV module possibly can generate is limited by its efficiency, which again is determined by what technology is being used in the module. The three main technologies are monocrystalline, polycrystalline and thin film. Both monocrystalline and polycrystalline is made out of silicon [45]. Monocrystalline PV modules usually have a higher efficiency [45].

Resulting power is also dependent on another factor; the temperature the module is surrounded by, and thus operating under. The optimal temperature for a PV module is defined as the nominal operating cell temperature (NOCT), and is usually listed as a limiting value in the PV module fabricator data sheet.

NOCT is defined as the open circuited cell temperature a PV module can have under the conditions of:

- Solar irradiance at 800 $\frac{W}{m^2}$
- Wind speed at 1 $\frac{m}{s}$
- Temperature at 20 °C
- Tilted 45 ° with an open back side

Polycrystalline 260 W_p panels

The efficiency of the polycrystalline solar panels used in the experiments at NTNU are 15.98 %, yet the total efficiency is also dependent on the operating temperature of the cells, see appendix F for data sheet. The temperature coefficient influencing the output power is rated -0.42 $\frac{\%}{K}$, meaning the panels will lose almost half a percent of the output power for every degree the temperature is rising above NOCT.

3.4 Shunt

A shunt is a component with a low rated resistance allowing high current to pass through it without resulting in a high voltage drop. This low voltage drop is used in several applications, one of them being voltage measurements. It is then placed in parallel with a voltmeter, to make all the current flow through the shunt where the voltage is to be measured across. The shunt used in the field work of this project is shown in figure 7.

Figure 7: The shunt used to measure the voltage

The shunt is rated 500 A and 50 mV, and is hence creating a low resistance path for the current. Using Ohms law results in a shunt resistance of 0,1 mΩ. The voltage can then be measured and the current calculated by use of Ohms law and the constant resistance as in equation 1.

$$R_{shunt} = \frac{V_{shunt,rated}}{I_{shunt,rated}} = \frac{V_{shunt,measured}}{I_{shunt,calculated}} \Rightarrow I_{shunt,calculated} = 10^4 \cdot V_{shunt,measured} \quad (1)$$

3.5 Pull-up and pull-down resistors

There are three possible logic levels in a digital circuit; high, low and floating (high impedance). The floating state occur when the microcontroller fails to decide if an input value is in a logical high state or a logical low state. An example of such situation is an open pin on a microcontroller board. The microcontroller then carries out an unpredictable interpretation deciding if the empty pin is a logical high or low.

Pull-up and pull-down resistors are used to prevent this scenario by either pulling the signal up to a logical high or down to a logical low in the absence of an input value. Pull-up resistors are connected between the voltage common collector (VCC) and the input pin to pull the value up, while the pull-down resistors are connected to ground (0 V) to pull the value down.

The values of the pull-up and pull-down resistors depend on the size of the connected impedance. However, the relative difference between the pull-up and the pull-down resistors are the most important.

3.6 Available energy

In this section the potential of the prototype is looked into. This includes calculating how much energy can be stored in the system, and what is the potential of that energy in terms of cooking water. The calculations are based on the dimensions and conditions of the system in Tanzania, as those are the most realistic values. Palm oil worked as the storage fluid, and the values for density and specific heat capacity for this oil was taken from Chempro cited as [46].

As illustrated in figure 8, there is a part of the tank volume that is not possible to use.

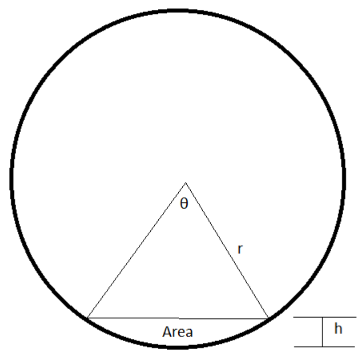


Figure 8: Cross section of the storage tank

This area can be found by subtracting the area of the triangle from the total area of the section:

$$A_{section} = \frac{\theta}{2} \cdot r^2$$

$$A_{section} = arccos(\frac{r-h}{r}) * r^2$$

The area of the triangle is found by:

$$A_{triangle} = (r-h) \cdot \sqrt{2rh - h^2}$$

Thus the area that cannot be used in the system can be expressed as the difference of the two:

$$A_{useless} = A_{sector} - A_{triangle}$$

$$A_{useless} = arccos(\frac{r-h}{r}) * r^2 - (r-h) \cdot \sqrt{2rh - h^2}$$

There is an equally large portion of useless area on the top part of the barrel, such that this will be subtracted twice from the total barrel area:

$$A_{useful} = A_{total} - 2 \cdot A_{useless}$$

The measured lengths from the system were:

$$r = 1.825dm$$

$$h = 0.7dm$$

$$L = 5.7dm$$

$$A_{useful} = 7.65dm^2$$

$$V_{useful} = L \cdot A_{useful} = 43.6L$$

Density at 240 °C will be the lowest, and will therefore be used when deciding the mass. The room temperature is assumed to be 25 °C. The density at 240 °C:

$$715 \frac{kg}{m^3}$$

$$m_{useful} = \rho \cdot V_{useful} = 31.17kg$$

The specific heat capacity at 240 °C which is the target temperature is:

$$c_{p,240} = 2.595 \frac{J}{kg \cdot K}$$

The specific heat capacity at room temperature is:

$$c_{p,25} = 1,948 \frac{kJ}{kg \cdot K}$$

In general the energy stored as heat in a material can be found by equation 2:

$$Q = m \cdot c_p \cdot T \tag{2}$$

It follows from equation 2 that the change in energy would then be:

$$\Delta Q = m \cdot (c_{p,i} \cdot T_i - c_{p,o} \cdot T_o) \tag{3}$$

The energy available in a full tank of oil at 240 °C is therefore found by the following:

$$Q_{available} = m \cdot [c_{p,240} \cdot (240 + 273) - c_{p,25} \cdot (25 + 273)] = 23400kJ = 23.4MJ$$

To put this in perspective it is interesting to see the theoretical amount of water this can bring to boil, assuming all the energy stored in the oil is used at 100 % efficiency. Using equation 3 gives:

$$m_{water} = \frac{Q_{available}}{cp \cdot \Delta T} = 74.3kg$$

Theoretically, given 100 % efficiency in the transfer from oil storage to the water, the system would be able to bring 74.3 kg of water from 25 °C to boiling.

4 Field work

The aim of the field work was to contribute to the completion of the system being built in Arusha spring 2019. The design of this system is based on results from previous work conducted at the NTNU laboratories in fall 2018, cited as [40]. The overview of the previous system is shown in figure 9 [40].

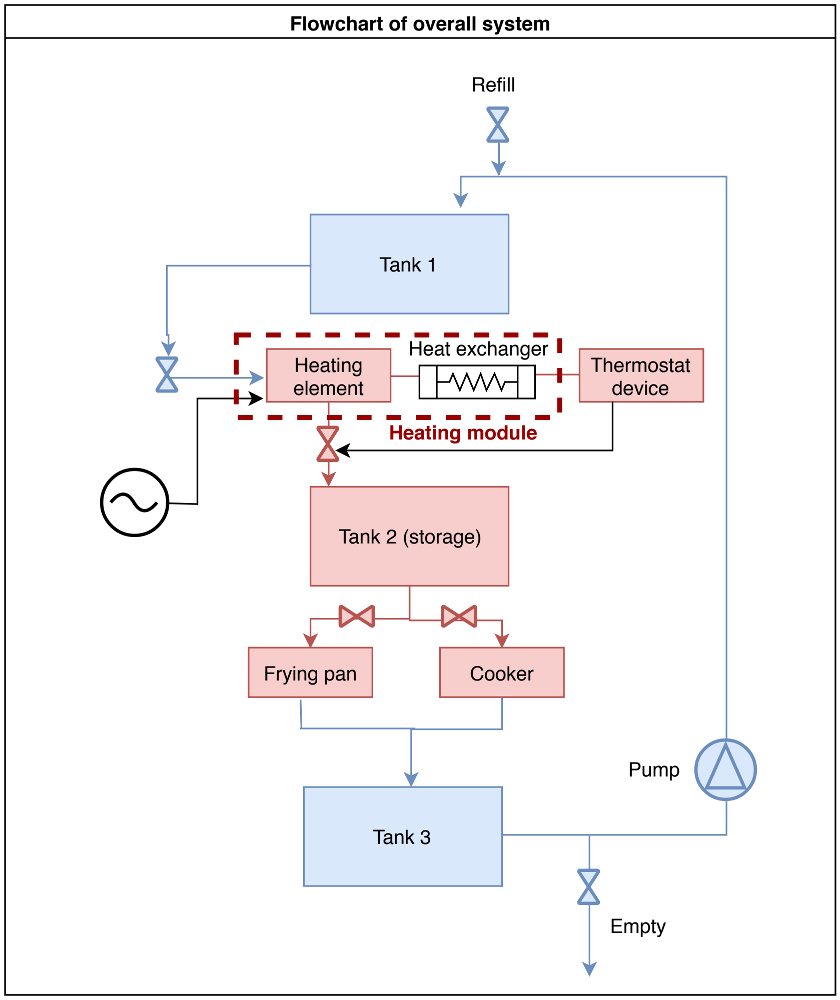


Figure 9: Flow scheme of previous system

As figure 9 shows, it consisted of three interconnected tanks aligned vertically. Industrial oil of the type Duratherm 630, see appendix H for more details, is flowing inside the system, driven only by gravity. The previous report describes the system as follows: The heat exchanger represents a separate coil with one end inside the heating module. This coil is a closed system with no access to air, and contains the same type of oil as the remaining system. At the other end of the coil, which is shown in the figure as the valve, two pistons are connected. The larger of the pistons is used to regulate the desired temperature level, and take the main part of the expansion. The smaller one will expand more on a lower volume change and controls the flow into the storage tank by opening and shutting a valve. As the temperature in the heating element increases, the oil expands in the closed system causing the pistons to move, opening the valve, hence oil will flow through. Overall, this closed loop system is a mechanical temperature control of the oil based heat storage. Gravity is the driving force behind the oil movement through the heat element, the cooking applications and down to tank 3. A hand pump will in turn be used to transfer the oil back to tank 1 for reuse [40].

After building and testing this system fall 2018, some flaws were uncovered. These included considerable heat losses present, which was associated with the transportation of oil from the heating elements to the cooking application. To limit these losses, putting the heating elements inside the storage tank was introduced as a suggestion in the further work section [40]. Another challenge was flushing the closed system for air. As a solution to this, a new cylinder was developed containing a valve installed for flushing and two pistons.

More specifically, the purpose of the field work was to establish the second generation of this system including the two suggested modifications and to install a logging system and other electronics to the supply circuit brought from Norway. Concept testing and collecting of data was another important aspect of the field work, and also for further development of the system. The testing to be conducted included a battery less system with a load controller as stated in the problem description in section 1.2.

4.1 Preparations

As a preparation for the field work, a temperature logger was developed. A logging system was needed to continuously display and save the data from the system in Arusha. Previously at NTNU, a PicoLogger was used in combination with a computer to visualize and save the data readings. Since the PicoLogger is expensive and requires a computer to display the readings, the aim was to develop a logger more suited for rural areas.

An important aspect of the system is the ability to store energy for longer periods. How the temperature changes over night or over a weekend is an aspect that needs to be measured. This required something other than a PicoLogger with a laptop, so the aim was to create a logger more suited for the purpose.

Requirements:

- Independent of a computer
- Save data to a SD-card continuously
- Print data readings to the screen continuously
- Keep track of the time independent of the power supply

4.1.1 Hardware

According to the logger requirements, the hardware needed more specifically was; a real-time-clock (RTC), a SD-card with a SD-card reader, a screen and a microcontroller to communicate with all the mentioned parts. In addition, an amplifier was needed for each sensor to scale up the measured signals making them readable for the microcontroller. A level shifter was required to ensure a step-down conversion from the operating voltage of the microcontroller, which is 5 V, to the required level of the rest of the hardware which is 3.3 V.

To supply the hardware needed, Arduino was chosen. It is an open-source, user-friendly, cheap and available hardware company offering microcontroller kits for building different devices. Arduino boards are equipped with both digital and analogue input and output pins, and can be controlled directly through the Arduino software.

4.1.2 Connections

The wiring scheme for the hardware is shown in figure 10.

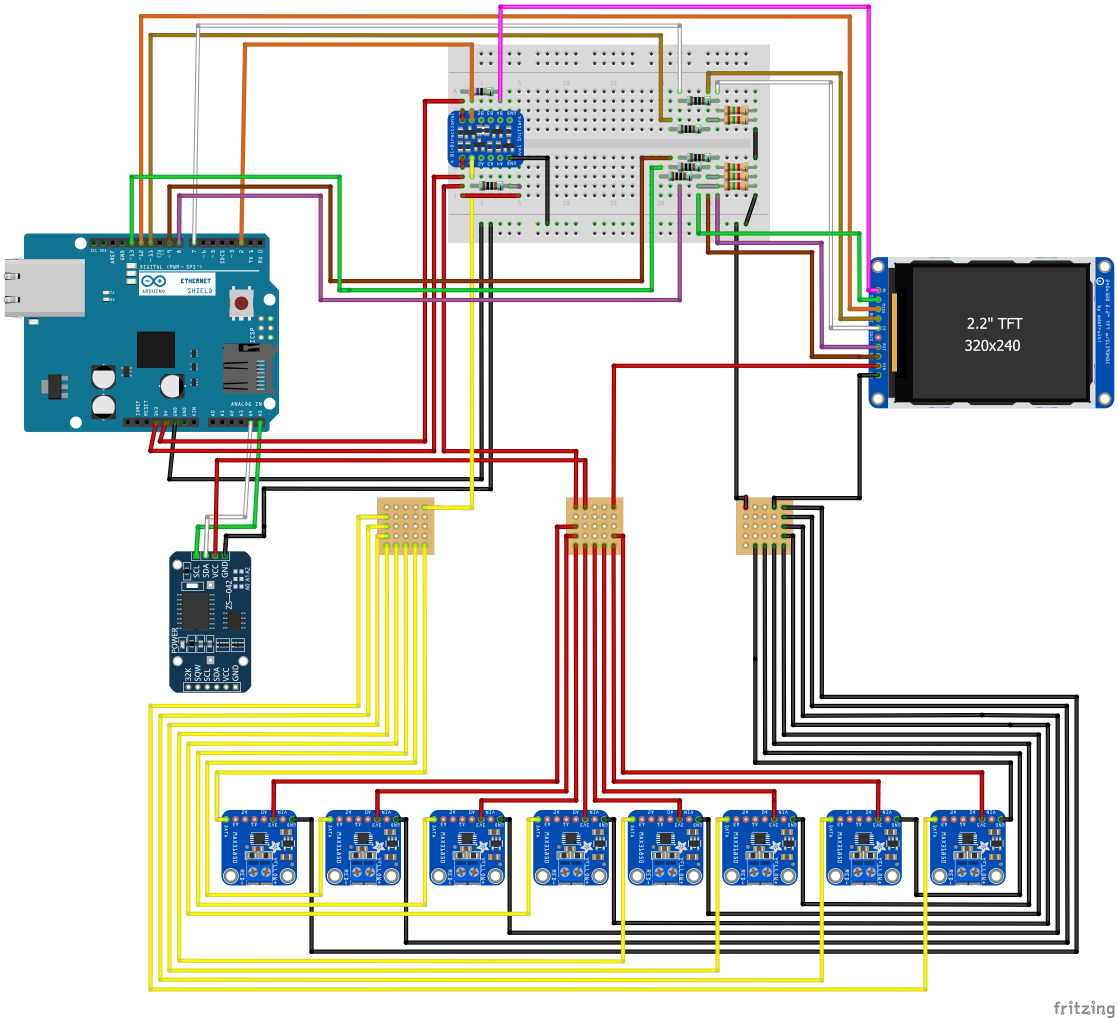


Figure 10: Wiring scheme including the Arduino UNO (microcontroller board) to the left, RTC below, 8 sensor amplifiers at the bottom, and the screen to the right

As figure 10 shows, resistors are connected both between the microcontroller and the screen (pull-up, blue in figure 10 equal to 1200 Ω), and between the screen and ground (pull-down, yellow in figure 10, equal to 1800 Ω). This limits the current flow, and prevents short circuits as explained in section 3.5. The blue upper resistor to the left is a strong pull-up resistor meaning it has a particularly low resistance (56 Ω) to ensure a sufficient amount of current flowing through it. This is necessary due to the connected pin being the LED pin, which controls all the light emitted in the screen.

For the wiring of the temperature logger, the program Fritzing was used. It is, like Arduino, an open source platform. The screen used in the wiring scheme is different than the one used in the actual logger due to the lack of the exact same model in the Fritzing catalogue. However, the only difference is that BL on the screen from Fritzing is equivalent to the LED pin on the actual screen.

4.1.3 Software

The software was written in the Arduino integrated development environment (IDE) which supports the languages C and C++, and can be found in appendix A. The code consists of a part that runs one time only, called the setup, and a part that runs continuously called the loop. In the setup, the layout of the screen is set, assigning each sensor a line and a number. The time and date is also manually set, started and printed to the screen updating itself separately. All the start functions for the components are called, preparing for the loop to print the values to the screen and the SD-card.

The loop prints the sensor readings by number to the screen and updates it every 3 seconds. It also creates a file on the SD-card and writes the reading, number of sensor and time of measurement for each sensor every 3 seconds. It is written in a convenient format for converting it to an Excel file for further analysis. The screen and the SD-card reader both uses Serial Peripheral Interface (SPI) as the communication protocol. According to the standards in SPI, the code has to indicate if the microcontroller is to communicate with the screen or the SD-card. This is done doing a digital write to the chip select pin, manually setting one of them as the active pin and one as the inactive.

To avoid the need to do a digital write for each of the 8 amplifiers at each measurement, an alternative communication protocol, called I2C, was introduced. It enables the option of using a single data line to transport the sensor measurements as shown in the connections.

4.2 Overview system

Figure 11 shows the complete test rig used in Arusha. Compared to figure 9, the main modification on the Arusha system are the heating module being put inside the storage tank as suggested in the further work section in the previous report [40]. The cooking application is also modified by excluding the pan due to available materials, leaving the cooker only. However, the size of the cooker is increased considerably. Other components such as the tanks, pipes, brackets and insulation are substituted due to utilization of local alternatives.

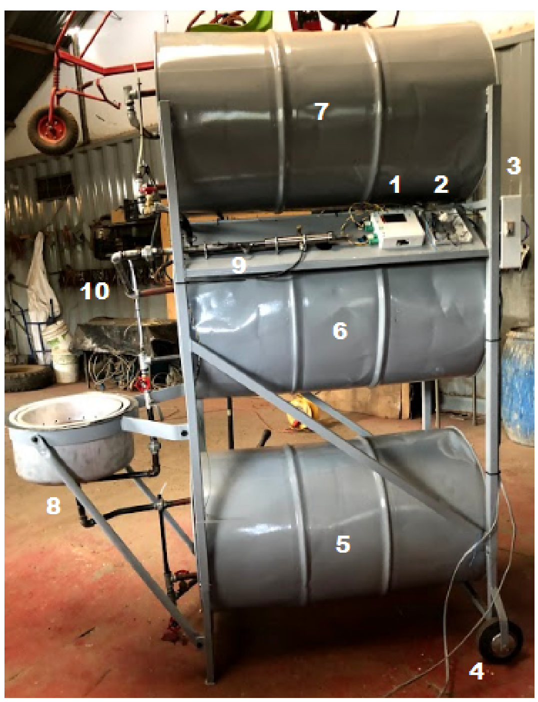


Figure 11: System overview

Table 1 explains the parts shown in figure 11.

Number	Part
1	Data logger
2	Control box
3	Power box
4	Supply cables from PV panels
5	Tank 3
6	Storage tank
7	Tank 1
8	Cooker
9	Pistons (mechanical thermostatic valve)
10	Inlet storage tank

Table 1: System overview by numbers

The next section will describe the process of establishing this test rig.

4.3 Methodology

The methodology is divided in two subsections. Firstly, the mechanical work leading to the complete system is described. Secondly, the electronics of the system is explained including both the power supply circuit and the measurement equipment circuits.

4.3.1 Establishing the test rig

When arriving in Arusha, some work had already been completed. The framework was welded together, and the outer tanks were in place. The next step was then to insulate, and insert the inner tanks. The outer tanks were 200 L oil barrels, while the inner tanks were 60 L. This gave room for a 10 cm thick layer of insulation in between, as shown in figure 12.

Figure 12: System during insulation process

The inner barrel was held in position by brackets as shown in figure 12, enabling insulation to be placed in between the barrels. A lid was then placed on top, also illustrated in the figure.

The heating elements, rated 220 V 800 W, the coil and the K-type thermal sensors were brought from Norway. Figure 13 shows how these are mounted inside the storage tank. This coil was dimensioned as described in section 3.1 and placed at the bottom of the storage tank in a S-shape.

Figure 13: The storage tank. Lower: the heating elements and the outlet. Upper: pipes from the coil, thermal sensor (green cable) and the inlet

A thermal sensor was also installed to measure the flow out of the cooker. Due to some difficulties during installation of the cooker, this sensor was installed on the outside of the pipe as shown in figure 14.

Figure 14: The thermal sensor taped to the pipe for measuring the temperature of the flow out of the cooker

This causes a certain thermal inertia that needs to be taken into account. The temperature will stabilize at the right temperature, but can be misleading at first which will be discussed in section 7.

Further, the cooker was insulated using the same principle with layers. As figure 15a shows, three casseroles with different dimensions were placed inside each other. This enables insulation to be placed in the outer layer, and holes to be drilled in the inner casserole, such that oil can flow from the inner to the intermediate layer.

(a) The cooker before drilling

(b) Cooker after drilling

Figure 15: The cooker

The result is shown in figure 15b. The size of the holes needed to cover a bigger area than the cross sectional area of the pipe, to get rid of the outlet flow.

When cooking rice, a fourth casserole was submerged in oil in the inner space as shown in figure 16a. The cylinder used as the thermostatic valve is shown in figure 16b with two pistons in one, where the smaller piston has a stronger spring to make sure it expands last.

(a) The cooker in use

(b) The cylinder including two pistons and a flushing mechanism

Figure 16: The cooker to the left and the cylinder to the right

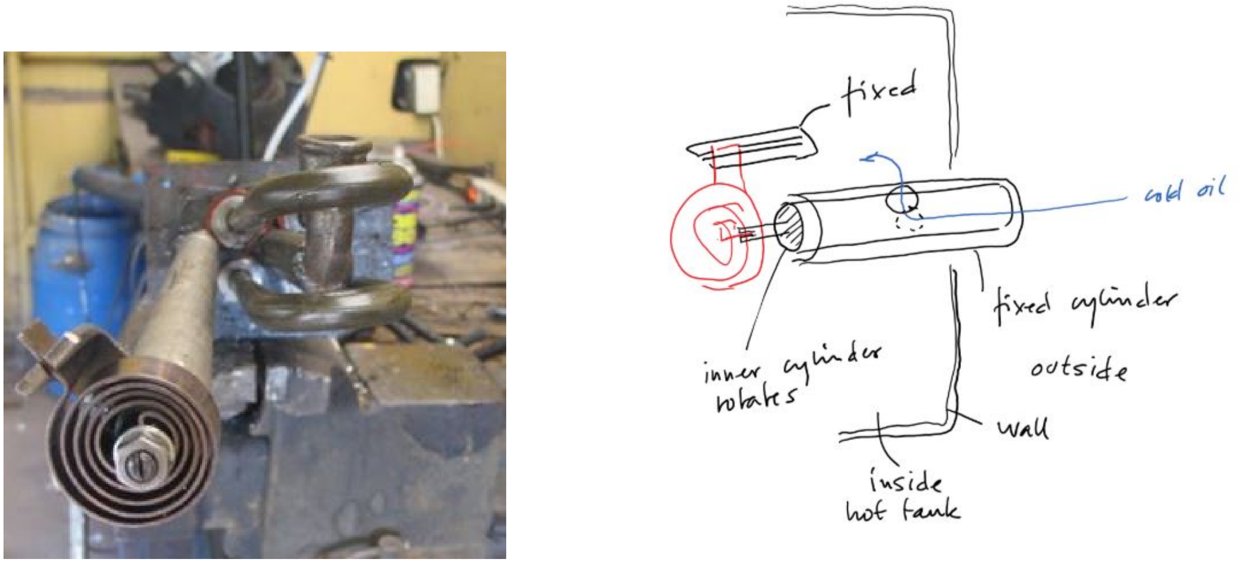
The piston was together with the cooker and the plumbing used in the first round of testing, and placed like figure 17 indicates.

Figure 17: The system after connecting the cooker, the pistons and plumbing

As figure 17 shows, the data logger, power box and controller box were also mounted on the rig at this point. The PV panels were installed on the roof of the work shop, see figure 18.

Figure 18: PV panels placed on the roof of the workshop rated 304.1 W and 36.2 V

The last part of the construction work was the pipe insulation and filling the tanks with oil, which was a pure refined palm oil. After the first round of testing, which included the pistons, a bimetallic spring as shown in figure 19a, was introduced as an alternative, for replacing the regulating mechanism in the thermostatic valve. The concept is shown in figure 19b below, where the spring (drawn in red) was tightened to the slider (inner cylinder), and kept in place by a guide that was welded on to the outer pipe (fixed cylinder). A slot was made in both the outer pipe and the slider, for the oil to flow when the spring signalized a high enough temperature in the heat storage.



(a) The bimetallic spring

(b) Sketch of concept with bimetallic spring (O. J. Nydal, personal communication, March 9 2019)

Figure 19: The bimetallic spring

As explained in section 3.2, the spring expands proportional to the temperature change it is being exposed to. Tests similar to the one described later in section 5.2 was conducted, and the angle of the spring was set. After the first test, it was discovered that oil was leaking from tank 1 into the storage tank, possibly due to rough treatment, like welding, of both the outer pipe and the slider. It was then decided to control the volume in the storage tank manually, and focus on the thermostatic valve including the bimetallic spring after returning from Tanzania. A pipe was drilled into the attachment of the heating elements as shown in figure 20.

Figure 20: The bimetallic spring connected to the heating element attachment

The outlet of the storage tank is, as figure 20 shows, placed above the heating elements, ensuring the oil level to stay above them. Hence, the entire setup with the pistons could be removed and resulted in the following system shown in figure 21:

Figure 21: The second setup after pipe insulation and removing the pistons

4.3.2 Collection of data

Volume and flow rate was found by emptying tank 3 before the test, and then timing the water when put to boil. After the test, the oil used in the test was removed from tank 3 for measuring the volume of it.

The temperature was measured by K-type thermal sensors placed around the system. One in each tank in addition to one sensor placed on the pipe out of the cooker. To read and save these sensor signals, the data logger was developed and used. The data was then converted to an Excel file and plotted as shown in section 4.5.

A thermal camera of the type CAT S60 was also used to measure temperatures, in terms of heat losses, in different parts of the system. Information about this camera is attached in appendix E.

To map the power delivered to the system from the PV panels, measurements was done manually with a multimeter like figure 22 indicates.

Figure 22: Measuring the current delivered from the PV panels on the roof

The data was then processed by calculating the power delivered every 10 minutes of the day. These data are presented in section 4.5.

The readings from the data logger was imported to Excel, and the relevant measures were taken. The data logger was used with a delay of 5 seconds, such that there were 12 temperature measurements every minute. This was shorted down to one reading per minute. Further irrelevant data was removed, such as temperature in the pipe after the flow was turned off. For overnight readings, only the temperature within the storage tank was interesting, and all the other readings were removed.

4.4 Power supply

The power supply for the test rig consisted of six PV panels, connected in series, to obtain a high voltage similar to the rated voltage level of the heating elements, which is shown in appendix C. These lines are marked as bold in figure 23. To enable power to the parts of the electronics at a lower voltage level, a separate connection was made from one of the panels.

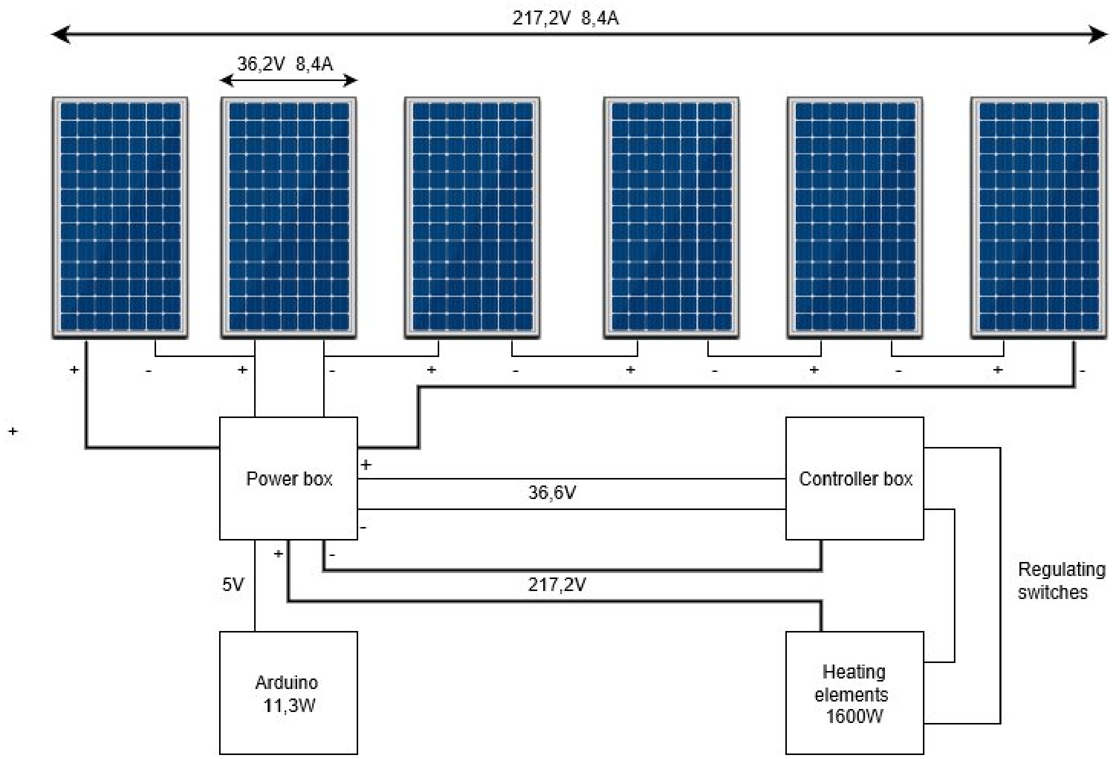


Figure 23: Flow scheme of the supply circuit

In the following figures of the connections, the placement of the components are in accordance with the flow scheme in figure 23.

The connections inside the power box is shown in figure 24.

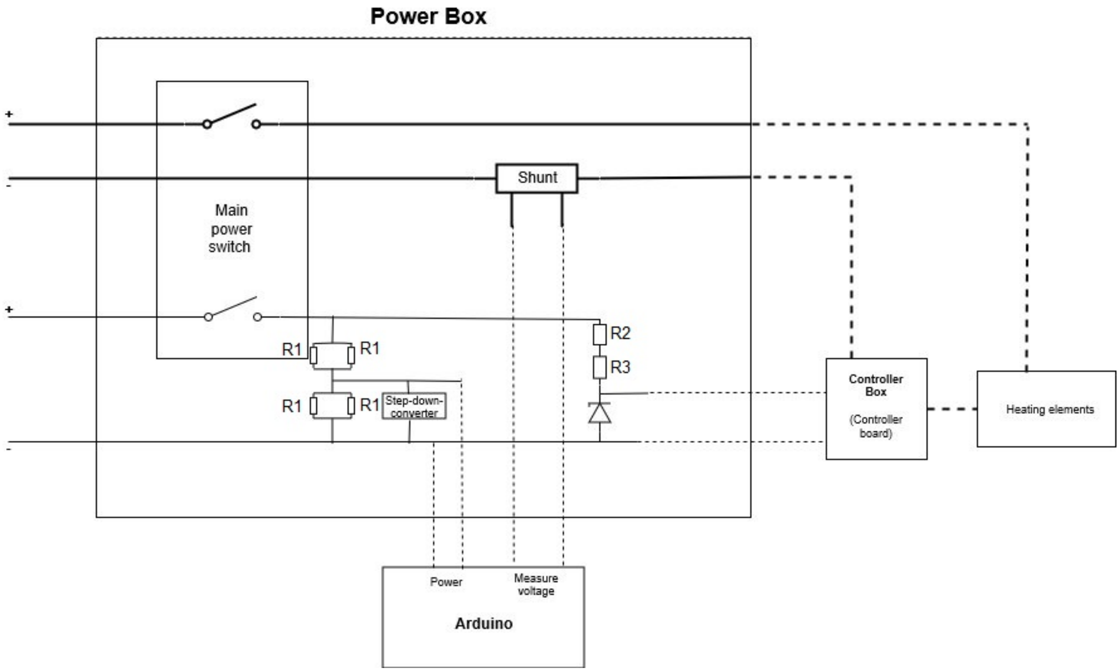


Figure 24: Inside the power box. R1 = 100 Ω
R2 = 180 Ω R3 = 10 Ω

In figure 24 the stipulated lines indicates cables exiting and entering the box. The actual power box is shown in figure 25 below.

Figure 25: The actual power box. The switch to the left, shunt at the bottom, the zenerdiode circuit at the top, and the voltage divider for the data logger to the right.

As figure 24 and figure 25 shows, the main switches in the power box controls the power flow to the data logger, the controller board and the heating elements. A shunt was connected in series with the main power switch to create a low-resistance path for the current as the maximum measurable voltage for the data logger is 5 V. This in turn results in a significantly reduced voltage drop across the shunt which enables the data logger to measure the voltage level supplied from the PV panels. As shown in section 3.4, the measurements are then used to calculate the actual values of the current and voltage. However, the data logger requires a converter in addition to be able to read voltage signals through the K-type thermal sensor sockets. To solve this, a terminal board as shown in figure 26 was connected to the K-type sockets of the data logger, found in appendix G. The remaining thermal sensors was numbered like the figure also shows.

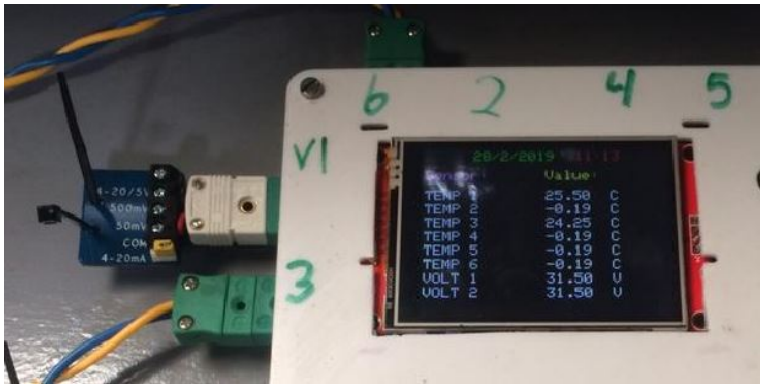


Figure 26: The terminal board connected to the data logger

The cables from the shunt was then connected to the terminal board, and a test was run to ensure proper measurements. This test revealed the data loggers inability to measure voltage signals with the present code. As the time was limited at this point of the field work, another solution was quickly put together for the tests to be conducted shortly after, instead of modifying the code. This alternative solution consisted in connecting the terminal board to the PicoLog system instead of the data logger as figure 27 shows.

Figure 27: The terminal board connected to the PicoLog system

Using this setup, the voltage could be measured and the tests could be executed within the time limits although the data logger did not manage to read voltage signals. This will be discussed further in section 7.

In addition to the measurement signal, the supply voltage level also had to be stepped down according to the maximum operating voltage of both the data logger and the controller board. As the desired voltage level for the data logger is 5 V, this was done using a voltage divider and then a converter as shown in figure 24 and 25 and section 4.4.2. In case of the controller board, the desired voltage level was below 30 V and hence a zenerdiode was used as shown in figure 24 and section 4.4.1.

Figure 28 displays the power flow within the controller box.

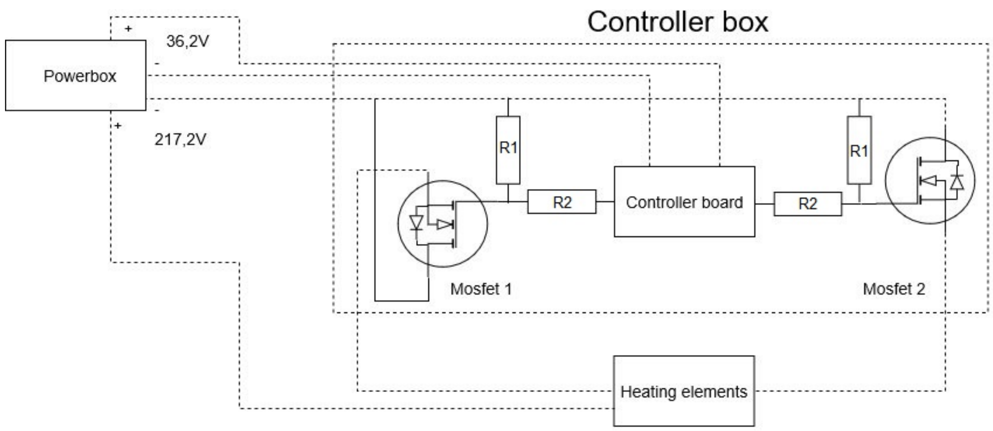


Figure 28: Inside the controller box. R1 = 500 kΩ, R2 = 10 kΩ

Figure 29: The actual controller box. The controller board at the upper part and the two switches with the connected resistors and aluminum below

As mentioned above, the controller board is supplied by one PV panel at 36.2 V and controls the gate signals sent to the switches. This in turn decides whether or not both of the heating elements should be enabled according to the level of power delivered from the PV panels. This is described in section 4.4.4. To be able to control this, the switches are connected through pull-up and a pull-down resistor as explained in section 3.5 and in series between the supply and the heating elements. To divert and dissipate the heat produced in the switches, one block of aluminum was placed behind each switch, as shown in figure 29.

4.4.1 Controller board circuit

For the controller, a zenerdiode was used and connected in series with two resistors to divide the voltage. The zenerdiode had a zener voltage of 30 V, and a P_{tot} of 1 W. Using this, results in the current through the diode being $I_z = 0,0333$ A. As this is a series connection, the same current passes through the resistors. The voltage drop across the resistor will then be 6.2 V according to Kirchhoff's Voltage Law [47]. With the information of the voltage drop over the resistors and the current flowing through them, the resistance can be calculated to be 186.2 Ω. Hence, this is the desired resistance.

4.4.2 Voltage divider for the data logger

For the data logger, a step-down-converter was brought from Norway. The converter had an input range of 9-32 V, and a fixed output of 5 V, that matched with the data logger that requires an operating voltage of 5 V. More information is found in appendix I. It was chosen to use the concept of voltage dividing; splitting the input voltage from one of the panels in half, and then step the voltage further down using the converter. The dividers were made out of 10 W and 100 Ω resistors, and put in parallel as figure 28 shows.

4.4.3 Voltage control for the switches

The switches operate based on gate signals from the controller board which indicates a high (logic 1) level or a low (logic 0) level. As figure 28 shows, resistors are connected across and in series with the switches. These resistors works as pull-up and pull-down resistors, and prevents short circuits. The values were decided based on the available resistors at the work shop and the principles described in section 3.5.

4.4.4 Controller board

The controller board connected to the switches served as the load controller in this system, and was already designed in advance by Per Bjerre. It is shown in figure 30.

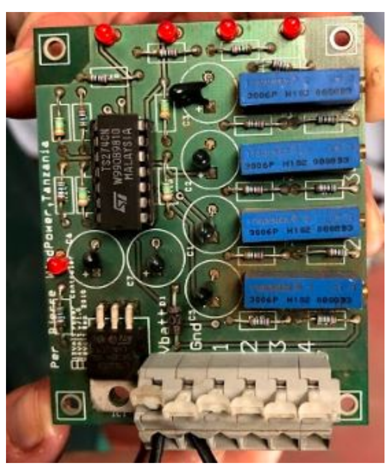
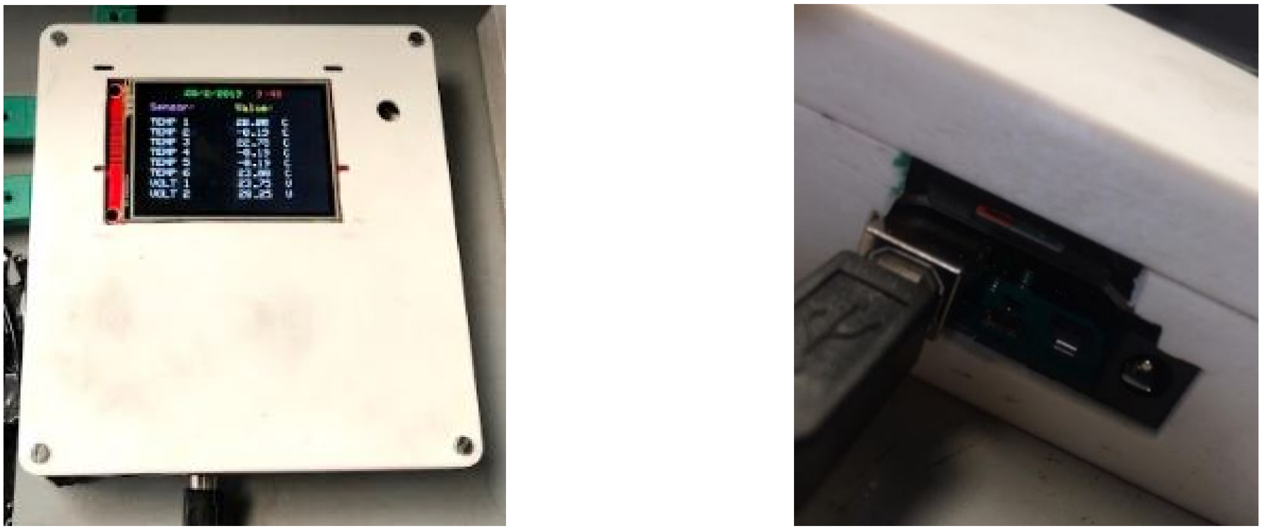


Figure 30: Controller board

When the power produced from the PV panels pass a certain threshold value, both heating elements are turned on by the controller board in order to utilize the capacity in the resistors. In the same way, to obtain as much heat transfer as possible, one of the heating elements was turned off when the level dropped below the adjustable threshold value.

4.4.5 Installation of the data logger

The data logger was installed in a shield with a hole enabling reading from the screen. Another hole was drilled for the SD-card to be injected and ejected for data extraction. The shield is shown in figure 31.



(a) The shield for the data logger

(b) The opening for the SD-card

Figure 31: The data logger

4.5 Results

As a result of the initial findings, two different designs of the thermostatic valve were tested.

4.5.1 Pistons as thermostatic valve

The first test was conducted with the cylinder containing two pistons as the thermostatic valve. The purpose was to measure the boiling time of 10 L of water at full flow. Figure 32 shows the results:

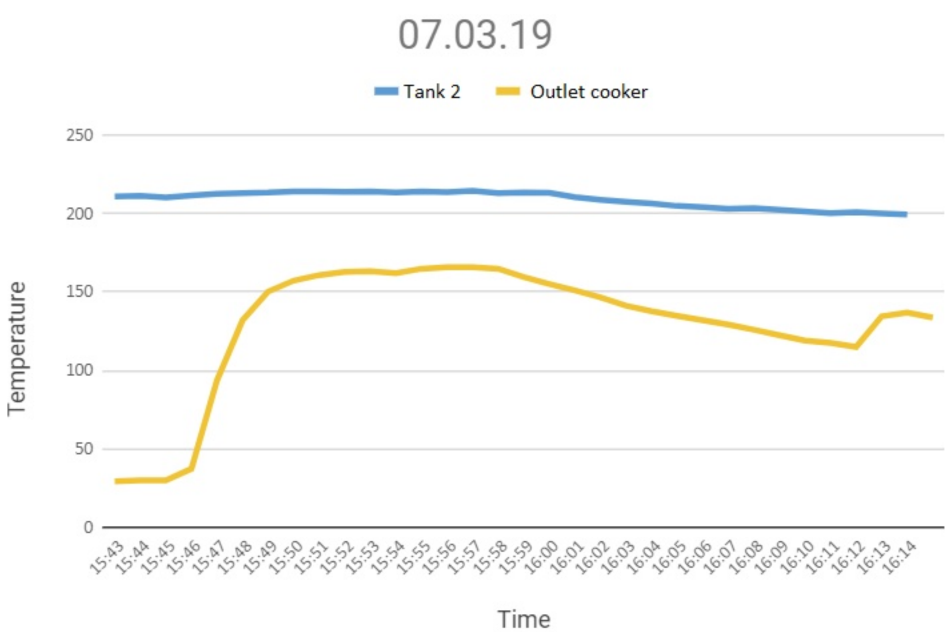


Figure 32: Fully open valve with the pistons as the regulating mechanism

From figure 32, it can be seen that the fully open valve results in a high measured temperature in the flow out of the cooker. Hence, the cooker is not able to extract a sufficient amount of the available heat. It did, however, manage to boil the 10 L of water after 13.5 minutes as the graph in figure 32 shows.

The test also revealed challenges associated with the cylinder. The movement of the largest piston was limited by friction. To solve this, one of the O-rings was removed like figure 33 shows.

Figure 33: The cylinder after removing one O-ring at the bigger piston

Both removing it and replacing it with a smaller O-ring was tested. Although it ended the friction related problems, in both cases it caused a leakage that made it difficult to obtain the desired results from the cylinder. Another aspect was the complexity related to the implementation of the closed system alternative in the future. As a result, the bimetallic spring was introduced as a simplified alternative to the thermostatic valve. Since the entire setup with the spring is placed inside the storage tank and hence is protected, it require less maintenance and less skilled operators.

4.5.2 Cooker test: boiling water

At this point, the bimetallic spring was installed. The purpose of this test was to boil water on half of the flow due to the results from the previous test.

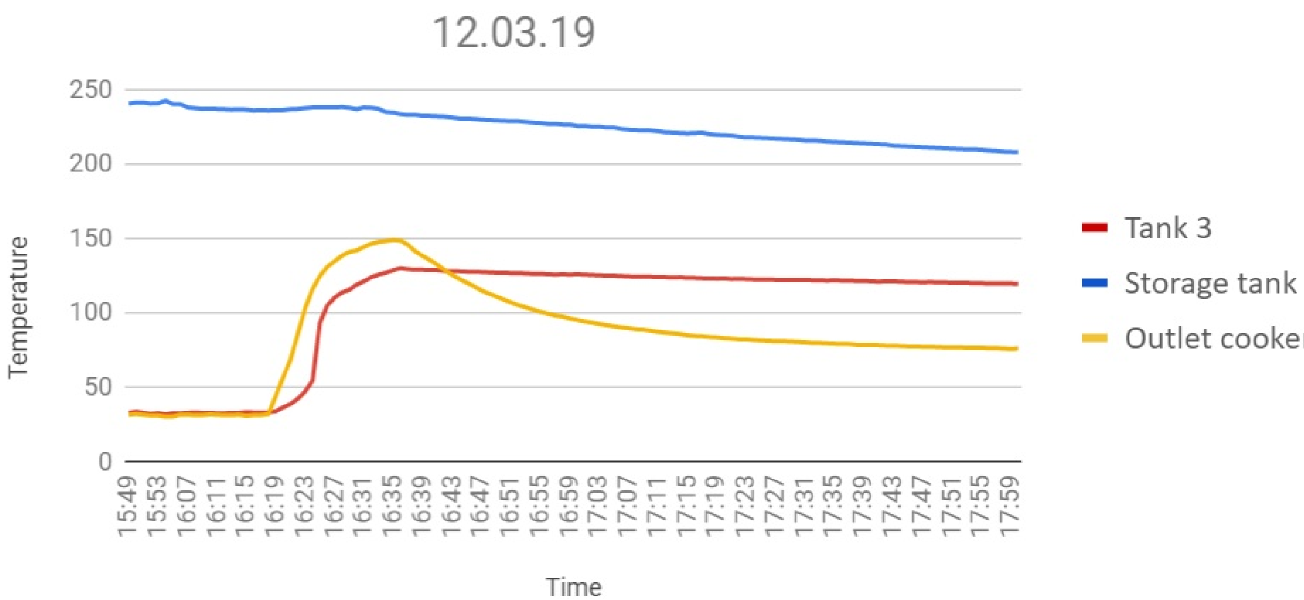


Figure 34: Halfway open valve

Figure 34 displays an improvement compared to the fully open valve as a result of the smaller flow. It is notable that the flow out of the cooker reaches the same temperature as for full flow, despite the difference in temperature in the storage tank being close to 30 °C.

4.5.3 Cooker test: boiling rice

The goal of this test was to find how much rice can actually be cooked with the current system. In preparation of this test, the pipes were insulated. The rice was boiled at a higher flow rate, then the flow rate was adjusted to a minimum to keep the water boiling.

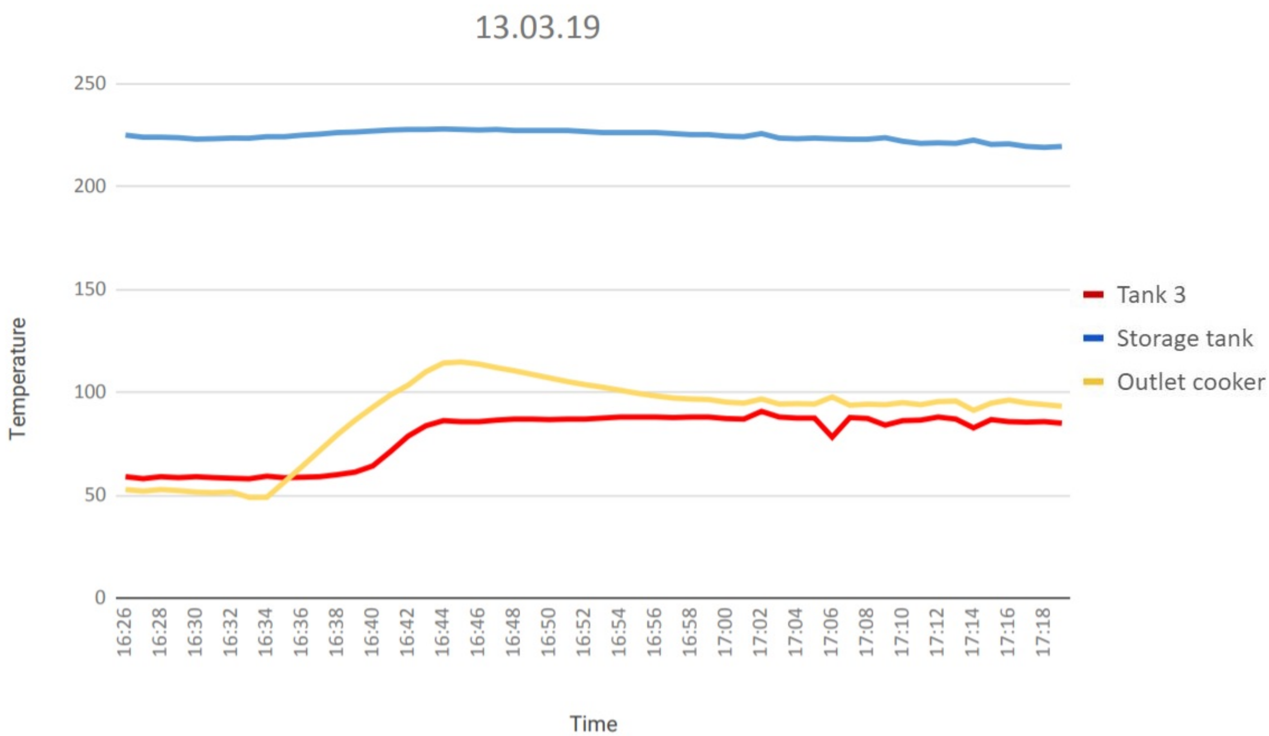


Figure 35: Cooking 1 kg of rice

The rice was a local variant that seemed quite different from the type experienced in Norway. The uncertainty of when it was done, caused it to be over cooked. This will need to be taken into consideration, that the actual oil used to cook will be significantly lower.

The volume of the oil used to cook the 1 kg of rice was found to be 12.5 L, at a temperature of 42 °C the next day. Since:

$$\rho_{42} = 879\frac{kg}{m^3}$$

the mass would be 11 kg. The temperature in the storage tank as seen in figure 35 stabilizes at 227 °C, while the flow out of the cooker is just about 100 °C. Using equation 3, with the relevant subscripts:

$$Q_{actual,rice} = \frac{m_o \cdot (c_{p,i} \cdot T_i - c_{p,o} \cdot T_o)}{m_{rice}}$$

This gives:

$$Q_{a,r} = 5427.7\frac{kJ}{m_{rice}}$$

To calculate the total amount of rice that can be cooked, the mass calculated in section 3.6 is used:

$$m_o = 31.17kg$$

Assuming the same heat extraction and heat loss, at the design temperature of 240 °C [46], the total energy extracted can be calculated as:

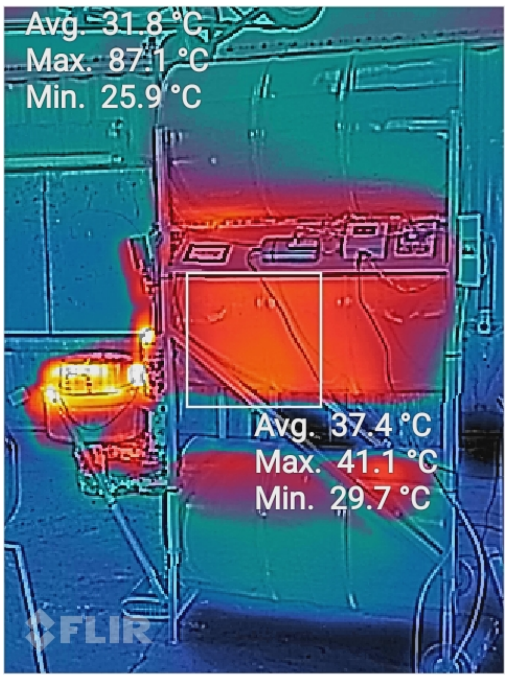
$$Q_{actual,full} = m \cdot (c_{p,240} \cdot (240 + 273) - c_{p100} \cdot (100 + 273))Q_{A,f} = 17300kJ$$

This means the amount of rice that can be cooked would be:

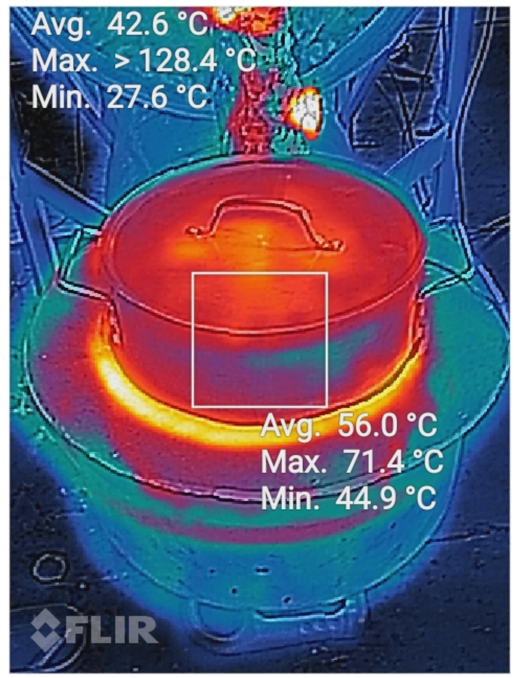
$$m_{rice} = \frac{Q_{a,f}}{Q_{a,r}} = 3.2kg$$

From conversations with locals, 100 g was considered a portion, such that 3.2 kg rice would feed 32 people. The actual amount of rice is likely considerably higher, as the rice cooked for 48 minutes it could be considered over cooked.

To map the heat dissipation, a thermal camera was used during the test and the results are shown in figure 36.



(a) The entire system captured with a thermal camera



(b) The cooker captured by the thermal camera in the process of cooking rice

Figure 36: Heat dissipation

The figure shows that the insulation works properly both around the pipes and the tanks. The biggest heat loss is related to the casserole in the cooker, as it can be seen in figure 36a. Figure 36b gives a more detailed picture of this, also captured by the thermal camera.

The figure emphasizes the insulating abilities of the cooker by maintaining a low temperature. Between the casserole and the cooker, heat is dissipated at a high rate, as there is a layer of oil directly in contact with the air. The casserole is also relatively hot compared to the insulated cooker, which again proves the abilities of the insulation.

Figure 37 shows the storage tank while cooking rice.

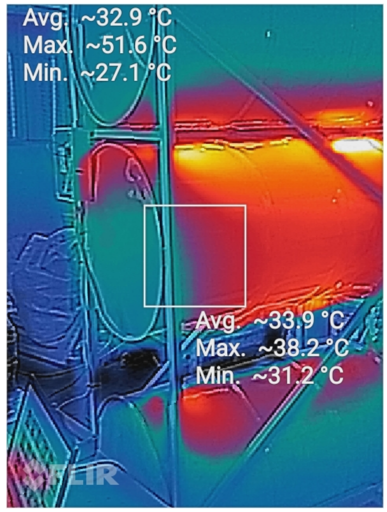


Figure 37: The storage tank captured with the thermal camera

According to the thermal camera, the maximum temperature detected on the picture was 51.6 °C, but this was only in certain areas where the insulation was not ideal. On average the temperature of the tank is shown to be slightly above 30 °C. In addition to the heating elements inside the storage tank, the weather conditions also contributed to a temperature increase on the surface of the tanks.

4.5.4 Test of insulation

In this test, the system was logged during the entire night to measure the overnight heat loss. This was done after a cooking test the day before, such that there was only 15 L of hot oil left.

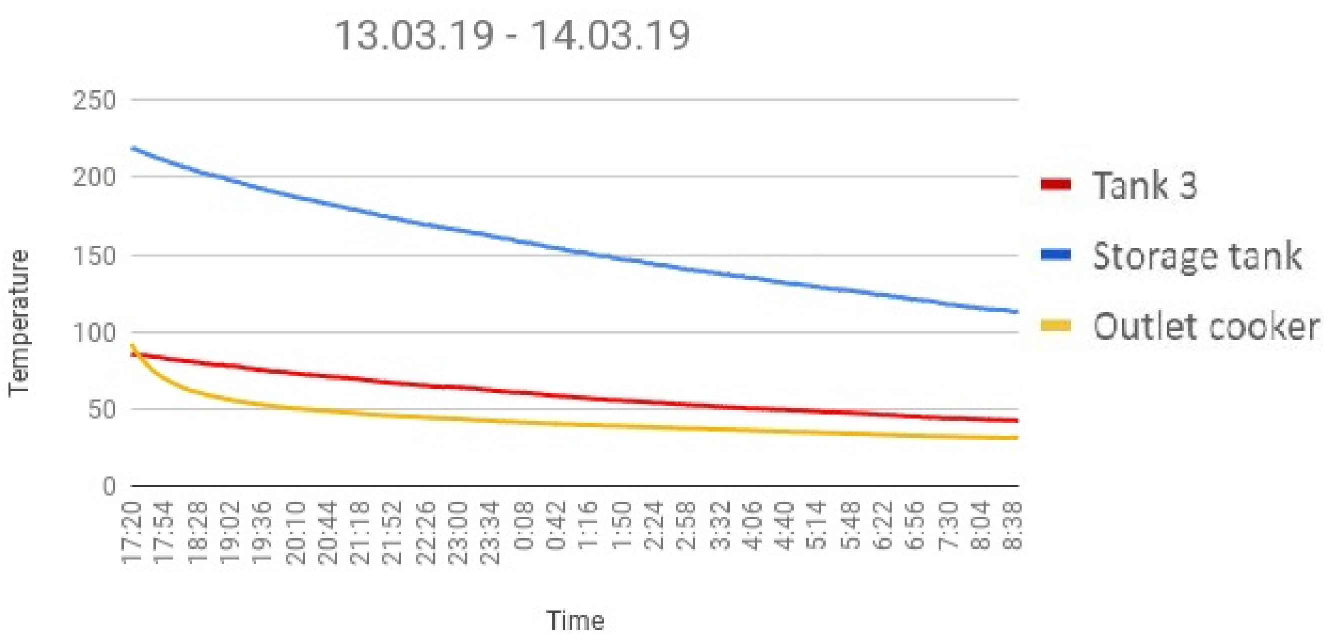


Figure 38: Logging overnight

Figure 38 indicates that the temperature in the morning was around 100 °C in the storage tank. This proves that the insulation is capable of retaining some of the heat stored in the oil. Since the system will be used as a dump load, it is an important property, which will be discussed more in section 7.

4.5.5 Time required to heat up the storage

The purpose of this test was to measure how long it would take to heat up a full storage tank to 250 °C. Then the aim was to log how long the full tank could keep 10 L of water at the boiling point.

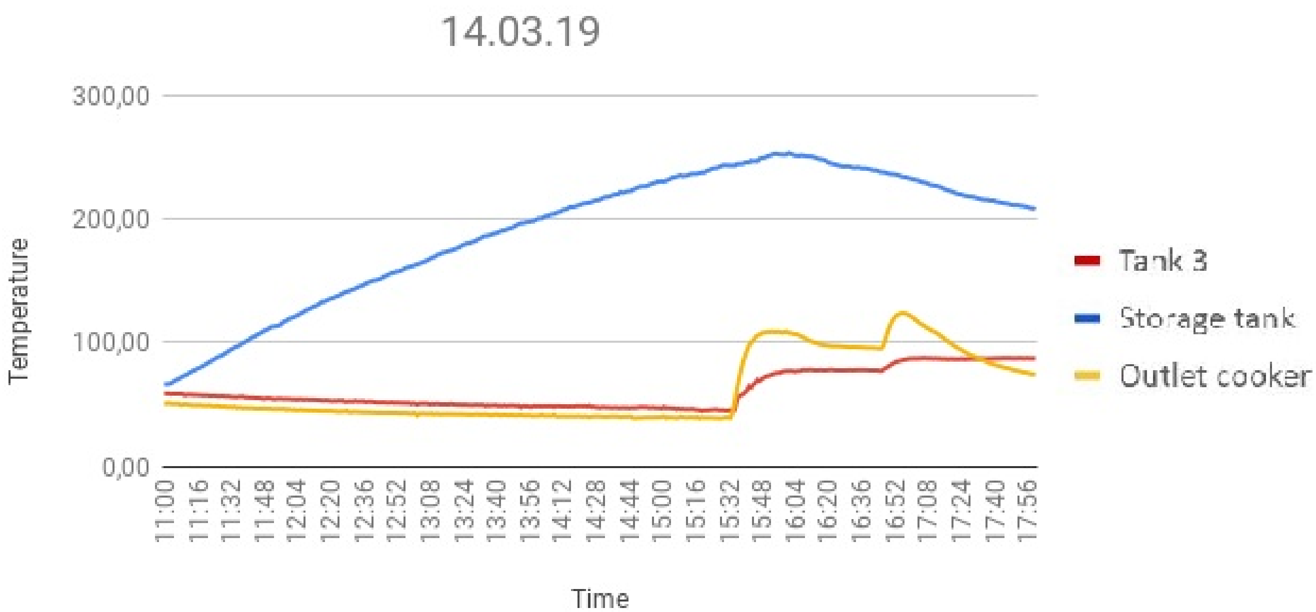


Figure 39: Heating up the storage tank

At the starting point, the oil in the storage tank was at 66 °C. As figure 39 shows, it takes about 5 hours to heat up the entire storage tank of 30.5 L from 66 °C to 250 °C. The angle of the valve, was adjusted to 35°initially, and then decreased to 25°at the boiling point. As the boiling stopped, the angle was too small and had to be adjusted up again to make the water boil. This resulted in a somewhat exaggerated flow and hence a bigger heat loss. However, the system managed to keep the 10 L of water at the boiling point for 1.5 hours as the figure shows.

Figure 40 maps the variations in the power supply during the test.

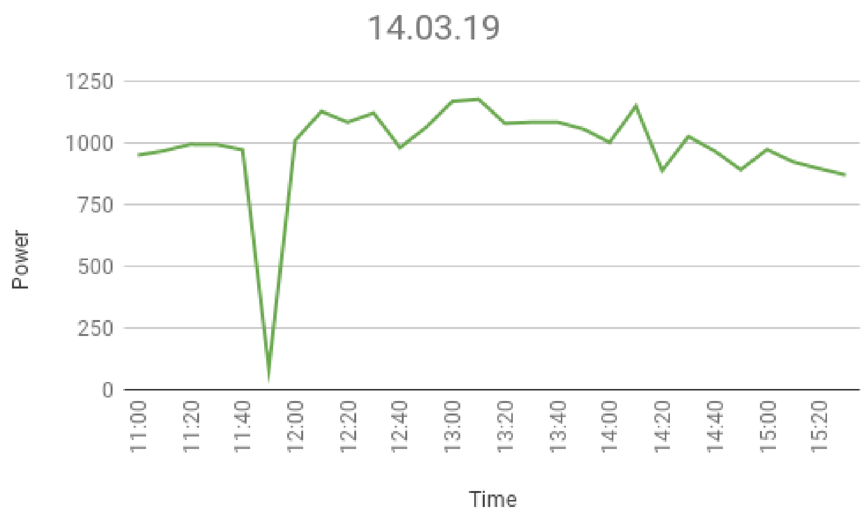


Figure 40: Power supply variations during a sunny day

The conditions were excellent, except from a cloudy period right before 12:00 as the figure indicates. Considering the heat loss present in the panels as a consequence of hot weather, see section 3.3, an average of around 1 kW is as desired.

4.5.6 Testing the system under cloudy conditions

This test was conducted to measure the capacity of the system on a more cloudy day compared to the previous test. The tank contains 18 L of oil at the starting point. The starting temperature in the storage tank was 76 °C.

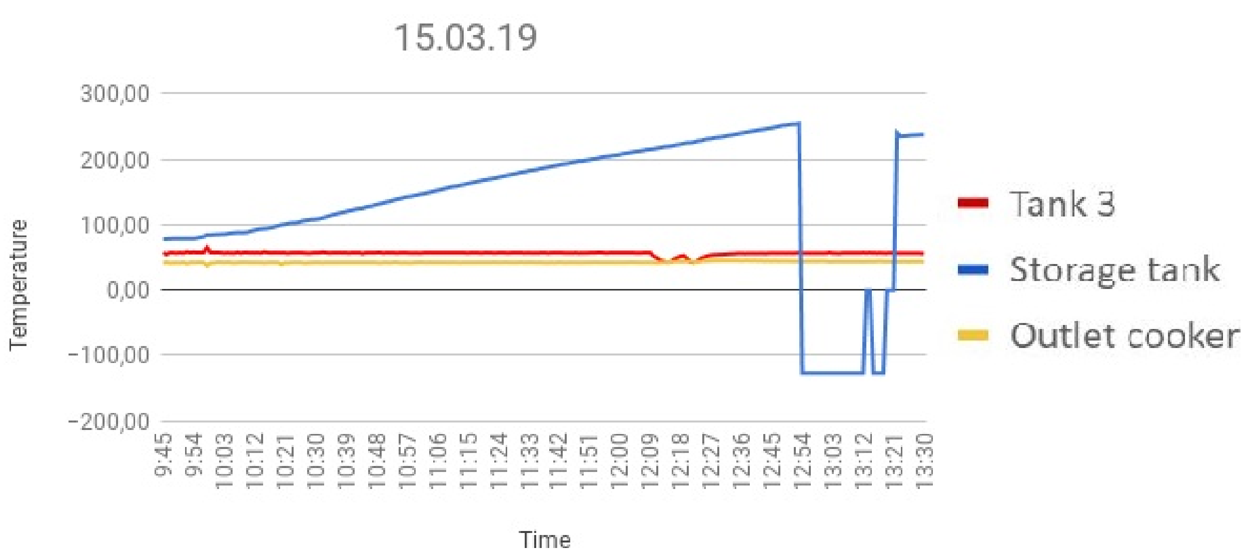


Figure 41: Capacity in cloudy conditions

It took, according to figure 41, around 3 hours to heat up 18 L from 76 °C to 250 °C under cloudy conditions. The test also revealed a problem with the data logger. As the temperature exceeds 256.75 °C, the data logger measures -127.00 °C. This is due to a bit-related software problem which will be further discussed in section 9.5.1

Figure 42 shows the power supply variations under cloudy conditions.

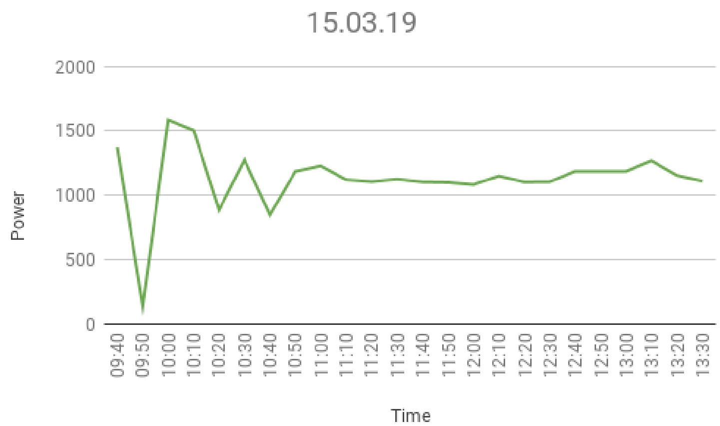


Figure 42: Power supply variations

Figure 42 is similar to figure 40, which emphasizes that cloudy conditions is sufficient for this system. During this test, the current was also measured another way. Results from this method, is shown in figure 43.

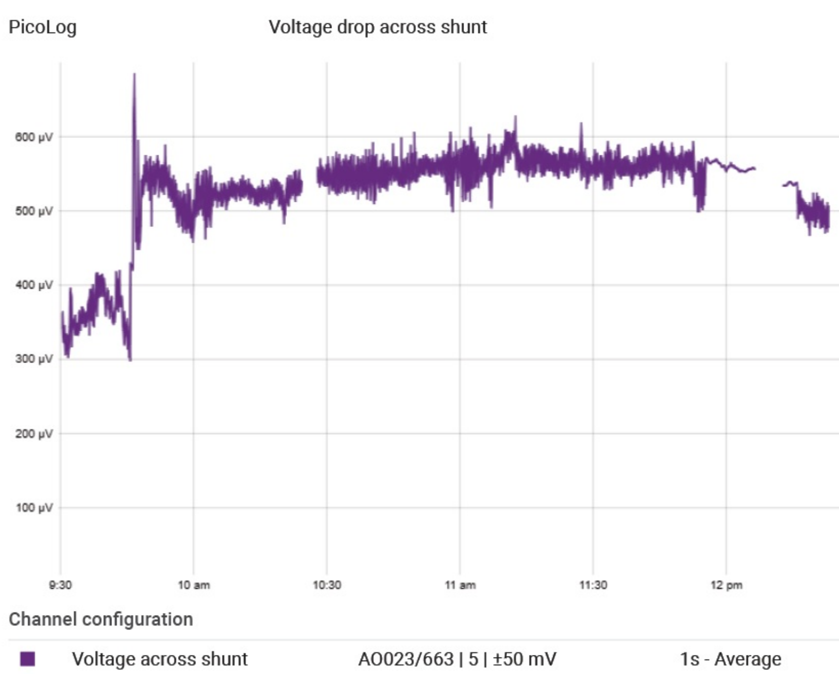


Figure 43: Voltage measured over the shunt by the PicoLogger

The voltage in figure 43 was found by measuring across the shunt as explained in section 3.4. The power was then calculated. However, this number did not match the manual tests done as seen in figure 42. What can be seen from this is a clear discrepancy between the two. The manual readings were double checked using different devices, and were consistent.

After heating up the tank, a test was conducted to compare the system to a water boiler with a capacity of 2 L and ratings 1800 W. The aim was to run the system on full flow to measure the boiling time.

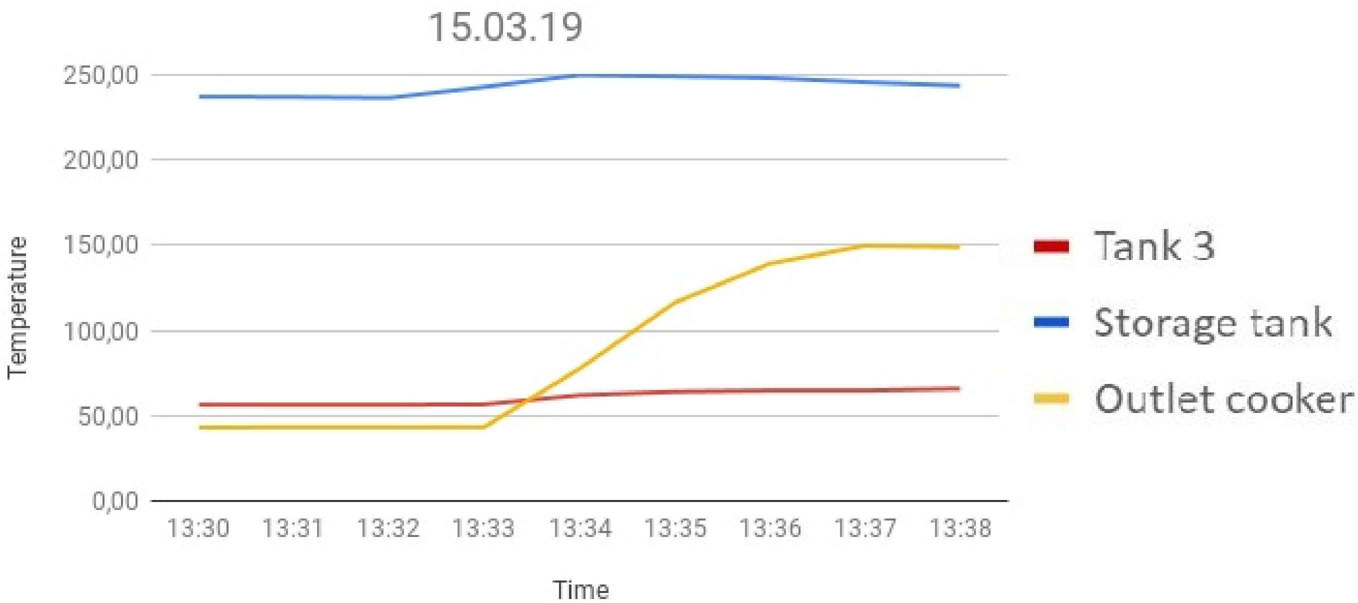


Figure 44: Boiling 2 L of water

As figure 44 shows, and as mentioned, the system looses a lot of heat on full flow resulting in a high temperature on the flow out of the cooker. After 3.5 minutes, the 2 L boils which is half of the time compared to the water boiler using 7 minutes.

4.6 Energy losses in cooking

During a test conducted, 10 L of water was boiled. The amount of oil used was measured to be 21 L. It is interesting to find how much energy was extracted from the oil, and how much of this was actually used to heat the water.

Energy removed from the oil can be calculated by equation 3 from section 3.6, which with the relevant subscriptions gives:

$$\Delta Q_o = m_o \cdot (c_{pi} \cdot T_i - c_{po} \cdot T_o)$$

Similarly the energy required to heat the water can be calculated from the same equation, which with inserted subscriptions is:

$$\Delta Q_w = m_w \cdot c_p \cdot \Delta T$$

At the start of the experiment the oil in the storage tank had a temperature of:

$$T_i = 238°C$$

When it was flowing out of the cooker it was down to:

$$T_o = 150°C$$

The water had a starting temperature of:

$$T_i = 33.9°C$$

and was boiling at:

$$T_b = 98°C$$

The total mass of the oil used was found by:

$$m_o = \rho_{48} \cdot V = 18.4kg$$

given that:

$$\rho_{48} = 875 \frac{kg}{m^3}$$

Adding these values to equation 3, the energy removed from the oil is found to be:

$$Q_o = 6744kJ$$

The same is done using equation 3, which gives:

$$Q_w = 2683kJ$$

This means that the wasted energy equates to:

$$Q_{wasted} = Q_o - Q_w = 4061kJ$$

The fact that the piping lacked insulation was a significant factor for heat loss. Based on thermal images the cooker itself had little heat loss other than a gap around the pot.

4.7 Challenges

The lack of available insulation in the relevant area is a challenge considering the system fully depends on an insulation of solid quality. Insulation was imported for the construction of the system, and is not usually available locally.

Another observation is that the palm oil used, tends to solidify at lower temperatures. This happened overnight, resulting in the pipes being clogged in the morning at the starting point of the test.

Figure 45: Heating up the oil

To solve this, a heat gun was used to melt the oil and make it flow again prior to the test which is shown in figure 45.

5 Methodology

As a result of the field work findings, the system was to be modified compared both to the previous setup from fall 2018, and the setup in Arusha. These changes includes, among others, replacement of the heating module inside rather than outside the storage tank, and installation of the bimetallic spring as an alternative to the pistons workings as a thermostatic valve in the previous work.

Testing of the bimetallic spring both separately, attached to the heating module and mounted inside the storage tank was a part of the methodology to find the correct setting. This setting was used in the main testing, and the results are shown in the next section.

Since the field work only included tests with a battery less system, a controller and batteries were to be connected at the NTNU laboratories, to simulate the dump loading principle with a diversion controller.

5.1 System modifications

Figure 46 shows the flow scheme which was the base for the modified system.

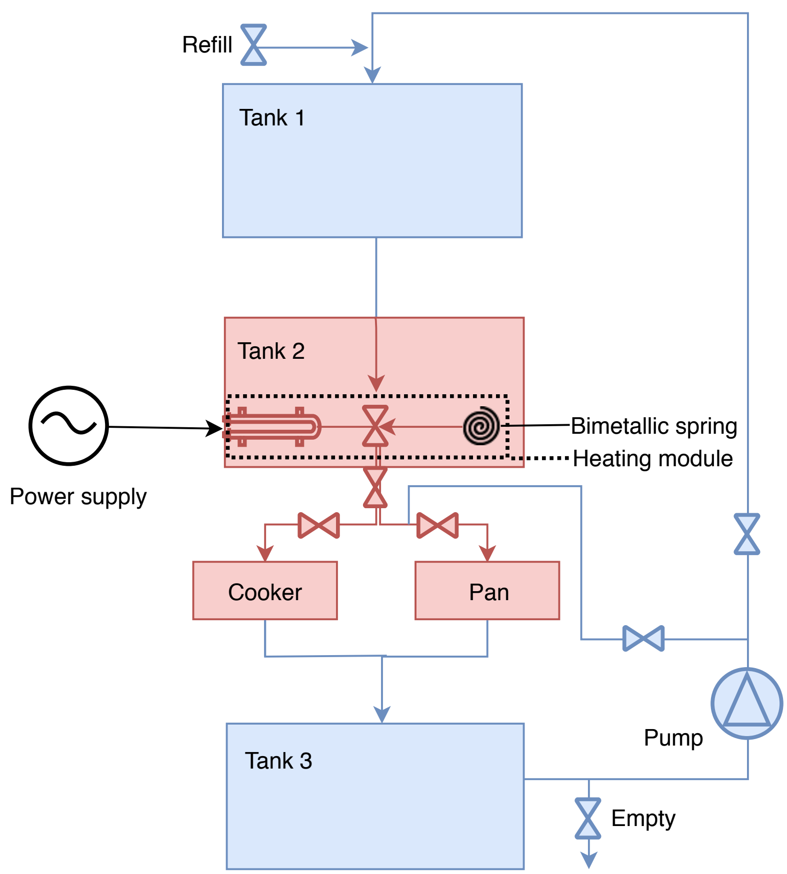


Figure 46: The updated flow scheme containing the following modifications: heating module inside tank, bimetallic spring instead of pistons, connection from pump to pan, and 3 valves added

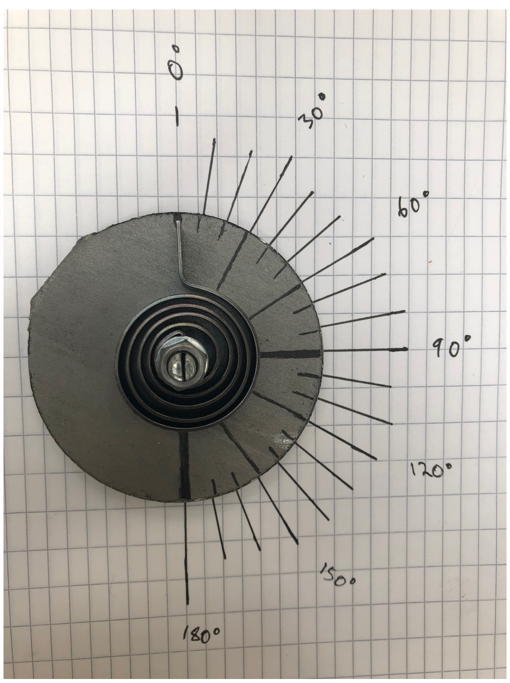
In the previous project, a flaw uncovered was the inability of the oil to properly flow through the frying pan. Besides the lowering of the oversized water trap, the first idea was to raise the height of the storage tank, to allow for higher pressure, but to minimize heat losses other alternatives were looked into. As was speculated before, bubbles in the frying pan might be throttling the flow. To solve this, a way of flushing the pan was needed. The solution implemented was a connection from the pump to the frying pan, allowing for oil to be pumped from tank 3 as shown in figure 46. This also included installing two additional valves out from the pump to direct the flow to be pumped and shut the other. The steel pipe from the pan to tank 3 was also substituted with a transparent silicon hose enabling visual inspection for air bubbles. This worked well, and after a few minutes of pumping, no more air bubbles were left in the flow out. When testing the flow from the storage tank through the pan, the flow was sufficient and steady.

Another modification was to put a valve directly under the storage tank as shown in figure 46. This limits the exposed surface when the system is not in use, because the surface area of the pipes will no longer be considered a heated surface.

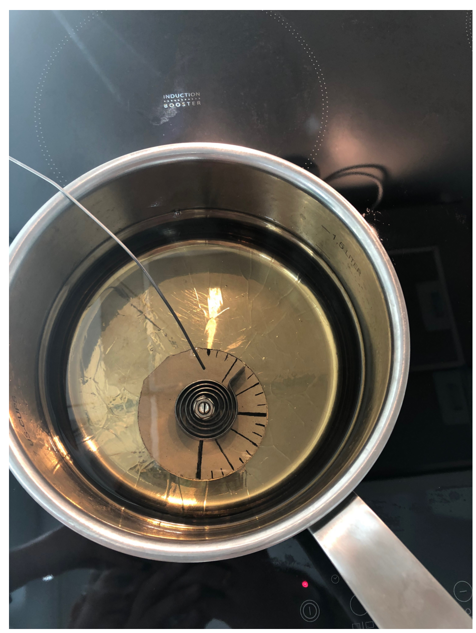
Additional thermal sensors were installed inside the storage tank close to the heating elements, to make sure the readings were consistent. The concern was that the initial one either touched the wall, or was exposed to air. It also allows the possibility to see if the temperature is significantly higher around the heating elements, compared to the opposite side of the storage tank.

5.2 Finding the right setting for the spring

To find the relationship between movement and temperature, the bimetallic spring was tested in prior to installation. As figure 47a shows, the spring was mounted onto a plate marked with the angles from the initial position.



(a) Bimetallic spring mounted on a plate to measure the angular movement in relation to temperature



(b) The test setup with the spring (here at 40°) mounted onto a plate and the temperature sensor

Figure 47: Finding the correct opening temperature

The device was then submerged in oil, the temperature was monitored by the PicoLog system continuously and the angular movement was recorded every 5°elapsed by manually reading from the plate. This is shown in figure 47b.

These angular movement readings were then plotted as a function of temperature, and the results are shown in figure 48.

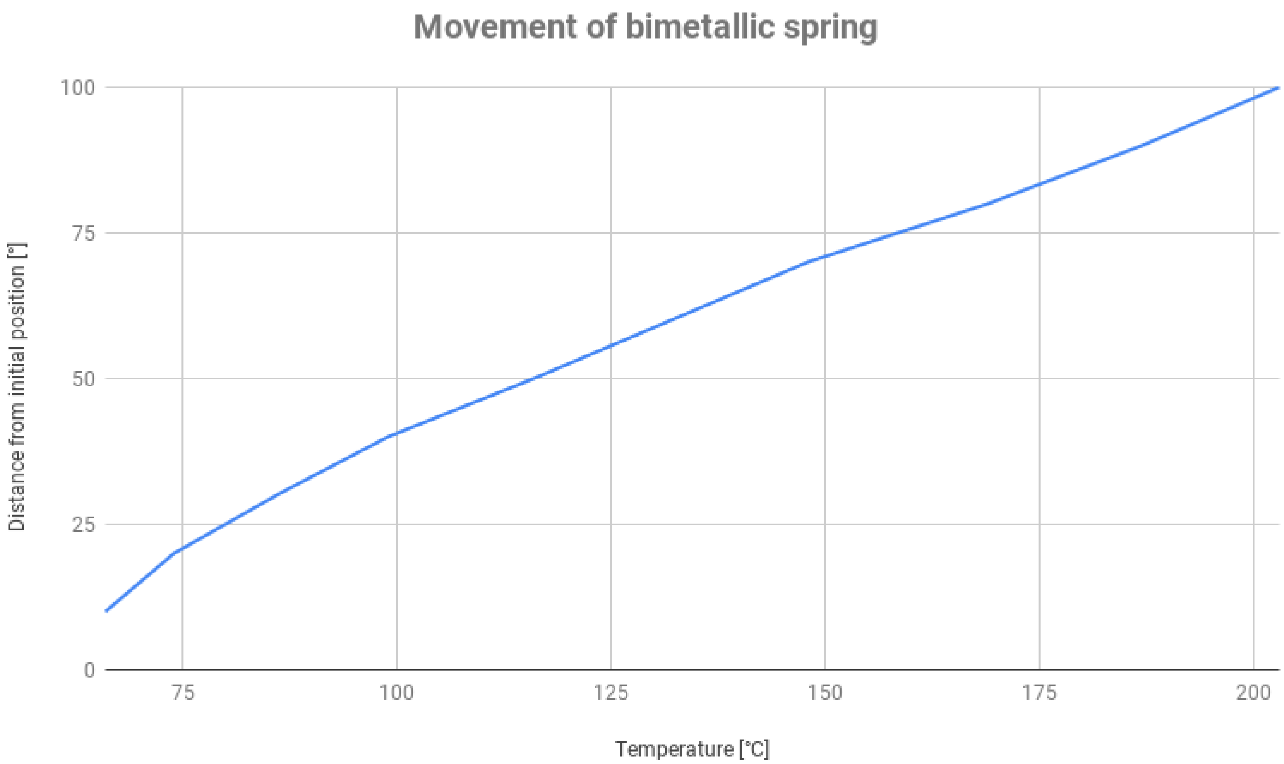


Figure 48: Movement of the bimetallic spring as a function of temperature

These results indicates a somewhat linear relation as expected according to section 3.2, which is useful for further testing. According to the requirement specifications in section 1.4, the desired storage temperature was 200 °C - 250 °C. To ensure a temperature stabilizing within this interval, an opening temperature of 200 °C was chosen as the spring moves gradually over a wide temperature range. Figure 48 then states that the initial position should be around 97°in further testing to obtain an opening at 200 °C.

5.3 Heating module modification

Figure 49 shows one of the two heating elements used in this system.

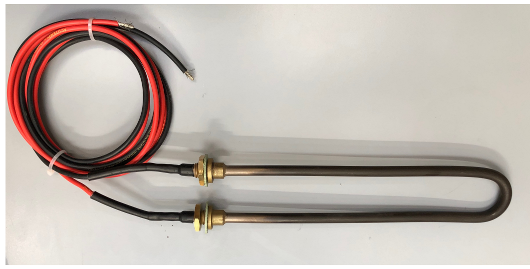


Figure 49: Heating element rated 24 V and 500 W

The properties of the heating element was determined by the PV panels connected. The drawings are shown in appendix J. The heating elements were mounted onto a plug together with the bimetallic spring arrangement as shown in figure 50.

Figure 50: The heating module consisting of the bimetallic spring and the heating elements attached to the plug

The center of the bimetallic spring was mounted on the moving inner pipe, the slider, and the end of the spring was mounted on the outer pipe. This is shown in figure 51. The opening angle was set to 97°as decided by previous testing shown in figure 48.

Figure 51: Bimetallic spring mounted on slider and pipe

For centering the forces, the end of the spring was guided by a bracket to let the center of the spring be the rotating part. The bracket was bent, enabling the spring to expand perpendicular to the pipe when exposed to heat, and the bracket was kept in place by a hose clamp. To avoid the spring from moving inside the bracket, it was kept in place by an aluminum splint drilled through the end of the bracket as figure 51 shows.

Modifications done in retrospective experience from Tanzania included drilling a hole instead of a slot for the opening of the valve. This was done to make the opening more gradually compared to the "on or off" effect for the slot. The hole was also moved closer to the spring to eliminate the leakages experienced in Tanzania. In addition, no heating treatment like welding, was performed on the heating module, removing possibilities to unintentionally bend or influence the mechanical properties of the slider or the outer pipe.

5.4 Testing the setting of the spring

As the results in figure 48 shows the movement of the spring attached to a separate plate, another test was conducted to map the movement when connected to the heating module. The heating module was then submerged in heated oil, as shown in figure 52.

Figure 52: The bimetallic spring submerged in oil during testing

The movement of the spring could then be measured by observing the inner pipe move in relation to the hole on the outer pipe. The results are mapped in figure 53.

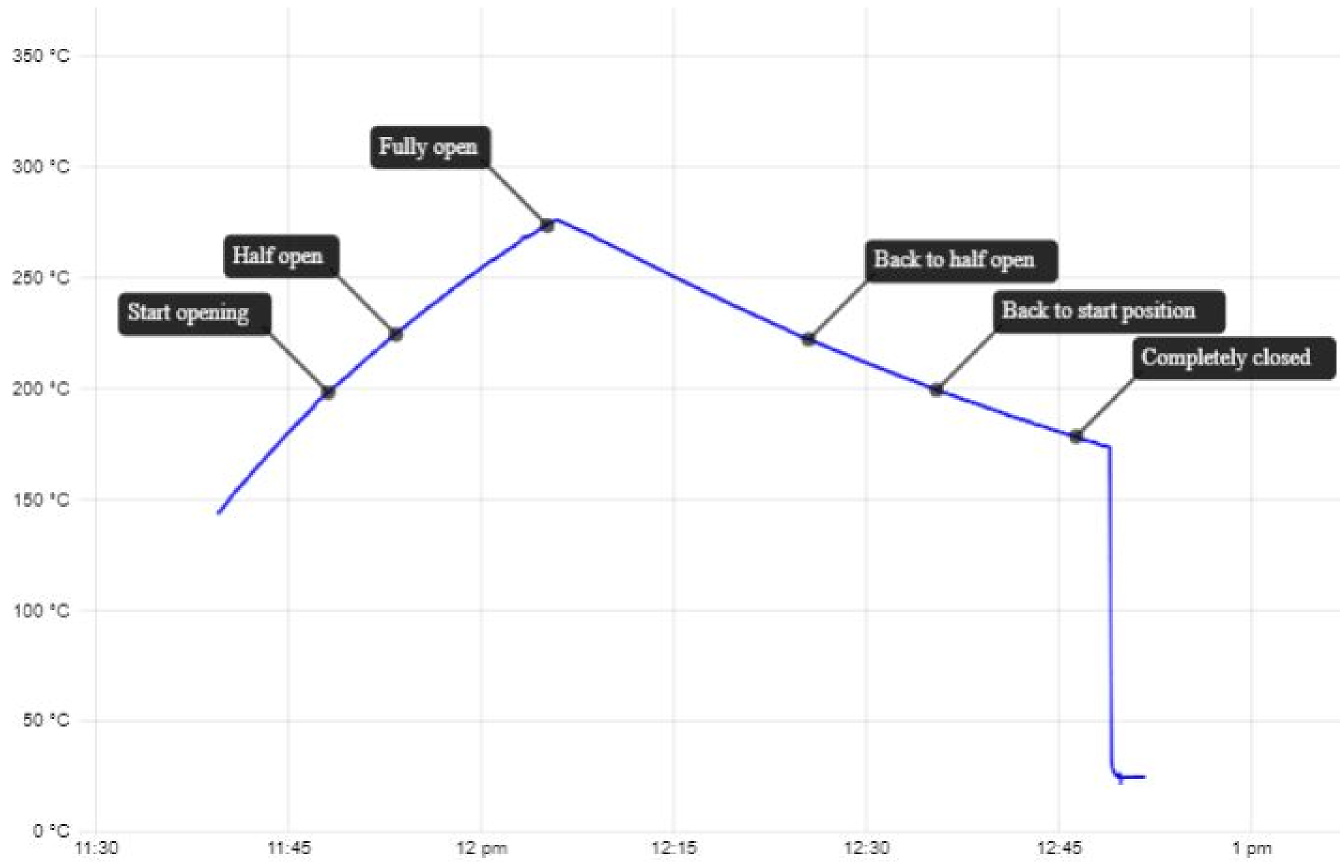


Figure 53: Test of the bimetallic spring movement in relation to temperature when attached to the heating module

As these results shows, the spring managed to open at the desired temperature of 200 °C as the previous test predicted. When installing the heating module inside the storage tank, this setting was hence used.

5.5 Resulting modified system

After modifying the system in accordance with figure 46 and installing the heating module inside the storage tank, the insulation work was done. The resulting system is shown in figure 54 with explanations in table 2.

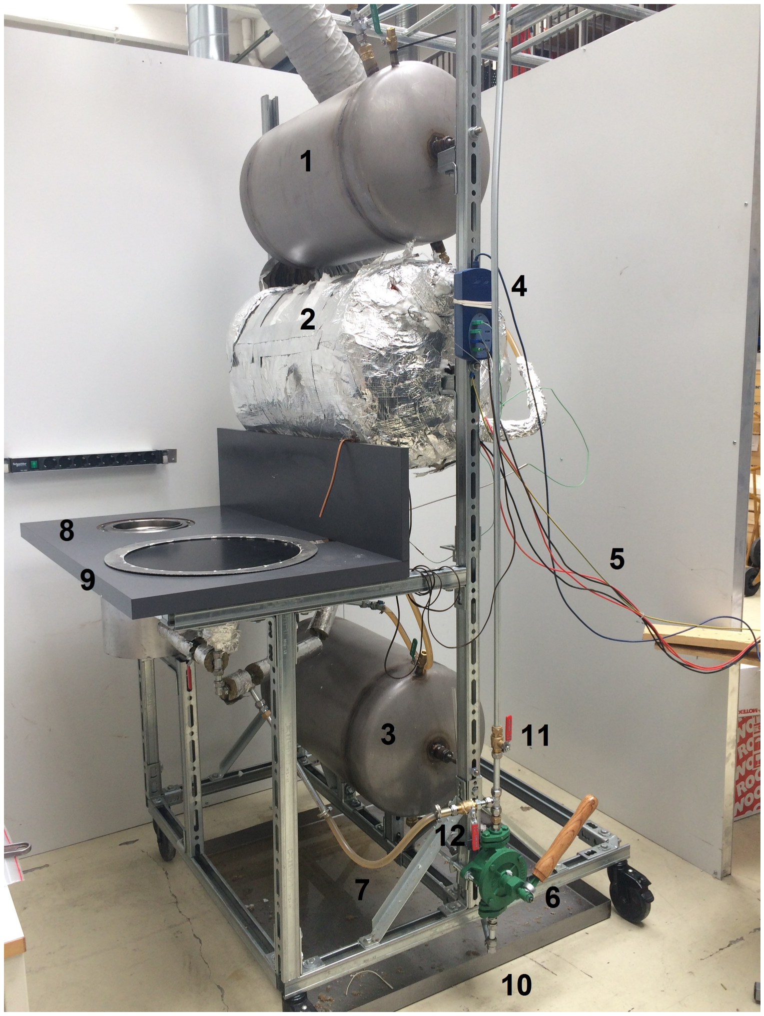


Figure 54: Overview modified system

Number	Part
1	Tank 1
2	Tank 2 (storage)
3	Tank 3
4	PicoLogger
5	Cables from power supply to heating elements
6	Hand pump
7	Hose to flush pan
8	Cooker
9	Frying pan
10	Tray for spilling
11	Valve to tank 1
12	Valve to frying pan

Table 2: System overview by numbers

Figure 55 shows the insulation work, the installed valve at the outlet of the storage tank, and the hose with a water trap from the pan to tank 3. A glass cylinder was also connected to the outlet of the storage tank to map the oil level and is shown to the right in figure 55.

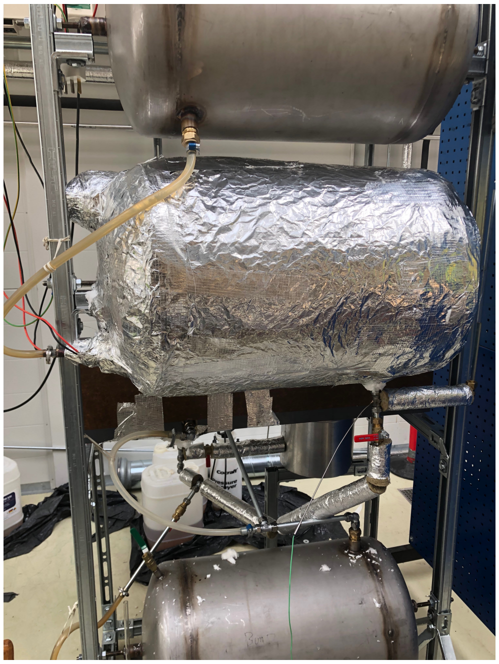


Figure 55: The system after insulation

At this point, the system was ready for testing of the bimetallic spring regulation.

5.6 Testing the bimetallic spring in the system

Due to a deformation of the threads, it was cumbersome to get the heating module in and out of the tank. To limit these difficulties, extensive testing was conducted outside the tank before inserting the heating module.

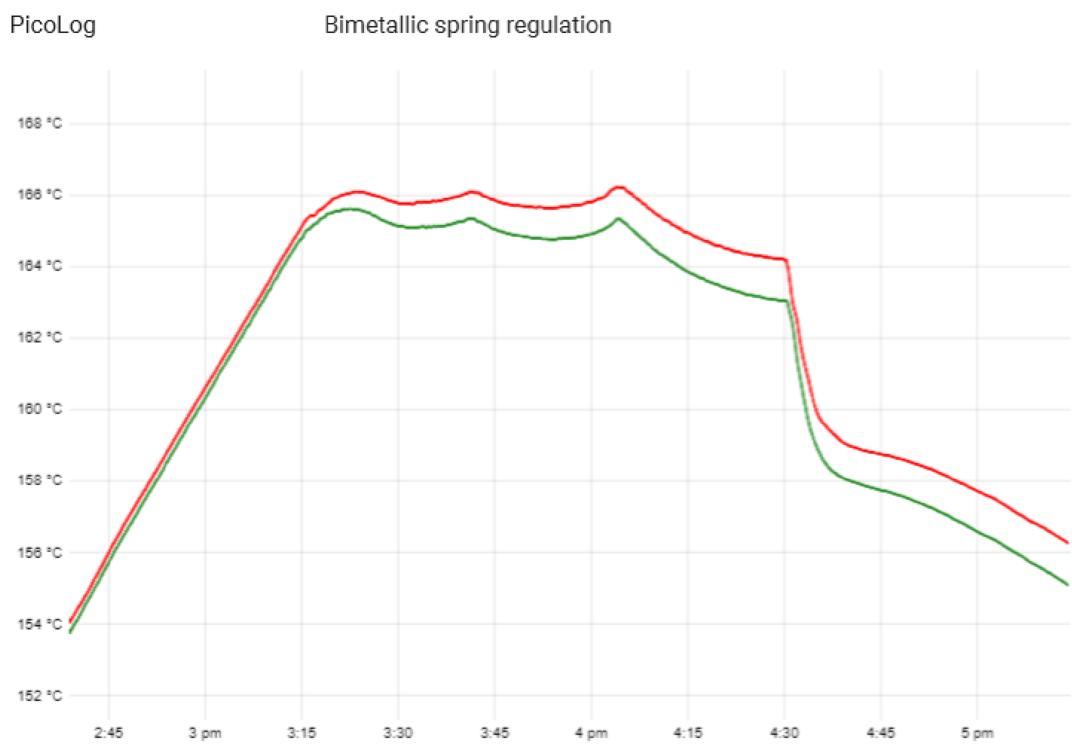
For maximum utilization of the storage tank volume, the heating module was positioned as low as possible inside the storage tank. When the heating module was mounted, there were some leakages detected as a result of the previously mentioned deformation around the threads. This was sealed using a red silicone cream, that could withstand up to 350 °C and is shown in figure 56.

Figure 56: The plug with the heating elements and the bimetallic spring sealed into the storage tank

During this test, the power was supplied from the grid using two adjustable voltage sources at the rated voltage of 24 V, that was capable of currents up to 20 A. These sources are shown in figure 57.

Figure 57: Adjustable voltage sources, rated 20 A, used for testing the spring

The purpose was to detect at which temperature the spring opened at, compared to previous testing, and the results are shown in figure 58.



Channel configuration

■	Inside storage tank	A0059/847 | 2 | Type T	1s - Average
■	Outlet storage tank	A0059/847 | 3 | Type K	1s - Average

Figure 58: Details of the bimetallic spring regulation

As figure 58 indicates, the spring managed to stabilize the temperature at 165 °C quite precisely with low thermal inertia. There were few spikes up and down in the temperature as was detected using the previous solution with the two pistons. However, considering the findings from the testing mapped in figure 53, the spring was suppose to open at around 200 °C.

This difference in opening temperature could be a consequence of the spring not being completely tightened around the pipe. As the difference in opening temperature is 35 °C, it is most likely that the spring has been able to move inside the tank. According to figure 48, the angular movement of the spring is around 80°when the temperature is 165 °C. Thus, the initial position is most likely changed by 15°and further testing needs to be done to reach the desired opening temperature of 200 °C.

Taking this into consideration, a new test had to be conducted despite the difficulties related to inserting and removing the heating module. The heating module was taken out of the system for further inspection. A black circle was marked, through the outer pipe, on the slider at the initial position to measure the angle between this mark and the hole. Using a protractor, this angle was found to be 97°as predicted using figure 48. In order to test the spring under the correct conditions, the spring was adjusted to an opening angle of 97°and the inner pipe was marked with a blue marker to map the difference between the correct and the displaced settings. This is shown in figure 59.

Figure 59: The difference between the correct and the displaced setting of the bimetallic spring

This emphasizes the importance of an improved attachment method, and will be discussed in further sections. It also emphasizes the linear behaviour of the bimetallic spring. After this test was conducted, the slider was mounted on the outer pipe particularly tight for the main testing to be conducted with the correct setting of the bimetallic spring.

5.7 Setup as dump load

The complete test setup consisted of the storage rig, two PV panels, a controller and two batteries connected like figure 60 shows below. The same figure can be seen in the manual from the fabricator in appendix D and shows how to connect the system using the controller in diversity mode. Using the heat storage as dump load for solar energy was the aim for this test setup. Data sheet for PV panels can be found in appendix F and data sheet for the batteries can be found in appendix B.

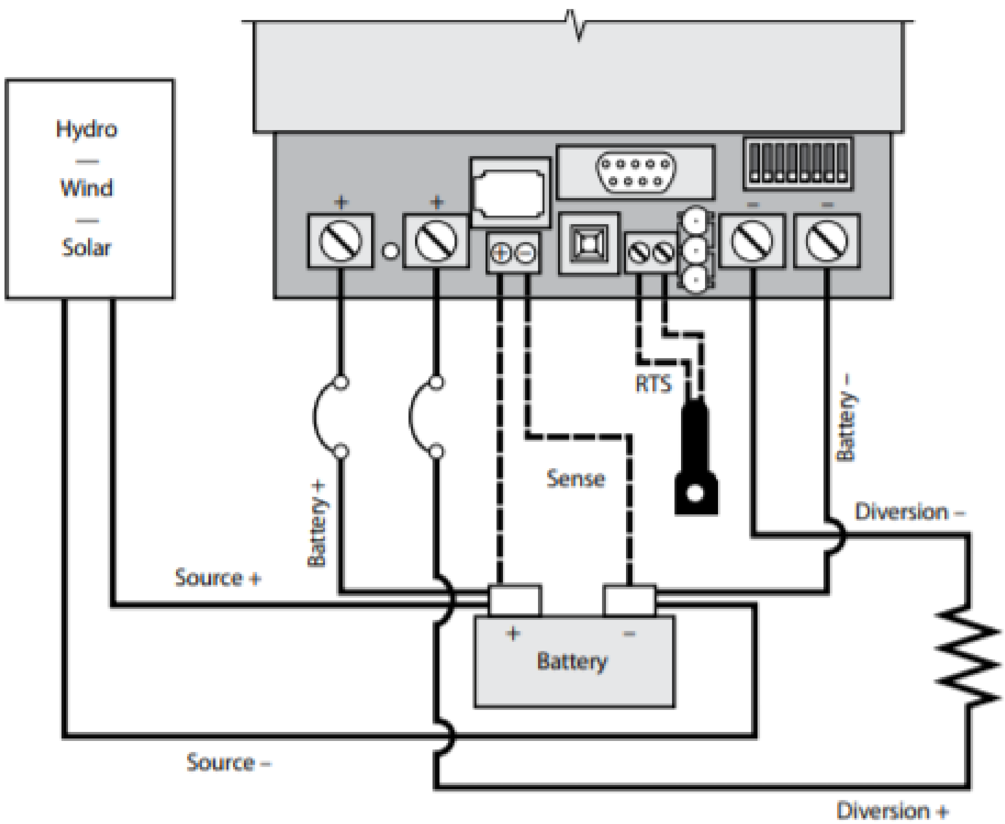
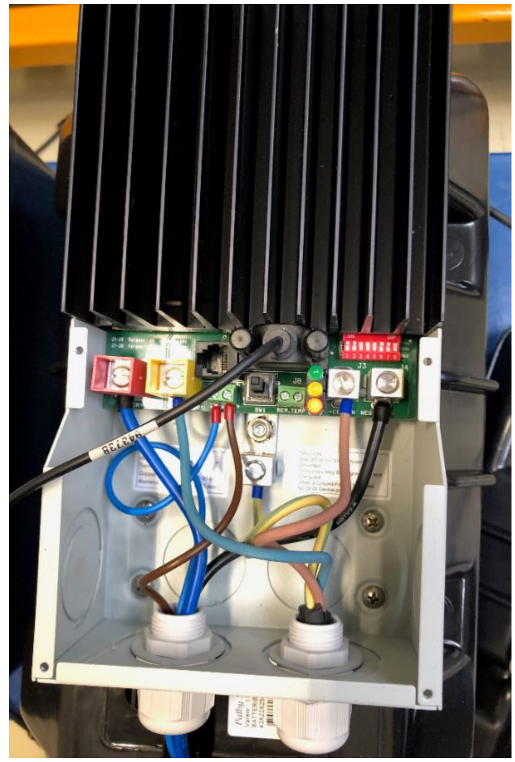


Figure 60: Installation wiring seen in appendix D

To ensure a control mechanism, a controller of the type Pro45 Multi Regulator, see figure 61, was connected to the system between the PV panels and the batteries. Connections can be seen in figure 61b, and was made according to wiring scheme seen in figure 60.

(a) Pro45 Multi Regulator



(b) Inside Pro45 Multi Regulator

Figure 61: Controller Pro45 Multi Regulator

The controller has three different operational modes; solar charging, load control or diversion charge control. For this case, the latter is the wanted mode, where the controller will prioritize to keep the batteries fully charged and then send the excess energy to the dump load. To set the controller at the correct mode, DIP switches inside the controller (see figure 61b, the red box in the upper right corner) were set according to diversion mode and the properties of the system: 24 V, see appendix 1 in appendix D for the Diversion Charge Control DIP Switch Settings.

From figure 60, it can be seen that the PV panels are connected directly to the battery, and the battery to the controller. The load (in this case the heating elements) are also connected to the controller to make the diversion mode possible. It is important that the load can take the entire capacity of the PV panels if all power generated is directed from the batteries.

To simulate the sun, high efficiency lamps from the laboratory at NTNU are used, see figure 62. Two PV panels connected in parallel, with ratings 260 W 30.92 V, are working as the renewable energy source, and the two batteries of 115 Ah 12 V connected in series, are chosen to match the maximum capacity of the system.

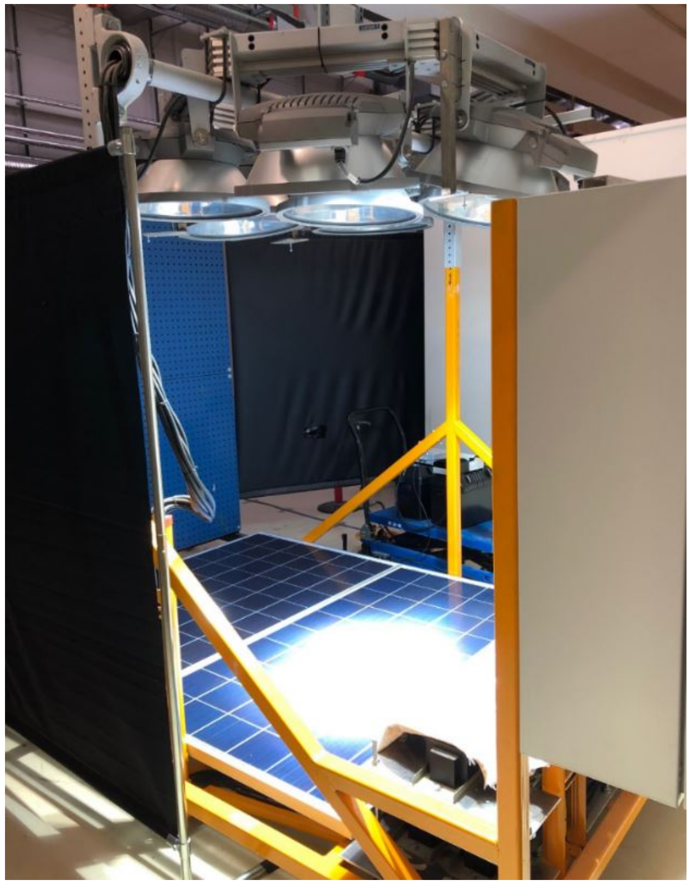


Figure 62: PV module setup with lamps and shielding

Figure 63 shows the two batteries placed in each container for safety. The controller is fastened on the left battery container and a fuse box is fastened on the right container, preventing the system from high currents.

Figure 63: Battery setup with controller and fuse box

5.8 Data collection

At the NTNU laboratories, temperatures was measured by the PicoLog system exclusively. This system plots the readings from the K-type sensors live as a graph, which is directly imported to the results section for further commenting and discussion. The thermal sensors were placed around the system; one in the flow out of the pan, one near the outlet of the storage tank and two in the storage tank close to the heating elements.

To measure the power delivered at the bimetallic spring test, an ammeter was used in combination with the regulating voltage sources, which was set to a known voltage level.

During the test with the complete setup, the controller measured the chosen relevant parameters. These readings were displayed and saved using the integrated software MSView, and presented in the results.

6 Analysis

The concept testing consisted of two parts. Firstly, the regulating abilities of the bimetallic spring was examined in combination with the heating elements inside the tanks, with power supplied from the grid. Secondly, the entire system was connected and tested in the dump loading mode with PV panels connected as the power source.

6.1 Bimetallic spring

Figure 64 shows the first test conducted with the spring inside the storage tank. It is the same test as shown in detail in figure 58, but this figure shows the entire logging period which is two days.

Figure 64: Test of bimetallic spring over 2 days

As figure 64 shows, and as previously mentioned, the system did not open at the desired temperature of 200 °C. However, it managed to stabilize both days at around 165 °C, which indicates that the regulation works. Despite the setting of the spring being displaced at this point, the results is included to evaluate other aspects of the test such as heat losses, cooking properties, and temperature variations.

An observation is the heat losses overnight. Compared to the system in Arusha, the system at the NTNU laboratories was more complex in terms of insulation. It contains several parts at the surface of the tanks making it difficult to insulate sufficiently. However, the system maintained a sufficient temperature after remaining turned off an entire night. During the 16 hours from when the system was turned off to the next day when it was turned back on, it only dropped by 80 °C which indicated a sufficient insulation.

At day two of testing, shown in figure 64, the flow to the cooking application was opened to test the pan. The temperature out of the pan was around 115 °C which indicates a considerable amount of heat being extracted in the pan. As figure 65 shows, the pan worked well for making pancakes and boiling of water.

As the oil was used in the cooking application, tank 1 was emptied as the graph in figure 64 indicates at around 3:00 pm. The result was a raised temperature in the storage tank as the oil level decreased and no cold oil entered. Oil was then pumped back to tank 1 from tank 3 and then let trough to the storage tank to make sure the heating elements were covered. The system was also turned off as a safety measure. This resulted in continued rise in temperature but after some minutes, the temperature decreased.

Figure 65: Boiling water and making pancakes

The final test was done to see the regulation at a higher temperature. The setting was as an estimate based on previous data collected and presented in figure 48.

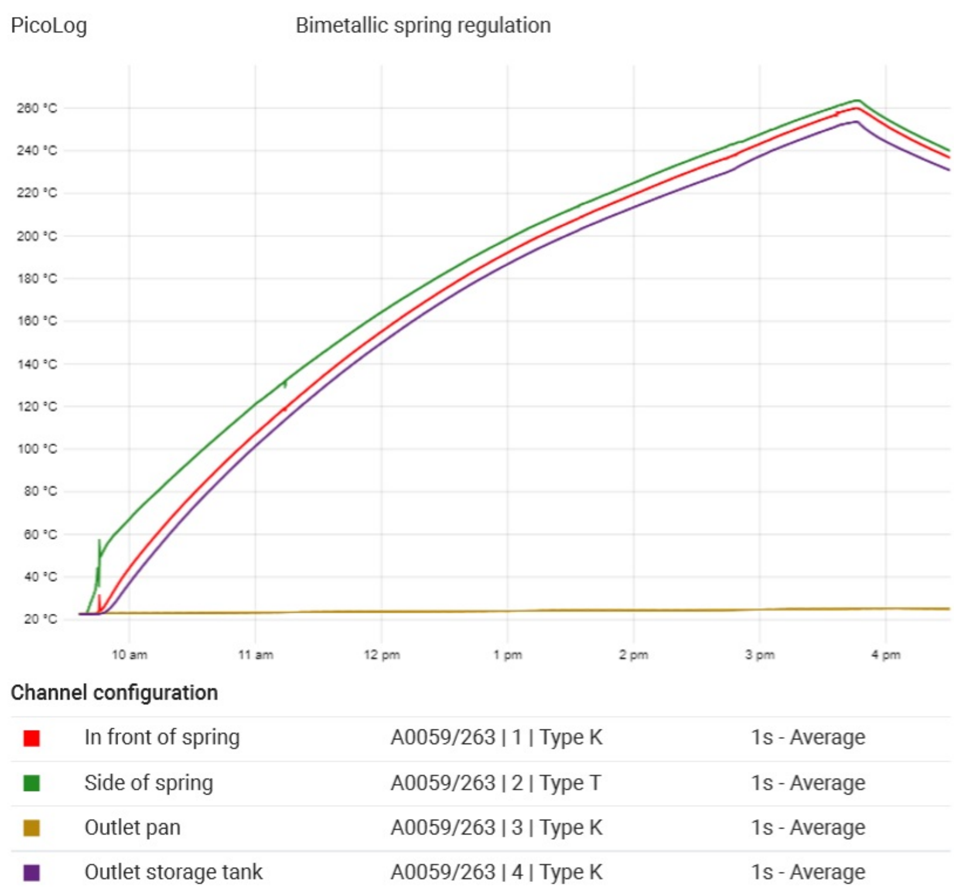


Figure 66: Failed test with bimetallic spring

Based on the results showed in figure 66, it might have been improperly placed due to the lack of regulation. This will be discussed further in section 7.

6.2 Complete setup as dump load

During testing of the complete setup, several flaws were uncovered. The surface temperature of the PV panels exceeded the NOCT, see section 3.3, as the lamps used generated too much heat. The resulting efficiency was low, and little power was generated for the test. The temperature sensor installed for security was not capable of detecting the correct temperature and inspection of the panels resulted in the discovery of a hot spot developed at the center of one of the panels.

In figure 67, the periods of 28 V is equivalent to power being sent to the dump load, as seen in figure 68.

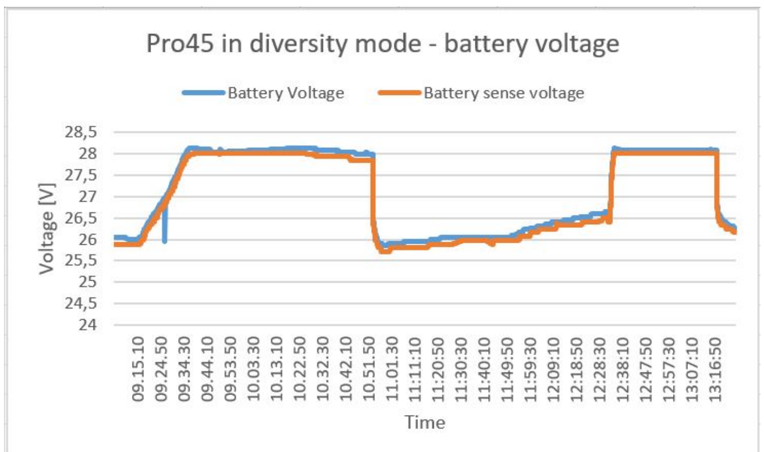


Figure 67: Tests showing the battery voltage and battery sense voltage

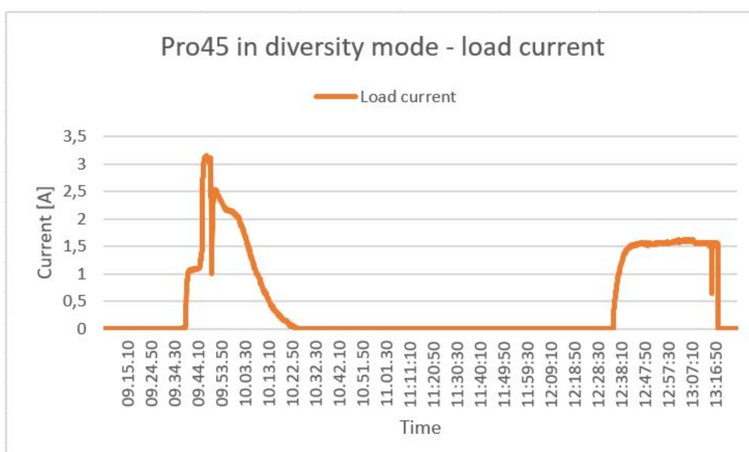


Figure 68: Test showing the load current

As it can be seen in figure 68, the current being drawn by the load is slightly above 3 A at maximum and the heating elements in the storage tank are dimensioned for 20 A.

To illustrate how this affected the temperature in the heat storage, see figure 69 for an indicator. The input power resulted in a small temperature increase in the oil from 24 °C to 26 °C. The disturbances in the graphs are probably due to the low stability of the energy source.

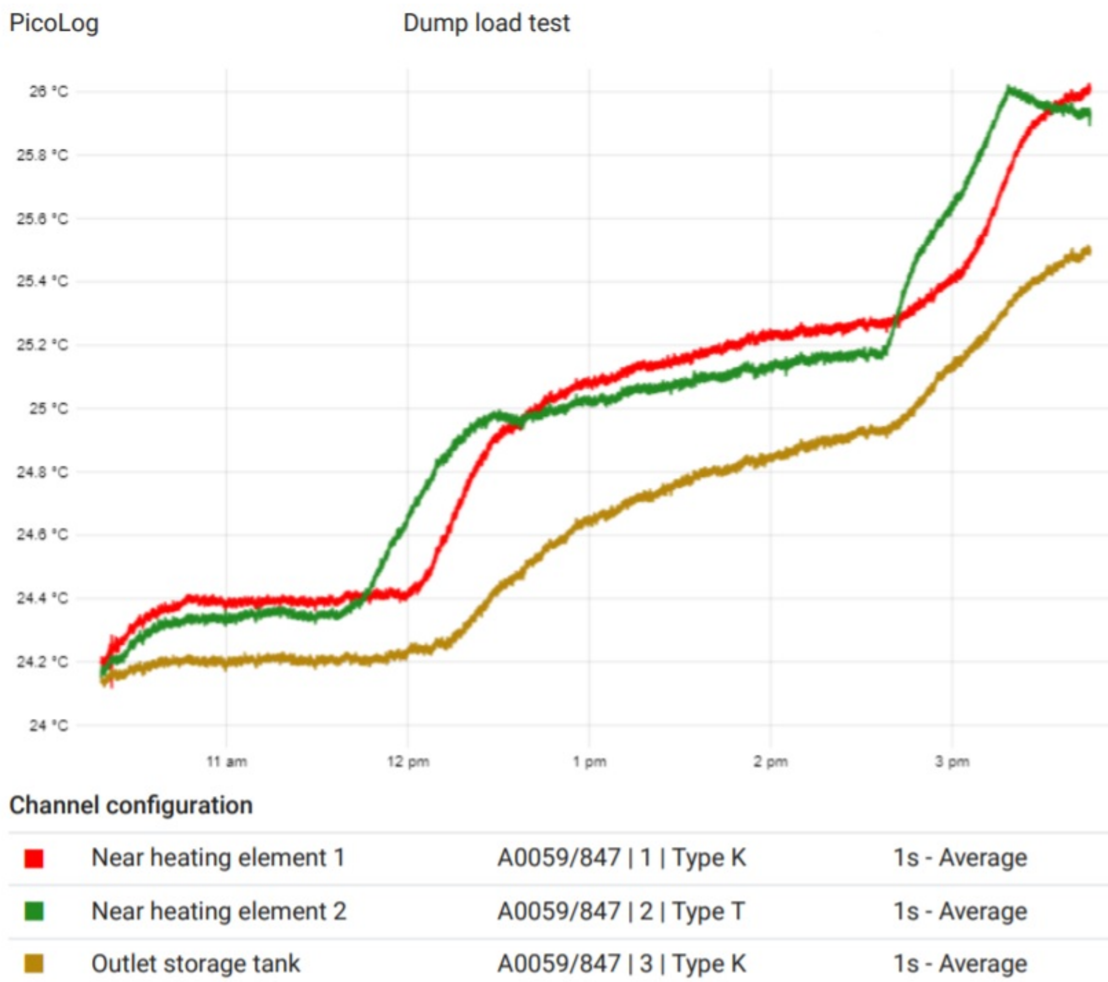


Figure 69: PicoLogger results

7 Discussion

In this section the experiences from the field work conducted in Tanzania will be discussed, and how this experience was used back at the NTNU laboratories.

7.1 Thermostatic valve

The first issue encountered was getting the piston valve to work. It required a closed loop of oil, with no air in it. This was something that was achieved at NTNU previously, but in the conditions in Tanzania, and with the equipment available this proved futile. The closed loop was leaking in air, and not doing what it was designed for. Furthermore, the O-rings around the piston were too large, and the piston ended up getting stuck. After searching for a smaller replacement with no success, it was decided to try the bimetallic spring instead. This looked promising, but in a rush to get this functioning before the time of the field work was up, a mistake was made, where the valve pipes were welded upon. This resulted in them becoming slightly deformed, which proved problematic for opening and closing. Further testing done at NTNU, after the field work, showed that the concept was viable. The thermostatic valve has now been made into a more complete part, that could be used anywhere. It requires no additional work besides the fine tuning of what opening temperature is desired. This is the sort of changes that is required for it to be successful in the intended areas. There is still work to be done in simplifying the fine tuning of the spring, the way it is now it requires some trial and error to find the right temperature. In addition, the set up consists of several moving parts that needs to be put in place which increases the chances of displacing the spring. This will be further discussed in the next section.

7.2 Data collection

Another slight problem that was discovered on the field work was the measuring equipment created. In order to collect all system readings automatically using one device exclusively, the data logger needs to be further developed. It encountered a software issue when it reached temperatures of 256.75 °C. This was briefly looked into, and the findings was that it possibly is a result of the 9-bit resolution. Using two's compliment on a 9-bit number gives values in the range of -256 to 255, which matches well with the upper limit for the temperatures the data logger read. Increasing the temperature precision above 9 bits in the code was tested without success. After a while, it was decided to not spend too much time on since the data logger was more of a tool to help gather data and not the main goal. In addition, since the problem temperature at 256.75 °C was above the designed temperature of 240 °C, the solution was to work around it.

Initially the idea was to measure the current using the data logger. This aspect did not get completed in time, as some additional changes would be needed. Therefore the solution became to use the PicoLogger. As shown in section 4.5.6, there was a significant difference between the values obtained from the PicoLogger, and the values checked manually. This was confirmed using different multimeters, thus the final data was gathered manually. It was speculated that the reason for the PicoLogger not working properly was the lack of a common ground. The current going to the prototype was part of the off-grid system with the PV panels, while the PicoLogger was connected to the computer that drew power from a different source. This could cause the readings to lack a reference, thus giving the wrong numbers even if the trends are the same.

The thermal sensor placement in Tanzania had to be somewhat improvised due to the plumbing. There was no easy way of getting a thermal sensor to touch the flow out of the cooker. The best available adaption was to put it in contact with the outside of the pipe, and insulate around. The thought was that even though it would not be as responsive when measuring the change in temperature of the outgoing oil, it would trend toward the right maximum temperature. This was one of the first improvements that was made to the system back at NTNU, where the thermal sensor was placed inside the pipe directly after the pan.

When doing tests with solar panels in Trondheim, the options were not ideal. The limited sun, would not give the desired power from the PV panels, so the solution was to try the simulated sun at NTNU. This had never been used for PV panels before, and was originally designed for simulating the sun for a solar concentrator. The result during testing was the surface temperature of the PV panels increasing rapidly, and causing a very low efficiency. Even though the supplied power was not what was hoped, the test was mainly done to see how the diversion controller would work. The tests showed clearly that when the set battery voltage was reached, the load current increased. Then after the battery reached a certain limit the controller focused power back to recharging the batteries.

7.3 Insulation

A test that was conducted several times was where the system was turned off over night to see how the temperature changed. This was generally done with a low oil level to see a worst case scenario, how much energy was stored. Since the system is designed to be a dump load, it is important that insulation is sufficiently good, where it can take small bursts of power from the heating element, and accumulate a high temperature over time. If the temperature change is too big, then this will not work. This is something that was experienced with the prototype at NTNU, but it looked better on the system in Tanzania. This was due to the barrel in barrel technique, where it was possible to get the insulation properly placed without applying too much pressure on it. The system at NTNU had to be held in place using insulation tape, which included applying enough pressure to keep it tightly wrapped. This removes a lot of the air pockets, thus reducing thermal resistance.

7.4 Safety

Safety has been a focus throughout the work, and measures were taken in case something should happen. Before the prototype could ever be a commercial product, several measures would be needed to make sure it is safe for use. Since this project has been more focused on testing, and finding if the concepts were viable, many of the safety systems have not been implemented.

The importance of safety systems was clearly seen through an episode that happened during testing. New heating elements were installed, and because of a misunderstanding it had been designed such that the surface temperature of the heating elements were higher than the boiling point of the oil. This caused the oil to boil at one side of the storage tank, and caused a lot of pressure to build up, which in turn increased the flow rate through the frying pan. This caused the oil level in the storage tank to quickly drop below the minimum, and the heating elements were exposed to air. Since the temperature was above the flash point, a sudden expansion caused some oil to be ejected out the air inlet. Fortunately, this was one of the worst case scenarios that were prepared for, and the oil had a place to eject where no one could be harmed. The power was cut from a place that was not exposed, and valuable information was gained. Measures were taken, such that this could not happen again. However this highlights the need for proper security systems to be in place. Even during testing when the potential risks were taken into account, accidents can happen. It was because of this episode more thermal sensors were added to the storage tank as well, to get a better understanding of the conditions inside, and ensure that the temperature was within a safe range, even close to the heating elements. Another change was to lower the power to the heating elements, such that the surface temperature did not boil the oil.

8 Conclusion

To provide a fossil fuel and pollution free alternative for cooking, a system was built and tested in Arusha, Tanzania and at NTNU. During testing, it was demonstrated that it is viable to use oil for heat storage and cooking.

Two different fully mechanical solutions were tested as thermostatic valves. This included a bimetallic spring and a cylinder with two pistons. The bimetallic spring was found to be more suited for the conditions in Tanzania as it is simpler. It also has the potential to be made into one finished part, that can easily be installed on a different system. Further testing, revealed that the bimetallic spring regulated the heat storage well at the target temperature of 165 °C. Testing also revealed difficulties related to the movement of the spring when the desired opening temperature was adjusted to 200 °C. The attachment method of the bimetallic spring caused it to get stuck when it expanded to a certain point. Because of this, it failed to regulate the flow. This is an important aspect to improve, and has a lot of potential as described in the next section.

The prototype built in Tanzania was connected to an off-grid PV system without battery storage, using a load controller. This successfully controlled whether the power flow should be directed at one or both of the heating elements, according to the level of power delivered from the panels.

The system was also demonstrated as a dump load with batteries, a charge controller and PV panels connected, at NTNU. Since the surface temperature of the solar panels exceeded the NOCT temperature, the test conditions were not ideal. However, it was shown that the charge controller diverted excess PV power to the heat storage, when the batteries were full, despite the low resulting current.

The setup was tested using solar successfully, but due to limited availability on the lab, there was no opportunity to test with hydro power. This will be discussed in further work.

9 Further work

9.1 Safety system

As described in the discussion section, a safety system is needed to prevent the system from overheating. Firstly, the system at the NTNU laboratories needs to be modified similarly to the Arusha system in terms of the outlet of the storage tank. The level of the outlet should be raised to ensure the oil level to remain above the heating elements in any case like it is in Arusha. In this way, the heating elements will not be exposed to air under any circumstances.

Secondly, the oil level in tank 1 needs to be monitored for the system to respond when tank 1 is empty. A solution to this could be a thermal switch monitoring the temperature inside the storage tank. Once the oil reaches a certain set threshold temperature, the switch turns of the power to the heating elements. Another option could be to drill a second hole in the slider to enable an inlet for cold oil if the spring moves past the hole as a result of the increased temperature inside. This is also a way of preventing the system from overheating, if the bimetallic spring fails to regulate the temperature.

9.2 Combinations with other systems

To increase the efficiency, a solution could be a combination with other systems. An option is to use a solar collector to preheat the oil before entering tank 1. Another suggestion is to connect a refrigeration system at the hot side for the same purpose as the collector. Both options will result in a higher efficiency by raising the initial temperature which leads to a decrease in required energy and time, to reach the desired storage temperature. Another benefit of this combination is that the preheating will limit the problem related to the solidifying of the edible oils. Although the heat will decrease the viscosity of the oil, it will also increase the area of hot surfaces requiring insulation.

9.3 Bimetallic spring modification

The results indicated movement of the spring relatively to the outer pipe. A way to improve this, could be to try another type of attachment to the slider and the outer pipe than the previously tested methods: welding (Arusha) and a hose clamp with a bracket (NTNU). To decrease the amount of moving parts, a solution could be to weld the bracket, the hose clamp and the aluminum splint together. This will result in one single part with a hole fitted for the spring, enabling expansion perpendicular to the pipe, and a tightening screw. Compared to the present setup with several moving parts, setting the initial position will be simplified by only having to move the tightening screw.

However, this method is also cumbersome as the entire heating module has to be taken out and modified to change the initial position of the spring. In addition comes the insulation work and sealing with the red silicone cream that has to dry in 24 hours before use. In general, as long as the module has to be taken out of the storage tank to be adjusted, the system is not optimal. A suggestion for further work is to develop a way to adjust the spring from outside the system. This could be done by connecting the outer pipe through a shaft seal, which enables sealing as well as the possibility to adjust the pipe. The initial setting of the spring could then be done from the outside, and markings could be made at different opening temperatures. As the aim is to develop the heating module as a fixed unit, the challenge will then be to find a way of connecting the spring to the module and not to the tank.

Another suggestion could be to increase the size of the spring, and hence increasing the size of the power exerted from it, to test how the system responds to this compare to the present one.

9.4 Dump loading

In order to prove the concept completely, a test needs to be conducted with the entire setup as the equipment used did not produce a sufficient amount of power. The heating elements should be exposed to a dump load over time to map how the system, and more specifically the heating elements inside the storage tank, responds to a alternating power supply.

9.5 Measurement systems

9.5.1 Data logger

Considering the inability of the data logger to read temperatures above 256.75 °C, the next step would be to look deeper into the software if temperatures are to be measured at this level. As the results indicates an overflow or an unsigned/signed related mistake, a suggestion could be to troubleshoot the source-code of the libraries used (L. T. Riple at Omega Workshop, personal communication, March 2019).

Another software problem associated with the data logger was using the terminal board in the K-type socket. As the voltage signals measured were not detected by the logger, a solution could be to look into the software here as well. Since the terminal board is designed to work in combination with a PicoLog system, it requires additional code to work with an external data logger. As the software developed lack some of this code, the voltage signals measured is not converted and is hence read as regular temperature signals. This additional software needs to be developed for the data logger to be able to read both temperature and voltage measurements.

9.5.2 PicoLog

The PicoLog system served as a backup for the created data logger. However, it did not manage to measure the voltage correctly either. Further development of the data logger will eliminate the need of the PicoLog to measure the voltage, as this, in addition to the temperature readings, will then be done by the data logger. If a PicoLog system is to be used for voltage measurements despite this, the next step could be to examine the grounding as some equipment requires a common ground with the object to be measured to work properly. Another suggestion could be to troubleshoot the method utilizing the shunt to step down the voltage and calculate the current as shown in section 3.4.

9.6 Using hydro power as energy source

As this work only presents results using a PV system, the next step could be to test with hydro power as the energy source. Originally, as mentioned in the problem description, this was suppose to be done but due to the available generators having limited power ratings, it was decided to focus on PV exclusively. Theoretically, the system should work similarly independent of the power source. However, it could be interesting to compare the abilities of the different sources to supply a dump load.

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Appendices

A Arduino IDE code

```
//Libraries included
#include <Adafruit_SPITFT_Macros.h>
#include <Adafruit_ILI9341.h>
#include <Adafruit_SPITFT.h>
#include <Adafruit_GFX.h>
#include <gfxfont.h>
#include <DallasTemperature.h>
#include <Sodaq_DS3231.h>
#include <OneWire.h>
#include <Wire.h>
#include <SPI.h>
#include <SD.h>

//Definitions, where the various pins are connected, allocating memory to
arrays and variables.
#define ONE_WIRE_BUS 2
#define SD_CS 4
#define TFT_CS 7
#define TFT_RST 8
#define TFT_DC 9
#define TEMPERATURE_PRECISION 9

char timeChar[100];
char dateChar[50];
char temperatureChar[10];
float temperature = 0;
float previousTemperature = 0;
uint32_t old_ts;
String dateString;
int minuteNow=0;
int minutePrevious=0;


Adafruit_ILI9341 tft = Adafruit_ILI9341(TFT_CS, TFT_DC, TFT_RST); //Define
how the screen is connected to the UNO.
OneWire oneWire(ONE_WIRE_BUS); // Setup a oneWire instance to communicate
with any OneWire devices (not just Maxim/Dallas temperature ICs)
DeviceAddress insideThermometer; // arrays to hold device addresses
DallasTemperature sensors(&oneWire);
File myFile; //Creating empty file for the SD functions

//Defining Functions used.
void printText(char *text, uint16_t color, int x, int y,int textSize)
{
  tft.setCursor(x, y);
  tft.setTextColor(color);
  tft.setTextSize(textSize);
  tft.setTextWrap(true);
  tft.print(text);
}
void setRTCTime()
{
  DateTime dt(2019, 3, 1, 9, 27, 0, 5); // Year, Month, Day, Hour, Minutes,
Seconds, Day of Week
  rtc.setDateTime(dt); //Adjust date-time as defined 'dt' above
}


void setup(){
// This only runs one time after startup.
```

```
  pinMode(SD_CS, OUTPUT);
  pinMode(TFT_CS,OUTPUT);
  digitalWrite(SD_CS, HIGH); //Disable the SD card pins, to free up the SPI
for the screen.
  Serial.begin(9600);
  tft.begin();
  tft.setRotation(-45);
  tft.fillScreen(ILI9341_BLACK);
  Wire.begin();
  rtc.begin();
  sensors.begin();

delay(1000); //1 second delay, to ensure that all processes has time to
begin.

digitalWrite(TFT_CS,LOW); // Enable the screen

//Screen setup
printText("Sensor:", ILI9341_PINK, 1, 30, 5/2);
printText("Value:", ILI9341_YELLOW, tft.width()/2, 30, 5/2);

printText("TEMP 1", ILI9341_WHITE, 1, 60, 2);
printText("TEMP 2", ILI9341_WHITE, 1, 80, 2);
printText("TEMP 3", ILI9341_WHITE, 1, 100, 2);
printText("TEMP 4", ILI9341_WHITE, 1, 120, 2);
printText("TEMP 5", ILI9341_WHITE, 1, 140, 2);
printText("TEMP 6", ILI9341_WHITE, 1, 160, 2);
printText("VOLT 1", ILI9341_WHITE, 1, 180, 2);
printText("VOLT 2", ILI9341_WHITE, 1, 200, 2);

 setRTCTime(); //uncomment this to set the time, then comment out again.

// Find Thermometer adresses
  if (!sensors.getAddress(insideThermometer, 0))
  if (!sensors.getAddress(insideThermometer, 1))
  if (!sensors.getAddress(insideThermometer, 2))
  if (!sensors.getAddress(insideThermometer, 3))
  if (!sensors.getAddress(insideThermometer, 4))
  if (!sensors.getAddress(insideThermometer, 5))
  if (!sensors.getAddress(insideThermometer, 6))
  if (!sensors.getAddress(insideThermometer, 7))

  sensors.setResolution(insideThermometer, TEMPERATURE_PRECISION);  // set
the resolution as defined.
}

void loop()
{
  // This runs continously in a loop.
  digitalWrite(TFT_CS,LOW); //Enables the Screen
  sensors.requestTemperatures(); //Request temperature update from the
sensors.

  DateTime now = rtc.now(); //get the current date-time
  uint32_t ts = now.getEpoch();
    if (old_ts == 0 || old_ts != ts) {
  old_ts = ts;
  minuteNow = now.minute();
  if (minuteNow!=minutePrevious){ //If the time has changed, update the
string
```

```
    dateString = String(now.date())+"/"+String(now.month());
    dateString= dateString+"/"+ String(now.year());
    minutePrevious = minuteNow;
    String hours = String(now.hour());
    if(now.minute()<10) //If the minute counter is less than 10, add a 0 in
front.
    {
      hours = hours+":0"+String(now.minute());
    }else
    {
      hours = hours+":"+String(now.minute());
    }
    //Print the Date and time to screen.
    hours.toCharArray(timeChar,100);
    tft.fillRect(00,00,tft.width(),25,ILI9341_BLACK);
    printText(timeChar, ILI9341_RED,200,1,2);
    dateString.toCharArray(dateChar,100);
    printText(dateChar, ILI9341_GREEN,65,1,2);
  }


}
//Print the temperature reading for sensors 0-5
for (uint8_t i = 0; i < 6; i++){
tft.fillRect(tft.width()/2,60 + (i*20),90,90,ILI9341_BLACK); //Fill with
black, to erase previous data.
         tft.setCursor(tft.width()/2,60 + (i*20));
    tft.setTextSize(2);
    tft.setTextColor(ILI9341_WHITE);
    tft.print(sensors.getTempCByIndex(i));
    tft.setCursor(tft.width()/2+85,60 + (i*20));
    tft.print("C");
}
//Print the voltage readings from sensors 6-7
    for (uint8_t i = 6; i < 8; i++){
tft.fillRect(tft.width()/2,100 + (i*25),90,90,ILI9341_BLACK); //Fill with
black, to erase previous data.
         tft.setCursor(tft.width()/2,60 + (i*20));
    tft.setTextSize(2);
    tft.setTextColor(ILI9341_WHITE);
    tft.print(sensors.getTempCByIndex(i));
    tft.setCursor(tft.width()/2+85,60 + (i*20));
    tft.print("V");
}
//Done writing to screen, so disable it, and enable the SD card.
digitalWrite(TFT_CS,HIGH);
digitalWrite(SD_CS,LOW);

if (SD.begin(SD_CS)) {
    myFile= SD.open("DATA.txt", FILE_WRITE); //Open the file called
DATA.txt, and create it if it doesn't exist.
  //Write the data readings to the SD card, with the desired format.
 for (uint8_t i = 0; i < 6; i++){
    myFile.print("Sensor ");
    myFile.print(i+1);
    myFile.print(": ");
    myFile.print(dateChar);
    myFile.print(" ");
    myFile.print(timeChar);
    myFile.print(" ");
    myFile.print(sensors.getTempCByIndex(i));
```

```
    myFile.println(" C");  }
 for (uint8_t i = 6; i < 8; i++){
    myFile.print("Sensor ");
    myFile.print(i+1);
    myFile.print(": ");
    myFile.print(dateChar);
    myFile.print(" ");
    myFile.print(timeChar);
    myFile.print(" ");
    myFile.print(sensors.getTempCByIndex(i));
    myFile.println(" V");}
myFile.close(); } //Close the file.

digitalWrite(SD_CS, HIGH); //Disable the SD card.
delay(3000); //30 second delay, to not flood the SD card with readings.
}
```

B Battery data sheet

SØNNAK BATTERIES

Marinebatterier

TYPE APPROVED PRODUCT
DNV·GL
MARITIME

Product registered and VERIFIED www.thencc.org.uk

Et enestående batterisortiment

Powering your freedom

Komplett batterisortiment for alle maritime behov:

Motor start

Forbruk

Start og Forbruk

Made in Europe
by Exide Technologies
Original Equipment
Manufacturer

Valget av riktig batteri sikrer lengere og tryggere båtturer

Til sjøs er sikkerheten og trivselen avhengig av nok strøm til båtens utstyr. Stort sett er det batterier som driver viktige funksjoner som startmotor, radio, GPS og lanterner. Exides nye marine sortiment sørger for at utstyret fungerer og dekker behovene for både profesjonelle og private brukere.

Med riktig marine batteri kan du nyte båtlivet uten å være urolig for at viktige funksjoner skal slutte å virke. Det nye sortimentet er også førstevalget blant båtprodusenter. Takket være DNV-sertifiseringen er det enklere å få godkjennelse i henhold til det europeiske regelverket for nybygde båter.

Hvordan velge de beste batteriløsningene:

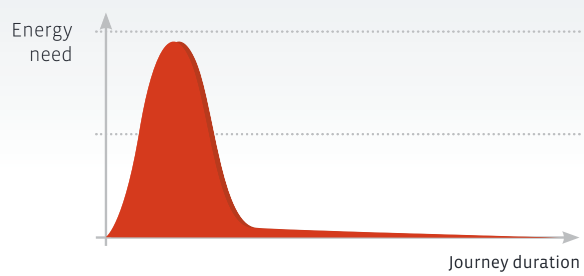
1. Identifiser båtens energibehov
2. Identifiser batteritype ut fra båtens elektriske system
3. Velg riktig batteriteknologi ut fra hvordan batteriet skal brukes

Hvordan velge de beste batteriløsningene:

1 Identifiser båtens energibehov

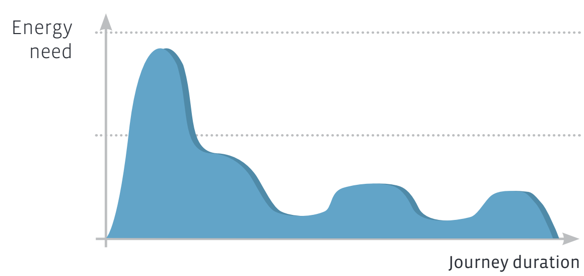
Engine Start Need

Når batteriet kun brukes til å starte motoren må det levere en høy startstrøm en kort stund. Når motoren har startet belastes ikke batteriet mer. En elektrisk enhet for å måle startkraft er MCA*.



Dual Supply Need

Når batteriet brukes til å starte motoren og som strømforsyning må det levere en høy startstrøm og samtidig tåle gjentatte utladinger. Den elektriske enheten for å måle energibehovet er Wh*.



Equipment Supply Need

Strømforsyning til installasjoner for komfort og sikkerhet bruker mye energi og fører til at batteriet blir utsatt for kraftige utladinger. Den elektriske enheten for å måle energibehovet er Wh*.

*MCA = Mål for marine startkraft, angis i A (strøm) og måles ved 0 °C.
*Wh = Batteriets tilgjengelig energi. Den energi, målt ved 20 timers bruk som et batteri kan avgi uten å overskride anbefalt maksimal utladning

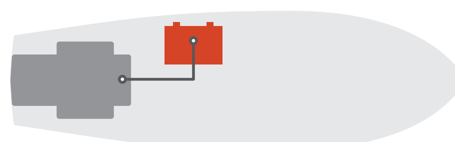
Hvordan velge de beste batteriløsningene:

2 Identifiser batteritype ut fra båtens elektriske system

Eksempler på forskjellige behov

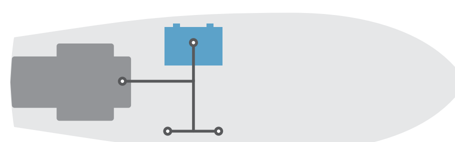
A. Kun motor

Båter der batteriet kun brukes til å starte motoren og der utstyret ikke har behov for strømforsyning i perioder når motoren ikke er i gang faller under gruppen Engine start need.



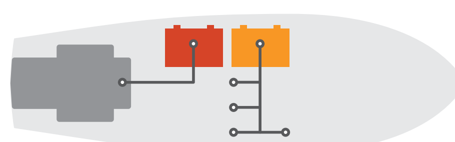
B. Motor og utstyr

Båter som har felles batteri for både startmotor og elektrisk utstyr faller under gruppen Dual supply need.



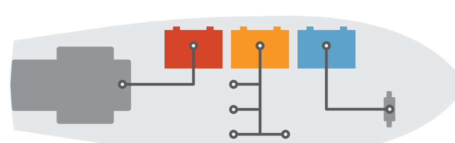
C. Motor + utstyr

Båter som har to adskilte batteribanker, en for start og en for forbruk, krever to ulike batteriløsninger; et startbatteri under gruppen Engine start need og et forbruksbatteri under gruppen Equipment supply need.

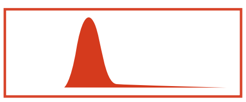


D. Motor + utstyr + annet

Båter som i tillegg til to adskilte batteribanker (start og forbruk) også har installert batterier for annet utstyr, f.eks. elektriske sidepropeller, vinsjer, ankerspill etc. bør utstyres med batteriløsninger av tre ulike grupper; Engine start need, Equipment sypply need og Dual supply need.

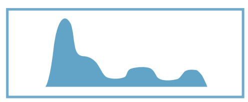


Hvert energibehov har sin optimale batteriløsning



Engine Start Need

START-batterier er utviklet for å levere høy startstrøm. De brukes vanligvis som strømkilde for å starte standardutstyrte båter (eksempel A), men også som en del av batteriinstallasjonen i båter med mye elektrisk utstyr (eksempel C og D). Ved denne bruken holdes batteriene fulladede siden dynamoen lader dem raskt opp når båten går. Batterier som anbefales for start har høy ytelse og lang levetid. START-sortimentet er utviklet for å dekke startbehovet for alle typer båtmotorer.



Dual Supply Need

DUAL-batterier er utviklet for bruk i båter med felles batteri for hele båtens strømforsyning (eksempel B), men batteriene kan også brukes til å drive elektriske sidepropeller, vinsjer og ankerspill eller annet utstyr (eksempel D). Disse typene installasjoner innebærer at batteriene blir delvis utladede under bruk og har derfor forsterkede batteriplater. DUAL-sortimentet har løsningen for å dekke energibehovet for de aller fleste små og middelsstore båter.

Equipment Supply Need

EQUIPMENT-batterier er utviklet for bruk i båter med adskilte strømkretser for elektrisk utstyr. Dette gjelder strømforsyning til navigator, redning, sikkerhet og komfort (eksempel C og D). Denne typen installasjon innebærer at batteriene blir delvis, eller til og med helt utladet ved bruk og derfor må man ha batterier som tåler hyppig lading. EQUIPMENT-sortimentet er løsningen for å dekke energibehovet til alt fra småelektronikk til reservekraft.

START

DUAL

EQUIPMENT

*MCA = Mål for marine startkraft, angis i A (strøm) og måles ved 0 °C.
*Wh = Batteriets tilgjenglige energi. Den energi, målt ved 20 timers bruk som et batteri kan avgi uten å overskride anbefalt maksimal utladning.

Hvordan velge de beste batteriløsningene:

3 Velg riktig batteriteknologi ut fra hvordan batteriet skal brukes

Engine Start Need

Teknologi:

Åpent standardbatteri med ventiler

Fordeler

- Overlegen startkraft
- Vedlikeholdsfritt
- Lav gassutvikling
- Skal installeres med utluftningsmulighet
- Kan monteres med svak helding

Teknologi:

AGM standard eller spriralteknologi.
Ventilreguleret uten flytende syre

Fordeler

- Overlegen startkraft
- Vedlikeholdsfritt
- Lang holdbarhet
- Innebygd rekombinasjon
- Ingen begrensninger på bruksområde *(sikker å montere i kabin)*
- Sikker og ren (*gnist & spill-tett)*
- Kan monteres med høy helding
- Motstandsdyktig mot høye vibrasjoner og vipping
- Opp til 50% hurtigere oppladning

Dual Supply

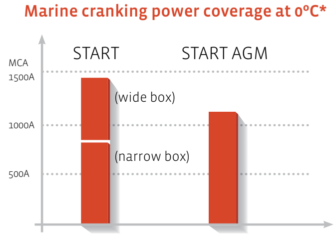
Teknologi:

Åpent standardbatteri med sentral avgasning

Fordeler

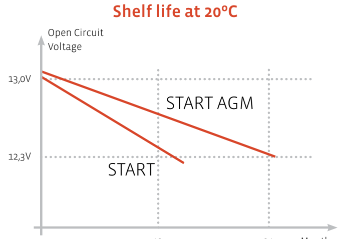
- Lavt vedlikeholdsbehov
- Lav gassutvikling
- gnist fanger & sentral utluftning for sikker gass utledning
- Monteres stående
- Motstandsdyktig mot vibrasjoner og delvis helding
- Start & Forbruk
- Indikator (Magic Eye) for kontroll av elektrolytt og ladning (*unntak ER660)*

START & START AGM
Marine cranking power coverage at 0°C*

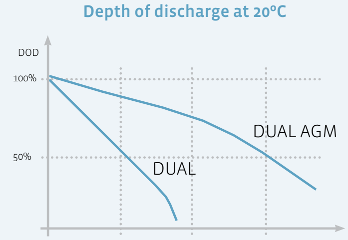


* Referred to BCI standard for Marine Cranking Amperes (MCA)

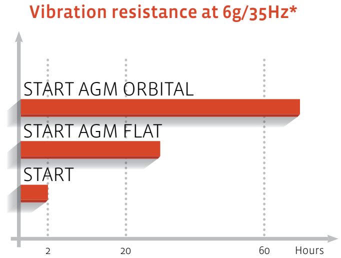
START & START AGM
Shelf life at 20°C



DUAL & DUAL AGM
Depth of discharge at 20°C



START & START AGM
Vibration resistance at 6g/35Hz*



* Referred to EN50342

Need

Equipment Supply Need

Teknologi:

AGM standard eller spiralteknologi. ventilreguleret uten flytende syre

Fordeler

- Vedlikeholdsfritt
- Lang holdbarhet

- Innebygd rekombinasjon
- Ingen begrensninger på bruksområde *(sikker å montere i kabin)*
- Sikker og ren (*gnist & spill-tett*)

- Kan monteres med høy heldning
- Motstandsdyktig mot høye vibrasjoner og heldninger

- Hurtig oppladning
- Opp til 50% hurtigere oppladning

- Ekstra start og forbruk

Teknologi:

Åpent standardbatteri med glassmatte seperator og pol-utluftning (semitraktion)

Fordeler

- Lavt vedlikeholdsbehov

- Overlegen startkraft

- Kan monteres med svak heldning
- Motstandsdyktig mot vibrasjoner og delvis heldning

Teknologi:

Gel batteri (elektrolytt fiksert i gele) Ventilregulert uten flytende syre

Fordeler

- Vedlikeholdsfritt
- Lang holdbarhet

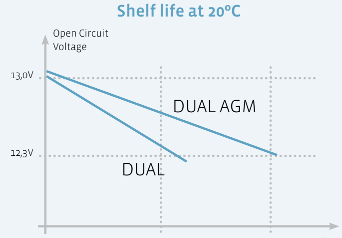
- Innebygd rekombinasjon
- Ingen begrensninger på bruksområde *(sikker å montere i kabin)*
- Sikker og ren (*gnist & spill-tett*)

- Kan monteres med høy heldning
- Motstandsdyktig mot høye vibrasjoner og heldninger

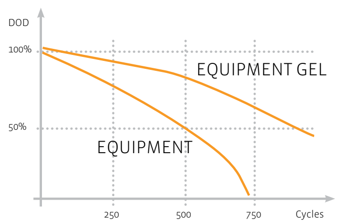
- Høy energitetthet
- Plassbesparende med opp til 30%

- Overlegen startkraft

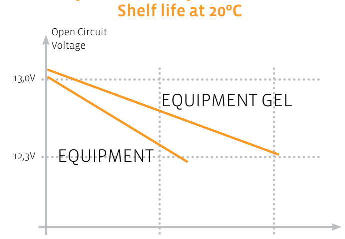
DUAL & DUAL AGM
Shelf life at 20°C



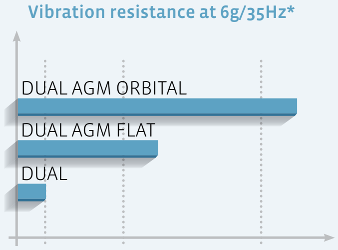
EQUIPMENT & EQUIPMENT GEL
Depth of discharge at 20°C



EQUIPMENT & EQUIPMENT GEL
Shelf life at 20°C

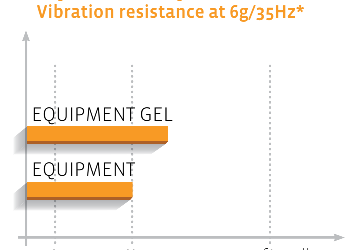


DUAL & DUAL AGM
Vibration resistance at 6g/35Hz*



* Referred to EN50342

EQUIPMENT & EQUIPMENT GEL
Vibration resistance at 6g/35Hz*



* Referred to EN50342

Avslutt ditt valg ved å beregne den nødvendige energi målt i watt pr. time

1. Start med å beregne enhetens forbruk

Enhet	Energiforbruk (W)	Daglig forbruk i tid (h)	Nødvendig energibehov (W)x(h)=(Wh)
Lyspære	25	4	100
Kaffemaskin	300	1	+ 300
TV	40	3	+ 120
Vannpumpe	35	2	+ 70
Kjøleskap	80	6	+ 480
		TOTALT ENERGIBEHOV	= 1,070

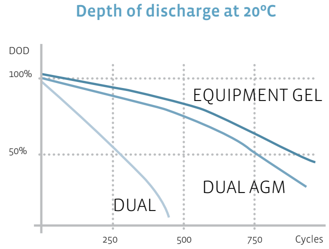
2. Tilføy en sikkerhetsfaktor for å dekke overforbruk (anbefalt)

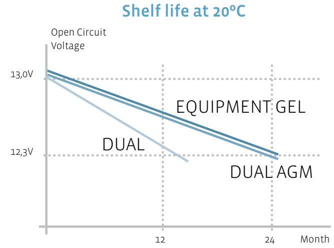
SIKKERHETSFAKTOR	x 1.2
TOTAL ENERGIBEHOV	= 1,284

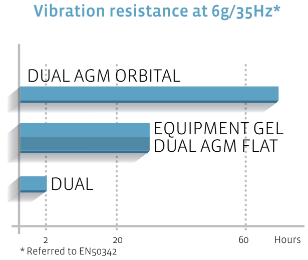
3. Velg batterier utfra energibehovet

EQUIPMENT GEL	1 batteri	ES1300	Yter	1,300 Wh*	med en vekt på	39 kg
DUAL AGM	2 batterier	EP 900	Yter 2x900=	1,800 Wh*	med en vekt på 2x32=	64 kg
DUAL	3 batterier	SR 450	Yter 3x450=	1,350 Wh*	med en vekt på 3x23=	69 kg

*Wh = Batteriets tilgjengelig energi. Den energi målt ved 20 timers bruk som et batteri kan avgi uten å overskride anbefalt maksimal utladning





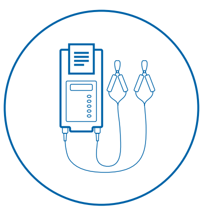


Visste du... ?

Når valgt batteriteknologi ikke oppnår det nødvendige Wh for en båt, må du enten øke antall batterier som er koblet parallelt eller oppgradere til Equipment Gel batterier

Mere enn batterier

Selv om marinebatterier er sesongbasert, er verktøy som testere og batteriladere avgjørende for både fagfolk og sluttbrukere. Exide har ett stort utvalg av tilbehør og support til batterier, for alle kjøretøy. Vi hjelper med å teste, lade, velge og bytte batterier samt resirkulere gamle batterier.



Testing

Battery Tester

Test alle batterier for å feilsøke og sikre batteriet.

Lading

Suitable for marine

Batteriladere

Exides ladere kan brukes for batterier til biler, båter og motorsykler, og de er ideelle for både forbrukere og profesjonelle. På verksteder brukes laderne for å sikre at kundene alltid forlater verkstedet med fulladede batterier etter service.

Valg av batteri

App for batterisøk

Søk etter bilmodell eller registreringsnummer, og finn riktig batteri raskt og enkelt.

QR-kode

Vil du raskt og enkelt finne ut mer om batteriet? Skann QRkoden på batterietiketten, og få mer informasjon med en gang.

Nettkatalog

Finn riktig batteri ved hjelp av vår nettbaserte katalog på www.sonnak.no

Sønnak resirkuleres!

Hva skal man gjøre med gamle batterier?
Gamle brukte batterier skal tas hånd om og gjenvinnes. Les om hvordan dette skjer, på batterireturs hjemmeside: www.batteriretur.no

Tekniske spesifikasjoner

	ART.NR	TEKNOLOGI			YTELSE			DIMENSJONER			TEKNISK INFO				DNV·GL
		GEL	AGM Flat	AGM Orbital	MCA* A (BCI)	KAPASITET Ah (20h)	CCA A (EN)	L (mm)	B (mm)	H (mm)	POLSTIL-LING	POLTYPE	Vekt (kg)	beho der-type	
START AGM 	EM 900			•	900	42	700	230	173	206	1	Standard + Skruvpol	16	G86	•
	EM1000			•	1000	50	800	260	173	206	1	Standard + Skruvpol	18	G34	•
	EM1100		•		1100	100	925	330	173	240	9	Standard + Skruvpol	33	G31	•
START 	SN 500				500	50	450	210	175	190	0	Standard	13	L01	
	SN 600				600	62	540	242	175	190	0	Standard	15	L02	
	SN 750				750	74	680	278	175	190	0	Standard	18	L03	
	SN 800				900	90	720	353	175	190	0	Standard	22	L05	
	SN 850				850	110	750	350	175	235	1	Standard	28	D02	
	SN 900				900	140	800	513	189	223	3	Standard	37	D04	
	SN1100				1100	180	1000	513	223	223	3	Standard	45	D05	

	ART.NR	TEKNOLOGI			YTELSE			DIMENSJONER			TEKNISK INFO				DNV·GL
		GEL	AGM Flat	AGM Orbital	Wh*	KAPASITET Ah (20h)	CCA A (EN)	L (mm)	B (mm)	H (mm)	POLSTIL-LING	POLTYPE	Vekt (kg)	Beho der-type	
DUAL AGM 	EP 450			•	450	50	750	260	173	206	1	Standard + Skruvpol	19	G34	•
	EP500		•		500	60	680	242	175	190	0	Standard	18	L02	•
	EP600		•		500	70	760	278	175	190	0	Standard	21	L03	•
	EP650		•		650	75	775	270	173	222	1	Standard + Skruvpol	23	D26	•
	EP800		•		600	95	850	353	175	190	0	Standard	27	L05	•
	EP 900		•		900	100	720	330	173	240	9	Standard + Skruvpol	32	G31	•
	EP1200		•		1200	140	700	513	189	223	3	Standard	45	D04	•
	EP1500		•		1500	180	900	513	223	223	3	Standard	55	D05	•
	EP2100		•		2100	240	1200	518	279	240	3	Standard	72	D06	•
DUAL 	SR 350				350	80	510	260	175	225	1	Standard	19	D26	
	SR 450				450	95	650	310	175	225	1	Standard	23	D31	
	SR 550				550	115	760	350	175	235	1	Standard	29	D02	
	SR 650				650	142	850	350	175	290	1	Standard	35	D03	

EQUIPMENT GEL

ART.NR	TEKNOLOGI			YTELSE			DIMENSJONER			TEKNISK INFO				DNV-GL
	GEL	AGM Flat	AGM Orbital	Wh*	KAPASITET Ah (20h)	CCA A (EN)	L (mm)	B (mm)	H (mm)	POLSTIL-LING	POLTYPE	Vekt (kg)	Behol-der-type	
ES 290	•			290	25	–	165	175	125	0	Flat Lug (M5)	10	P24	•
ES 450	•			450	40	–	210	175	175	0	Flat Lug (19)	15	LB1	•
ES 650	•			650	56	–	278	175	190	0	Standard	21	L03	•
ES 900	•			900	80	–	350	175	190	0	Standard	27	L05	•
ES 950	•			950	85	–	350	175	235	1	Standard	30	D02	•
ES1000-6	•			1000	190 (6V)	–	245	190	275	0	Standard	29	GC2	•
ES1100-6	•			1100	200 (6V)	–	245	190	275	0	Threaded insert	32	GC2	•
ES1200	•			1200	110	–	285	270	230	2	Standard	39	D07	•
ES1300	•			1300	120	–	350	175	290	0	Standard	39	D03	•
ES1350	•			1350	120	–	513	189	223	3	Standard	40	D04	•
ES1600	•			1600	140	–	513	223	223	3	Standard	47	D05	•
ES2400	•			2400	210	–	518	279	240	3	Standard	67	D06	•

EQUIPMENT

ART.NR	GEL	AGM Flat	AGM Orbital	Wh*	KAPASITET Ah (20h)	CCA A (EN)	L (mm)	B (mm)	H (mm)	POLSTIL-LING	POLTYPE	Vekt (kg)	Behol-der-type	DNV-GL
ET 650				650	100	–	350	175	190	0	Standard	27	L05	
ET 950				950	135	–	513	189	223	3	Standard	40	D04	
ET1300				1300	180	–	513	223	223	3	Standard	50	D05	
ET1600				1600	230	–	518	279	240	3	Standard	65	D06	

VINTAGE

Et komliterende sortiment for eldre kjøretøy med 6 og 12 V systemer

ART.NR	GEL	AGM Flat	AGM Orbital	Wh*	KAPASITET Ah (20h)	CCA A (EN)	L (mm)	B (mm)	H (mm)	POLSTIL-LING	POLTYPE	Vekt (kg)	Behol-der-type	DNV-GL
EU 77-6				–	77 (6V)	360	215	169	184	0	Standard	18	H02	
EU 80-6				–	80 (6V)	600	158	165	220	0	Standard	11	M02	
EU 140-6				–	140 (6V)	900	257	175	236	0	Standard	19	M04	
EU 165-6				–	165 (6V)	900	330	174	234	0	Standard	25	M05	
EU 260-6				–	260 (6V)	1300	350	175	290	0	Standard	40	M08	

*MCA = Mål for marin startkraft, angis i A (strøm) og måles ved 0 °C.
*Wh = Batteriets tilgjenglige energi. Den energi målt ved 20 timers bruksom et batteri kan avgi uten å overskride anbefalt maksimal utladning.

Visste du...?

Exide produserer også batterier for bil, lastebiler, motorsykler og bobil. Kontakt din lokale Exide forhandler eller besøk www.sonnak.no for mer informasjon.

CODE STRUCTURE

E M 1000

BRAND: E – EXIDE

RANGE NAME		ELECTRICAL UNIT		PERFORMANCE
M	START AGM	MCA*	1000	1000 A
N	START	MCA*	1000	1000 A
P	DUAL AGM	Wh*	1000	1000 Wh
R	DUAL	Wh*	1000	1000 Wh
S	EQUIPMENT GEL	Wh*	1000	1000 Wh
T	EQUIPMENT	Wh*	1000	1000 Wh
U	VINTAGE	C20h	100-6	100 Ah/ 6V

Exide Technologies er aktivt i mer enn 80 land og har mer enn 120 års erfaring innen batteribransjen. Selskapet er en av verdens største produsenter og gjenvinningsforetak innen blybatterier. Selskapet utvikler energilagringsløsninger for kjøretøy- og industrimarkedet, og ledende bil-, lastebil- og truckprodusenter bruker Exide Technologies som leverandør til originalproduktene sine. Exide forsyner ettermarkedet med en portefølje bestående av ledende og velkjente varemerker.

Exide Transportation produserer batterier både for lette kjøretøy, inkludert kommersielle kjøretøy og jordbruksmaskiner, samt batterier til bruk i marin- og fritidssektoren. Industribatterimarkedet – under divisjonen GNB Industrial Power – omfatter energilagringsløsninger til forretningsområdet Motive, med applikasjoner som gaffeltrucker, rengjøringsmaskiner og andre kommersielle el-kjøretøy samt til forretningsområdet Network, med batterier for avbruddsfri strømforsyning til bl.a. telekommunikasjonssystemer, fornybare energikilder og avbruddsfri strømforsyning (UPS).

Exide tilbyr også tjenester, tilbehør og veiledning innen løsning for lagring av elektrisk energi.

Exides FoU har alltid ligget i forkant av den teknologiske utviklingen på batteriområdet og kontinuerlig lansert innovative produkter på markedet. Produksjonen foregår på ISO/TS-sertifi serte fabrikker, noe som sikrer at produktene produseres på en effektiv måte i tråd med de strengeste kriter for kvalitet og miljøhensyn.

Exides omfattende salgs- og distribusjonsnett gir høy service og leveringssikkerhet. Selskapet har også resirkuleringsanlegg for håndtering av brukte batterier. Der resirkuleres brukte batterier, som blir til råmaterialer som brukes i produksjonen av nye batterier.

Alle produksjonsanlegg er sertifi sert i henhold til ISO 9001.
Fabrikkene der bilbatteriene produseres, er sertifi sert i henhold til ISO/TS 16949.
Fabrikkene er sertifi sert i henhold til ISO 14001.

Sønnak
Exide Technologies AS
Brobekkveien 101
Tlf: 22 07 47 00
www.sonnak.no
startnorge@eu.exide.com

Exide Battery Finder

C Ratings of PV panels and heating elements

Part	Power rating [W]	Voltage rating [V]	Current ratings [A]
PV panels Arusha	305	36.2	8.43
Heating elements Arusha	800	220	
PV panels Norway	260	30.92	8.43
Heating elements Norway	500	24	

Table 3: Ratings of equipment used

D TriStar installation, operation, and maintenance manual

TRISTAR™

Solar Charging System Controller

Installation, Operation and Maintenance Manual

For the most recent manual revisions, see the version at:
www.morningstarcorp.com

.....

Solar Battery Charging

.....

Load Control

.....

Diversion Control

MORNINGSTAR
PROFESSIONAL SERIES
World's Leading Solar Controllers & Inverters

www.morningstarcorp.com

MODELS

TS-45
TS-60
TS-60M

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(Please do not print this copy)

Table of Contents

(continued)

IMPORTANT SAFETY INSTRUCTIONS

SAVE THESE INSTRUCTIONS.

This manual contains important safety, installation, operating and mantenance instructions for the TriStar-PWM solar controller.

The following symbols are used throughout this manual to indicate potentially dangerous conditions or mark important safety instructions:

WARNING: *Indicates a potentially dangerous condition. Use extreme caution when performing this task.*

CAUTION: *Indicates a critical procedure for safe and proper operation of the controller.*

NOTE: *Indicates a procedure or function that is important to the safe and proper operation of the controller.*

CONSIGNES IMPORTANTES DE SÉCURITÉ

CONSERVEZ CES INSTRUCTIONS.

Ce manuel contient des instructions importantes de sécurité, d'installations et d'utilisation du contrôleur solaire. TriStar-PWM. Les symboles suivants sont utilisés dans ce manuel pour indiquer des conditions potentiellement dangereuses ou des consignes importantes de sécurité.

AVERTISSEMENT: *Indique une condition potentiellement dangereuse. Faites preuve d'une prudence extrême lors de la réalisation de cette tâche.*

PRUDENCE: *Indique une procédure critique pour l'utilisation sûre et correcte du contrôleur.*

REMARQUE: *Indique une procédure ou fonction importante pour l'utilisation sûre et correcte du contrôleur.*

Safety Information

- Read all of the instructions and cautions in the manual before beginning installation.
- There are no user serviceable parts inside the TriStar-PWM. Do not disassemble or attempt to repair the controller.

continued...

WARNING: *RISK OF ELECTRICAL SHOCK.*
NO POWER OR ACCESSORY TERMINALS ARE ELECTRICALLY ISOLATED FROM DC INPUT, AND MAY BE ENERGIZED WITH HAZARDOUS SOLAR VOLTAGE. UNDER CERTAIN FAULT CONDITIONS, BATTERY COULD BECOME OVER-CHARGED. TEST BETWEEN ALL TERMINALS AND GROUND BEFORE TOUCHING.

- External solar and battery disconnects are required.
- Disconnect all sources of power to the controller before installing or adjusting the TriStar-PWM.
- There are no fuses or disconnects inside the TriStar-PWM Do not attempt to repair.

Informations de Sécurité

- Lisez toutes les instructions et les avertissements figurant dans le manuel avant de commencer l'installation.
- Le TriStar-PWM ne contient aucune pièce réparable par l'utilisateur. Ne démontez pas ni ne tentez de réparer le contrôleur.

AVERTISSEMENT: *RISQUE DE CHOC ÉLECTRIQUE. NON ALIMENTATION OU AUX BORNES D'ACCESSOIRES SONT ISOLÉS ÉLECTRIQUEMENT DE L'ENTRÉE DE C.C ET DOIT ÊTRE ALIMENTÉS À UNE TENSION DANGEREUSE SOLAIRE. SOUS CERTAINES CONDITIONS DE DÉFAILLANCE, LA BATTERIE POURRAIT DEVENIR TROP CHARGÉE. TEST ENTRE TOUTES LES BORNES ET LA MASSE AVANT DE TOUCHER.*

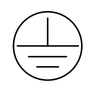
- External solaire et la batterie se déconnecte sont nécessaires.
- Déconnectez toutes les sources d'alimentation du contrôleur avant d'installer ou de régler le TriStar-PWM.
- Le TriStar MPPT ne contient aucun fusible ou interrupteur. Ne tentez pas de réparer.
- Installez des fusibles/coupe-circuits externes selon le besoin.

Installation Safety Precautions

WARNING: *This unit is not provided with a GFDI device. This charge controller must be used with an external GFDI device as required by the Article 690 of the National Electrical Code for the installation location.*

- Mount the TriStar-PWM indoors. Prevent exposure to the elements and do not allow water to enter the controller.
- Install the TriStar-PWM in a location that prevents casual contact. The TriStar-PWM heatsink can become very hot during operation.
- Use insulated tools when working with batteries.
- Avoid wearing jewelry during installation.

- The battery bank must be comprised of batteries of same type, make, and age.
- IEC 62109 certified for use in negative ground or floating systems only
- Do not smoke near the battery bank.
- Power connections must remain tight to avoid excessive heating from a loose connection.
- Use properly sized conductors and circuit interrupters.
- The grounding terminal is located in the wiring compartment and is identified by the symbol below:



Ground Symbol

- This charge controller is to be connected to DC circuits only. These DC connections are identified by the symbol below:

Direct Current Symbol

The TriStar-PWM controller must be installed by a qualified technician in accordance with the electrical regulations of the country where the product is installed. A means of disconnecting all power supply poles must be provided. These disconnects must be incorporated in the fixed wiring.

A permanent, reliable earth ground must be established with connection to the TriStar-PWM wiring compartment ground terminal.

The grounding conductor must be secured against any accidental detachment. The knock-outs in the TriStar-PWM wiring compartment must protect wires with conduit or rubber rings.

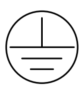
Précautions de Sécurité D'installation

AVERTISSEMENT: *L'appareil n'est pas fourni avec un dispositif GFDI. Ce contrôleur de charge doit être utilisé avec un dispositif GFDI externe tel que requis par l'Article 690 du Code électrique national de l'emplacement de l'installation.*

- Montez le TriStar-PWM à l'intérieur. Empêchez l'exposition aux éléments et la pénétration d'eau dans le contrôleur.
- Installez le MPPT ProStar dans un endroit qui empêche le contact occasionnel. Le dissipateur de chaleur TriStar-PWM peut devenir très chaud pendant

le fonctionnement.

- Utilisez des outils isolés pour travailler avec les batteries.
- Évitez le port de bijoux pendant l'installation.
- Le groupe de batteries doit être constitué de batteries du même type, fabricant et âge.
- UL/IEC 62109 certifié pour utilisation au négatif à la masse ou les systèmes flottants seulement.
- Ne fumez pas à proximité du groupe de batteries.
- Les connexions d'alimentation doivent rester serrées pour éviter une surchauffe excessive d'une connexion desserrée.
- Utilisez des conducteurs et des coupe-circuits de dimensions adaptées.
- La borne de mise à la terre se trouve dans le compartiment de câblage et est identifiée par le symbole ci-dessous:



- Ces connexions CC sont identifiées par le symbole ci-dessous:

WARNING: *A battery can present a risk of electrical shock or burn from large amounts of short-circuit current, fire, or explosion from vented gases. Observe proper precautions.*

AVERTISSEMENT: *Une batterie peut présenter a risque de choc électrique ou de brûlure de grandes quantités de court-circuit curlouer, incendie ou explosion de ventilé gaz. Observer précautions appropriées.*

WARNING: Risk of Explosion. *Proper disposal of batteries is required. Do not dispose of batteries in fire. Refer to local regulations or codes for requirements.*

AVERTISSEMENT: Risque d'Explosion. *Au rebut des piles est nécessaire. Ne pas jeter les piles dans le feu. Se référer aux réglementations locales ou des codes pour les exigences.*

CAUTION: *When replacing batteries, use properly specified number, sizes, types, and ratings based on application and system design.*

PRUDENCE: *Lorsque le remplacement des piles, utilisez correctement nombre spécifié, tailles, types et les évaluations basées sur conception de système et d'application.*

CAUTION: *Do not open or mutilate batteries. Released electrolyte is harmful to skin, and may be toxic.*

PRUDENCE: *Ne pas ouvrir ou mutiler les piles. L'électrolyte est nocif pour la peau et peut être toxique.*

- Servicing of batteries should be performed, or supervised, by personnel knowledgeable about batteries, and the proper safety precautions.
- Be very careful when working with large lead-acid batteries. Wear eye protection and have fresh water available in case there is contact with the battery acid.
- Remove watches, rings, jewelry and other metal objects before working with batteries.
- Wear rubber gloves and boots
- Use tools with insulated handles and avoid placing tools or metal objects on top of batteries.
- Disconnect charging source prior to connecting or disconnecting battery terminals.
- Determine if battery is inadvertently grounded. If so, remove the source of contact with ground. Contact with any part of a grounded battery can result in electrical shock. The likelihood of such a shock can be reduced if battery grounds are removed during installation and maintenance (applicable to equipment and remote battery supplies not having a grounded supply circuit).
- Carefully read the battery manufacturer's instructions before installing / connecting to, or removing batteries from, the TriStar-PWM.
- Be very careful not to short circuit the cables connected to the battery.
- Have someone nearby to assist in case of an accident.
- Explosive battery gases can be present during charging. Be certain there is enough ventilation to release the gases.
- Never smoke in the battery area.
- If battery acid comes into contact with the skin, wash with soap and water. If the acid contacts the eye, flood with fresh water and get medical attention.
- Be sure the battery electrolyte level is correct before starting charging. Do not attempt to charge a frozen battery.
- Recycle the battery when it is replaced.

• Entretien des batteries devrait être effectué ou supervisé, par un personnel bien informé sur les piles et les précautions de sécurité appropriées.

• Soyez très prudent quand vous travaillez avec des grandes batteries au plomb. Portez des lunettes de protection et ayez de l'eau fraîche à disposition en cas de contact avec l'électrolyte.

• Enlevez les montres, bagues, bijoux et autres objets mé talliques avant de travailler avec des piles.

• Porter des bottes et des gants de caoutchouc

• Utiliser des outils avec poignées isolantes et évitez de placer des outils ou des objets métalliques sur le dessus de batteries.

- Débrancher la source de charge avant de brancher ou dis reliant les bornes de la batterie.
- Utilisez des outils isolés et évitez de placer des objets métalliques dans la zone de travail.
- Déterminer si batterie repose par inadvertance. Dans l'affirmative, supprimer la source du contact avec le sol. Contact avec n'importe quelle partie d'une batterie mise à la terre peut entraîner un choc électrique. La probabilité d'un tel choc peut être réduite si des motifs de batterie sont supprimés pendant l'installation et maintentretien (applicable à l'équipement et les fournitures de pile de la télécommande n'ayant ne pas un circuit d'alimentation mise à la terre).
- Lisez attentivement les instructions du fabricant de la batterie avant d'installer / connexion à ou retrait des batteries du TriStar-PWM.
- Veillez à ne pas court-circuiter les câbles connectés à la batterie.
- Ayez une personne à proximité qui puisse aider en cas d'accident.
- Des gaz explosifs de batterie peuvent être présents pendant la charge. Assurez-vous qu'une ventilation suffisante évacue les gaz.
- Ne fumez jamais dans la zone des batteries
- En cas de contact de l'électrolyte avec la peau, lavez avec du savon et de l'eau. En cas de contact de l'électrolyte avec les yeux, rincez abondamment avec de l'eau fraîche et consultez un médecin.
- Assurez-vous que le niveau d'électrolyte de la batterie est correct avant de commencer la charge. Ne tentez pas de charger une batterie gelée.
- Recyclez la batterie quand elle est remplacée.

1.0 TriStar Description

The TriStar is a technically advanced solar system controller. There are three operating modes programmed into each TriStar. This manual describes solar battery charging, and specific load control or diversion charge control instructions are inserted where required.

This manual will help you to become familiar with the TriStar's features and capabilities. Some of these follow:

- ETL Listed (UL 1741) and cETL Listed (CSA-C22.2 No. 107.1)
- TUV Listed (IEC 62109)
- Complies with the US National Electrical Code
- Complies with the Canadian Electrical Code
- Complies with EMC and LVD standards for CE marking
- Rated for 12, 24, 48 volt systems, and 45 or 60 amps current
- Fully protected with automatic and manual recovery
- Seven standard charging or load programs selected with DIP switches
- Adjustability by means of an RS-232 connection with PC software
- Continuous self-testing with fault notification
- LED indications and push-button functions
- Terminals sized for 35mm^2 (#2 AWG) wire
- Includes battery voltage sense terminals
- Digital meter options (mounted to TriStar or remote)
- Optional remote battery temperature sensor
- 5-year warranty (see Section 10.0)

1.1 Versions and Ratings

There are two standard versions of TriStar controllers:

TriStar-45:
Rated for maximum 45 amps continuous current
(solar, load or diversion load)
Rated for 12, 24, 48 Vdc systems

TriStar-60:
Rated for maximum 60 amps continuous current
(solar, load or diversion load)
Rated for 12, 24, 48 Vdc systems

TriStar-60M:
Rated for maximum 60 amps continuous current
(solar, load or diversion load)
Rated for 12, 24, 48 Vdc systems
Includes on-board meter display

1.2 Operating Modes

There are three distinct and independent operating modes programmed into each TriStar. Only one mode of operation can be selected for an individual TriStar. If a system requires a charging controller and a load controller, two TriStars must be used.

1.3 Adjustibility

Eight DIP switches permit the following parameters to be adjusted at the installation site:

DIP switch	Solar Battery Charging
1	Battery charge control mode
2-3	Select battery voltage
4-6	Standard battery charging programs
7	Manual or automatic equalization
8	PWM charging or on-off charging

DIP switch	Load Control
1	DC load control mode
2-3	Select battery voltage
4-6	Standard low voltage disconnects and reconnects
7	not used for load control
8	not used for load control

DIP switch	Diversion Charge Control
1	DC load control mode
2-3	Select battery voltage
4-6	Standard diversion charge control programs
7	Select diversion charge control mode
8	Manual or automatic equalization

In addition to the DIP switches, the TriStar provides for additional adjustments using a PC program. An RS-232 connection between the TriStar and a personal computer will enable extensive adjustments using PC software from Morningstar's website.

1.4 General Use

☞ NOTE: This manual describes solar battery charging. Specific instructions for the load control and diversion charge control modes are provided as notes throughout this manual.

☞ REMARQUE : Ce manuel décrit la charge de batteries solaires. Des instructions spécifiques aux modes de contrôle du chargement et de contrôle de la charge de diversion figurent en tant que remarques dans ce manuel.

The TriStar is suitable for a wide range of solar applications including homes, telecom and industrial power needs.

TriStar controllers are configured for negative ground systems. There are no parts in the controller's negative leg. The enclosure can be grounded using the ground terminal in the wiring compartment.

The TriStar is protected from faults electronically with automatic recovery. There are no fuses or mechanical parts inside the TriStar to reset or change.

Solar overloads up to 130% of rated current will be tapered down instead of disconnecting the solar. Over-temperature conditions will also taper the solar input to lower levels to avoid a disconnect.

The NEC requires overcurrent protection externally in the system (see Section 2.3 step 6). There are no system disconnects inside the TriStar enclosure.

Any number of TriStars can be connected in parallel to increase solar charging current. TriStars can be paralleled ONLY in the battery charging mode. DO NOT parallel TriStars in the load mode, as this can damage the controller or load.

The TriStar enclosure is rated for indoor use. The controller is protected by conformal coated circuit boards, stainless steel hardware, anodized aluminum, and a powder coated enclosure, but it is not rated for corrosive environments or water entry.

The construction of the TriStar is 100% solid state.

Battery charging is by a series PWM constant current charging, with bulk charging, PWM absorption, float and equalization stages.

The TriStar will accurately measure time over long intervals to manage events such as automatic equalizations or battery service notification.

Day and night conditions are detected by the TriStar, and no blocking diodes are used in the power path.

LEDs, a push-button, and optional digital meters provide both status information and various manual operations.

The date of manufacture can be found on the two bar code labels. One label is on the back of the TriStar, and the other is in the wiring compartment. The year and week of manufacture are the first four digits of the serial number. For example:

year	week	serial #
03	36	0087

1.5 Safety and Regulatory Information

☞ NOTE: This section contains important information for safety and regulatory requirements.

☞ REMARQUE : Cette section contient des informations importantes relatives à la sécurité et aux obligations réglementaires.

The TriStar controller is intended for installation by a qualified technician according to electrical rules of each country in which the product will be installed.

TriStar controllers comply with the following EMC standards:

Immunity: EN 61000-4-3: 2006; EN 61000- 4-6: 2009
Emissions: CISPR 22: 2008
Safety: EN60335-1 and EN60335-2-29 (battery chargers)

A means shall be provided to ensure all pole disconnection from the power supply. This disconnection shall be incorporated in the fixed wiring.

Using the TriStar grounding terminal (in the wiring compartment), a permanent and reliable means for grounding shall be provided. The clamping of the earthing shall be secured against accidental loosening.

The entry openings to the TriStar wiring compartment shall be protected with conduit or with a bushing.

FCC requirements:
This device complies with Part 15 of the FCC rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by Morningstar for compliance could void the user's authority to operate the equipment.

Note: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communication. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment on and off, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

This Class B digital apparatus complies with Canadian ICES-003.

Cet appareil numerique de la classe B est conforme a la norme NMB-003 du Canada.

1.6 Optional Accessories

Remote Temperature Sensor (RTS)
If the temperature of the system battery varies more than 5˚C (9˚F) during the year, temperature compensated charging should be considered. Because the battery's chemical reactions change with temperature, it can be important to adjust charging to account for the temperature effects. The RTS will measure the battery temperature, and the TriStar uses this input to adjust the charging as required.

The battery charging will be corrected for temperature as follows:

- 12 V battery – 0.030 Volts per ˚C (–0.017V per ˚F)
- 24 V battery – 0.060 Volts per ˚C (–0.033V per ˚F)
- 48 V battery – 0.120 Volts per ˚C (–0.067V per ˚F)

The RTS should be used only for battery charging and diversion control. Do not use the RTS for load control. The charging parameters that are adjusted for temperature include:

- PWM regulation
- Equalization
- Float
- High Voltage Disconnect

See Installation, Step 4, for connecting the RTS to the TriStar.

Digital Meter Displays
Two digital meters can be added to the TriStar at any time during or after installation. One version is mounted on the controller (TS-M), the other is suitable for remote locations (TS-RM). The manual for installation and operation of the meter displays is included with the meter.

The display is a 2x16 LCD meter with backlighting. Four push-buttons are used to scroll through the displays and to execute manual functions.

There are a series of display screens that provide information such as:

- operating information and data
- operating bar charts (voltage and current)
- alarms and faults
- diagnostics
- settings

In addition, there are various manual functions built into the meter. For example, the meter can be used to reset Ah data or start/stop equalizations.

One of 5 languages can be selected for the meter.

Ethernet Communications Adapter (EMC-1)
This product is an Ethernet gateway that provides web monitoring services, a Modbus TCP/IP server, and a local web page server. End users can collect information about their off-grid PV system remotely. One EMC-1 supports all products with MeterBus ports by bridging MODBUS TCP/IP requests to serve LiveView pages for each product.

USB Communications Adapter (UMC-1)
A modular unit that uses a USB-B plug, usually from a USB A-B computer cable, and an RJ-11 plug to connect with a Morningstar controller's MeterBus port, for monitoring and programming using MSView PC software.

2.0 TriStar Installation

The installation instructions describe solar battery charging. Specific instructions for the load control and diversion modes are provided as notes.

2.1 General Information

The mounting location is important to the performance and operating life of the controller. The environment must be dry and protected as noted below. The controller may be installed in a ventilated enclosure with sealed batteries, but never in a sealed battery enclosure or with vented batteries.

If the solar array exceeds the current rating of the controller, multiple TriStars can be installed in parallel. Additional parallel controllers can also be added in the future. The load controllers cannot be used in parallel. To parallel diversion controllers, refer to Morningstar's website.

If solar charging and load control are both required, two separate controllers must be used.

Stranded wires to be connected to the terminals should be prepared first with e.g. clamped copper heads, etc. to avoid the possibility of one conductor free out of the connection screw, and possible contact with the metal enclosure.

WARNING: *Solar and battery fuses or DC breakers are required in the system. These protection devices are external to the controller, and must be a maximum of 70 amps for the TriStar-PWM-45, and 90 amps for the TriStar-PWM-60/M.*

AVERTISSEMENT: *Solaire et batterie fusibles ou disjoncteurs DC sont nécessaires dans le système. Ces dispositifs de protection sont externes au contrôleur, et doivent être un maximum de 70 ampères pour le TriStar-PWM-45, et 90 ampères pour le TriStar-PWM-60/M.*

WARNING: *Installation must comply with all US National Electrical Code and Canadian Electrical Code requirements. Breakers and fuses may require lower ratings than referenced above, so as not to exceed any specific wire ampacity.*

AVERTISSEMENT: *Installation doit être conforme à toutes les requirments US National Electrical Code et Code Canadien d'Electricité. Disjoncteurs et fusibles peuvent exiger des cotes inférieures que mentionnés ci-dessus de manière à ne pas pour dépasser n'importe quel fils particulier admissible.*

Maximum battery short-circuit current rating must be less than the interrupt current rating of the battery over-current protection device referenced above.

2.2 Installation Overview

The installation is straightforward, but it is important that each step is done correctly and safely. A mistake can lead to dangerous voltage and current levels. Be sure to carefully follow each instruction in Section 2.3 and observe all cautions and warnings.

The following diagrams provide an overview of the connections and the proper order.

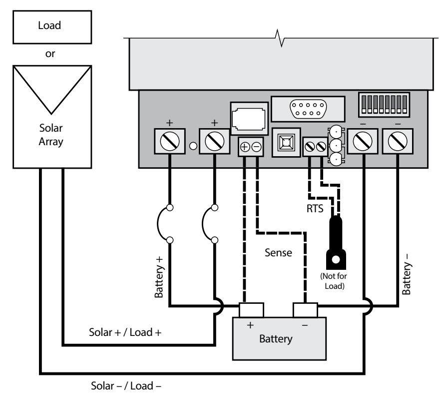


Figure 2.2a Installation Wiring for Solar Charging and Load Control

Step	Solar Charging and Load Control
1.	Remove the access cover
2.	Mount the TriStar using the enclosed template.
3.	Adjust the 8 switches in the DIP switch. Each switch must be in the correct position.
4.	Attach the RTS if battery charging will be temperature compensated (not for load control).
5.	Connect battery voltage sense wires (recommended).
6.	Connect the battery power wires to the TriStar. Then connect the solar array wires (or load).
7.	Connect a computer to the TriStar if making adjustments with PC software.
8.	Replace the cover.

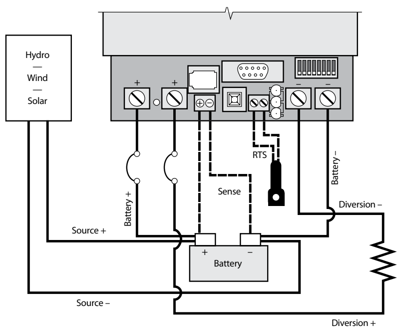


Figure 2.2b Installation Wiring for Diversion Charge Control

NOTE: TriStar negative terminals are common negative.

Steps #3 and #6 are required for all installations.

Steps #4, #5, and #7 are optional.

Step	Diversion Charge Control
1.	Remove the access cover
2.	Mount the TriStar using the enclosed template.
3.	Adjust the 8 switches in the DIP switch. Each switch must be in the correct position.
4.	Attach the RTS if battery charging will be temperature compensated.
5.	Connect battery voltage sense wires (recommended).
6.	Connect the battery power wires to the TriStar. Then connect the diversion load wires.

Step	Diversion Charge Control (continued)
7.	Connect a computer to the TriStar if making adjustments with PC software.
8.	Replace the cover.

2.3 Installation Steps

The TriStar controller must be installed properly and in accordance with the local and national electrical codes. It is also important that the installation be done safely, correctly and completely to realize all the benefits that the TriStar can provide for your solar system.

Refer to Sections 4.0 and 9.0 for information about the TriStar's standard battery charging programs and general charging needs for different battery types. Refer to Section 5.0 for load control information, and Section 6.0 for diversion.

Recommended tools:

• wire cutter	• phillips screwdrivers	• wire stripper
• torque wrench (to 50 in-lb)	• slotted screw drivers	• flashlight

Before starting the installation, review these safety notes:

- Do not exceed a battery voltage of 48V nominal (24 cells). Do not use a battery less than 12V (6 cells).
- Do not connect a solar input greater than a nominal 48V array for battery charging. Never exceed a Voc (open-circuit voltage) of 125V.
- Charge only 12, 24, or 48 volt lead-acid batteries when using the standard battery charging programs in the TriStar.
- Verify the nominal charging voltage is the same as the nominal battery voltage.
- Do not install a TriStar in a sealed compartment with batteries.
- Never open the TriStar access cover unless both the solar and battery power has been disconnected.
- Never allow the solar array to be connected to the TriStar with the battery disconnected. This can be a dangerous condition with high open-circuit solar voltages present at the terminals.

Follow the installation steps in order: #1 through #8

Step 1 - Remove the Cover

Remove the 4 screws in the front cover. Lift the cover until the top edge clears the heat sink, and set it aside. If an LCD meter display is attached to the cover, disconnect the RJ-11 connector at the meter for access.

CAUTION: Do not remove the cover if power is present at any of the terminals. Verify that all power sources to the controller are disconnected.

PRUDENCE : N'enlevez pas le couvercle en cas de tension à une des bornes. Vérifiez que toutes les sources d'alimentation au contrôleur sont déconnectées.

Step 2 - Mounting

Locate the TriStar on a wall protected from direct sun, high temperatures, and water. Do not install in a confined area where battery gasses can accumulate.

NOTE: When mounting the TriStar, make sure the air flow around the controller and heat sink is not obstructed. There should be open space above and below the heat sink, and at least 75 mm (3 inches) clearance around the heat sink to allow free air flow for cooling.

REMARQUE : Lors du montage du TriStar, assurez-vous que l'écoulement d'air autour du contrôleur et du puits de chaleur n'est pas obstrué. Un espace doit se trouver au-dessus et en dessous du puits de chaleur et un dégagement de 75 mm (3 po) doit exister autour du puits de chaleur pour permettre l'écoulement de l'air à des fins de refroidissement.

Before starting the installation, place the TriStar on the wall where it will be mounted and determine where the wires will enter the controller (bottom, side, back). Remove the appropriate knockouts before mounting the controller. The knockouts are sized for 1 inch and 1.25 inch conduit.

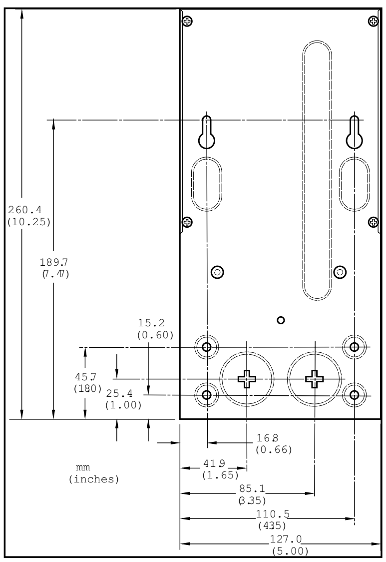


Figure 2.3 - Step 2 Mounting Dimensions

Step 2 - Mounting (continued)

Refer to Figure 2.3. Use the template provided in the shipping carton for locating the mounting holes and for stripping the wires. Use two of the #10 screws provided for the two keyhole slots. Leave the screw heads protruding enough to lock inside the keyhole slots (about 3.8 mm / 0.150 inch). Mount the controller and pull it down to lock the screws into the slots. Use the remaining two screws to fasten the controller to the wall.

Provide for strain relief for the bottom knockouts if conduit will not be used. Avoid excessive pulling forces on the terminals from the wires.

Step 3 - Adjust the DIP Switches

An 8-position DIP switch is used to set-up the controller for its intended use. All major functions can be set with the DIP switches. See Section 7.0 for additional custom settings using PC software.

☞ NOTE: The instructions below are for solar battery charging.
Refer to Appendix 1 for Load Control DIP switch settings, and Appendix 2 for Diversion Charge Control DIP switch settings.

☞ REMARQUE : Les instructions ci-dessous concernent la charge de batteries solaires. Reportez-vous à l'Annexe 1 pour les réglages du commutateur DIP de contrôle de charge et à l'Annexe 2 pour les réglages du commutateur DIP de contrôle de charge de diversion.

The DIP switches are located behind the negative power terminals. Each switch is numbered. The solar battery charging functions that can be adjusted with the DIP switches follow:

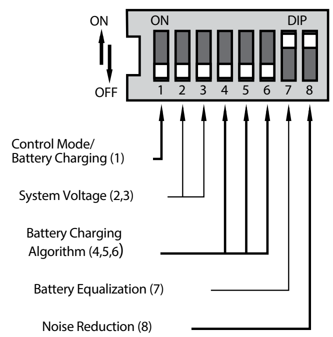


Figure 2.4 - Step 3 DIP Switch Functions

As shown in the diagram, all the positions are in the "OFF" position except switch numbers 7 and 8, which are in the "ON" position.

☞ NOTE: The DIP switches should be changed only when there is no power to the controller. Turn off disconnect switches and remove all power to the controller before changing a DIP switch. A fault will be indicated if a switch is changed while the controller is powered.

☞ REMARQUE : Les commutateurs DIP ne doivent être remplacés que si le contrôleur est hors tension. Mettez tous les interrupteurs sur arrêt et mettez le contrôleur hors tension avant de changer un commutateur DIP. Une panne sera indiquée en cas de changement d'un commutateur alors que le contrôleur est sous tension.

⚠ CAUTION: The TriStar is shipped with all the switches in the "OFF" position. Each switch position must be confirmed during installation. A wrong setting could cause damage to the battery or other system components.

⚠ PRUDENCE : Le TriStar est expédié avec tous les interrupteurs en position « ARRÊT ». La position de chaque interrupteur doit être confirmée pendant l'installation. Un mauvais réglage peut endommager la batterie ou d'autres composants du système.

The DIP switch settings described below are for Solar Battery Charging only. Load and Diversion switch settings can be found in Appendixes 1 and 2.

The DIP switches are shipped in the OFF position. With the switches in the OFF position, the following functions are present:

Switch	Function
1	Battery charge mode
2, 3	Auto voltage select
4, 5, 6	Lowest battery charging voltage
7	Manual equalization
8	Normal PWM charging mode

To configure your TriStar for the battery charging and control you require, follow the DIP switch adjustments described below. To change a switch from OFF to ON, slide the switch up toward the top of the controller. Make sure each switch is fully in the ON or OFF position.

DIP Switch Number 1 - Control Mode: Solar Battery Charging

Control	Switch 1
Charging	Off
Load	On

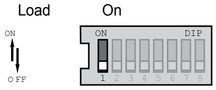


Figure 2.5 - Step 3 DIP Switch #1

For the Solar Battery Charging control mode, leave the DIP switch in the OFF position as shown.

DIP Switches Number 2,3 - System Voltage:

Voltage	Switch 2	Switch 3
Auto	Off	Off
12	Off	On
24	On	Off
48	On	On

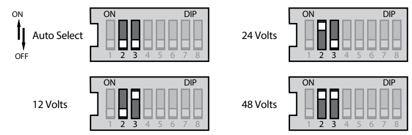


Figure 2.6 - Step 3 DIP Switches # 2,3

The auto voltage selection occurs when the battery is connected and the TriStar starts-up. There should be no loads on the battery that might cause a discharged battery to indicate a lower system voltage.

The DIP switch selectable voltages are for 12V, 24V or 48V lead-acid batteries. Although the “auto voltage” selection is very dependable, it is recommended to use the DIP switches to secure the correct system voltage.

DIP Switches Number 4,5,6 - Battery Charging Algorithm:

Battery Type	PWM	Switch 4	Switch 5	Switch 6
1	14.0	Off	Off	Off
2	14.15	Off	Off	On
3	14.35	Off	On	Off
4	14.4	Off	On	On
5	14.6	On	Off	Off
6	14.8	On	Off	On
7	15.0	On	On	Off
8	Custom	On	On	On

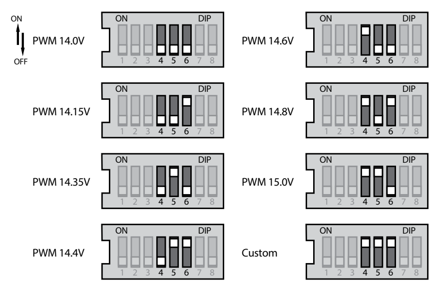


Figure 2.7 - Step 3 DIP Switch # 4,5,6

2.0

Select one of the 7 standard battery charging algorithms, or select the "custom" DIP switch for special custom settings using the PC software.

Refer to Section 9.0 of this manual for battery charging information. The 7 standard charging algorithms above are described in Section 4.2 - Standard Battery Charging Programs.

DIP Switch Number 7 - Battery Equalization:

Equalize	Switch 7
Manual	Off
Auto	On

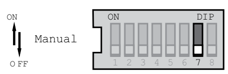


Figure 2.8 - Step 3 DIP Switch # 7

In the Auto Equalization mode (switch #7 On), battery equalization will automatically start and stop according to the battery program selected by the DIP switches 4,5,6 above. See Section 4.0 for detailed information about each standard battery algorithm and the equalization.

In the Manual Equalization mode (switch #7 Off), equalization will occur only when manually started with the push-button. Automatic starting of equalization is disabled. The equalization will automatically stop per the battery algorithm selected.

In both cases (auto and manual mode), the push-button can be used to start and stop battery equalization.

DIP Switch Number 8 - Noise Reduction:

Charging	Switch 8
PWM	Off
On-Off	On

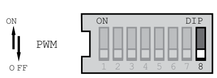


Figure 2.9- Step 3 DIP Switch # 8

The PWM battery charging algorithm is standard for all Morningstar charge controllers. However, in cases where the PWM regulation causes noise interference with loads (e.g. some types of telecom equipment or radios), the TriStar can be converted to an On-Off method of solar charge regulation.

It should be noted that the On-Off solar charge regulation is much less effective than PWM. Any noise problem should be suppressed in other ways, and only if no other solution is possible should the TriStar be changed to an On-Off charger.

LOAD CONTROL

DIP switch settings are in Appendix 1.

DIVERSION CHARGE CONTROL

DIP switch settings are in Appendix 2.

NOTE: Confirm all dip-switch settings before going to the next installation steps.

REMARQUE : Confirmez les réglages de tous les commutateurs dip avant de passer aux étapes suivantes d'installation.

Step 4 - Remote Temperature Sensor (RTS)

For solar battery charging and diversion load control, a remote temperature sensor (RTS) is recommended for effective temperature compensated charging. This remote temperature probe should not be installed for dc load control.

The optional Morningstar RTS is connected to the 2-position terminal located between the push-button and the LEDs. See the diagram below:

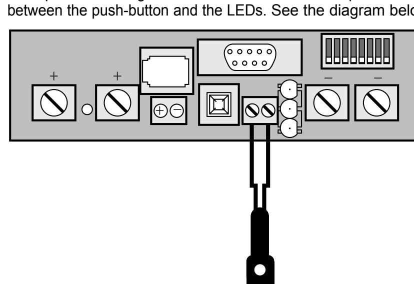


Figure 2.10- Step 4 RTS Connection

The RTS is supplied with 10 meters (33 ft) of 0.34 mm^2 (22 AWG) cable. There is no polarity, so either wire (+ or –) can be connected to either screw terminal. The RTS cable may be pulled through the conduit with the power wires. Tighten the connector screws with 0.56 Nm (5 in-lb) of torque.

Refer to the installation instructions provided with the RTS.

WARNING: Risk of Fire.

If no Remote Temperature Sensor (RTS) is connected, use the TriStar-PWM within 3m (10 ft) of the batteries. Internal Temperature Compensation will be used if the RTS is not connected. Use of the RTS is strongly recommended.

AVERTISSEMENT: Risque d'incendie.

Si non Capteur de température distant (RTS) est connecté, utilisez le TriStar-PWM moins de 3m (10 pi) de les batteries. Compensation de la température interne sera utilisée si la RTS n'est pas connecté. Utilisation de la RTS est fortement recommandé.

NOTE: Never place the temperature sensor inside a battery cell. Both the RTS and the battery will be damaged.

REMARQUE : Ne placez jamais la sonde de température dans un élément de batterie. Le RTS et la batterie seraient endommagés.

Step 5 - Battery Voltage Sense Connection

A battery voltage sense connection is not required to operate your TriStar controller, but it is recommended for best performance in all charging and load control modes. The battery voltage sense wires carry almost no current, so the voltage sense input avoids the large voltage drops that can occur in the battery power conductors. The voltage sense connection allows the controller to measure the actual battery voltage under all conditions.

In addition, if a TriStar meter will be added to the controller, the battery voltage sense will ensure that the voltage and diagnostic displays are very accurate.

The two battery voltage sense wires are connected to the TriStar at the 2-position terminal located between the push-button and the positive (+) terminal lug. See the diagram below:

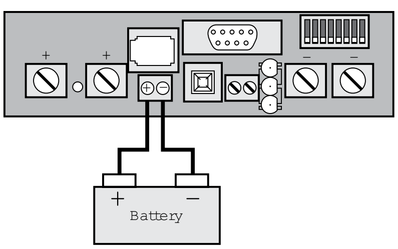


Figure 2.11 - Step 5 Battery Sense Connection

The two voltage sense wires (not provided with the controller) should be cut to length as required to connect the battery to the voltage sense terminal. The wire size can be from 1.0 to 0.25 mm^2 (16 to 24 AWG). It is recommended to twist the wires together every few feet (twisted pair), but this is not required. The voltage sense wires may be pulled through the conduit with the power wires.

Fuse the positive (+) voltage sense wire as close to the battery as possible. Size the fuse based on wire ampacity - a 1A fuse can be used for #24 wire.

Tighten the connector screws with 0.56 Nm (5 in-lb) of torque.

The maximum length allowed for each battery voltage sense wire is 30 meters (98 ft).

The battery sense terminal has polarity. Be careful to connect the battery positive (+) terminal to the voltage sense positive (+) terminal. No damage will occur if the polarity is reversed, but many functions of the controller can be affected. If a TriStar meter is installed, check the "TriStar Settings" to confirm the Voltage Sense and the RTS (if installed) are both present and "seen" by the controller. The PC software can also be used to confirm the voltage sense is working correctly.

Do not connect the voltage sense wires to the RTS terminal. This may cause an alarm. Review the installation diagram for the correct battery voltage sense connection.

Note that the battery voltage sense connection does not power (start-up) the controller.

Step 6 - System Wiring and Power-Up

To comply with the NEC, the TriStar must be installed using wiring methods in accordance with the latest edition of the National Electric Code, NFPA 70.

Wire Size

The four large power terminals are sized for 35 - 2.5 mm^2 (2-14 AWG) wire. The terminals are rated for copper and aluminum conductors.

Good system design generally requires large conductor wires for the solar and battery connections that limit voltage drop losses to 3% or less. The following table provides the maximum wire length (1-way distance / 2-wire pair) for connecting the battery, solar array or load to the TriStar with a maximum 3% voltage drop.

Wire Size	60 Amps	45 Amps	30 Amps	15 Amps
95 mm^2 (3/0 AWG)	12.86 m (42.2 ft.)	17.15 m (56.3 ft.)	25.72 m (84.4 ft.)	51.44 m (168.8 ft.)
70 mm^2 (2/0 AWG)	10.19 m (33.4 ft.)	13.58 m (44.6 ft.)	20.38 m (66.8 ft.)	40.75 m (133.7 ft.)
50 mm^2 (1/0 AWG)	8.10 m (26.6 ft.)	10.80 m (35.4 ft.)	16.21 m (53.1 ft.)	32.41 m (106.3 ft.)
35 mm^2 (2 AWG)	5.12 m (16.8 ft.)	6.83 m (22.4 ft.)	10.24 m (33.6 ft.)	20.48 m (67.2 ft.)
25 mm^2 (4 AWG)	3.21 m (10.5 ft.)	4.27 m (14.0 ft.)	6.41 m (21.0 ft.)	12.82 m (42.1 ft.)
16 mm2 (6 AWG)	2.02 m (6.6 ft.)	2.69 m (8.8 ft.)	4.04 m (13.2 ft.)	8.07 m (26.5 ft.)
10 mm^2 (8 AWG)	1.27 m (4.2 ft.)	1.70 m (5.6 ft.)	2.54 m (8.3 ft.)	5.09 m (16.7 ft.)
6 mm^2 (10 AWG)		1.06 m (3.5 ft.)	1.60 m (5.2 ft.)	3.19 m (10.5 ft.)
4 mm^2 (12 AWG)			1.00 m (3.3 ft.)	2.01 m (6.6 ft.)
2.5 mm^2 (14 AWG)				1.26 m (4.1 ft.)

Table 2.3-6a Maximum 1-Way Wire Distance (12 Volts)

NOTES:

- The specified wire length is for a pair of conductors from the solar, load or battery source to the controller (1-way distance).
- Figures are in meters (m) and feet (ft).
- For 24 volt systems, multiply the 1-way length in the table by 2.
- For 48 volt systems, multiply the 1-way length in the table by 4.

The NEC requires that manually operated disconnect switches or circuit breakers must be provided for connections between the TriStar and the battery. If the overcurrent devices being used are not manually operated disconnects, then manual disconnect switches must be added. These manual switches must be rated the same as the overcurrent devices noted above.

- Refer to the NEC for more information.

Minimum Wire Size

The NEC requires that the wires carrying the system current never exceed 80% of the conductors' current rating. The table below provides the minimum size of copper wire allowed by NEC for the TS-45 and TS-60 versions. Wire types rated for 75˚C and 90˚C are included.

Minimum wire sizes for ambient temperatures to 45˚C are provided in the table below:

TS-45	75C Wire	90C Wire	TS-60	75C Wire	90C Wire
≤ 45C	16 mm^2 (6 AWG)	10 mm^2 (8 AWG)	≤ 45C	25 mm^2 (4 AWG)	16 mm^2 (6 AWG)

Table 2.3-6b Minimum Wire Size

Both copper and aluminum conductors can be used with a TriStar controller. If aluminum wire is used, the minimum size of the aluminum conductor must be one wire size larger than the minimum wire size specified in the table above.

Ground Connection

Use the grounding terminal in the wiring compartment to connect a copper wire to an earth ground or similar grounding point. The grounding terminal is identified by the ground symbol shown below that is stamped into the enclosure:

Ground Symbol

Per NEC 690.45 (A) and NEC Table 250.122, minimum sizes for copper grounding wire are:

TS-45 10 AWG (5 mm^2)

TS-60/M 8 AWG (8 mm^2)

OR, of the same, or greater, cross-sectional area as the PV wires.

Connect the Power Wires

First, confirm that the DIP switch #1 is correct for the operating mode intended.

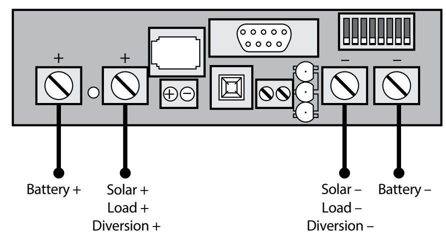


Figure 2.12 - Step 6 Power Wire Connections

CAUTION: The solar PV array can produce open-circuit voltages over 100 Vdc when in sunlight. Verify that the solar input breaker has been opened (disconnected) before installing the system wires (if the controller is in the solar charging mode).

PRUDENCE : Le réseau PV solaire peut produire des tensions de circuit ouvert supérieures à 100 V cc à la lumière du soleil. Vérifiez que le coupe-circuit solaire a été ouvert (déconnexion) avant d'installer les câbles du système (si le contrôleur est en mode de charge solaire).

Using the diagram on the previous page, connect the four power conductors in the following steps:

1. Confirm that the input and output disconnect switches are both turned off before connecting the power wires to the controller. There are no disconnect switches inside the TriStar.
2. Provide for strain relief if the bottom knockouts are used and conduit is not used.
3. Pull the wires into the wiring compartment. The temperature probe wires and battery voltage sense wires can be inside the conduit with the power conductors.
4. Connect the Battery + (positive) wire to the Battery + terminal.
5. Connect the Battery – (negative) wire to a TriStar common – terminal.
6. Connect the Solar + wire (positive) to the Solar + terminal. (or Load + / Diversion +)
7. Connect the Solar – (negative) wire a TriStar common – terminal. (or Load – / Diversion –)

NOTE: TriStar negative terminals are common negative.

The CE certification requires that the battery conductors, the battery voltage sense wires, and the remote temperature sensor shall not be accessible without the use of a tool and are protected in the battery compartment.

Do not bend the power wires up toward the access cover. If a TS-M meter is used now or in the future, these large wires can damage the meter assembly when the access cover is attached to the controller.

Torque each of the four power terminals to 5.65 Nm (50 in-lbs).

Power-Up
- Confirm that the solar (or load) and battery polarities are correct.
- Turn the battery disconnect on first. Observe the LEDs to confirm a successful start-up. (LEDs blink Green - Yellow - Red in one cycle)
- Note that a battery must be connected to the TriStar to start and operate the controller. The controller will not operate from a solar input only.
- Turn the solar (or load) disconnect on.

Step 7 - RS-232 Adjustments

The TriStar must be powered from the battery to enable use of the RS-232 / PC computer connection. Refer to Section 7.0 for using the RS-232 and Morningstar's PC software to change set-points or confirm the installation settings.

Step 8 - Finish Installation

Inspect for tools and loose wires that may have been left inside the enclosure.

Check the power conductors to make sure they are located in the lower part of the wiring compartment and will not interfere with the cover or the optional meter assembly.

☞ NOTE: If the power conductors are bent upwards and touch the meter assembly (TS-M option), pressing the cover down on the wires can damage the meter.

☞ REMARQUE : Si les conducteurs d'alimentation sont courbés vers le haut et touche l'ensemble de mesure (option TS-M), la pression du couvercle sur les câbles peut endommager l'appareil de mesure.

Carefully place the cover back on the controller and install the 4 cover screws.

Closely observe the system behavior and battery charging for 2 to 4 weeks to confirm the installation is correct and the system is operating as expected.

3.0 TriStar Operation

The TriStar operation is fully automatic. After the installation is completed, there are few operator tasks to perform. However, the operator should be familiar with the basic operation and care of the TriStar as described below.

3.1 Operator's Tasks

- Use the push-button as needed *(see 3.2 below)*
- Check the LEDs for status and faults *(see 3.3 below)*
- Support recovery from a fault as required *(see 3.4 below)*
- Routine inspection and maintenance *(see 3.6 below)*

If a TriStar digital meter is installed, please refer to the meter manual.

3.2 Push-button

In the battery charging mode (both solar and diversion), the following functions can be enabled with the push-button (located on the front cover):

PUSH: Reset from an error or fault.

PUSH: Reset the battery service indication if this has been activated with the PC software. A new service period will be started, and the flashing LEDs will stop blinking. If the battery service is performed before the LEDs begin blinking, the push-button must be pushed at the time when the LEDs are blinking to reset the service interval and stop the blinking.

PUSH AND HOLD 5 SECONDS: Begin battery equalization manually. This will begin equalization in either the manual or automatic equalization mode. The equalization will automatically stop per the battery type selected (see Section 4.4).

PUSH AND HOLD 5 SECONDS: Stop an equalization that is in progress. This will be effective in either the manual or automatic mode. The equalization will be terminated.

Note that if two or more TriStars are charging in parallel, the equalization cycles may start on different days for various reasons (such as one controller is disconnected and restarted). If this happens, the push-button on each controller can be used to manually start and then stop an equalization, and this will reset the equalizations to the same schedule.

LOAD & LIGHTING CONTROL

PUSH: Reset from an error or fault.

PUSH AND HOLD 5 SECONDS: After a low voltage disconnect (LVD) of the load, the push-button can be used to reconnect the loads again. The loads will remain on for 10 minutes, and will then disconnect again. The push-button can be used to override the LVD without limit.

NOTE: The purpose of the LVD is to protect the battery. Repeated overrides of an LVD can deeply discharge the battery and may damage the battery.

3.3 LED Indications

Valuable information can be provided by the three LEDs in the front cover. Although there are many different LED indications, they have similar patterns to make it easier to interpret each LED display. Consider as three groups of indications: General Transitions // Battery or Load Status // Faults.

LED Display Explanation:

G = green LED is lit
Y = yellow LED is lit
R = red LED is lit
G/Y = Green and Yellow are both lit at the same time
G/Y - R = Green & Yellow both lit, then Red is lit alone
Sequencing (faults) has the LED pattern repeating until the fault is cleared

1. General Transitions:

• Controller start-up	G - Y - R (one cycle)
• Push-button transitions	blink all 3 LEDs 2 times
• Battery service is required	all 3 LEDs blinking until service is reset

2. Battery Status

• General state-of-charge	*see battery SOC indications below*
• PWM absorption	G blinking (1/2 second on / 1/2 second off)
• Equalization state	G fast blink (2 to 3 times per second)
• Float state	G slow blink (1 second on / 1 second off)

Battery State-of-Charge LED Indications (when battery is charging):

• G on	80% to 95% SOC
• G/Y on	60% to 80% SOC
• Y on	35% to 60% SOC
• Y/R on	0% to 35% SOC
• R on	battery is discharging

Refer to the Specifications (Section 11.0) for the State-of-Charge voltages. Another LED chart is provided at the end of this manual (Appendix 3) for easier reference.

Note that because these State-of-Charge LED displays are for all battery types and system designs, they are only approximate indications of the battery charge state.

LOAD & LIGHTING CONTROL

2. Load Status

	12V	24V	48V
LVD+	0.60V	1.20V	2.40V
LVD+	0.45V	0.90V	1.80V
LVD+	0.30V	0.60V	1.20V
LVD+	0.15V	0.30V	0.60V
LVD			

The load status LEDs are determined by the LVD voltage plus the specified transition voltages. As the battery voltage rises or falls, each voltage transition will cause a change in the LEDs.

3. Faults & Alarms

• Short circuit - solar/load	R/G - Y sequencing
• Overload - solar/load	R/Y - G sequencing
• Over-temperature	R - Y sequencing
• High voltage disconnect	R - G sequencing
• Reverse polarity - battery	no LEDs are lighted
• Reverse polarity - solar	No fault indication
• DIP switch fault	R - Y - G sequencing
• Self-test faults	R - Y - G sequencing
• Temperature probe (RTS)	R/Y - G/Y sequencing
• Battery voltage sense	R/Y - G/Y sequencing

3.4 Protections and Fault Recovery

The TriStar protections and automatic recovery are important elements of the operating system. The system operator should be familiar with the causes of faults, controller protections, and any actions that may be required.

Some basic fault conditions are reviewed below:

Short circuit:
(R/G-Y sequencing) When a short circuit occurs, the FET switches are opened in micro-seconds. The FETs will probably open before other protective devices in the system can react, so the short circuit may remain in the system. The TriStar will try to reconnect the FETs two times. If the short circuit remains, the LEDs will continue sequencing.

After the short in the system is repaired, there are two ways to restart the controller:

- Power should have been disconnected to repair the short. When power is restored, the TriStar does a normal start-up and will reconnect the solar input or load.
- The push-button can also be used to reconnect the FET switches (if there is battery power to the TriStar).

NOTE: There will always be a 10 second delay between attempts to reconnect the FET switches. Even if power is disconnected, the TriStar will wait for the remainder of the 10 seconds when the power is restored.

REMARQUE : Il existera toujours un délai de 10 secondes entre les tentatives de reconnexion des commutateurs TEC. Même si l'alimentation est déconnectée, le TriStar attend la fin des 10 secondes quand l'alimentation est rétablie.

Solar overload:
(R/Y-G sequencing) If the solar input exceeds 100% of the controller's current rating, the controller will reduce the average current below the TriStar's rating. The controller is capable of managing up to 130% of the rated solar input.

When 130% rated current is exceeded, the solar will be disconnected and a fault will be indicated. The input FET switches will remain open for 10 seconds. Then the switches are closed again and charging resumes. These cycles can continue without limit.

The current overload is reduced to the "equivalent heating" of the rated current input. For example, a 72A solar array (120% overload) will PWM down to 50A, which is equivalent to the heating from a normal 60A solar input.

LOAD & LIGHTING CONTROL

Load overload:
(R/Y-G sequencing) If the load current exceeds 100% of the controller's rating, the controller will disconnect the load. The greater the overload, the faster the controller will disconnect. A small overload could take a few minutes to disconnect.

The TriStar will attempt to reconnect the load two times. Each attempt is at least 10 seconds apart. If the overload remains after 2 attempts, the load will remain disconnected. The overload must be corrected and the controller restarted. The push-button can also be used to reconnect the load.

DIVERSION CHARGE CONTROL

Diversion overload:
(R/Y-G sequencing) If the current to the diversion load exceeds the TriStar rating, the controller will attempt to reduce the load. If the overload is too large, the TriStar will disconnect the diversion load. The controller will continue attempts to reconnect the load.

If the overload LEDs are sequencing, the diversion load is too large for the controller. The size of the load must be reduced.

Reversed polarity:
If the battery polarity is reversed, there will be no power to the controller and no LEDs will light. If the solar is reversed, the controller detects nighttime and there will be no LED indication and no charging. If the load is reversed, loads with polarity will be damaged. Be very careful to connect loads to the controller with correct polarity. See Section 5.4.

DIP switch fault:
(R-Y-G sequencing) If a DIP switch is changed while there is power to the controller, the LEDs will begin sequencing and the FET switches will open. The controller must be restarted to clear the fault.

Solar high temperature:
(R-Y sequencing) When the heatsink temperature limit is reached, the TriStar will begin reducing the solar input current to prevent more heating. If the controller continues heating to a higher temperature, the solar input will then be disconnected. The solar will be reconnected at the lower temperature (see Section 8.0).

LOAD & LIGHTING CONTROL

Load high temperature:
(R-Y sequencing) When the heatsink temperature limit is reached (90˚C / 194˚F), the TriStar will disconnect the load. The load will be reconnected at the lower temperature setting (70˚C / 158˚F).

DIVERSION CHARGE CONTROL

Diversion high temperature:
(R-Y sequencing) When the heat sink temperature reaches 80˚C, the TriStar will change to an on-off regulation mode to reduce the temperature. If the temperature reaches 90˚C, the load will be disconnected. The load is reconnected at 70˚C.

3.0

Solar high voltage disconnect (HVD):
(R-G sequencing) If the battery voltage continues increasing beyond normal operating limits, the controller will disconnect the solar input (unless the FET switches cannot open due to a failure). *See Section 11.0 for the disconnect and reconnect values.*

LOAD & LIGHTING CONTROL

Load HVD:
(R-G sequencing) In the Load Control mode, the HVD can only be enabled using the PC software. At the battery voltage value selected in the software, the TriStar will disconnect the load. At the selected lower voltage, the load will be reconnected.

DIVERSION CHARGE CONTROL

Diversion HVD:
In the Diversion mode, an HVD condition will not be indicated with the LEDs, and there is no disconnect. An HVD condition will be indicated on the optional meter.

Battery removal voltage spike:
(no LED indication) Disconnecting the battery before the solar input is disconnected can cause a large solar open-circuit voltage spike to enter the system. The TriStar protects against these voltage spikes, but it is best to disconnect the solar input before the battery.

Very low battery voltage:
(LEDs are all off) Below 9 volts the controller will go into brownout. The controller shuts down. When the battery voltage rises, the controller will restart. In the Load Control mode, the TriStar will recover in the LVD state.

Remote temperature sensor (RTS) failure:
(R/Y-G/Y) If a fault in the RTS (such as a short circuit, open circuit, loose terminal) occurs after the RTS has been working, the LEDs will indicate a failure and the solar input is disconnected. However, if the controller is restarted with a failed RTS, the controller may not detect that the RTS is connected, and the LEDs will not indicate a problem. A TriStar meter or the PC software can be used to determine if the RTS is working properly.

Battery voltage sense failure:
(R/Y-G/Y) If a fault in the battery sense connection (such as a short circuit, open circuit, loose terminal) occurs after the battery sense has been working, the LEDs will indicate a failure. However, if the controller is restarted with the failure still present in the battery sense, the controller may not detect that the battery sense is connected, and the LEDs will not indicate a problem. A TriStar meter or the PC software can be used to determine if the battery sense is working properly.

3.5 Data-Logging

The TriStar records daily records of key system information. Data is stored in all operating modes: Charging, Load/Lighting, Diversion. In Charge mode records are written after dusk each day. In Load and Diversion modes, records are written every 24 hours and may not coincide with the natural day/night cycle. The logged data can be viewed using the TriStar Digital Meter 2 or TriStar Remote Meter 2. Data can also be accessed using MSView™ PC software, which is available for download on our website.

☞ ***NOTE: The Data Logging feature is available in TriStar firmware version v12 and later. Firmware update files and instructions are available on our website.***

3.6 Inspection and Maintenance

WARNING: RISK OF ELECTRICAL SHOCK.

NO POWER OR ACCESSORY TERMINALS ARE ELECTRICALLY ISOLATED FROM DC INPUT, AND MAY BE ENERGIZED WITH HAZARDOUS SOLAR VOLTAGE. UNDER CERTAIN FAULT CONDITIONS, BATTERY COULD BECOME OVER-CHARGED. TEST BETWEEN ALL TERMINALS AND GROUND BEFORE TOUCHING.

AVERTISSEMENT: RISQUE DE CHOC ÉLECTRIQUE.

ON ALIMENTATION OU AUX BORNES D'ACCESSOIRES SONT ISOLÉS ÉLECTRIQUEMENT DE L'ENTRÉE DE C.C ET DOIT ÊTRE ALIMENTÉS À UNE TENSION DANGEREUSE SOLAIRE. SOUS CERTAINES CONDITIONS DE DÉFAILLANCE, LA BATTERIE POURRAIT DEVENIR TROP CHARGÉE. TEST ENTRE TOUTES LES BORNES ET LA MASSE AVANT DE TOUCHER.

WARNING: Shock Hazard

Disconnect all power sources to the controller before removing the wiring box cover. Never remove the cover when voltage exists on the TriStar-PWM power connections.

AVERTISSEMENT: Risque de décharge électrique

Un moyen de déconnexion de tous les poteaux d'alimentation doit être fourni. Ceux-ci se déconnecte doit être intégrée dans le câblage fixe. Ouvrir que toutes les source d'énergie se déconnecte avant de retirer le couvercle de la contrôleur, ou accès au câblage.

The TriStar does not require routine maintenance. The following inspections are recommended two times per year for best long-term performance.

1. Confirm the battery charging is correct for the battery type being used. Observe the battery voltage during PWM absorption charging (green LED blinking 1/2 second on / 1/2 second off). Adjust for temperature compensation if an RTS is used *(see Table 4.3)*.

   For load and diversion modes, confirm that the operation is correct for the system as configured.
2. Confirm the controller is securely mounted in a clean and dry environment.
3. Confirm that the air flow around the controller is not blocked. Clean the heat sink of any dirt or debris.
4. Inspect for dirt, nests and corrosion, and clean as required.

4.0 Battery Charging

4.1 PWM Battery Charging

PWM (Pulse Width Modulation) battery charging is the most efficient and effective method for recharging a battery in a solar system. *Refer to "Why PWM?" on Morningstar's website for more information.*

Selecting the best method for charging your battery together with a good maintenance program will ensure a healthy battery and long service life. Although the TriStar's battery charging is fully automatic, the following information is important to know for getting the best performance from your TriStar controller and battery.

4.1.1 Four Stages of Solar Charging

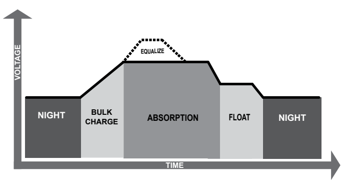


Figure 4.1.1 Solar Charging Stages

1. **Bulk Charging:** In this stage, the battery will accept all the current provided by the solar system. The LEDs will display an indication of the battery charge state as the battery is being recharged.
2. **PWM Absorption:** When the battery reaches the regulation voltage, the PWM begins to hold the voltage constant. This is to avoid over-heating and over-gasing the battery. The current will taper down to safe levels as the battery becomes more fully charged. The green LED will blink once per second. *See Section 4.2.*
3. **Equalization:** Many batteries benefit from a periodic boost charge to stir the electrolyte, level the cell voltages, and complete the chemical reactions. The green LED will blink rapidly 2-3 times per second. *See Section 4.4.*
4. **Float:** When the battery is fully recharged, the charging voltage is reduced to prevent further heating or gasing of the battery. The green LED will blink slowly once every 2 seconds. *See Section 4.5.*

4.1.2 Battery Charging Notes

The TriStar manages many different charging conditions and system configurations. Some useful functions to know follow below.

Solar Overload: Enhanced radiation or "edge of cloud effect" conditions can generate more current than the controller's rating. The TriStar will reduce this overload up to 130% of rated current by regulating the current to safe levels. If the current from the solar array exceeds 130%, the controller will interrupt charging *(see Section 3.4).*

Battery Voltage Sense: Connecting a pair of voltage sense wires from the controller to the battery is recommended. This allows a precise battery voltage input to the controller and more accurate battery charging. *See Section 4.3 for more information.*

Temperature Compensation: All charging set-points are based on 25˚C (77˚F). If the battery temperature varies by 5˚C, the charging will change by 0.15 volts for a 12 volt battery. This is a substantial change in the charging of the battery, and a remote temperature sensor is recommended to adjust charging to the actual battery temperature. *See Section 4.3 for more information.*

Day-Night Detection: The TriStar will automatically detect day and night conditions. Any functions that require measuring time or starting at dawn, for example, will be automatic.

PWM Noise: In some installations, the PWM charging may cause audible noise in certain equipment. If this occurs, the PWM can be changed to "On-Off" solar charging to reduce the noise. This requires DIP switch number 8 to be turned On. However, it is strongly recommended to try to remedy the noise problem with grounding or filtering first, because the benefits from PWM battery charging are significant.

Battery Types: The TriStar's standard battery charging programs are suitable for a wide range of lead-acid battery types. These standard programs are reviewed in the following Section 4.2. A general review of battery types and their charging needs is provided in Section 9.0.

4.2 Standard Battery Charging Programs

The TriStar provides 7 standard battery charging algorithms (programs) that are selected with the DIP switches (see Step 3 in Installation). These standard algorithms are suitable for lead-acid batteries ranging from sealed (gel, AGM, maintenance free) to flooded to L-16 cells. In addition, an 8th DIP switch provides for custom set-points using the PC software.

The table below summarizes the major parameters of the standard charging algorithms. Note that all the voltages are for 12V systems (24V = 2X, 48V = 4X).

All values are 25°C (77°F).

DIP Switches (4-5-6)	A. Battery Type	B. PWM Absorp. Voltage	C. Float Voltage	D. Equal. Voltage	E. Time in Equal. (hours)	F. Equalize Interval (days)	G. Max Equal. Cycle (hours)
off-off-off	1 - Sealed	14.0	13.4	none	–	–	–
off-off-on	2 - Sealed	14.15	13.4	14.2	1	28	1
off-on-off	3 - Sealed	14.35	13.4	14.4	2	28	2
off-on-on	4 - Flooded	14.4	13.4	15.1	3	28	4
on-off-off	5 - Flooded	14.6	13.4	15.3	3	28	5
on-off-on	6 - Flooded	14.8	13.4	15.3	3	28	5
on-on-off	7 - L-16	15.0	13.4	15.3	3	14	5
on-on-on	8 - Custom		Custom			Custom	

Table 4.2 Standard Battery Charging Programs

A. Battery Type - These are generic lead-acid battery types. *See Section 9.0 for more information about battery types and appropriate solar charging.*

B. PWM Voltage–This is the PWM Absorption stage with constant voltage charging. The "PWM voltage" is the maximum battery voltage that will be held constant. As the battery becomes more charged, the charging current tapers down until the battery is fully charged.

C. Float Voltage–When the battery is fully charged, the charging voltage will be reduced to 13.4 volts for all battery types. The float voltage and transition values are adjustable with the PC software. *See Section 4.5 for more details.*

D. Equalization Voltage–During an equalization cycle, the charging voltage will be held constant at this voltage.

E. Time in Equalization–The charging at the selected equalization voltage will continue for this number of hours. This may take more than one day to complete. See Section 4.4.

F. Equalization Interval–Equalizations are typically done once a month. Most of the cycles are 28 days so the equalization will begin on the same day of the week. Each new cycle will be reset as the equalization starts so that a 28 day period will be maintained.

G. Maximum Equalization Cycle–If the solar array output cannot reach the equalization voltage, the equalization will terminate after this many hours to avoid over gasing or heating the battery. If the battery requires more time in equalization, the manual push-button can be used to continue for one or more additional equalization cycles.

These (7) standard battery charging algorithms will perform well for the majority of solar systems. However, for systems with specific needs beyond these standard values, any or all of these values can be adjusted using the PC software. *See Section 7.0.*

4.3 Temperature Effects & Battery Voltage Sense

4.3.1 Remote Temperature Sensor (RTS)

The RTS is used for temperature compensated battery charging. As the battery gets warmer, the gasing increases. As the battery gets colder, it becomes more resistant to charging. Depending on how much the battery temperature varies, it may be important to adjust the charging for temperature changes.

There are three battery charging parameters that are affected by temperature:

PWM Absorption
This is the most important part of charging that is affected by temperature because the charging may go into PWM absorption almost every day. If the battery temperature is colder, the charging will begin to regulate too soon and the battery may not be recharged with a limited solar resource. If the battery temperature rises, the battery may heat and gas too much.

Equalization
A colder battery will lose part of the benefit of the equalization. A warmer battery may heat and gas too much.

Float
Float is less affected by temperature changes, but it may also undercharge or gas too much depending on how much the temperature changes.

The RTS corrects the three charging set-points noted above by the following values:

- 12 volt battery: –0.030 volts per ˚C (–0.017 volts per ˚F)
- 24 volt battery: –0.060 volts per ˚C (–0.033 volts per ˚F)
- 48 volt battery: –0.120 volts per ˚C (–0.067 volts per ˚F)

Variations in battery temperature can affect charging, battery capacity, and battery life. The greater the range of battery temperatures, the greater the impact on the battery. For example, if the temperature falls to 10˚C (50˚F) this 15˚C (27˚F) change in temperature will change the PWM, equalization and float set-points by 1.80V in a 48V system.

If a remote temperature sensor is not used and the temperatures near the battery are stable and predictable, the PWM absorption setting can be adjusted using the PC software per the following table:

Temperature	12 Volt	24 Volt	48 Volt
40°C / 104°F	– 0.45 V	– 0.90 V	– 1.80 V
35°C / 95°F	– 0.30 V	– 0.60 V	– 1.20 V
30°C / 86°F	– 0.15 V	– 0.30 V	– 0.60 V
25°C / 77°F	0 V	0 V	0 V
20°C / 68°F	+ 0.15 V	+ 0.30 V	+ 0.60 V
15°C / 59°F	+ 0.30 V	+ 0.60 V	+ 1.20 V
10°C / 50°F	+ 0.45 V	+ 0.90 V	+ 1.80 V
5°C / 41°F	+ 0.60 V	+ 1.20 V	+ 2.40 V
0°C / 32°F	+ 0.75 V	+ 1.50 V	+ 3.00 V
– 5°C / 23°F	+ 0.90 V	+ 1.80 V	+ 3.60 V
– 10°C / 14°F	+ 1.05 V	+ 2.10 V	+ 4.20 V
– 15°C / 5°F	+ 1.20 V	+ 2.40 V	+ 4.80 V

Table 4.3 Temperature Compensation

The need for temperature compensation depends on the temperature variations, battery type, how the system is used, and other factors. If the battery appears to be gasing too much or not charging enough, an RTS can be added at any time after the system has been installed. *See Section 2.3 - Step 4 for installation instructions.*

The TriStar will recognize the RTS when the controller is started (powered-up).

4.3.2 Battery Voltage Sense

There can be voltage drops typically up to 3% in the power cables connecting the battery to the TriStar. If battery voltage sense wires are not used, the controller will read a higher voltage at the controller's terminals than the actual battery voltage while charging the battery.

Although limited to 3% as the generally accepted wiring standard, this can result in a 0.43 voltage drop for 14.4V charging (or 1.72V for a 48 volt nominal system).

These voltage drops will cause some undercharging of the battery. The controller will begin PWM absorption, or limit equalization, at a lower battery voltage because the controller measures a higher voltage at the controller's terminals than is the actual battery voltage. For example, if the controller is programmed to start PWM absorption at 14.4V, when the controller "sees" 14.4V at its battery terminals, the true battery voltage would only be 14.1V if there is a 0.3V drop between the controller and battery.

Two sense wires, sized from 1.0 to 0.25 mm² (16 to 24 AWG), can be used for battery voltage sense. Because these wires carry no current, the voltage at the TriStar will be identical to the battery voltage. A 2-position terminal is used for the connection

Note that the battery sense wires will not power the controller, and the sense wires will not compensate for losses in the power wires between the controller and the battery. The battery sense wires are used to improve the accuracy of the battery charging.

See Section 2.3 - Step 5 for instructions how to connect the battery sense wires.

4.4 Equalization

Routine equalization cycles are often vital to the performance and life of a battery — particularly in a solar system. During battery discharge, sulfuric acid is consumed and soft lead sulfate crystals form on the plates. If the battery remains in a partially discharged condition, the soft crystals will turn into hard crystals over time. This process, called "lead sulfation," causes the crystals to become harder over time and more difficult to convert back to soft active materials.

Sulfation from chronic undercharging of the battery is the leading cause of battery failures in solar systems. In addition to reducing the battery capacity, sulfate build-up is the most common cause of buckling plates and cracked grids. Deep cycle batteries are particularly susceptible to lead sulfation.

Normal charging of the battery can convert the sulfate back to the soft active material if the battery is fully recharged. However, a solar battery is seldom completely recharged, so the soft lead sulfate crystals harden over a period of time. Only a long controlled overcharge, or equalization, at a higher voltage can reverse the hardening sulfate crystals.

In addition to slowing or preventing lead sulfation, there are also other benefits from equalizations of the solar system battery. These include:

Balance the individual cell voltages.
Over time, individual cell voltages can drift apart due to slight differences in the cells. For example, in a 12 cell (24V) battery, one cell is less efficient in recharging to a final battery voltage of 28.8 volts (2.4 V/c). Over time, that cell only reaches 1.85 volts, while the other 11 cells charge to 2.45 volts per cell. The overall battery voltage is 28.8V, but the individual cells are higher or lower due to cell drift. Equalization cycles help to bring all the cells to the same voltage.

Mix the electrolyte.
In flooded batteries, especially tall cells, the heavier acid will fall to the bottom of the cell over time. This stratification of the electrolyte causes loss of capacity and corrosion of the lower portion of the plates. Gasing of the electrolyte from a controlled overcharging (equalization) will stir and remix the acid into the battery electrolyte.

NOTE: Excessive overcharging and gasing too vigorously can damage the battery plates and cause shedding of active material from the plates. An equalization that is too high or for too long can be damaging. Review the requirements for the particular battery being used in your system.

REMARQUE : Une surcharge excessive et un dégagement gazeux trop vigoureux peuvent endommager les plaques de batteries et provoquer l'élimination du matériau actif des plaques. Une compensation trop élevée ou trop longue peut provoquer des dégâts. Examinez les exigences pour la batterie particulière utilisée dans votre système.

4.4.1 Standard Equalization Programs

Both automatic and manual equalizations can be performed using either the standard charging programs (see 4.2) or a custom program (see 7.0).

Manual Equalization
The TriStar is shipped with the DIP switch set for manual equalization only. This is to avoid an unexpected or unwanted automatic equalization. In the manual mode, the push-button is used to both start or stop a manual equalization. Hold the push-button down for 5 seconds to start or stop an equalization (depending on whether an equalization is in progress or not).

The LEDs will confirm the transition (all 3 LEDs blink 2 times). When the battery charging enters into equalization, the Green LED will start fast blinking 2-3 times per second.

There are no limits to how many times the push-button can be used to start and stop equalizations. Equalizations will be terminated automatically per the charging program selected if the push-button is not used to manually stop the equalization.

Automatic Equalization
If the equalization DIP switch is moved to the ON position (see 2.3 - Step 3), the equalizations will begin automatically per the charging program selected. Other than starting, the automatic and manual equalizations are the same and follow the standard charging program selected. The push-button can be used to start and stop equalizations in both the manual and automatic mode.

4.4.2 Typical Equalizations

The automatic equalizations will occur every 28 days (except L-16 cells at 14 days). When an equalization begins (auto or manual), the battery charging voltage increases up to the equalization voltage (Veq). The battery will remain at Veq for the time specified in the selected charging program (see table in 4.2).

If the time to reach Veq is too long, the maximum equalization cycle time will end the equalization. A second manual equalization cycle can be started with the push-button if needed.

If the equalization cannot be completed in one day, it will continue the next day or days until finished. After an equalization is completed, charging will return to PWM absorption.

4.4.3 Preparation for Equalization

First, confirm that all your loads are rated for the equalization voltage. Consider that at 0˚C (32˚F) the equalization voltage will reach 16.05V in a 12V system (64.2V in a 48V system) with a temperature sensor installed. Disconnect any loads at risk.

If Hydrocaps are used, be sure to remove them before starting an equalization. Replace the Hydrocaps with standard battery cell caps. The Hydrocaps can get very hot during an equalization. Also, if Hydrocaps are used, the equalization should be set for manual only (DIP switch #7 is Off).

After the equalization is finished, add distilled water to each cell to replace gasing losses. Check that the battery plates are covered.

4.4.4 When to Equalize

The ideal frequency of equalizations depends on the battery type (lead-calcium, lead-antimony, etc.), the depth of discharging, battery age, temperature, and other factors.

One very broad guide is to equalize flooded batteries every 1 to 3 months or every 5 to 10 deep discharges. Some batteries, such as the L-16 group, will need more frequent equalizations.

The difference between the highest cell and lowest cell in a battery can also indicate the need for an equalization. Either the specific gravity or the cell voltage can be measured. The battery manufacturer can recommend the specific gravity or voltage values for your particular battery.

4.4.5 "Equalize" a Sealed Battery?

The standard battery charging table (see Section 4.2) shows two sealed batteries with an "equalization" cycle. This is only a 0.05 volt (12V battery) boost cycle to level individual cells. This is not an equalization, and will not vent gas from sealed batteries that require up to 14.4V charging (12V battery). This "boost" charge for sealed cells allows for adjustability with the PC software.

Many VRLA batteries, including AGM and gel, have increased charging requirements up to 14.4V (12V battery). The 0.05V boost shown in the table (Section 4.2) is less than the accuracy range of most charge controllers. Alternatively, for these two sealed battery charging programs you may prefer to consider the PWM absorption stage to be 14.2V and 14.4V (12V battery).

The 14.0, 14.2, and 14.4 volt standard charging programs should be suitable for most sealed batteries. If not optimum for your battery, the PC software can be used to adjust these values. *Refer to Section 9.0 for more information about charging sealed batteries.*

4.5 Float

When a battery becomes fully charged, dropping down to the float stage will provide a very low rate of maintenance charging while reducing the heating and gasing of a fully charged battery. When the battery is fully recharged, there can be no more chemical reactions and all the charging current is turned into heat and gasing.

The purpose of float is to protect the battery from long-term overcharge. From the PWM absorption stage, charging is dropped to the float voltage. This is typically 13.4V, and is adjustable with the PC software.

The transition to float is based on the previous 24 hour history. Factors include the battery voltage, the state of charge the night before, the battery type, and the PWM duty cycle and stability of the duty cycle. The battery will be charged for part of the day until the transition to float.

If there are loads for various periods of time during float, the TriStar will cancel float and return to bulk charge.

Float is temperature compensated.

5.0 Load and Lighting Control

5.1 General Load & Lighting Control Notes

IMPORTANT:

5.1.1 Inductive loads

Do not connect inductive loads such as inverters, motors, pumps, compressors, generators to the load terminals. Inductive loads can generate large voltage spikes that may damage the controller's lightning protection devices. Connect inductive loads directly to the battery.

If a heavy load must be connected to the TriStar's load terminals e.g. for LVD purposes, contact your dealer or Morningstar Tech Support for a design solution.

5.1.2 Parallel TriStars

Two or more TriStars should never be put in parallel for a large load. The controllers cannot share the load.

5.1.3 Reverse Polarity

If the battery is correctly connected (LEDs are on), the load should be connected very carefully with regard to polarity (+ / –).

If the polarity is reversed, the controller cannot detect this. There are no indications.

Loads without polarity will not be affected.

Loads with polarity can be damaged. It is possible that the TriStar will go into short circuit protection before the load is damaged. If the LEDs indicate a "short", be certain to check for both shorts and reversed polarity connections.

If the controller does not go into short circuit protection, the loads with polarity will be damaged.

CAUTION: Carefully verify the polarity (+ and –) of the load connections before applying power to the controller.

PRUDENCE : Vérifiez avec précaution la polarité (+ et –) des connexions de la charge avant de mettre le contrôleur sous tension.

5.2 Load Control Settings

The primary purpose of a low voltage load disconnect function (LVD) is to protect the system battery from deep discharges that could damage the battery.

In the Load Control mode, the TriStar provides for seven standard LVD settings that are selected by the DIP switches. These are described in the table below. Custom LVD settings are possible using the PC software (see Section 7.0).

DIP Switch	12V LVD	24V LVD	48V LVD	Battery SOC%	12V LVD_R	24V LVD_R	48V LVD_R
off-off-off	11.1	22.2	44.4	8	12.6	25.2	50.4
off-off-on	11.3	22.6	45.2	12	12.8	25.6	51.2
off-on-off	11.5	23.0	46.0	18	13.0	26.0	52.0
off-on-on	11.7	23.4	46.8	23	13.2	26.4	52.8
on-off-off	11.9	23.8	47.6	35	13.4	26.8	53.6
on-off-on	12.1	24.2	48.4	55	13.6	27.2	54.4
on-on-off	12.3	24.6	49.2	75	13.8	27.6	55.2
on-on-on		Custom		Custom		Custom	

Table 5.1

The table above describes the standard selectable LVD battery voltages for 12, 24 and 48 volt systems. The LVD_R values are the load reconnect setpoints. The "Battery SOC %" provides a general battery state-of-charge figure for each LVD setting. The actual battery SOC can vary considerably depending on the battery condition, discharge rates, and other specifics of the system.

NOTE: The lowest LVD settings are intended for applications such as telecom that only disconnect the load as a last resort. These lower LVD settings will deeply discharge the battery and should not be used for systems that may go into LVD more than once a year.

REMARQUE : Les réglages les plus bas du disjoncteur basse tension sont prévus pour les applications comme celles de télécom qui ne déconnectent la charge qu'en dernier recours. Ces réglages les plus bas du disjoncteur basse tension déchargent fortement la batterie et ne doivent pas être utilisés avec les systèmes qui risquent de déclencher le disjoncteur basse tension plus d'une fois par an.

The LVD values in table 5.1 above are current compensated. Under load, the battery voltage will be reduced in proportion to the current draw by the load. A short-term large load could cause a premature LVD without the current compensation. The LVD values in the table above are adjusted lower per the following table:

	TS-45	TS-60
12V	–15 mV per amp	–10 mV per amp
24V	–30 mV per amp	–20 mV per amp
48V	–60 mV per amp	–40 mV per amp

As an example, consider a 24V system using a TriStar-60 with a 30 amp load. The LVD will be reduced by 0.02V (per the table above) times 30 amps. This equals –0.6V. A DIP-switch selected LVD of 23.4V would be reduced to 22.8V in this example.

Note that the LEDs are linked to the LVD setting, so the LEDs are also current compensated.

continued...

After an LVD, the load reconnect voltages are 0.25 volts per battery cell higher than the LVD (for example, in a 12V system the LVD_R would be 1.5 volts above LVD). Battery voltages can rise quickly after an LVD, typically from 1.0 to 1.3 volts or more (12V system). The LVD_R value must be high enough to avoid cycling in and out of LVD.

5.3 LVD Warning

When the battery is discharging and the green LED changes to the next state (G-Y LEDs on), there are four remaining transitions to LVD (refer to the LED indications in Section 3.3). Each of these LED displays will serve as a warning of an approaching LVD. The final warning is a blinking red LED state.

The amount of time from the initial G-Y display until the load disconnect will depend on many factors. These include:

• The rate of discharge.

• The health of the battery

• The LVD setting

For a "typical" system with a healthy battery and an LVD setting of about 11.7 volts, there could be approximately 10 hours per LED transition. The LVD would occur about 40 hours from the first G-Y display (under constant load with no charging).

Another significant factor affecting the warning time is the LVD voltage setpoint. Lower LVD voltage settings may result in the battery discharging 70% or 80% of its capacity. In this case, the battery's very low charge state will result in the voltage dropping much faster. At the lowest LVD settings, there could be as little as 2 or 3 hours of warning between LED transitions for a healthy battery.

The amount of time it takes to transition through the LEDs to LVD can vary greatly for different systems. It may be worthwhile to measure the time it takes for your system to transition from one LED state to the next. Do this under "typical" discharging loads.

This will provide a good reference for how long it will take for your system to reach LVD. It can also provide a benchmark for judging the health of your battery over time.

6.0 Diversion Charge Control

The TriStar's third mode of operation is diversion load battery charge control. As the battery becomes fully charged, the TriStar will divert excess current from the battery to a dedicated diversion load. This diversion load must be large enough to absorb all the excess energy, but not too large to cause a controller overload condition.

6.1 Diversion Charge Control

In the diversion mode, the TriStar will use PWM charging regulation to divert excess current to an external load. As the battery becomes fully charged, the FET switches are closed for longer periods of time to direct more current to the diversion load.

As the battery charges, the diversion duty cycle will increase. When fully charged, all the source energy will flow into the diversion load if there are no other loads. The generating source is typically a wind or hydro generator. Some solar systems also use diversion to heat water rather than open the solar array and lose the energy.

The most important factor for successful diversion charge control is the correct sizing of the diversion load. If too large, the controller's protections may open the FET switches and stop diverting current from the battery. This condition can damage the battery.

If you are not confident and certain about the installation, a professional installation by your dealer is recommended.

6.2 Diversion Current Ratings

The maximum diversion load current capability for the two TriStar versions is 45 amps (TS-45) and 60 amps (TS-60/M). The diversion loads must be sized so that the peak load current cannot exceed these maximum ratings.

See section 6.4 below for selecting and sizing the diversion loads.

The total current for all combined charging sources (wind, hydro, solar) should be equal or less than two-thirds of the controller's current rating: 30A (TS-45) and 40A (TS-60/M). This limit will provide a required margin for high winds and high water flow rates as well as a margin for error in the rating and selection of the diversion load. This protects against an overload and a safety disconnect in the TriStar controller, which would leave the battery charging unregulated.

CAUTION: If the TriStar's rating is exceeded and the controller disconnects the diversion load, Morningstar will not be responsible for any damage resulting to the system battery or other system components. Refer to Morningstar's Limited Warranty in Section 10.0.

PRUDENCE : Si la capacité du TriStar est dépassée et que le contrôleur déconnecte la charge de diversion, Morningstar ne sera pas responsable de tout dommage résultant de la batterie du système ou d'autres composants du système. Reportez-vous à la Garantie limitée de Morningstar dans la Section 10.0.

6.3 Standard Diversion Battery Charging Programs

The TriStar provides 7 standard diversion charging algorithms (programs) that are selected with the DIP switches. An 8th algorithm can be used for custom set-points using the PC software.

The table below summarizes the major parameters of the standard diversion battery charging algorithms. Note that all the voltages are for 12V systems (24V = 2X, 48V = 4X).

All values are @25°C (77°F).

DIP Switches (4-5-6)	A. PWM Absorp. Voltage	B. Float Voltage	C. Time Until Float (hours)	D. Equalization Voltage	E. Time in Equal. (hours)	F. Equalize Interval (days)	G. Max. Equalize Cycle (hours)
off-off-off	13.8	13.6	4	14.1	3	28	3
off-off-on	14.0	13.6	4	14.3	3	28	3
off-on-off	14.2	13.6	4	14.5	3	28	4
off-on-on	14.4	13.6	4	14.7	4	28	4
on-off-off	14.6	13.7	4	14.9	4	28	5
on-off-on	14.8	13.7	4	15.1	4	28	5
on-on-off	15.0	13.7	4	15.3	4	28	5
on-on-on		Custom		Custom		Custom	

Table 6.1 Standard Diversion Charging Programs

A. PWM Absorption Voltage - This is the PWM Absorption stage with constant voltage charging. The PWM absorption voltage is the maximum battery voltage that will be held constant.

B. Float Voltage - When the battery is fully charged, the charging voltage will be reduced to the float voltage for all diversion settings. The float voltage and transition values are adjustable with the PC software.

C. Time Until Float - This is the cumulative time in PWM before the battery voltage is reduced to the float voltage. If loads are present during the PWM absorption, the time to transition into float will be extended.

D. Equalization Voltage - During an equalization cycle, the charging voltage will be held constant at this voltage. Equalizations are manual, and can be selected for automatic *(See Section 4.4.1)*.

E. Time in Equalization - Charging at the selected equalization voltage will continue for this number of hours.

F. Equalization Interval - Equalizations are typically done once a month. The cycles are 28 days so the equalization will begin on the same day of the week. Each new cycle will be reset as the equalization starts so that a 28 day period will be maintained.

G. Maximum Equalization Cycle - If the battery voltage cannot reach the equalization voltage, the equalization will terminate after this number of hours to avoid over gasing or heating the battery. If the battery requires more time in equalization, the manual push-button can be used to continue for one or more additional equalization cycles.

6.3.1 Battery Charging References

The diversion load battery charging is similar to conventional solar charging. Refer to the following sections in this manual for additional battery charging information.

4.1 Four stages of charging (applies to diversion)
4.3 Temperature Effects and Battery Voltage Sense
4.4 Equalization
4.5 Float
9.0 Battery Information

6.4 Selecting the Diversion Load

It is critical that the diversion load be sized correctly. If the load is too small, it cannot divert enough power from the source (wind, hydro, etc). The battery will continue charging and could be overcharged.

If the diversion load is too large, it will draw more current than the rating of the TriStar. The controller's overload protection may disconnect the diversion load, and this will result in all of the source current going to the battery.

CAUTION: The diversion load must be able to absorb the full power output of the source, but the load must never exceed the current rating of the TriStar controller. Otherwise, the battery can be overcharged and damaged.

PRUDENCE : La charge de diversion doit être capable d'absorber toute la puissance de sortie de la source, mais la charge ne doit jamais dépasser l'intensité nominale du contrôleur TriStar, pour ne pas surcharger et endommager la batterie.

6.4.1 Suitable Loads for Diversion

Water heating elements are commonly used for diversion load systems. These heating elements are reliable and widely available. Heating elements are also easy to replace, and the ratings are stable.

NOTE: Do not use light bulbs, motors, or other electrical devices for diversion loads. These loads will fail or cause the TriStar to disconnect the load. Only heating elements should be used.

REMARQUE : N'utilisez pas d'ampoules, de moteurs ou d'autres appareils électriques pour les charges de diversion. Ces charges ne fonctionneront pas ou provoqueront une déconnexion de la charge par le TriStar. Seuls les éléments de chauffe doivent être utilisés.

Water heating elements are typically 120 volts. Elements rated for 12, 24 and 48 volts are also available, but more difficult to source. The de-rating for 120 volt heating elements is discussed in 6.4.3 below.

6.4.2 Definition of Terms

Maximum Source Current:
This is the maximum current output of all the energy sources (hydro, wind, solar, etc.) added together. This current will be diverted through the TriStar to the diversion load.

Maximum Battery Voltage:
This maximum voltage is the PWM regulation voltage selected with the DIP switches, plus the increase with an equalization, plus the increase due to lower temperatures. The highest battery voltage is commonly 15, 30 and 60 volts for 12-, 24- and 48-volt systems.

Peak Load Current:
At the maximum battery voltage, this is the current the diversion load will draw. This peak load current must not exceed the TriStar's rating.

☞ ***NOTE: Because the battery can supply any size load, the peak load current is not limited by the source (hydro or wind rating). The diversion load's power rating is the critical specification for reliable battery charging.***

☞ ***REMARQUE : La batterie pouvant fournir une charge de n'importe quelle dimension, le pic d'intensité de la charge n'est pas limité par la source (puissance hydro ou éolienne). La puissance nominale de la charge de diversion constitue la spécification critique pour une charge fiable de la batterie.***

6.4.3 Load Power Ratings

The power rating of the diversion load will depend on the voltage of the battery being charged. If the heating element is not rated for the same voltage as the diversion system, the power rating of the load must be adjusted to the diversion system's voltage.

The manufacturers typically rate the heating elements for power at a specified voltage. The peak load current at the load's rated voltage will be the power divided by the rated voltage (I = P / V). For example: 2000W / 120V = 16.7 amps of current.

If the load is being used at a voltage less than the load's rated voltage, the power can be calculated by the ratio of the voltages squared. For example, a 120 volt 1000 watt heating element being used at 60 volts:

1000W x $(60/120)^2$ = 250 watts

The 1000W element will only dissipate 250W when being used at 60 volts.

☞ ***NOTE: The loads (heating elements) can be used at the manufacturer's voltage rating, or at a lower voltage. Do not use the load at a higher voltage than the load's rating.***

☞ ***REMARQUE : Les charges (éléments de chauffe) peuvent être utilisées à la tension nominale du fabricant ou à une tension inférieure. N'utilisez pas la charge à une tension supérieure à la tension nominale.***

6.4.4 Maximum Diversion Load

The diversion load should never exceed the TriStar's current rating (45A or 60A). Note that the load is not limited by the source (wind, hydro), and will draw its rated current from the battery.

The following table specifies the absolute maximum diversion loads that can be used with each TriStar version. These loads (heating elements) are rated for the same voltage as the system voltage.

Nominal Voltage	TriStar-45	TriStar-60
48V	2700W at 60V	3600W at 60V
24V	1350W at 30V	1800W at 30V
12V	675W at 15V	900W at 15V

These maximum power ratings are translated to the equivalent at 120 volts in the following table. If using heating elements rated for 120 volts, the power ratings of all the elements can be simply added up and the sum compared with this table and no further math is required.

Nominal Voltage	TriStar-45	TriStar-60
48V	10,800W at 120V	14,400W at 120V
24V	21,600W at 120V	28,800W at 120V
12V	43,200W at 120V	57,600W at 120V

To illustrate the same point from the opposite perspective, a heating element rated for 120 volts will draw reduced load current as indicated by the following table. A standard 2,000 watt / 120 Vac heating element is used as the reference.

Voltage	Power	Current
120V	2000 W	16.7 A
60V (48V nominal)	500 W	8.3 A
30V (24V nominal)	125 W	4.2 A
15V (12V nominal)	31 W	2.1 A

Whether using dc rated loads (the first table) or 120V elements, the total diversion load current must not exceed the current rating of the TriStar.

6.4.5 Minimum Diversion Load

The diversion load must be large enough to divert all the current produced by the source (wind, hydro, etc.). This value is the maximum battery voltage times the maximum source current.

For example, if a hydro source can generate up to 30 amps of current in a nominal 48 volt system (60V maximum), the minimum diversion load size = 60V x 30A = 1,800 watts (for loads rated at 60 volts).

General Sizing Example
Consider a 24V system with a wind turbine that is rated to generate 35A of current. A TriStar-45 will not provide the 150% diversion load margin, and the TS-45 is only rated for 30A of source current. The TS-45 will not provide enough margin for wind gusts and overloads, so a TS-60/M should be used.

The diversion load should be sized for 52.5A (150% of the source current) up to 60A (the rating of the TriStar-60). If 55A is selected for the diversion load, the load must be capable of diverting 55A at 30V (maximum battery voltage). If a 30V heating element is used, it would be rated for 1,650 watts (or from 1,575W to 1,800W per the load range noted above).

If a 2,000 watt / 120 volt heating element is used, 13 of these elements in parallel will be required for the diversion load (4.2 amps per element [Table in 6.4.4] x 13 = 54.6 amps).

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6.0

The minimum diversion load would be the source output (35A) times the voltage (30V). This would require a 1,050 watt heating element rated at 30 volts. Or if a 2,000W heater element rated for 120 volts is used, 9 heater elements will be required to draw the required minimum diversion load at 30 volts.

6.5 NEC Requirements

To comply with NEC 690.72 (B), the following requirements will apply when the TriStar is being used as a diversion charge controller in a photovoltaic system.

6.5.1 Second Independent Means

If the TriStar is the only means of regulating the battery charging in a diversion charging mode, then a second independent means to prevent overcharging the battery must be added to the system. The second means can be another TriStar, or a different means of regulating the charging.

6.5.2 150 Percent Rating

The current rating of the diversion load must be at least 150% of the TriStar source current rating. *Refer to Section 6.2 (Diversion Current Rating).* The maximum allowable current ratings for both TriStar versions are summarized below:

	Max. Input Current	Max. Diversion Load Rating
TS-45	30 A	45 A
TS-60/M	40 A	60 A

CAUTION: The NEC requirement that the diversion load must be sized at least 150% of the controller rating does NOT mean the diversion load can exceed the maximum current rating of the TriStar. NEVER size a diversion load that can draw more than the 45 amps or 60 amps maximum rating of the TriStar controllers.

PRUDENCE : L'obligation de la CNE indiquant que la charge de diversion doit être 150 % plus grande que la puissance nominale du contrôleur NE signifie PAS que la charge de diversion peut dépasser l'intensité maximum du TriStar. Ne dimensionnez JAMAIS une charge de diversion qui peut appeler plus de 45 A ou l'intensité maximum de 60 A des contrôleurs TriStar.

6.6 Additional Information

Visit Morningstar's website (www.morningstarcorp.com) for additional diversion charge control information. The website provides expanded technical support for more complex diversion load systems.

7.0 Custom Settings with PC Software

An RS-232 connection between the TriStar and an external personal computer (PC) allows many set-points and operating parameters to be easily adjusted. The adjustments can be simply a small change to one setpoint, or could include extensive changes for a fully customized battery charging or load control program.

CAUTION: Only qualified service personnel should change operating parameters with the PC software. There are minimal safeguards to protect from mistakes. Morningstar is not responsible for any damage resulting from custom settings.

PRUDENCE : Seul le personnel d'entretien qualifié doit modifier les paramètres de fonctionnement avec le logiciel sur ordinateur. Des protections minimales protègent contre les erreurs. Morningstar n'est pas responsable des dommages résultants de réglages personnalisés.

Consult Morningstar's website for the latest TriStar PC software and instructions.

7.1 Connection to a Computer

An RS-232 cable with DB9 connectors (9 pins in 2 rows) will be required.

If the computer will be used to change battery charging or load control set-points, verify that DIP switches 4, 5, 6 are in the custom position (On, On, On) before connecting the TriStar to a computer. The custom position is required to change set-points. See Section 2.3 - Step 3. Disconnect power before changing DIP switches.

7.2 Using the PC Software

Download the TriStar PC software from Morningstar's website. Follow the instructions on the website for installing the software on your computer.

Open the TriStar PC software. This software will make the connection with the TriStar via the RS-232 cable. The TriStar must be powered by the battery or a power supply to complete the connection. If there is a conflict between the TriStar and PC comm ports, the software will provide instructions to resolve the problem.

7.3 Changing Set-points

Follow the instructions in the PC software.

CAUTION: There are few limits to the changes that can be made. It is the responsibility of the operator to be certain all changes are appropriate. Any damage resulting to the controller or the system from TriStar setpoint adjustments will not be covered under warranty.

PRUDENCE : Les modifications pouvant être effectuées sont sujettes à quelques limites. Il incombe à l'opérateur de s'assurer que toutes les modifications sont appropriées. Tout dommage au contrôleur ou au système résultant de réglages des points de consigne du TriStar ne sera pas couvert par la garantie.

If you are not certain about each of the changes you are making, the software provides for returning to the factory default settings.

7.4 Finish

Confirm that the changes made to the TriStar are as you intended. It is advisable to make a record of the changes for future reference. Observe the system behavior and battery charging for a few weeks to verify that the system is operating correctly and as you intended.

Exit the software. The PC/TriStar connection can either be disconnected or left in place.

8.0 Self-Test / Diagnostics

The TriStar performs a continuous self-test to monitor controller and system operation. Detected problems are classified as either faults or alarms. Typically, faults are problems that stop the normal operation of the controller and require immediate attention. Alarms indicate an abnormal condition, but will not stop the controller's operation.

If a problem is detected, the TriStar will alert the user to an existing fault or alarm. In this situation, the LED indicators will flash a particular sequence. Section 3.3 references these sequences with their associated faults and alarms. Flashing LED sequences can indicate conditions ranging from a simple battery service reminder to an existing short circuit in the system. It is recommended that the user become familiar with the LED indications and their meanings.

If a TriStar meter option has been added, more detailed information concerning faults and alarms will be available. Menus provide text displays of the specific fault as well as indicating on the standard display screens when a problem exists. *Consult the meter manual for further details.*

8.1 General Troubleshooting

TriStar is not powering up

- Confirm that all circuit breakers and switches in the system are closed
- Check all fuses
- Check for loose wiring connections and wiring continuity
- Verify that the battery voltage is not below 9Vdc *(brownout: section 3.4)*
- Verify that the battery power connection is not reversed polarity

Flashing/Sequencing LEDs

- *Reference Section 3.3 for a list of LED indications and their corresponding faults/alarms*

Self-Test Indication (R - Y - G sequencing)

- Self-testing will also detect various system wiring faults outside the TriStar
- Check for both TriStar faults and external system wiring problems

The RTS or Battery Sense is not working properly

- R/Y – G/Y sequencing LEDs indicates an RTS or Sense fault
- Check for a reverse polarity connection on the sense leads
- Verify that the RTS and Sense connections are wired to the correct terminals
- Check for shorts and continuity in the cables
- Verify that good electrical contact is made at the terminals
- Note that if the TriStar is restarted with an RTS or Sense fault present, it will not detect the RTS or Sense connection and the LED indication will stop.

8.2 Troubleshooting Solar Charging

- Over-charging or under-charging the battery
- DIP switch settings may be wrong
- RTS is not correcting for high or low temperatures
- Over-temperature condition is reducing the charging current (heat sink cooling may be blocked — indicated with LEDs)
- Voltage drop between TriStar and battery is too high *(connect the battery voltage sense — see Section 2.3 Step 5)*
- Battery charging requires temperature compensation (connect a remote temperature sensor)
- Load is too large and is discharging the battery

Not charging the battery

- DIP switch settings may be wrong (check each switch position carefully)
- TriStar has detected a fault *(indicated by sequencing LEDS, refer to Section 3.3)*
- Solar circuit breaker or disconnect is open
- Reversed polarity connections at the solar terminals (TriStar will not detect the solar array)
- Short circuit in the solar array has eliminated part of the array output
- Solar array is not providing enough current (low sun or fault in the array)
- Battery is failing and cannot hold a charge

8.3 Troubleshooting Load Control

No power to the load

- DIP switch settings may be wrong (check each switch position carefully)
- Controller is in LVD (check the LEDs)
- Load circuit breaker or disconnect may be open
- Check the load cables for continuity and good connection
- An over-temperature condition may have caused the load to be disconnected

8.4 Troubleshooting Diversion Control

- Diversion load is too small so PWM reaches 99%
- Diversion load is burned out so PWM reaches 99%
- Diversion load is too large so TriStar faults on overcurrent
- An overtemperature condition may have caused the load to be disconnected
- The RTS is not correcting for high or low temperatures
- Voltage drops between the TriStar and battery are too high

Still having problems? Point your web browser to http://www.morningstarcorp.com for technical support documents, FAQs, or to request technical support.

9.0 Battery Information

The standard battery charging programs in the TriStar controller, as described in Section 4.2, are typical charging algorithms for three battery types:

- sealed (VRLA)
- flooded (vented)
- L-16 group

Other battery chemistries such as NiCad, or special voltages such as 36V, can be charged using a custom charging algorithm modified with the PC software. Only the standard TriStar battery charging programs will be discussed here.

CAUTION: Never attempt to charge a primary (non-rechargeable) battery.

PRUDENCE : N'essayez jamais de charger une batterie primaire (non-rechargeable).

All charging voltages noted below will be for 12V batteries at 25˚C.

9.1 Sealed Batteries

The general class of sealed batteries suitable for solar systems are called VRLA (Valve Regulated Lead-Acid) batteries. The two main characteristics of VRLA batteries are electrolyte immobilization and oxygen recombination. As the battery recharges, gasing is limited and is recombined to minimize the loss of water.

The two types of VRLA batteries most often used in solar are AGM and Gel.

AGM:
Absorbed Glass Mat batteries are still considered to be a "wet cell" because the electrolyte is retained in fiberglass mats between the plates. Some newer AGM battery designs recommend constant voltage charging to 2.45 volts/cell (14.7V). For cycling applications, charging to 14.4V or 14.5V is often recommended.

AGM batteries are better suited to low discharge applications than daily cycling. These batteries should not be equalized since gasing can be vented which causes the battery to dry out. There is also a potential for thermal runaway if the battery gets too hot, and this will destroy the battery. AGM batteries are affected by heat, and can lose 50% of their service life for every 8˚C (15˚F) over 25˚C (77˚F).

It is very important not to exceed the gas recombination capabilities of the AGM. The optimum charging temperature range is from 5 to 35˚C (40 to 95˚F).

Gel:
Gel batteries have characteristics similar to AGM, except a silica additive immobilizes the electrolyte to prevent leakage from the case. And like AGM, it

is important to never exceed the manufacturer's maximum charging voltages. Typically, a gel battery is recharged in cycling applications from 14.1V to 14.4V. The gel design is very sensitive to overcharging.

For both AGM and Gel batteries, the goal is for 100% recombination of gases so that no water is lost from the battery. True equalizations are never done, but a small boost charge may be needed to balance the individual cell voltages.

Other Sealed Batteries:
Automotive and "maintenance-free" batteries are also sealed. However, these are not discussed here because they have very poor lifetimes in solar cycling applications.

NOTE: Consult the battery manufacturer for the recommended solar charging settings for the battery being used.

REMARQUE : Consultez le fabricant de la batterie quant aux réglages recommandés de charge solaire pour la batterie utilisée.

9.2 Flooded Batteries

Flooded (vented) batteries are preferred for larger cycling solar systems. The advantages of flooded batteries include:

- ability to add water to the cells
- deep cycle capability
- vigorous recharging and equalization
- long operating life

In cycling applications, flooded batteries benefit from vigorous charging and equalization cycles with significant gasing. Without this gasing, the heavier electrolyte will sink to the bottom of the cell and lead to stratification. This is especially true with tall cells. Hydrocaps can be used to limit the gasing water loss.

Note that a 4% mixture of hydrogen in air is explosive if ignited. Make certain the battery area is well ventilated.

Typical equalization voltages for flooded batteries are from 15.3 volts to 16 volts. However, a solar system is limited to what the solar array can provide. If the equalization voltage is too high, the array I-V curve may go over the "knee" and sharply reduce the charging current.

Lead-Calcium:
Calcium batteries charge at lower voltages (14.2 to 14.4 typically) and have strong advantages in constant voltage or float applications. Water loss can be only 1/10th of antimony cells. However, calcium plates are not as suitable for cycling applications.

Lead-Selenium:
These batteries are similar to calcium with low internal losses and very low water consumption throughout their life. Selenium plates also have poor cycling life.

Lead-Antimony:
Antimony cells are rugged and provide long service life with deep discharge capability. However, these batteries self-discharge much faster and the self-discharging increases up to five times the initial rate as the battery ages. Charging the antimony battery is typically from 14.4V to 15.0V, with a 120% equalization overcharge. While the water loss is low when the battery is new, it will increase by five times over the life of the battery.

There are also combinations of plate chemistries that offer beneficial tradeoffs. For example, low antimony and selenium plates can offer fairly good cycling performance, long life, and reduced watering needs.

NOTE: Consult the battery manufacturer for the recommended solar charging settings for the battery being used.

REMARQUE : Consultez le fabricant de la batterie quant aux réglages recommandés de charge solaire pour la batterie utilisée.

9.3 L-16 Cells

One particular type of flooded battery, the L-16 group, is often used in larger solar systems. The L-16 offers good deep-cycle performance, long life, and low cost.

The L-16 battery has some special charging requirements in a solar system. A study found that nearly half of the L-16 battery capacity can be lost if the regulation voltage is too low and the time between finish-charges is too long. One standard charging program in the TriStar is specifically for L-16 batteries, and it provides for higher charging voltages and more frequent equalizations. Additional equalizations can also be done manually with the push-button.

A good reference for charging L-16 batteries is a Sandia National Labs report (year 2000) titled "PV Hybrid Battery Tests on L-16 Batteries." Website: www.sandia.gov/pv.

NOTE: The best charging algorithm for flooded, deep-cycle batteries depends on the normal depth-of-discharge, how often the battery is cycled, and the plate chemistry. Consult the battery manufacturer for the recommended solar charging settings for the battery being used.

REMARQUE : Le meilleur algorithme de charge pour les batteries à électrolyte liquide à décharge poussée dépend de l'amplitude de la décharge, de la fréquence du cycle de batterie et de la composition chimique des plaques. Consultez le fabricant de la batterie quant aux réglages recommandés de charge solaire pour la batterie utilisée.

10.0 Warranty

LIMITED WARRANTY

Morningstar TriStar-PWM

The TriStar-PWM is warrantied to be free from defects in material and workmanship for a period of FIVE (5) years from the date of shipment to the original end user. Morningstar will, at its option, repair or replace any such defective products.

WARRANTY EXCLUSIONS AND LIMITATIONS:

This warranty does not apply under the following conditions:

♦ Damage by accident, negligence, abuse or improper use

♦ PV or load currents exceeding the ratings of the product

♦ Unauthorized product modification or attempted repair

♦ Damage occurring during shipment

♦ Damage results from acts of nature such as lightning and weather extremes

THE WARRANTY AND REMEDIES SET FORTH ABOVE ARE EXCLUSIVE AND IN LIEU OF ALL OTHERS, EXPRESS OR IMPLIED. MORNINGSTAR SPECIFICALLY DISCLAIMS ANY AND ALL IMPLIED WARRANTIES, INCLUDING, WITHOUT LIMITATION, WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. NO MORNINGSTAR DISTRIBUTOR, AGENT OR EMPLOYEE IS AUTHORIZED TO MAKE ANY MODIFICATION OR EXTENSION TO THIS WARRANTY.

MORNINGSTAR IS NOT RESPONSIBLE FOR INCIDENTAL OR CONSEQUENTIAL DAMAGES OF ANY KIND, INCLUDING BUT NOT LIMITED TO LOST PROFITS, DOWN-TIME, GOODWILL OR DAMAGE TO EQUIPMENT OR PROPERTY.

R17-8/16

11.0 Technical Specifications

ELECTRICAL

- System voltage ratings — 12, 24, 48 Vdc
- Current ratings — **Solar Input**

TS-45: 45 A
TS-60/M: 60 A

- Current ratings — **Battery Charge Control**

TS-45: 45 A
TS-60/M: 60 A

- Current ratings — **Load Control**

TS-45: 45 A
TS-60/M: 60 A

- Current ratings — **Diversion Charge Control**

TS-45: 45 A diversion load
TS-60/M: 60 A diversion load

• Accuracy	12/24V: ≤ 0.1 % ± 50 mV 48V: ≤ 0.1 % ± 100 mV
• Min. voltage to operate	9 V
• Max. solar array Voc	125 V
• Max. operating voltage	68 V
• Self-consumption	less than 20 mA
• High temp shutdown	95°C disconnect solar 90°C disconnect load / diversion load 70°C reconnect solar / load / diversion load
• Solar high voltage disconnect HVD reconnect	highest equalization + 0.2V 13.0V
• Transient surge protection:	4500 watts
• Pulse power rating response	< 5 nanosec

BATTERY CHARGING / RTS

• Charge algorithm:	PMW, constant voltage
• Temp comp. coefficient	–5mV/°C/cell (25°C ref)
• Temp comp. range:	–30°C to +80°C
• Temp comp. set-points	PWM, float, equalize, HVD (with RTS option)

11.0

BATTERY CHARGING STATUS LEDs

G	13.3 to PWM
G/Y	13.0 to 13.3 V
Y	12.65 to 13.0 V
Y/R	12.0 to 12.65 V
R	0 to 12.0 V

Note: Multiply x 2 for 24V systems, x 4 for 48V systems

Note: The LED indications are for charging a battery. When discharging, the LEDs will typically be Y/R or R.

MECHANICAL

• Dimensions (mm/inch)	H: 260.4 mm / 10.25 inch W: 127.0 mm / 5.0 inch D: 71.0 mm / 2.8 inch
• Weight (kg/lb)	1.6 kg / 3.5 lb
• Power terminals:	compression connector lug
largest wire	35 mm² / 2 AWG
smallest wire	2.5 mm² / 14 AWG
• Terminal wire slot	8.2 mm / 0.324 in wide 9.4 mm / 0.37 in high
• Knockout sizes	1 and 1.25 inch
• Torque terminals	5.65 Nm / 50 in-lb
• RTS / Sense terminals:	
wire sizes	1.0 to 0.25 mm² / 16 to 24 AWG
torque	0.40 Nm / 3.5 in-lb

ENVIRONMENTAL

• Operating Altitude	Below 2000 meters
• Ambient temperature	–40 to +45°C
• Storage temperature	–55 to +85°C
• Humidity	100% (NC)
• Enclosure	IP20 Type 1 (indoor & vented), powder coated steel

Appendix 1 — Load & Lighting Control DIP Settings

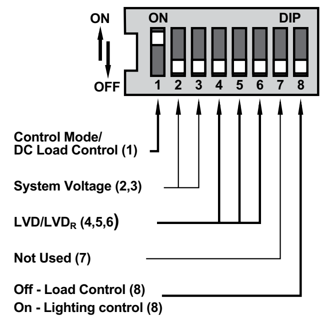

Figure A1-1 - Step 3. Load / lighting DIP Switch Functions

***NOTE**: The DIP switches should be changed only when there is no power to the controller. Turn off disconnect switches and remove power to the controller before changing a DIP switch. A fault will be indicated if a switch is changed with the controller powered.*

***REMARQUE** : Les commutateurs DIP ne doivent être changés que si le contrôleur est hors tension. Mettez les interrupteurs sur arrêt et mettez le contrôleur hors tension avant de changer un commutateur DIP. Une panne sera indiquée en cas de changement d'un commutateur quand le contrôleur est sous tension.*

***CAUTION**: The TriStar is shipped with all the switches in the "OFF" position. Each switch position must be confirmed during installation. An incorrect setting could cause damage to the load or other system components.*

***PRUDENCE** : Le TriStar est expédié avec tous les interrupteurs en position « ARRÊT ». La position de chaque interrupteur doit être confirmée pendant l'installation. Un mauvais réglage peut endommager la charge ou d'autres composants du système.*

Appendices

The DIP switch settings described below are for **Load and Lighting Control** only.

The DIP switches are shipped in the OFF position. The OFF settings will operate as follows:

Switch	Function
1	Must be ON for Load, Lighting or Diversion Control
2, 3	Auto voltage select
4, 5, 6	Lowest LVD = 11.1V
7	Diversion Control mode OFF
8	Lighting Control mode OFF

To configure your TriStar for the Load Control you require, follow the DIP switch adjustments described below. To change a switch from OFF to ON, slide the switch up toward the top of the controller. Make sure each switch is fully in the ON or OFF position.

DIP Switch Number 1 - Control Mode: Load & Lighting Control

Mode	Switch 1
Charging	Off
Load/Lighting	On

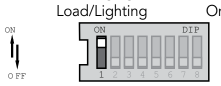

Figure A1-2 - Step 3 DIP Switch #1

For Load or Lighting Control mode, move the DIP switch to the ON position as shown.

DIP Switches Number 2,3 - System Voltage:

Voltage	Switch 2	Switch 3
Auto	Off	Off
12	Off	On
24	On	Off
48	On	On

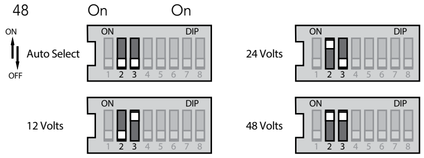

Figure A1-3 - Step 3 DIP Switches # 2,3

The auto voltage selection occurs when the battery is connected and the TriStar starts up. There should be no loads on the battery that might cause a discharged battery to indicate a lower system voltage.

The DIP switch selectable voltages are for 12V, 24V or 48V lead-acid batteries. Although the “auto voltage” selection is very dependable, it is recommended to use the DIP switches to secure the correct system voltage.

DIP Switches Number 4,5,6 - Load Control Algorithm:

For normal Load Control Mode, set the DIP switches 4,5,&6 according to the table below. For Lighting Control, see the table and Figure 2.4 on the next page.

LVD	Switch 4	Switch 5	Switch 6
11.1	Off	Off	Off
11.3	Off	Off	On
11.5	Off	On	Off
11.7	Off	On	On
11.9	On	Off	Off
12.1	On	Off	On
12.3	On	On	Off
Custom	On	On	On

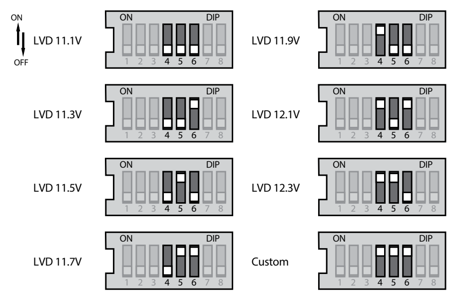

Figure A1-4 - Step 3 DIP Switch # 4,5,6

Select one of the 7 standard load control algorithms, or select the “custom” DIP switch for special custom settings using the PC software.

Refer to Section 5.1 for the 7 standard LVD settings, LVD_R reconnect settings, and current compensation values.

DIP Switches Number 4,5,6 - Lighting Control Algorithm:

For Lighting Control mode, set the DIP switches 4,5,& 6 according to the table below.

hrs after Sunset	hrs before Sunrise	Switch 4	Switch 5	Switch 6
6	0	Off	Off	Off
8	0	Off	Off	On
10	0	Off	On	Off
3	1	Off	On	On
4	2	On	Off	Off
6	2	On	Off	On
Dusk to Dawn		On	On	Off
Custom		On	On	On

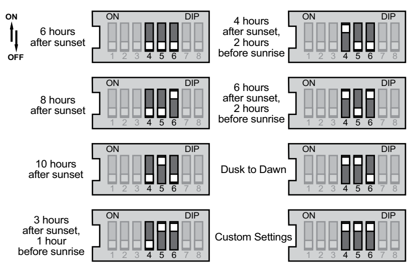

Figure A1-5 - Step 3 DIP Switch # 4,5,6

Select one of the 7 standard Lighting Control algorithms, or select the "custom" DIP switch for special custom settings using the PC software.

The default LVD and LVD reconnect settings for Lighting Control are listed below. These values can be changed in custom settings.

LVD 11.40 Volts
LVDR 13.00 Volts

DIP Switch Number 7 - Must be OFF:

Switch 7
Off

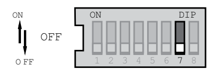

Figure A1-6 - Step 3 DIP Switch # 7

In Load Control and Lighting modes, DIP switch #7 must be in the OFF position.

DIP Switch Number 8 - Lighting Control:

Control	Switch 8
Lighting Disabled	Off
Lighting Enabled	On

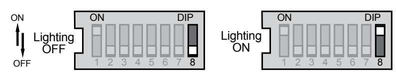

Figure A1-7 - Step 3 DIP Switch # 8

To enable lighting control, DIP switch #8 must be in the ON position.

NOTE: Confirm all dip-switch settings before going to the next installation steps.

REMARQUE : Confirmez les réglages de tous les commutateurs dip avant de passer aux étapes suivantes d'installation.

Appendix 2 - Diversion Charge Control DIP Switch Settings

The **Diversion Charge Control** DIP function adjustments:

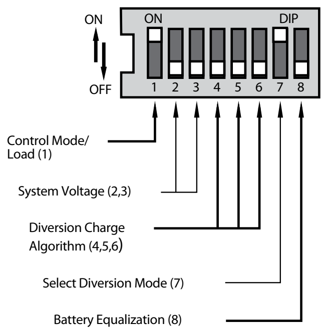

Figure A2-1 - Step 3 (Diversion) DIP Switch Functions

As shown in the diagram, all the positions are in the "OFF" position except switches 1 and 7, which are "ON".

☞ ***NOTE: The DIP switches should be changed only when there is no power to the controller. Turn off disconnect switches and remove all power to the controller before changing a DIP switch. A fault will be indicated if a switch is changed with the controller powered.***

☞ ***REMARQUE : Les commutateurs DIP ne doivent être changés que si le contrôleur est hors tension. Mettez les interrupteurs sur arrêt et mettez le contrôleur hors tension avant de changer un commutateur DIP. Une panne sera indiquée en cas de changement d'un commutateur quand le contrôleur est sous tension.***

⚠ ***CAUTION: The TriStar is shipped with all the switches in the "OFF" position. Each switch position must be confirmed during installation. A wrong setting could cause damage to the battery or other system components.***

⚠ ***PRUDENCE : Le TriStar est expédié avec tous les interrupteurs en position « ARRÊT ». La position de chaque interrupteur doit être confirmée pendant l'installation. Un mauvais réglage peut endommager la charge ou d'autres composants du système.***

The DIP switch settings described below are **Diversion Charge Control** only.

The DIP switches are shipped in the OFF position. With switches 1 and 7 in

the ON position, Diversion Charge Contol is set. The OFF settings will operate as follows:

Switch	Function
1	Must be ON to set Diversion Control
2, 3	Auto voltage selected
4, 5, 6	Lowest battery charging voltage
7	Must be ON to set Diversion Control
8	Manual Equalization

To configure your TriStar for the diversion battery charging and control you require, follow the DIP switch adjustments described below. To change a switch from OFF to ON, slide the switch up toward the top of the controller. Make sure each switch is fully in the ON or OFF position.

DIP Switch Number 1 - Control Mode: Solar Battery Charging

Control	Switch 1
Charging	Off
Load	On

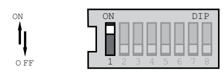

Figure A2-2 - Step 3 DIP Switch #1

For the Diversion Charge Control mode, move the DIP switch to the ON position as shown.

DIP Switches Number 2,3 - System Voltage:

Voltage	Switch 2	Switch 3
Auto	Off	Off
12	Off	On
24	On	Off
48	On	On

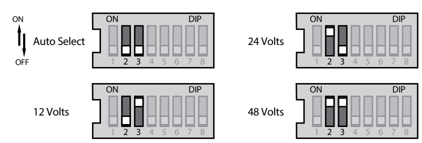

Figure A2-3 - Step 3 DIP Switches # 2,3

The auto voltage selection occurs when the battery is connected and the TriStar starts-up. There should be no loads on the battery that might cause a discharged battery to indicate a lower system voltage.

The DIP switch default voltages are for 12V, 24V or 48V lead-acid batteries. Although the "auto voltage" selection is very dependable, it is recommended to use the DIP switches to secure the correct system voltage.

DIP Switches Number 4,5,6 - Diversion Charge Control:

Battery Type	PWM	Switch 4	Switch 5	Switch 6
1	13.8	Off	Off	Off
2	14.0	Off	Off	On
3	14.2	Off	On	Off
4	14.4	Off	On	On
5	14.6	On	Off	Off
6	14.8	On	Off	On
7	15.0	On	On	Off
8	Custom	On	On	On

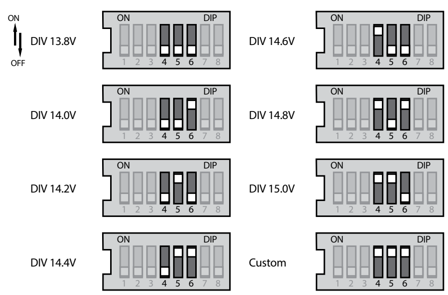

Figure A2-4 - Step 3 DIP Switches # 4,5,6

Select one of the 7 standard diversion charging algorithms, or select the "custom" DIP switch for special custom settings using the PC software.

Refer to Section 6.3 for information describing the 7 standard diversion charging algorithms. Refer to Section 9.0 of this manual for battery charging information.

DIP Switch Number 7 - Select Diversion:

	Switch 7
On	

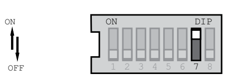

Figure A2-5 - Step 3 DIP Switch # 7

In the Diversion Charge Control mode, DIP switch 7 must be in the ON position.

DIP Switch Number 8 - Battery Equalization:

Equalize	Switch 8
Manual	Off
Auto	On

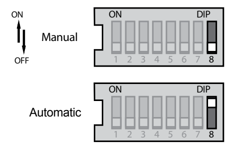

Figure A2-6 - Step 3 DIP Switch # 8

In the Auto Equalization mode (switch 8 On), battery equalization will automatically start and stop according to the battery program selected by the DIP switches 4,5,6 above. See Section 6.0 for detailed information about each standard diversion battery charging algorithm and equalization.

In the Manual Equalization mode (switch # Off), equalization will occur only when manually started with the push-button. Automatic starting of equalization is disabled. The equalization will automatically stop per the battery algorithm selection.

In both cases (auto and manual mode), the push-button can be used to start and stop battery equalization.

NOTE: Confirm all dip-switch settings before going to the next installation steps.

REMARQUE : Confirmez les réglages de tous les commutateurs dip avant de passer aux étapes suivantes d'installation.

Appendix 3 - LED Indications

LED Display Explanation:

G = green LED is lit
Y = yellow LED is lit
R = red LED is lit
G/Y = Green and Yellow are both lit at the same time
G/Y - R = Green & Yellow both lit, then Red is lit alone
Sequencing (faults) has the LED pattern repeating until the fault is cleared

1. General Transitions:

• Controller start-up	G - Y - R (one cycle)
• Push-button equalize start	G/Y/R - G/Y/R - G (one cycle)
• Push-button equalize stop	G/Y/R - G/Y/R - R (one cycle)
• Battery service is required	all 3 LEDs blinking until service is reset

2. Battery Status

• General state-of-charge	*see battery SOC indications below*
• PWM absorption	G blinking (1/2 second on / 1/2 second off)
• Equalization state	G fast blink (2 to 3 times per second)
• Float state	G slow blink (1 second on / 1 second off)

Battery State-of-Charge LED Indications (when battery is charging):

• G on	80% to 95% SOC
• G/Y on	60% to 80% SOC
• Y on	35% to 60% SOC
• Y/R on	0% to 35% SOC
• R on	battery is discharging

LOAD CONTROL

2. Load Status

LED		12V	24V	48V
G	LVD+	0.60V	1.20V	2.40V
G/Y	LVD+	0.45V	0.90V	1.80V
Y	LVD+	0.30V	0.60V	1.20V
Y/R	LVD+	0.15V	0.30V	0.60V
R-Blinking	LVD			
R-LVD				

The load status LEDs are determined by the LVD voltage plus the specified transition voltages. As the battery voltage rises or falls, each voltage transition will cause a change in the LEDs.

3. Faults & Alarms

• Short circuit - solar/load	R/G - Y sequencing
• Overload - solar/load	R/Y - G sequencing
• Over-temperature	R - Y sequencing
• High voltage disconnect	R - G sequencing
• Reverse polarity - battery	no LEDs are lighted
• Reverse polarity - solar	No fault indication
• DIP switch fault	R - Y - G sequencing
• Self-test faults	R - Y - G sequencing
• Temperature probe (RTS)	R/Y - G/Y sequencing
• Battery voltage sense	R/Y - G/Y sequencing

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12.0 Certifications

- Complies with ETL UL 1741 and cETL CSA-C22.2 No. 107.1
- Complies with TUV IEC 62109-1
- Complies with the US National Electrical Code
- Complies with the Canadian Electrical Code
- FCC Class B compliant

ENs Directives:

Complies with ENs and LVD standards for CE marking

- Immunity: EN 61000-4-3: 2006
EN 61000- 4-6: 2009
- Emissions: CISPR 22: 2008
- Safety: EN60335-1, EN60335-2-29 (battery chargers)
EN 62109-1: 2010

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www.modbus-ida.org

E Thermal camera data sheet

Cat® S60 Thermal Camera Technical Specifications

Camera module	
Thermal and visual cameras with MSX	
Thermal sensor	17µm pixel size, 8 – 14 µm spectral range
Thermal resolution	80x60
Visual resolution	640x480
HFOV / VFOV	46° ± 1° / 35° ± 1°
Frame rate	8.7Hz
Focus	Fixed 15cm - Infinity
Built in shutter	Automatic/Manual
Radiometry	
Scene dynamic range	-20 °C – 120 °C
Accuracy	Typically ±5°C or ±5% Percent of the difference between ambient and scene temperature. Applicable 60s after start-up when the unit is within 15 °C – 35 °C and the scene is within 10 °C – 120 °C.
Thermal sensitivity (MRDT)	150mK
MyFLIR	
Live Image	Thermal (MSX)
Save Image	Radiometric jpeg
Save video (mpeg)	Thermal (MSX) as mpeg
Swipe to VIS	Yes, in Edit mode
Palettes	Iron, Black hot, White hot, Rainbow, Contrast, Arctic, Lava, Coldest, Hottest
IR Scale	Automatic, Lockable min/max, Editable min/max
Thermal Image Analytics	-Up to three movable spot meters -Whole image ROI with min/max/avg -Center 16x16pix ROI with min/max/avg
Emissivity settings	Matte: 95%, Semi-Matte: 80%, Semi-Glossy: 60%, Glossy: 30%
Timer	Off, 3s, 10s
Time lapse video recording	Delay time, Frame interval, Playback rate
Panorama	Yes
GPS Location is saved in image	Yes
Export to other FLIR analysis and reporting software	Link from MyFLIR app to FLIR Tools
User alignment	Yes

F PV panels data sheet

PVP - Polycrystalline series:

-option: black frame

Type	PVP25030	PVP26030	PVP27030
Nominal output Pmpp	250Wp	260Wp	270Wp
Nominal voltage Umpp	30,70V	30,92V	30,94V
Nominal current Impp	8,18A	8,43A	8,80A
Short circuit current Isc	8,41A	9,01A	9,41A
Open circuit voltage Uoc	37,80V	38,00V	39,26V
Module conversion efficiency	15,37%	15,98%	16,40%

Electrical characteristics (at Standard Test Conditions (STC) of irradiance 1000W / m2 , spectrum AM 25°C)

Design	
Frontside	3,2mm anti-reflective glass
Cells	60polycrystalline high efficiency cells 156x156 mm (6")
Backside	Composite film
Frame	40mm silver anodized aluminium frame

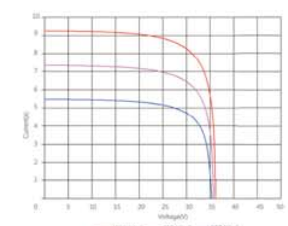
Mechanical data	
LxWxH	1650x992x40 mm
Weight	19,5kg with frame

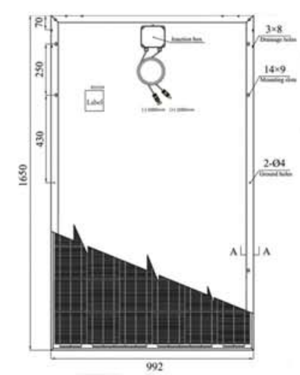
Power conection	
Socket	Protection classe IP65 (3 bypass diodes
Wire	Approx 110 cm / 4 mm2
Plug-in system	Plug / Socket IP67

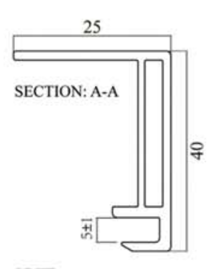
Limit values	
System voltage	1000VDC
NOCT*	45°C +/- 2K
Max. load-carring capacity	5400 N/m² tested to 8000 Pa
Reverse current feed IR	16,0A

*NOCT, irradiance 800 W/m2 AM 1,5; wind speed 1 m/sec; Temperature 20°C

Temperature coefficient	
Voltage Uoc	-0,30%K
Current Isc	+0,04%K
Output Pmpp	-0,42%K







solartek®

PVMB - Monocrystalline all black series:

Type	PVMB25030	PVMB26030	PVMB27030	PVMB28030
Nominal output Pmpp	250Wp	260Wp	270Wp	280Wp
Nominal voltage Umpp	29,65V	30,42V	30,94V	31,30V
Nominal current Impp	8,47A	8,60A	8,80A	8,96A
Short circuit current Isc	8,80A	9,06A	9,41A	9,50A
Open circuit voltage Uoc	37,98V	38,30V	39,26V	39,32V
Module conversion efficiency	15,37%	15,98%	16,60%	17,20%

Electrical characteristics (at Standard Test Conditions (STC) of irradiance 1000W / m2 , spectrum AM 25°C)

Design	
Frontside	3,2mm anti-reflective glass
Cells	60monocrystalline high efficiency cells 156x156 mm (6")
Backside	Composite film
Frame	40mm silver anodized aluminium frame

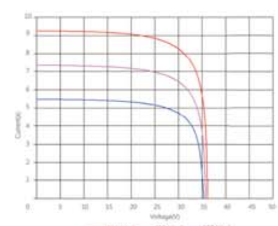
Mechanical data	
LxWxH	1650x992x40 mm
Weight	19,5kg with frame

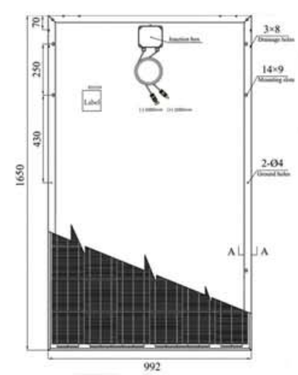
Power conection	
Socket	Protection classe IP65 (3 bypass diodes
Wire	Approx 110 cm / 4 mm2
Plug-in system	Plug / Socket IP67

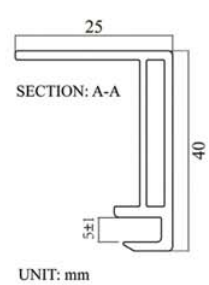
Limit values	
System voltage	1000VDC
NOCT*	45°C +/- 2K
Max. load-carring capacity	N/m² tested to 8000 Pa 5400
Reverse current feed IR	16,0A

*NOCT, irradiance 800 W/m2 AM 1,5; wind speed 1 m/sec; Temperature 20°C

Temperature coefficient	
Voltage Uoc	-0,30%K
Current Isc	+0,04%K
Output Pmpp	-0,42%K







PVMHE -
MonoCrystalline hight efficiency series:

Type	PVMHE28030	PVMHE29030	PVMHE30030
Nominal output Pmpp	280Wp	290Wp	300Wp
Nominal voltage Umpp	31,30V	31,58V	32,10V
Nominal current Impp	8,96A	9,20A	9,41A
Short circuit current Isc	9,50A	9,66A	9,97A
Open circuit voltage Uoc	39,50V	39,60V	39,80V
Module conversion efficiency	17,20%	17,60%	18,35%

Electrical characteristics (at Standard Test Conditions (STC) of irradiance 1000W / m2 , spectrum AM 25°C)

Design	
Frontside	3,2mm anti-reflective glass
Cells	60monocrystalline high efficiency cells 156x156 mm (6")
Backside	Composite film
Frame	40mm silver anodized aluminium frame

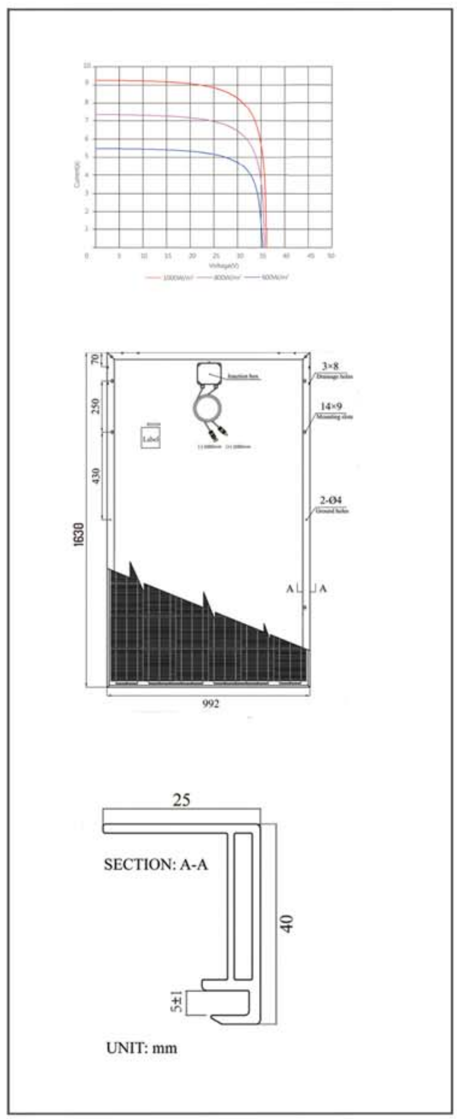
Mechanical data	
LxWxH	1630x992x40 mm
Weight	19,5kg with frame

Power conection	
Socket	Protection classe IP65 (3 bypass diodes
Wire	Approx 110 cm / 4 mm2
Plug-in system	Plug / Socket IP67

Limit values	
System voltage	1000VDC
NOCT*	42,9°C +/- 2K
Max. load-carring capacity	N/m² tested to 8000 Pa 5400
Reverse current feed IR	16,0A

*NOCT, irradiance 800 W/m2 AM 1,5; wind speed 1 m/sec; Temperature 20°C

Temperature coefficient	
Voltage Uoc	-0,29%K
Current Isc	+0,05%K
Output Pmpp	-0,42%K

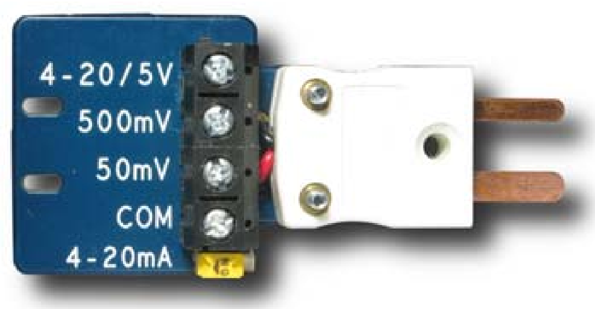


GETEK AS Stavsjøveien 23 N-7550 Hommelvik Norway +47 7398 0200 www.getek.no post@getek.no

G Single channel terminal voltage logger

USB TC-08 Single-Channel Terminal Board

User's Guide



1 Safety notices

You **MUST** observe the following safety notices to prevent damage to equipment and personal injury.

DO NOT do not connect the terminal board to any voltage source exceeding the maximum input range printed on the board.

DO NOT connect the terminal board to a mains (line voltage) electrical supply. The high voltage will damage or destroy the equipment and may cause serious or fatal injury.

2 Overview

2.1 Introduction

The USB TC-08 Single-Channel Terminal Board is an accessory for the Pico Technology USB TC-08 8-Channel Thermocouple Data Logger. The screw terminals allow wires to be attached to the data logger without soldering and enable the USB TC-08 to measure voltages from 0 to + 5 V or 4-20 mA loop currents.

The terminal board is designed for use with the USB TC-08 and is not guaranteed to work with other thermocouple data loggers.

2.2 Specifications

Dimensions	57 x 27 x 14 mm (approx. 2.3 x 1.1 x 0.6 in.)
Weight	12 g nominal (approx. 0.5 oz)
Terminal wire size	1.5 mm^2 solid, 1.0 mm^2 stranded, 16-26 AWG

2.3 Inputs and switch

Name	**Function**
4-20/5V	Input for the positive side of a 4-20 mA loop or 0 to 5 V signal
500mV	Input for the positive side of a 0 to 500 mV signal
50mV	Input for the positive side of a 0 to 50 mV signal
COM	Input for the negative side of any voltage or current signal.
4-20 mA	Set switch to "ON" for a 4-20 mA loop signal. Set switch to "OFF" for all voltage signals.

3 Measuring voltages and currents

1) Connect the negative side of your circuit to the COM terminal.
2) Connect the positive side of your circuit to the "5 V", "500 mV" or "50 mV" terminal depending on the voltage range of the signal. For a 4-20 mA loop signal, use the "5 V" input.
3) For a 4-20 mA loop signal, set the switch to "ON". For a voltage signal, set the switch to "OFF".
4) Plug the terminal board into the USB TC-08.
5) Connect the USB TC-08 to the computer using the USB cable supplied with the logger.
6) Run PicoLog on the computer.
7) Go to File -> New Settings.
8) Set the converter type to USB TC-08.
9) Edit one of the USB TC-08 channels and set the "Thermocouple" control to "mV".
10) PicoLog will display the voltage or current applied to the terminal board in the monitor window.

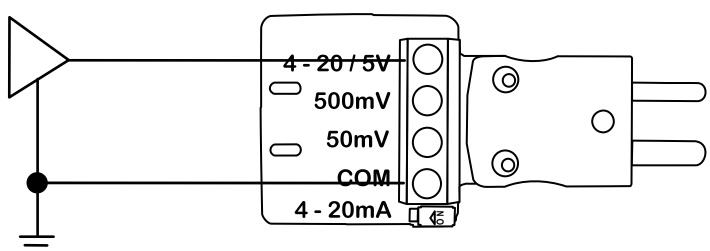


Figure 1: Example connection for measuring a 0 to 5 volt signal

Figure 2: The terminal board fitted to the USB TC-08

The voltage displayed in PicoLog corresponds to the input voltage as follows:

Input range	PicoLog voltage
0 – 5 V	0 – 50 mV
0 – 500 mV	0 – 50 mV
0 – 50 mV	0 – 50 mV
4 – 20 mA	9.6 – 48 mV

Issue history:

1) 14.9.09. New.

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H Duratherm data sheet

DURATHERM
Heat Transfer Fluids

DURATHERM 630

A high performance, efficient and environmentally friendly thermal fluid engineered for applications requiring high temperature stability to 332°C (630°F). Offering precise temperature control it's a great alternative to aromatic/synthetic fluids, at a fraction of the cost.

It is ideal for a wide range of applications including, high temperature batch processing, chemical reactions, pharmaceutical and resin manufacturing among others.

APPLICATION

Duratherm 630 is a high performance, efficient and environmentally friendly fluid engineered for applications requiring high temperature stability to 332°C (630°F). Offering precise temperature control it's a great alternative to high temperature aromatic fluids, at a fraction of the cost.

It is ideal for a wide range of applications including, high temperature batch processing, chemical reactions, pharmaceutical and resin manufacturing among others.

THE DIFFERENCE

Our exclusive additive package, including a proprietary dual stage anti-oxidant, ensures long trouble free operation. **Duratherm 630** also incorporates metal deactivators, a seal and gasket extender, de-foaming and particle suspension agents.

LASTS LONGER

Oxidation can cripple your system. Left unchecked, it will ultimately cause catastrophic failure and costly downtime. That's why **Duratherm 630** offers unsurpassed levels of protection against oxidation, and a service life that other fluids simply can't match.

RUNS CLEANER

Duratherm 630 delivers superior resistance to sludging, a problem plaguing most other fluids. That makes it the best defense against extreme oxidation found in many of today's demanding manufacturing environments.

ENVIRONMENTAL

Duratherm 630 is environmentally friendly, non-toxic, non-hazardous and non-reportable. It poses no ill effect to worker safety and does not require special handling. After its long service life, **Duratherm 630** can easily be disposed of with other waste oils.

SYSTEM CLEANING

If your existing fluid has let you down and left you with a system full of sludge or carbon, we've developed a full line of heat transfer system cleaners to get your system back to like-new condition. Contact us for complete details.

1 800 446 4910

www.durathermfluids.com

DURATHERM 630

- Maximum temperature: 332°C / 630°F
- Flash point 229°C / 444°F
- Alternative to chemical aromatic fluids
- Non-toxic/non-hazardous
- Includes free fluid analysis and tech support

1 800 446 4910

www.durathermfluids.com

TEMPERATURE RATINGS

Maximum Bulk/Use Temp.	332°C	630°F
Maximum Film Temp.	354°C	670°F
Pour Point ASTM D97	-18°C	-1°F

SAFETY DATA

Flash Point ASTM D92	229°C	444°F
Fire Point ASTM D92	244°C	472°F
Autoignition ASTM E-659-78	368°C	693°F

THERMAL PROPERTIES

Thermal Expansion Coefficient	0.1011 %/°C	0.0562 %/°F
Thermal Conductivity	W/m K	BTU/hr F ft
38°C / 100°F	0.143	0.083
260°C / 500°F	0.131	0.076
316°C / 600°F	0.128	0.074
332°C / 630°F	0.127	0.073
Heat Capacity	kJ/kg K	BTU/lb F
38°C / 100°F	1.991	0.475
260°C / 500°F	2.724	0.650
316°C / 600°F	2.908	0.694
332°C / 630°F	2.962	0.707

PHYSICAL PROPERTIES

Appearance: colorless, clear and bright liquid		
Viscosity ASTM D445		
cSt at 40°C / 104°F	42.31	
cSt at 100°C / 212°F	6.82	
cSt at 316°C / 600°F	0.79	
cSt at 332°C / 630°F	0.74	
Density ASTM D1298	kg/m3	lb/ft3
38°C / 100°F	853.39	53.29
260°C / 500°F	702.45	43.85
316°C / 600°F	665.74	41.50
332°C / 630°F	652.5	40.79
Vapor Pressure ASTM D2879	kPa	psi
38°C / 100°F	0.00	0.00
260°C / 500°F	2.28	0.33
316°C / 600°F	9.75	1.40
332°C / 630°F	14.2	2.04
Distillation Range ASTM D2887	10%	383°C (721°F)
	90%	494°C (921°F)
Average Molecular Weight	395	

The values quoted are typical of normal production. They do not constitute a specification.

DURATHERM 630

PROPERTY VS. TEMPERATURE CHART
METRIC

TEMPERATURE (Celsius)	DENSITY (kg/m^3)	KINEMATIC VISCOSITY (Centistoke)	DYNAMIC VISCOSITY (Centipoise)	THERMAL CONDUCTIVITY (W/m-K)	HEAT CAPACITY (kJ/kg-K)	VAPOR PRESSURE (kPa)
-5	882.63	683.16	602.98	0.146	1.849	0.00
5	875.83	307.70	269.49	0.145	1.882	0.00
15	869.03	156.16	135.71	0.145	1.915	0.00
25	862.23	87.38	75.34	0.144	1.948	0.00
35	855.43	52.97	45.31	0.144	1.981	0.00
45	848.63	34.31	29.11	0.143	2.014	0.00
55	841.84	23.47	19.76	0.142	2.047	0.00
65	835.04	16.81	14.04	0.142	2.080	0.00
75	828.24	12.51	10.37	0.141	2.113	0.00
85	821.44	9.62	7.90	0.141	2.146	0.00
95	814.64	7.60	6.19	0.140	2.179	0.00
105	807.84	6.15	4.97	0.140	2.212	0.00
115	801.04	5.08	4.07	0.139	2.245	0.01
125	794.24	4.26	3.39	0.138	2.278	0.01
135	787.44	3.64	2.86	0.138	2.311	0.02
145	780.64	3.14	2.45	0.137	2.344	0.03
155	773.84	2.75	2.13	0.137	2.377	0.05
165	767.04	2.43	1.86	0.136	2.410	0.08
175	760.24	2.16	1.65	0.135	2.443	0.12
185	753.45	1.95	1.47	0.135	2.476	0.18
195	746.65	1.76	1.32	0.134	2.509	0.26
205	739.85	1.61	1.19	0.134	2.542	0.38
215	733.05	1.47	1.08	0.133	2.575	0.54
225	726.25	1.36	0.99	0.133	2.608	0.77
235	719.45	1.26	0.91	0.132	2.641	1.06
245	712.65	1.17	0.84	0.132	2.674	1.45
255	705.85	1.10	0.78	0.131	2.707	1.96
265	699.05	1.03	0.72	0.130	2.740	2.60
275	692.25	0.97	0.67	0.130	2.773	3.44
285	685.45	0.92	0.63	0.129	2.806	4.49
295	678.65	0.87	0.59	0.129	2.839	5.82
305	671.86	0.83	0.56	0.128	2.872	7.47
315	665.06	0.79	0.53	0.128	2.905	9.51
325	658.26	0.76	0.50	0.127	2.938	12.00
332	653.39	0.74	0.48	0.126	2.960	15.03

The values quoted are typical of normal production.
They do not constitute a specification.

DURATHERM 630

PROPERTY VS. TEMPERATURE CHART
STANDARD

TEMPERATURE (Fahrenheit)	DENSITY (lb/ft^3)	KINEMATIC VISCOSITY (Centistoke)	DYNAMIC VISCOSITY (Centipoise)	THERMAL CONDUCTIVITY (BTU/hr-F-ft)	HEAT CAPACITY (BTU/lb-F)	VAPOR PRESSURE (Psia)
15	55.29	1018.91	902.98	0.084	0.438	0.00
25	55.06	621.05	548.04	0.084	0.443	0.00
35	54.82	395.64	347.63	0.084	0.447	0.00
45	54.58	262.15	229.35	0.084	0.451	0.00
55	54.35	179.91	156.72	0.084	0.456	0.00
65	54.11	127.41	110.51	0.084	0.460	0.00
75	53.88	92.80	80.14	0.083	0.464	0.00
85	53.64	69.32	59.60	0.083	0.469	0.00
95	53.40	52.97	45.34	0.083	0.473	0.00
105	53.17	41.31	35.20	0.083	0.478	0.00
115	52.93	32.81	27.83	0.083	0.482	0.00
125	52.70	26.49	22.38	0.082	0.486	0.00
135	52.46	21.72	18.26	0.082	0.491	0.00
145	52.23	18.04	15.10	0.082	0.495	0.00
155	51.99	15.18	12.65	0.082	0.499	0.00
165	51.75	12.91	10.71	0.082	0.504	0.00
175	51.52	11.09	9.16	0.082	0.508	0.00
185	51.28	9.62	7.91	0.081	0.513	0.00
195	51.05	8.42	6.89	0.081	0.517	0.00
205	50.81	7.42	6.04	0.081	0.521	0.00
215	50.57	6.59	5.34	0.081	0.526	0.00
225	50.34	5.88	4.75	0.081	0.530	0.00
235	50.10	5.29	4.25	0.080	0.534	0.00
245	49.87	4.78	3.82	0.080	0.539	0.00
255	49.63	4.34	3.46	0.080	0.543	0.00
265	49.40	3.97	3.14	0.080	0.548	0.00
275	49.16	3.64	2.87	0.080	0.552	0.00
285	48.92	3.35	2.63	0.080	0.556	0.00
295	48.69	3.09	2.42	0.079	0.561	0.01
305	48.45	2.87	2.23	0.079	0.565	0.01
315	48.22	2.67	2.06	0.079	0.569	0.01
325	47.98	2.49	1.92	0.079	0.574	0.01
335	47.75	2.33	1.79	0.079	0.578	0.02
345	47.51	2.19	1.67	0.079	0.583	0.02
355	47.27	2.06	1.56	0.078	0.587	0.02
365	47.04	1.95	1.47	0.078	0.591	0.03
375	46.80	1.84	1.38	0.078	0.596	0.03
385	46.57	1.74	1.30	0.078	0.600	0.04
395	46.33	1.66	1.23	0.078	0.604	0.05
405	46.09	1.58	1.16	0.077	0.609	0.06
415	45.86	1.50	1.10	0.077	0.613	0.08
425	45.62	1.43	1.05	0.077	0.618	0.08
435	45.39	1.37	1.00	0.077	0.622	0.11
445	45.15	1.31	0.95	0.077	0.626	0.13
455	44.92	1.26	0.91	0.077	0.631	0.15
465	44.68	1.21	0.87	0.076	0.635	0.19
475	44.44	1.17	0.83	0.076	0.639	0.22
485	44.21	1.12	0.80	0.076	0.644	0.26
495	43.97	1.08	0.76	0.076	0.648	0.31
505	43.74	1.05	0.73	0.076	0.653	0.36
515	43.50	1.01	0.71	0.076	0.657	0.42
525	43.26	0.98	0.68	0.075	0.661	0.48
535	43.03	0.95	0.65	0.075	0.666	0.56
545	42.79	0.92	0.63	0.075	0.670	0.66
555	42.56	0.89	0.61	0.075	0.674	0.76
565	42.32	0.87	0.59	0.075	0.679	0.87
575	42.09	0.84	0.57	0.074	0.683	1.00
585	41.85	0.82	0.55	0.074	0.688	1.14
595	41.61	0.80	0.53	0.074	0.692	1.31
605	41.38	0.78	0.52	0.074	0.696	1.49
615	41.14	0.76	0.50	0.074	0.701	1.69
625	40.91	0.74	0.49	0.074	0.705	1.92
630	40.79	0.74	0.48	0.073	0.707	2.04

The values quoted are typical of normal production.
They do not constitute a specification.

I DC-DC converter

Features

- Adjustable Output Voltage
- Non-Isolated
- 1-2AMP Adjustable Positive Step Down
- Integrated Switching Regulator
- Internal Short Circuit Protection
- ON/OFF Control(Ground Off)
- UL94V-0 Package Material
- Wide Input Range
- Efficiency to 96 %
- See Innoline Application Notes for use as an Inverter

INNOLINE
DC/DC-Converter
with 3 year Warranty

RECOM

1-2 AMP SIP12 Vertical & Horizontal

RoHS 2011/65/EU 6/6

EN-60950-1 Certified

R-6xxx

Description

The R-6XXX series is a high performance 1.5V to 15V (18V), 1.1Amp to 2.0Amp,12-Pin SIP (single in-line package) switching regulator. Synchronuous rectification yields excellent efficiencies of up to 97%. Short circuit protection reduces the short circuit input current to under 50mA.

Selection Guide

Part Number SIP12	Input Range (V)	Nominal Output Voltage (V)	Vout Adjust Range (V)	Output Current (A)	Efficiency (%) Vin min. (%)	Efficiency (%) Vin max. (%)
R-611.8x	9 – 32	1.8	1.5 – 3.6	1	79	67
R-612.5x	9 – 32	2.5	1.5 – 4.5	1	84	74
R-613.3x	9 – 32	3.3	1.8 – 6	1	88	79
R-615.0x	9 – 32	5	1.8 – 9	1	92	84
R-619.0x	11 – 32	9	3.3 – 15	1	96	90
R-6112x	14 – 32	12	3.3 – 15	1	97	92
R-621.8x	9 – 32	1.8	1.5 – 3.6	2	76	68
R-622.5x	9 – 32	2.5	1.5 – 4.5	2	81	74
R-623.3x	9 – 32	3.3	1.8 – 6	2	86	80
R-625.0x	9 – 32	5	1.8 – 9	2	90	85
R-629.0x	11 – 32	9	3.3 – 15	2	95	91
R-6212x	14 – 32	12	3.3 – 15	2	96	93

Note: Vin -Vout ≥ 1.5V if adjust function is used!

Suffix x: (see mechanical drawing for details)
x = P pins vertical through hole
x = D pins bent for horizontal through hole mounting

Specifications (refer to the standard application circuit, Ta: 25°C)

Characteristics	Conditions	Min.	Typ.	Max.
Input Voltage Range	Vout = 1.8V	9V		32V
	Vout = 2.5V	9V		32V
	Vout = 3.3V	9V		32V
	Vout = 5V	9V		32V
	Vout = 9V	11V		32V
	Vout = 12V	14V		32V
	Vout = 18V	20V		32V
Output Voltage Adjust Range (see table 1)	Vout = 1.8V	1.5V	1.8V	3.6V
	Vout = 2.5V	1.5V	2.5V	4.5V
	Vout = 3.3V	1.8V	3.3V	6V
	Vout = 5V	1.8V	5V	9V
	Vout = 9V	3.3V	9V	15V
	Vout = 12V	3.3V	12V	15V
	Vout = 18V		18V	

Continued on next page

Refer to Application Notes

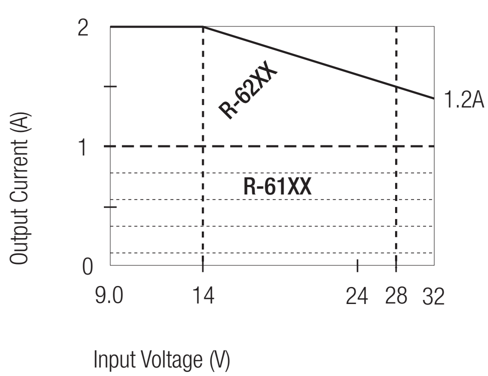
R-6xxxP_D Series

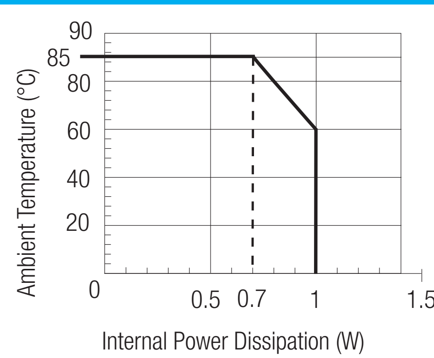
Specifications (refer to the standard application circuit, Ta: 25°C)

Characteristics	Conditions	Min.	Typ.	Max.
Output Current	R-61xxP/D R-62xxP/D	0.1A 0.2A		1.1A 2.0A
Output Current Limit		4A	4.5A	5A
Short Circuit Input Current	Vin > 12V	20mA		100mA
Short Circuit Protection			Continuous, automatic recovery	
Output Voltage Accuracy	At 100% Load		±1%	±2%
Line Voltage Regulation (Vin = min. to max. at full load)			0.5%	
Load Regulation (10 to 100% full load)	R-61xxP/D R-62xxP/D			0.5% 1.0%
Vo Ripple & Noise	R-61xxP/D R-62xxP/D		40mVpp 40mVpp	100mVpp 120mVpp
Transient Response (see note 1)	50% Load Change Vout Over / Undershoot		100us 5%	200us
Remote ON / OFF (see note 2) (positive logic) Remote Off Input Current	Open or high (Power ON) Low (Power OFF) Remote ON/OFF low level	2.0V	 100µA	10V 0.8V
Max capacitance Load	with normal start-up time, no external diodes with <1 second start up time + diode protection circuit			200µF 6800µF
Switching Frequency		200kHz	250kHz	300kHz
Quiescent Current	Vin = min. to max. at 0% load		6mA	10mA
Operating Temperature Range		-40°C		+85°C
Storage Temperature Range		-40°C		+125°C
Case Material				Non-Conductive Black Plastic
Potting Material				Epoxy (UL94V-0)
internal Power Dissipation	Io x Vo x (1-Efficiency)			1.0W
Package Weight				9g
Packing Quantity				15 pcs per Tube
MTBF (Nominal Vout, 100% load)	Tamb. = +25°C Tamb. = +71°C	*Detailed Information see Application Notes chapter "MTBF"*		563 x 10³ hours 117 x 10³ hours
EN General Safety	Report: SPCLVD 1301028-1			EN60950-1:2006 + A12:2011

Notes:
1. Requires a 100µF electrolytic or tantalum output capacitor for proper operation in all applications (the capacitor to be placed as close as possible to the output pins).
2. ON / OFF pin can be driven by TTL (logic gate), open-collector bipolar transistor or open-drain MOSFET.
3. Output Current vs. Input Voltage (see graph below).

Output Current vs Input Voltage





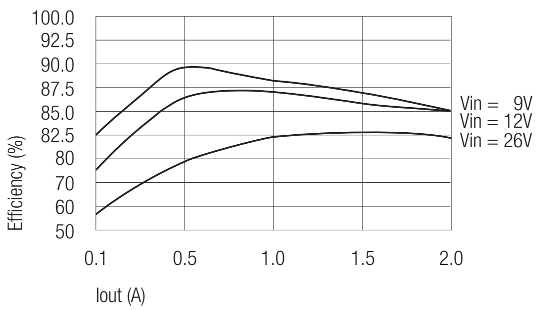
Max output current calculation:
Internal power dissipation
(1W) = Io x Vo x (1-Efficiency)
Io = 1(W) / Vo x (1-Efficiency)

Example : R-6212P

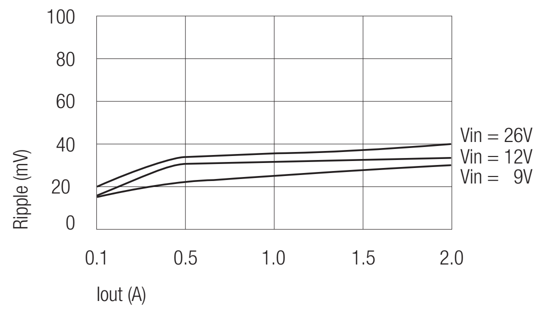
at Vin = 32VDC	**at Vin = 14VDC**
Efficiency = 93% (see "Selection Guide" table)	Efficiency = 96% (see "Selection Guide" table)
Vo = 12VDC	Vo = 12Vdc
Io = 1W / 12V x (1-0.93) = 1.19A	Io = 1W / 12V x (1-0.96) = 2.08A

Characteristics

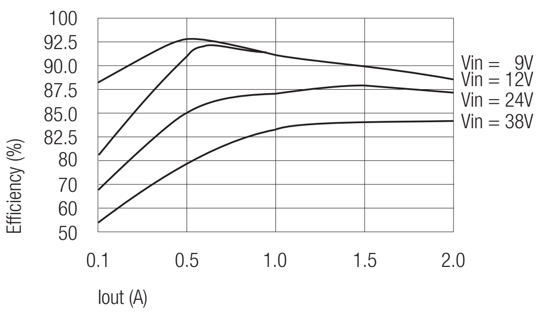
R-623.3 / R-613.3
Efficiency vs Output Current



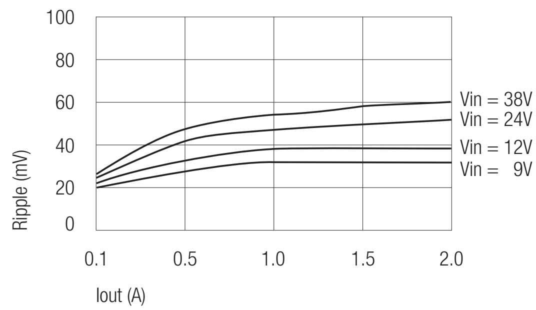
R-623.3 / R-613.3
Ripple vs Output Current



R-625.0 / R-615.0
Efficiency vs Output Current

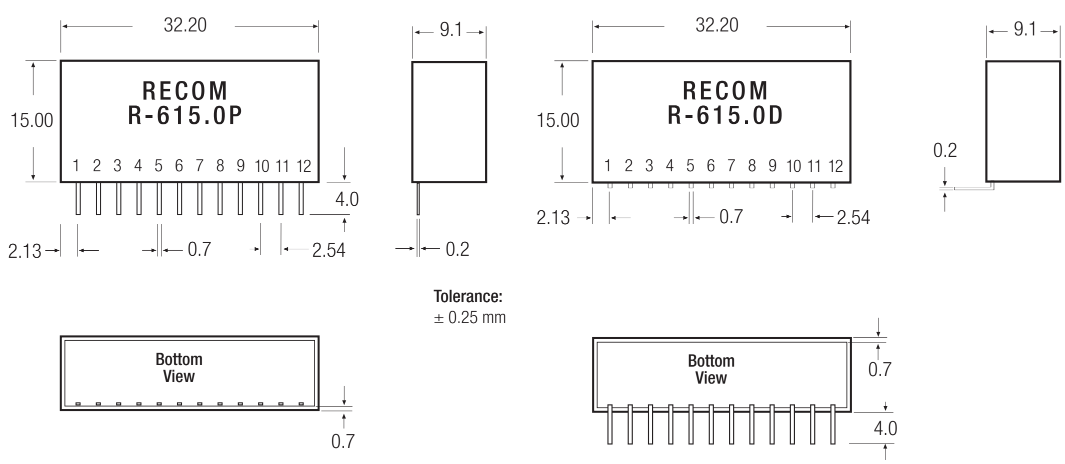


R-625.0 / R-615.0
Ripple vs Output Current



Package Style and Pinning (mm)

SIP12 PIN Package



Tolerance:
± 0.25 mm

Pin Connections

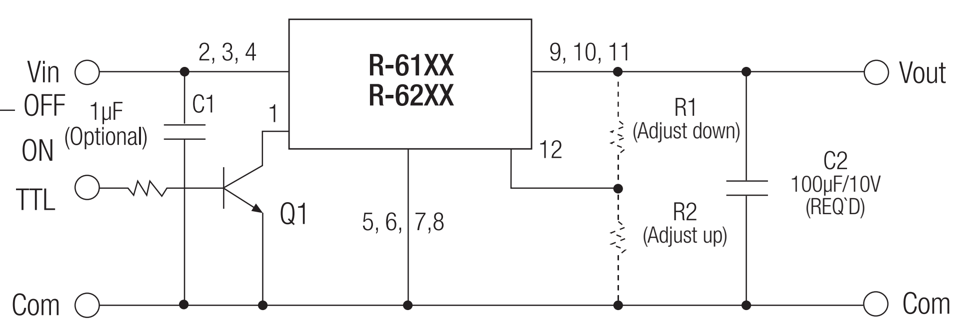
Pin #	Name	Description
1	ON / OFF	Input pin : Active low (less than 0.8V) to disable the device
2, 3, 4	Vin	Power input
5, 6, 7, 8	GND	Input and output ground (common)
9 , 10, 11	Vout	Power output
12	Vout-Adj	With external resistors R1,R2 to selected output voltage

R-6xxxP_D Series

Table 1: Adjustment Resistor Values

1.1Adc	R-611.8P/D		R-621.5P/D		R-613.3P/D		R-615.0P/D		R-619.0P/D		R-6112P/D	
2.0Adc	R-621.8P/D		R-622.5P/D		R-623.3P/D		R-625.0P/D		R-629.0P/D		R-6212P/D	
Vout (nominal)	1.8Vdc		2.5Vdc		3.3Vdc		5Vdc		9Vdc		12Vdc	
Vout (adj)	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
1.5	13.6KΩ		3.3KΩ									
1.8			8.2KΩ		3.1KΩ		820Ω					
2.0		10KΩ	15KΩ		5.1KΩ		1.5KΩ					
2.5		5.1KΩ			13KΩ		3.6KΩ					
3.0		2.5KΩ		10KΩ	51KΩ		7.0KΩ					
3.3		1.7KΩ		5.9KΩ			9.7KΩ		0Ω		0Ω	
3.6		1.2KΩ		3.9KΩ		18KΩ	14KΩ		1.5KΩ		560Ω	
3.9				2.8KΩ		9.1KΩ	20KΩ		3.3KΩ		1.2KΩ	
4.5				1.6KΩ		3.9KΩ	60KΩ		7.5KΩ		2.1KΩ	
5.0						2.4KΩ			11KΩ		4.0KΩ	
5.1						2.2KΩ		60KΩ	12KΩ		4.3KΩ	
5.5						1.6KΩ		15KΩ	17KΩ		5.6KΩ	
6.0						1.1KΩ		7.2Ω	24KΩ		7.5KΩ	
7.0								2.8KΩ	51KΩ		12KΩ	
8.0								1.5KΩ	130KΩ		19KΩ	
9.0								880Ω			31KΩ	
10								450Ω		36KΩ	55KΩ	
11								180Ω		15KΩ	125KΩ	
12										8.2KΩ		
13										4.7KΩ		11KΩ
14										2.7KΩ		4.0KΩ
15										1.3KΩ		1.6KΩ

Standard Application Circuit

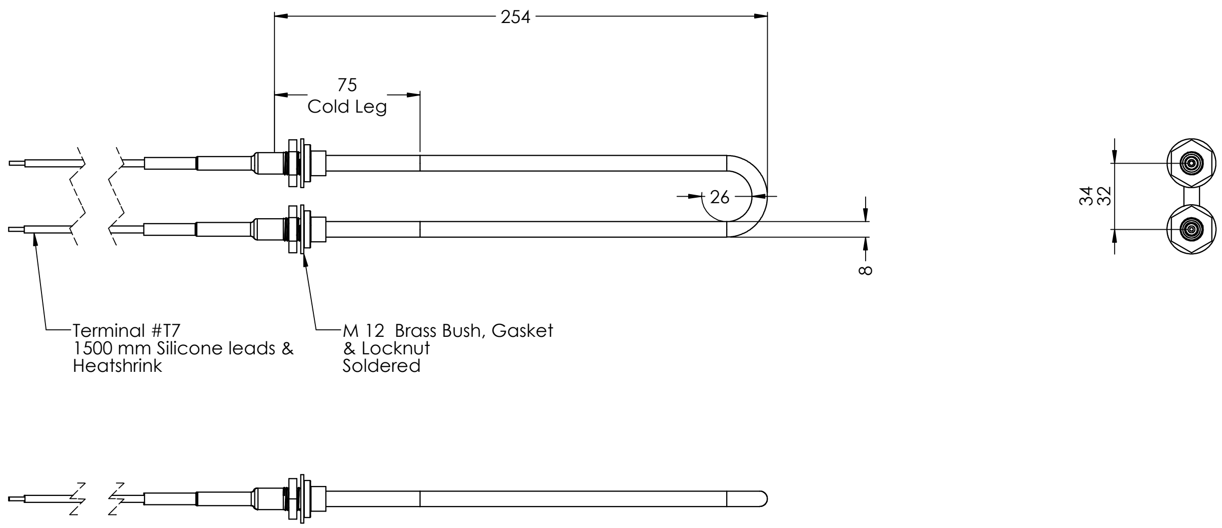


Add a blocking diode to Vout if current can flow backwards into the output, as this can damage the converter.

Protection diodes are required for high capacitive loads.

Refer to R-5xxxA Datasheet (see Optional Diode Protection Circuit) for circuit suggestions.

J Heating elements



Element Info	
Type of Application	OIL
Voltage	24
Wattage	500
Quantity	6
Sheath material	321 SS
Temperature C°	300 °C
Special fittings	

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: TOLERANCES: LINEAR: ANGULAR:	FINISH:	DEBUR AND BREAK SHARP EDGES	DO NOT SCALE DRAWING — REVISION 1
			Cynebar

	NAME	SIGNATURE	DATE
DRAWN	Jensen Nydal		7/09/2018
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: QU108488

MATERIAL: 8MM 321SS

DWG NO. Figure 1 - U shaped tubular Template #T7 + Bush

A3

WEIGHT: 0 kg

SCALE:1:1

SHEET 1 OF 1

K Risk assesment report

Risk Assessment Report

Excess energy to high temperature heat storage

Prosjektnavn	Excess energy to high temperature heat storage
Apparatur	Oil based heat storage rig
Enhet	NTNU
Apparaturansvarlig	Ole Jørgen Nydal
Prosjektleder	Ole Jørgen Nydal
HMS-koordinator	Morten Grønli
HMS-ansvarlig (linjeleder)	Therese Løvås
Plassering	EPT-TermiskLab
Romnummer	C114
Risikovurdering utført av	Marie Kolderup

Approval:

Apparatur kort (UNIT CARD) valid for:	12 months
Forsøk pågår kort (EXPERIMENT IN PROGRESS) valid for:	12 months

Rolle	Navn	Dato	Signatur
Prosjektleder	Ole Jørgen Nydal		
HMS koordinator	Morten Grønli		
HMS ansvarlig (linjeleder)	Therese Løvås		

NTNU SINTEF

TABLE OF CONTENTS

1 INTRODUCTION

The setup consists of a small pipe system, including two heating elements (24V, 500W), connected to a heat storage. The heat storage is composed of three large steel tanks containing thermal oil (Duratherm 630). The heating elements are located inside the storage tank. There is oil initially filled in the upper tank (cold reservoir) flowing into the storage tank, when a thermostatic valve opens. The valve is made out of a bimetallic feather rotating a slider, opening the flow from the cold reservoir at a certain temperature. The maximum temperature for the experiment will be around 230°C (flash point of Duratherm 630). The flow in this system is driven by gravitational forces. There is a valve in each of the three tanks to ensure atmospheric pressure.

The purpose of the experiment is to test the thermostatic valve, the flowing component, the resulting heat in the cooker and see if the gravitational forces can be used as a driving force for this system.

The experimental rig is located at room C114, in Varmeteknisk Lab.

2 ORGANISATION

Rolle	
Prosjektleder	Ole Jørgen Nydal
Apparaturansvarlig	Ole Jørgen Nydal
Romansvarlig	Paul Svendsen
HMS koordinator	Morten Grønli
HMS ansvarlig (linjeleder):	Therese Løvås

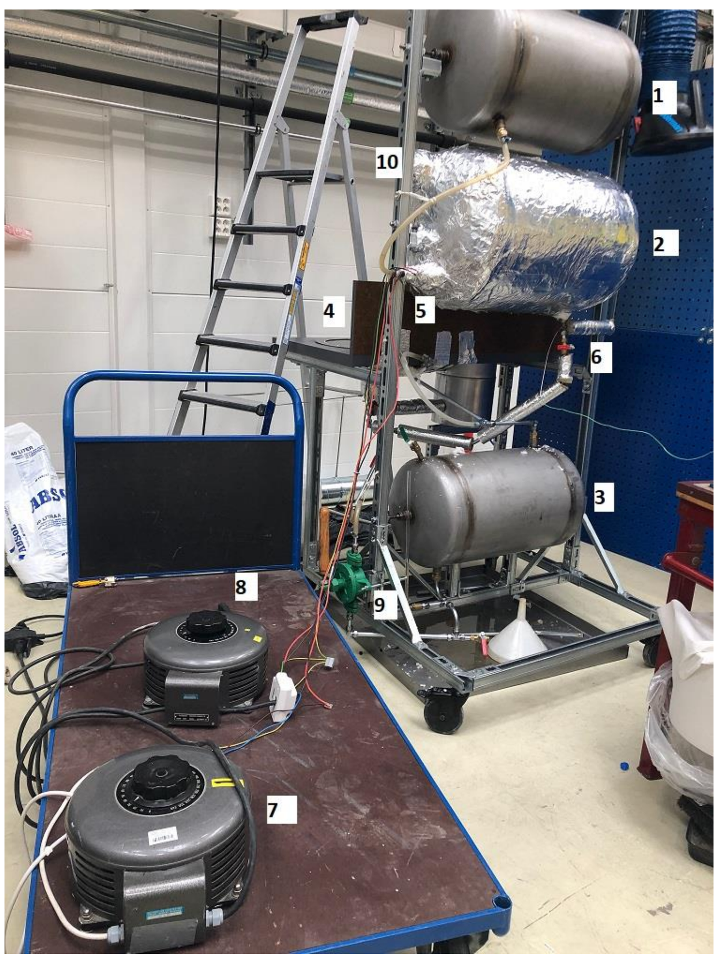
3 RISK MANAGEMENT IN THE PROJECT

Hovedaktiviteter risikostyring	Nødvendige tiltak, dokumentasjon	DATE
Prosjekt initiering	Prosjekt initiering mal	31.08.2017
Veiledningsmøte Guidance Meeting	Skjema for Veiledningsmøte med pre-risikovurdering	30.08.2017
Innledende risikovurdering Initial Assessment	Fareidentifikasjon – HAZID Skjema grovanalyse	
Vurdering av teknisk sikkerhet Evaluation of technical security	Prosess-HAZOP Tekniske dokumentasjoner	
Vurdering av operasjonell sikkerhet Evaluation of operational safety	Prosedyre-HAZOP Opplæringsplan for operatører	
Sluttvurdering, kvalitetssikring Final assessment, quality assurance	Uavhengig kontroll Utstedelse av apparaturkort Utstedelse av forsøk pågår kort	

4 DESCRIPTIONS OF EXPERIMENTAL SETUP

The rig consists of the following components (see figure below):

1. Cold oil reservoir, upper tank
2. Heat storage, mid tank, with a measuring glass for monitoring oil level
3. Used oil reservoir, lower tank
4. Cooking arrangement
5. Placement of two heating elements (inside tank), 24V 500W
6. Valve for controlling flow out of heat storage
7. Variac for controlling power in heating element 1
8. Variac for controlling power in heating element 2
9. Manually hand pump for transporting oil from lower reservoir to upper
10. Removable lid for refill of oil (and able to see inside tank)



The shutdown of the system is done by unplugging the two power supplies to the heating element. An additional length is added to the power supplies, so that these can be accessed and monitored at a safe distance. If required, the oil can be drained from the system by using the valve below the lower tank.

5 EVACUATION FROM THE EXPERIMENTAL AREA

Evacuate at signal from the alarm system or local gas alarms with its own local alert with sound and light outside the room in question, see 6.2

Evacuation from the rigging area takes place through the marked emergency exits to the assembly point, (corner of Old Chemistry Kjelhuset or parking 1a-b.)

Action on rig before evacuation:
Turn off the power supply of the electrical heater by unplugging it.

6 WARNING

6.1 Before experiments

Send an e-mail with information about the planned experiment to:
iept-experiments@ivt.ntnu.no

The e-mail must include the following information:

- Name of responsible person:
- Experimental setup/rig:
- Start Experiments: (date and time)
- Stop Experiments: (date and time)

You must get the approval back from the laboratory management before start up. All running experiments are notified in the activity calendar for the lab to be sure they are coordinated with other activity.

6.2 Non-conformance

FIRE

If you are NOT able to extinguish the fire, activate the nearest fire alarm and evacuate area. Be then available for fire brigade and building caretaker to detect fire place.
If possible, notify:

NTNU	SINTEF
Morten Grønli, Mob: 918 97 515	Linda Helander, Mob: +47 406 48 621
Terese Løvås: Mob: 918 97 209	Petter Røkke, Mob: 901 20 221
NTNU – SINTEF Beredskapstelefon	800 80 388

GAS ALARM
If a gas alarm occurs, close gas bottles immediately and ventilate the area. If the level of the gas concentration does not decrease within a reasonable time, activate the fire alarm and evacuate the lab. Designated personnel or fire department checks the leak to determine whether it is possible to seal the leak and ventilate the area in a responsible manner.

PERSONAL INJURY
- First aid kit in the fire / first aid stations
- Shout for help
- Start life-saving first aid
- **CALL 113** if there is any doubt whether there is a serious injury

OTHER NON-CONFORMANCE (AVVIK)

NTNU:
You will find the reporting form for non-conformance on:
https://innsida.ntnu.no/wiki/-/wiki/Norsk/Melde+avvik

SINTEF:
Synergi

7 ASSESSMENT OF TECHNICAL SAFETY

7.1 HAZOP

The experiment set up is divided into the following nodes:

Node 1	Testing the oil stratification in the storage

Attachments, Form: Hazop_mal
Conclusion: No real dangers. Avoid touching potential hot surfaces (storage, pipes, heat component).

7.2 Flammable, reactive and pressurized substances and gas

Are any flammable, reactive and pressurized substances and gases in use?

NO	

Attachments: EX zones
Conclusion: No real dangers.

7.3 Pressurized equipment

Is any pressurized equipment in use?

NO	

Attachments: Certificate for pressurized equipment (see Attachment to Risk Assessment)
Conclusion: No real dangers. No attachment necessary

7.4 Effects on the environment (emissions, noise, temperature, vibration, smell)

NO	

Attachments: No attachment necessary.
Conclusion: The experiment shall not generate emission of smoke, gas, odour, etc when operated properly. Still, there should be used a ventilation channel over the node of valves from the three tanks "just in case". The oil should be stored safe in an own container and considered as special waste when the experiments are done.

7.5 Radiation

See Chapter 13 "Guide to the report template".

NO	

Attachments: No attachment necessary
Conclusion: No real dangers. No attachment necessary.

7.6 Chemicals

YES	Duratherm 630 thermal oil

Attachments: No attachment necessary
Conclusion: The oil used is a high heat transfer oil but it is not dangerous for health, you can smell it and touch it like the common oil we use in our houses. Of course, you must not use it like an edible product.

7.7 Electricity safety (deviations from the norms/standards)

NO	

Attachments: No attachment necessary.
Conclusion: No real dangers.

8 ASSESSMENT OF OPERATIONAL SAFETY

Ensure that the procedures cover all identified risk factors that must be taken care of. Ensure that the operators and technical performance have sufficient expertise.

8.1 Procedure HAZOP

The method is a procedure to identify causes and sources of danger to operational problems.
Procedure:

1) Put a tray in the bottom of the structure to avoid spills of hot oil.
2) Tested all the system connections using cold oil to check for leaks.
3) Ensure the heating elements are working properly
4) Connect the heating elements to a power supply that ensures the right power (variacs)
5) Insulate some of the pipes and heating storage where necessary.
6) Use thermocouples several places to ensure that the temperature monitored is correct

Attachments:: HAZOP_MAL_Prosedyre
Conclusion: The procedure is safe, only needs avoid the contact with the hot elements during the heating of the oil.

8.2 Operation procedure and emergency shutdown procedure

The operating procedure is a checklist that must be filled out for each experiment.
Emergency procedure should attempt to set the experiment set up in a harmless state by unforeseen events.

Attachments: Procedure for running experiments
Emergency shutdown procedure: Pull out the plug connected to the heat element box (no power means no heat)

8.3 Training of operators

A Document showing training plan for operators
- *What are the requirements for the training of operators?*
- *What it takes to be an independent operator*
- *Job Description for operators*

Attachments: Training program for operators

8.4 Technical modifications

- Because the cooker is not insulated/closed properly, the hot oil is open to air. By using water as the heating medium in the cooker, the importance of not spilling should be stressed because water expands rapidly in hot oil (boiling point is lower).
- In addition, a hole is to be drilled in the storage tank, increasing the risk of spilling hot oil if water is present

Conclusion: No water should enter the system due to the low boiling point of water compared to oil. Careful when (potentially) using water as the heating medium in the cooker.

8.5 Personal protective equipment

Eye protection should be used in the rig zone. Gloves should be used when handling the tubes as some of them can be hot.

Conclusion: Plastic glasses and gloves is the only special equipment needed to protect.

8.6 General Safety

Warning signs must be close the hot elements.
An operator must be controlling the rig.

Conclusion: Signs and monitoring by operator.

8.7 Safety equipment

A welding screen (not flammable) is located around the set up to protect from possible oil splash.

8.8 Special predations

One operator must be in the rig zone during tests to make sure the temperature is within safe range and there is no major leaks.

9 QUANTIFYING OF RISK - RISK MATRIX

See Chapter 13 "Guide to the report template".
The risk matrix will provide visualization and an overview of activity risks so that management and users get the most complete picture of risk factors.

IDnr	Aktivitet-hendelse	Frekv-Sans	Kons	RV
1	*People getting burned on heat element*	2	B	B2
3	*Oil leakage*	2	B	B2

Conclusion: We consider the risk to people, environment and economic very small. The aim of the risk assessment is to achieve avoid all the risk related with the possible burns.

CONSEQU						
	Catastrophic	E1	E2	E3	E4	E5
	Major	D1	D2	D3	D4	D5
	Moderate	C1	C2	C3	C4	C5
	Minor	B1	B2	B3	B4	B5

E N S E S	Insignificant	A1	A2	A3	A4	A5
		Rare	Unlikely	Possible	Likely	Almost
		PROBABILITY				

Table 8. Risk's Matrix

COLOUR		DESCRIPTION
Red		Unacceptable risk Action has to be taken to reduce risk
Yellow		Assessment area. Actions has to be considered
Green		Acceptable risk. Action can be taken based on other criteria

Table 9. The principle of the acceptance criterion. Explanation of the colors used in the matrix

10 REGULATIONS AND GUIDELINES

Se http://www.arbeidstilsynet.no/regelverk/index.html

- Lov om tilsyn med elektriske anlegg og elektrisk utstyr (1929)
- Arbeidsmiljøloven
- Forskrift om systematisk helse-, miljø- og sikkerhetsarbeid (HMS Internkontrollforskrift)
- Forskrift om sikkerhet ved arbeid og drift av elektriske anlegg (FSE 2006)
- Forskrift om elektriske forsyningsanlegg (FEF 2006)
- Forskrift om utstyr og sikkerhetssystem til bruk i eksplosjonsfarlig område NEK 420
- Forskrift om håndtering av brannfarlig, reaksjonsfarlig og trykksatt stoff samt utstyr og anlegg som benyttes ved håndteringen
- Forskrift om Håndtering av eksplosjonsfarlig stoff
- Forskrift om bruk av arbeidsutstyr.
- Forskrift om Arbeidsplasser og arbeidslokaler
- Forskrift om Bruk av personlig verneutstyr på arbeidsplassen
- Forskrift om Helse og sikkerhet i eksplosjonsfarlige atmosfærer
- Forskrift om Høytrykksspyling
- Forskrift om Maskiner
- Forskrift om Sikkerhetsskilting og signalgivning på arbeidsplassen
- Forskrift om Stillaser, stiger og arbeid på tak m.m.
- Forskrift om Sveising, termisk skjæring, termisk sprøyting, kullbuemeisling, lodding og sliping (varmt arbeid)
- Forskrift om Tekniske innretninger
- Forskrift om Tungt og ensformig arbeid
- Forskrift om Vern mot eksponering for kjemikalier på arbeidsplassen (Kjemikalieforskriften)
- Forskrift om Vern mot kunstig optisk stråling på arbeidsplassen
- Forskrift om Vern mot mekaniske vibrasjoner
- Forskrift om Vern mot støy på arbeidsplassen

Veiledninger fra arbeidstilsynet
se: http://www.arbeidstilsynet.no/regelverk/veiledninger.html

11 DOCUMENTATION

- Tegninger, foto, beskrivelser av forsøksoppsetningen
- Hazop_mal
- Sertifikat for trykkpåkjent utstyr
- Håndtering avfall i NTNU
- Sikker bruk av LASERE, retningslinje
- HAZOP_MAL_Prosedyre
- Forsøksprosedyre
- Opplæringsplan for operatører
- Skjema for sikker jobb analyse, (SJA)

- Apparaturkortet
- Forsøk pågår kort

L Aperture Card

FORSØK PÅGÅR

Enhet (unit) og bygg/romnr. (building/room no.):

NTNU-E	302	C114	1. etg

Laboratorium TermiskLab

Dette kortet SKAL henges opp før forsøk kan starte!
This card MUST be posted on the unit before the experiment startup!

Apparatur (Unit) **Oil-based Heat Storage Rig**	**Dato godkjent (Date Approved)** torsdag 18. oktober 2018
Prosjektleder (Project Leader) Ole Jørgen Nydal	**Telefon mobil/privat (Phone no. mobile/private)** 977 15 994
Apparaturansvarlig (Unit Responsible) Ole Jørgen Nydal	**Telefon mobil/privat (Phone no. mobile/private)** 977 15 994

Godkjente operatører (Approved Operators)

Navn/Name	Telefon/Phone	Mobil
Kolderup, Marie		45002523
Gustafson, Kaja		95237098
Thaule, Sigurd		9946 8624

Prosjekt (Project)

Excess energy to high temperature heat storage

Forsøkstid / Experimental time (start - stop)

18.10.2018 - 18.10.2019

Kort beskrivelse av forsøket og relaterte farer (Short description of the experiment and related hazards)

The purpose of the experiment is to test the thermostatic valve, the flowing component, the resulting heat in the cooker and see if the gravitational forces can be used as a driving force for this system.

NTNU

Institutt for energi og prosessteknikk

Dato 24/10 -18

Signert Terese Løvås

NTNU SINTEF

APPARATURKORT

Enhet (unit) og bygg/romnr. (building/room no.):

NTNU-E	302	C114	1. etg

Laboratorium TermiskLab

Dette kortet SKAL henges godt synlig ved maskinen!
This card MUST be posted on a visible place on the unit!

Apparatur (Unit) **Oil-based Heat Storage Rig**	**Dato Godkjent (Date Approved)** torsdag 18. oktober 2018
Prosjektleder (Project Leader) Ole Jørgen Nydal	**Telefon mobil/privat (Phone no. mobile/private)** 977 15 994
Apparaturansvarlig (Unit Responsible) Ole Jørgen Nydal	**Telefon mobil/privat (Phone no. mobile/private)** 977 15 994

Sikkerhetsrisikoer (Safety hazards)
Hot surfaces
Oil fumes
Heated oil

Sikkerhetsregler (Safety rules)
Use safety gloves and googles
Do not touch the rig without approval of the operato

Nødstopp prosedyre (Emergency shutdown)
Pull out the plug of the heat element box (the only plug connected to the power supply)

Her finner du (Here you will find): **Prosedyrer (Procedures)** **Bruksanvisning (User manual)**	 Rig folder Rig folder
Brannslukningsapparat (Fire extinguisher) **Førsthjelpsskap (First aid cabinet)**	1. etasje lab (nord) 1. etasje lab (nord)

NTNU
Institutt for energi og prosessteknikk

Dato 24/10-18

Signert Terese Løvås

NTNU SINTEF

NTNU

Norwegian University of
Science and Technology