NTNU – Trondheim
Norwegian University of
Science and Technology

DC Supply in Buildings

Aurora Bøhle Foss

Master of Energy and Environmental Engineering
Submission date: June 2014
Supervisor: Eilif Hugo Hansen, ELKRAFT
Co-supervisor: Olav Økern, COWI

Norwegian University of Science and Technology
Department of Electric Power Engineering

NORGES TEKNISK-NATURVITENSKAPELIGE UNIVERSITET

NTNU

MASTEROPPGAVE

Name	Aurora Bøhle Foss
Subject	ELECTRIC POWER ENGINEERING
Title (Norw.)	**DC-forsyning i bygninger**
Title (English)	**DC Supply in Buildings**

Background

In existing buildings, equipment is supplied by converted power from the 230 V AC system, as the majority of end loads are original DC loads. Meanwhile, alternative power supply for example based on solar cells, provides DC voltage directly.

Converters between different voltage levels provide losses, in addition to the cost of the equipment itself. The question is whether future buildings should be equipped with one or more DC supply system, in addition to or instead of, the current 230 V AC supply.

The candidate shall simulate a system solution for a modern building by looking at the possibility of maintaining the link from AC loads to the existing AC system and to develop a separate LVDC system that supplies equipment that originally uses DC. The idea is to apply a simulation tool. The system simulated is thought to be a chosen building, so one can also simulate the existing solution with an AC system with associated converters for DC equipment and compare loss or savings of energy, energy efficiency, safety aspects and possibly economic aspects of the two different system solutions. It is also thought that some physical measurements of a selected building can be performed to provide a better basis for the size of a DC system solution.

If there is time, it is thought to look at options for future equipment, the DC system with connection to UPS and renewable energy sources.

The candidate must:

- Outline and analyse the existing AC system solution with connection to original DC loads, and outline and analyse a DC system with connection to original DC loads, and compare the results from the simulations
- Consider different planning aspects with such system solutions

Oppgaven gitt	16.01.14
Besvarelsen leveres innen	12.06.14

Trondheim, 16.01.14

Eilif H. Hansen

faglærer

Preface

This report is written as part of the course TET4900 – Electrical Power Engineering, Master at the Norwegian University of Science and Technology (NTNU) during the spring 2014. The course is mandatory for students enrolled in the master program Energy and Environment following the Electrical Power Engineering specialization. This report is a continuation of the work in the specialization project *DC Supply for Buildings* from fall 2013. This report examines the opportunities with having DC supply in buildings, by the use of existing articles, specialists experience and simulation on component level.

The report has been performed at the Department for Electric Power Engineering at the Norwegian University of Science and Technology, and is prepared in Microsoft Word for Mac 2011.

I would like to thank:

- My supervisor, Associate Professor Eilif Hugo Hansen at the Department of Electric Power Engineering, for his valuable advice and guidance.

- Co-supervisors Olav Økern and Morten Halten Eggen at COWI AS for good cooperation and help with access to information and a building for the measurements and measuring equipment. As well as giving me the opportunity to work with a realistic and existing example of a building that could possibly benefit from introducing the proposed system solution, and for giving me an introduction to the analysis tool FEBDOK.

- PhD student at the Department of Electric Power Engineering, Santiago Acevedo Sanchez, for letting me use his predefined model for the Voltage Source Converter, in addition to great help with the development of AC-DC converter models.

- Uncle Bjørn Foss at Jatronic AS and Chris Gordon at FossTech AS for using your expertise in electronics and English to help me with proofreading.

Trondheim, June 2014

Aurora Bøhle Foss

Abstract
In this study, existing work, opportunities, standards and essential safety aspects on development of LVDC distribution systems have been considered. It can be summarised that the standard requirements for AC systems also applies to DC systems, and that one does not come apart DC-DC regulators in equipment due to the galvanic separation which is needed to fulfil the safety requirements. One of the main challenges of introducing an LVDC system is the non-existence of building codes and standards intended for an LVDC system in buildings.

The critical step of developing a DC distribution system is selecting the voltage level. Earlier studies conclude that:

- A standard voltage level of 230 V DC is proven to be sufficient for normal office loads, as long as the cable length does not exceed 80 m
- For higher power loads up to 6.5 kW the voltage level has to be increased to 326 V DC for systems with a cable length of maximum 47 m and 2.5 mm^2

This study proposes an LVDC system supplied by converted power from the main grid (AC-DC), where the size of the LVDC system is decided by performed measurements at an example building. In order to compare the losses in an AC and DC system, it was chosen to perform simulations on component level. It can be concluded that:

- An LVDC system supplied by a central VSC converting power from the AC grid is an energy efficient system solution compared to the existing AC system solution, largely depending on the performance of the VSC

Simulations and calculations resulted in a requirement of performance > 97.7 % of the VSC in order for it to be more energy efficient with an DC system instead of the existing AC system solution with AC-DC converters in each link with a performance of approximately 97 %. Experts believe that it is possible to gain this performance in the future based on performance for smaller converters developed by leading manufactures.

Based on the different aspects considered regarding introduction of an LVDC distribution system, simulated models, and performed measurements, it can be concluded that:

- From earlier studies it can be concluded that on the economic side, an LVDC distribution system seems benefitual
- Original DC loads will benefit from having a separate DC system in terms of power loss at a voltage level of 230 V DC
- AC loads require high power delivered and it will be most energy efficient to keep the connection to the existing AC system
- An LVDC system with a size of approximate 20 kW is realistic in the future, supplying a floor in a building with DC loads

From the material presented in this report, it can be summarised that it is a realistic possibility for future distribution systems in buildings to have an energy efficient mixed supply system, AC and DC.

Sammendrag

I denne rapporten er det eksisterende arbeidet med å utvikle systemløsninger for et lavspent DC system presentert. Det kan oppsummeres at standard krav til AC systemer også gjelder for DC systemer, og at man ikke kommer utenom DC-DC regulatorer i utstyr på grunn av det galvaniske skillet som er nødvendig for å oppfylle sikkerhetskravene. En av de største utfordringene med å innføre et DC system er at det ikke eksisterer standarder som er beregnet for et lavspent DC anlegg i bygninger.

I tillegg er det kritiske utfordringer, som valg av spenningsnivå, ved innføring av en ny systemløsning. Tidligere studier viser at:

- Et standard spenningsnivå på 230 V DC er bevist å være tilfredsstillende for normale kontorlaster, så lenge kabellengden ikke overstiger 80 m
- For laster som krever høyere effekt enn 6.5 kW, må spenningsnivået økes til 326 V DC med en kabellengde på maksimum 47 m og 2.5 mm^2

Denne rapporten foreslår en ny systemløsning, med et lavspent DC system forsynt med omformet energi fra nettet (AC-DC), hvor størrelsen av DC systemet bestemmes av utførte målinger på en eksempel bygning. For å kunne sammenligne tapene i et AC og DC system, ble det utført simuleringer på komponent nivå. Ut i fra dette kan det konkluderes at:

- Det avhenger sterkt av virkningsgraden til en sentral omformer som forsyner det lavspente DC anlegget med likerettet effekt fra AC nettet, når det kommer til om det er en mer energieffektiv løsning enn den eksisterende

Simuleringer og beregninger resulterte i et krav om at virkningsgraden til den sentrale omformeren må være > 97.7 % for at det skal være mer energieffektivt med et DC system istedenfor den eksisterende AC systemløsningen med omformere i hvert ledd med en ytelse på ca. 97 %. Eksperter mener at det er mulig å oppnå denne ytelsen i fremtiden basert på virkningsgraden for mindre omformere utviklet frem til i dag.

Ut i fra de vurderte aspektene, simulerte modeller og utførte målinger, kan det ved innføring av et lavspent DC anlegg også konkluderes at:

- Fra tidligere studier kan det konkluderes at fra et økonomisk synspunkt virker det fordelaktig med et DC system
- Originale DC laster vil ha nytte av et eget DC system når det kommer til effekttap i kabler med et spenningsnivå på 230 V DC
- AC laster krever høy effekt levert og det vil derfor være mest energi effektivt å beholde koblingen til det eksisterende AC systemet
- Det er realistisk for et DC system som forsyner en etasje i fremtiden å ha en størrelse på ca. 20 kW

Fra materialet presentert i denne rapporten kan det konkluderes at det er en realistisk mulighet for fremtidige fordelingssystem i bygninger å ha et energieffektiv kombinert system, med både AC og DC.

Contents

List of Abbreviations

AC	Alternating Current
CENELEC	European Committee for Electrotechnical Standardization
CrM	Critical Conduction Mode
DC	Direct Current
DES	Distributed Energy Sources
DGS	Distributed Generator Sources
ECC	Energy Control Centre
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ETSI	European Telecom Standard Institute
EV	Electrical Vehicle
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IT	Information Technology
LED	Light Emitting Diode
LVDC	Low Voltage Direct Current
MCB	Miniature Circuit Breakers
PDU	Power Distribution Unit
PF	Power Factor
PFC	Power Factor Corrector
PSU	Power Supply Unit
PWM	Pulse Width Modulation
RES	Renewable Energy Source
RMS	Root Mean Square
THD	Total Harmonic Distortion
UPS	Uninterruptible Power Supply
USB PD	Universal Serial Bus Power Delivery
VSC	Voltage Source Converter
VSD	Variable Speed Drive

1 Introduction

In today's buildings, equipment is supplied with power from the 230 V AC system, but the majority of the end loads needs DC power from rectifiers on various voltage levels. With today's AC distribution system solution, power is converted up and down between different voltage levels and to DC. These conversions result in loss of valuable energy and high costs due to the converters.

The aim of this project is to try to identify the possibilities for having one or more separate DC supply systems for DC loads in future buildings.

With the current focus on having a sustainable environment, interest in energy saving, recycling and increased developments in the DC end use equipment, supports the possibility of having a future DC system.

Furthermore, with the invention of Smart Grid, it is possible to connect different Distributed Generator Sources (DGS) from renewables as wind, photovoltaic and fuel cells. Wind turbines are able to produce both AC and DC power, but due to the variable wind, the electricity generated needs to pass through battery banks before it can be distributed to the grid, which result in wind parks effectively being DC compatible.

Moreover, with the on-growing trend of electrical vehicles, it is natural to think of them as part of a DC system, in that the battery bank in the car is connected to the grid. The proposed solution of having a separated DC system would have great efficiency improvements and also provides opportunities for simplification of the system, by reducing the conversion process from DC-AC-DC, to exploit DC power directly.

This report consider the complex problem of comparing the existing 230 V AC supply system in buildings, to having one or more separate DC supply systems supplying DC loads in addition to the existing AC system supplying AC loads. These systems are weighted against each other in terms of opportunities and benefits. In addition to examining safety aspects, it outlines and analyses a hypothetical system solution. The main objective is to investigate the opportunities of having a DC system in future buildings.

2 Development of the Power Supply System

The need for electricity supply in domestic and commercial buildings is obvious. This is especially the case in Norway where electricity is supplied to electrical dependant equipment such as heating ovens, lighting, and computers.

In this case, the European Standard, ETSI EN 300 123-3-1 V2.1.1 [1], and the regulations on low voltage electrical installations [2], mainly applies.

Electricity supply also ensures increased comfort in addition to being an energy source that people are entirely dependent of.

2.1 Historical Development

In the 19th century, Thomas Edison, invented the first electric power system which was direct current (DC) compatible [3]. The DC power transmission was replaced by Nicola Tesla´s alternating current (AC) electric power system, as the AC transmission system was proven to transmit power over long distances with small losses by stepping up the voltage level. Even though high voltage DC effectively can be transmitted over long distances today, none cost-efficient technologies existed at that time [4]. The AC transmission system was therefore chosen to be the standard [5][6].

Today, AC power is converted to DC power to make the power applicable for the majority of loads in buildings [7]. These transformations commence inefficiencies, losses, and potential fault elements [4].

With the development of intelligent systems on the load side, there is also a trend on the supply side, Distributed Generators Sources (DGS) and Smart Grids. The need for more intelligent, efficient and advanced system controlling gives incentives to look into having a separated DC supply system in addition to the existing AC supply system in buildings. The possibility of having a separate DC supply system connected to multiple renewable energy sources and energy storage elements, could be an alternative or in addition to the existing AC system, providing zero emission and energy efficiency in buildings [8].

The current power grid is able to ensure secure power supply as the demand varies by overdesign, redundancy and system configurations, which are electromechanically controlled. The infrastructure of today's grid is aging, which leads to a slow and unreliable system [8].

With the direct use of DC power it is possible to have more energy efficient consumption. This is due to the reduction in rectifiers, which reduces the size of the system. This leads to decreased costs and power conversion stages, which could result in increased efficient consumption of energy [7]. The concept of having a separated DC grid opens up the possibility for a new market for electronic device manufacturers and a new distribution network [9].

2.2 AC versus DC: Advantages and Disadvantages

Alternating Current (AC) is a flow of electrons that varies periodically in both directions of a leader. Alternating Current (AC) has two natural current zero crossings each period. This can be seen from the mathematical description of a single-phase harmonic sinusoidal current [10]:

$$I = I_0 \sin(\omega t) \qquad (2.2.1)$$

where I is the current, I_0 is the value of the current amplitude, t is time and ω is the angular frequency $\omega = 2\pi f$.

As the AC current has two natural zero crossings each cycle, in case of a fault a switch will operate (open) and there will exist an arch until the current is zero, which means that the arch will extinguish. If it is assumed that the voltage is almost in phase with the current at the zero crossing, the voltage will be low at that time. This will give the ionized air from the arch some time to dissipate before the voltage rises, and the air gap should be sufficient [11][12].

Unlike AC, DC current is a flow of electrons that moves steadily in one direction with constant magnitude, and there are no natural zero crossing [5][13]. In the case of a fault, the switch has to break the current by separating the contacts with enough distance across air, so the voltage across the gap is to small to maintain the ionized path. This is the reason for the need of higher AC rating than it is for DC rating. Another challenge connected to DC switch applications, is the case where batteries are involved. This is because the spark from the arch could trigger a hydrogen explosion if the batteries are close in distance and not sealed [12].

AC has a lot of advantages compared to DC, in that high voltage AC power can be transported in long transmission lines safely and result in small losses, and it can be transformed up and down in voltage level. It is therefore possible to transport large amounts of energy with small losses. Moreover, sinusoidal AC can easily be generated and is inexpensive to distribute. However, in AC circuits, phase shift occurs due to the shift in phase angle of the current and voltage [3][10].

Since the flow of electrons varies periodically in both directions of a leader, AC has the advantage of being able to handle power flow in both directions; from the grid to the consumption point and from the consumption point to the grid. This property is especially benefitual when the consumer has alternative energy sources as wind, photovoltaic and fuel cells connected, and the consumer produce more energy than it utilize [3][10].

AC is preferred when small amounts of energy are transported in transmission lines because the capacitive losses are acceptable in long cables. With increased amount of energy in long cables DC is considered as an effective solution instead of AC, because; with increased amount of energy, capacitive losses are decreased, even though inverters has to be installed in both ends of the cable [10].

In earlier studies calculations on cable losses in AC and DC systems has been performed. In [14] it is concluded that; "when comparing the current in the DC system with the single-phase AC feeder, and they both deliver the same active power, the current is lower in the DC case". This can be seen from Ohms law and the relation [15]:

$$|P| = |U| \cdot |I| \tag{2.2.2}$$

It is possible to draw the conclusion that reduced current would give reduced losses, as in the DC case. However, in the three-phase case for power factor higher than 0.57, the losses is higher in the DC network than in the AC network, due to the transmission of the same amount of power in two lines instead of three, this could be changed with increased voltage [14].

Further on in [14], it has been detected losses in the AC system due to transformation between various voltage levels, and in DC systems, switching and conduction losses occur in the AC-DC-conversion by the voltage source controller and losses appear due to the DC-DC conversion between different voltage levels.

LVDC has some advantages compared to the existing AC distribution system, in that it is more reliable, the electromagnetic compatibility (EMC) is improved, and the opportunity of storing energy in battery blocks [4].

Table 1: Represents challenges related to supplying AC or DC power [16][17].

<table>
<tr><th colspan="2">Challenges related to supplying</th></tr>
<tr><th>AC</th><th>DC</th></tr>
<tr><td colspan="2">Frequency problems, affect the quality of the supplied power and possibly equipment performance.</td></tr>
<tr><td colspan="2">Harmonics, effects of distortion in the supplied voltage can disturb the operation of sensitive devices, such as; regulation devices (temperature), computer hardware, and control & monitoring devices (protection devices).</td></tr>
<tr><td>RMS voltage challenges, difference in RMS and instantaneous power</td><td>Slow and rapid voltage fluctuations</td></tr>
<tr><td colspan="2">Voltage variations, affect the quality of power and can introduce flicker problems.</td></tr>
<tr><td>The waveform, and problems connected with reactive power</td><td></td></tr>
</table>

In existing AC systems, the supplied current to installations in domestic and commercial buildings will normally have a current level of $I_n < 1kA$. In industrial processes, where there exist some DC systems, for example in smelting plants, where they manufacture metals, the supplied power is equivalent to several tens of kA [18]. DC is also widely used in control systems for power supply. Siemens for example, have control systems applicable to DC with voltage levels from 48 V and up to 220 V DC. DC supply systems require other types of equipment than AC supply systems to ensure safe operation of the system; miniature circuit breakers (MCB) and contractors need to replace automatic breakers that no longer fulfil its purpose [18].

The reason for choosing DC power in control systems is the advantages it has compared to the problems associated with AC power in this type of system. With 50 Hz AC power, problems with the capacitance and reactive part, delays the inductor in the control circuit. By having a DC power supply system, no capacitance problems exist and it is therefore benefitual to apply DC power in this case. The motor technique that moves the switch in control systems is also DC compatible. The disadvantage with applying DC to control systems is the non-existence of natural zero crossing, to be able to break the power, DC-DC contactors are applied. DC-DC contactors are more expensive and the volume of the component is increased, compared to AC automatic breakers [18].

3 Background for Considering an LVDC System with One Voltage Level

The reason for looking at the possibility of introducing an LVDC system, are the possibilities such a system offers in terms of direct use of energy to DC loads such as:

- Lighting (LED)
- Phone chargers
- Televisions
- IT equipment
- Network equipment
- Servers
- Batteries
- Large number of electric motors

In this equipment, losses are occurring due to the AC-DC conversion in the power converters and it produces high heat losses during operation and in stand-by mode, with power supplied from the existing AC system. The idea is to try to reduce these losses by applying DC power directly to the end use equipment.

The power required for LVDC loads vary with the activity when using the equipment. In a computer for example, the supplied 230 V AC is converted to mainly 5 and 12 V DC. It is therefore evident that a power supply unit (PSU) for a computer that is rated at 650 W, does not utilize power of 650 W all the time. The PSU of the computer only draws the power required when the computer is working, and the computer does therefore not require 650 W constantly. The 650 W is therefore not necessarily the power that the computer utilizes, but it is the maximum power the charger can deliver [19]. This is represented in Figure 1 below, which contains measurements performed in [19].

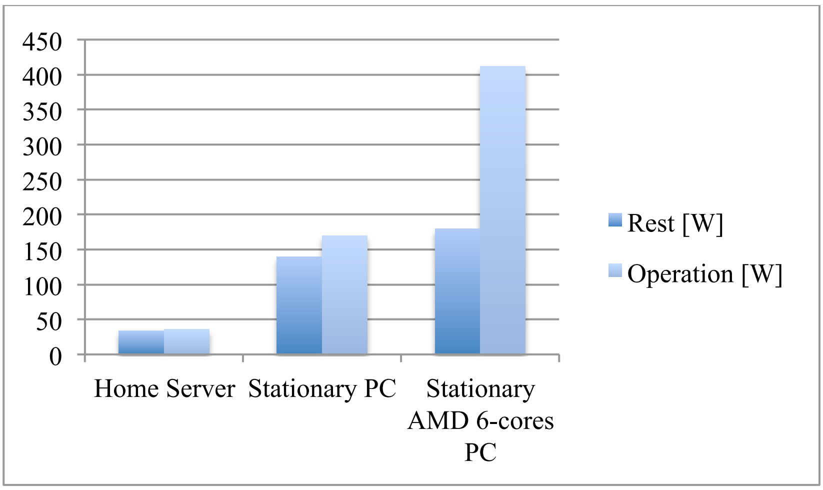


Figure 1: The diagram represents power [W] utilized in appliances at rest and in operation [19].

It is convenient to look into having an LVDC network because the end use equipment are mainly low voltage components and does not represent high power loads. An LVDC distribution system is effective mainly for DC equipment, which does not depend on large effects provided. A low voltage system is defined by the European Union directive 2006/95/EC to be [20]: “DC voltages between 75-1500 V DC and AC voltages between 50-1000 V AC”.

Some of the end use equipment such as:

- Induction heaters
- Different washing machines
- Refrigerators
- Microwave ovens
- Electrical heaters

represent large loads and require high power delivered to be effective. When it comes to these loads, it would be more efficient to keep the connection to the existing AC distribution system, than an LVDC distribution system [11][21]. This is because an LVDC system would have problems with delivering power in that ranges effectively. An example of this, is connecting a stove to an LVDC system, where this solution results in higher energy losses in the feeder cable due to the high current, compared to the existing AC solution applied today [6]. DC motors exist and can replace the motors in some of the mentioned equipment, but due to the increased costs of replacing an AC motor with a DC motor, AC compatible apparatus is still the leading one on the market. DC motors are produced differently than AC motors and this technique increases the production cost of the DC motors. AC also has three phases, which can be effectively utilized when producing power [18].

In the existing AC supply system only one set of cables is needed. With the development of a separate AC and DC system, it would be necessary to have another set of cables, which complicates the system solution. It would be costly to install this system in existing buildings, as the DC distribution system would represent an increased cost, but it might be earned with the energy effective system solution it represents over time. However, earlier studies conclude that the same cables can be used in an DC system, as in the AC system, (with some restrictions to the cable length to be efficient), and might not introduce an increased cost [14]. Moreover, in new buildings, the DC system would not represent an increased investment costs, as the same amount of cables as in the existing AC distribution case is needed.

When having a separated DC system, it could be an idea to have different voltage levels in the system for different equipment, as a 5 V, 12 V and 24 V DC system. However, this have been proven to not be efficient, as the DC power reduces significantly with increased cable length, and with very low voltage levels, this would represent high losses. It could therefore be more efficient to supply a standard voltage level in the LVDC system and to have regulators in the end use equipment that control the required DC voltage for the application [22].

In [22] the efficiency of a DC-DC converter has been calculated to be 95 % and for a AC-DC converter the efficiency has been calculated to 90 %, it has further on been performed calculations which shows that an appliance with an DC-DC converter has an efficiency of 95 %, while an appliance with AC-DC converter has an efficiency of 85 %. These results represent one of the potential benefits and energy saving potentials an LVDC distribution system could gain compared to the existing AC distribution system.

4 Requirements for Low Voltage Installations

In Norway, the standard distribution system has a voltage level of 230 V AC three-phase with a frequency of 50 Hz [10]. This voltage level is regulated in the equipment in buildings to fit the voltage level necessary [11].

AC current and voltage are constantly changing direction, with a frequency of 50 Hz, this means that the voltage and current are changing direction 50 times per second, which complicates the technical level of AC [3]. For example, this results in a lamp that is connected to the distribution grid is turned on/off 100 times per second. The human eye has the ability to accumulate individual repeat-flash and summing all, as long as the dark intervals are not too long. This is the effect that makes it possible to look at a screen, and the image on the screen is perceived as a constant slide, and not a series of flickering frames [23]. *The Flicker fusion frequency* or the *Critical fusion frequency* is defined in [23] to be: “The number of flashes per. seconds needed for appearance of flickering shall cease and be replaced by a continuous visual images”. Humans are able to see 50 Hz, and cannot normally see 100 Hz, the *Critical fusion frequency* ≈ 60 Hz [24].

The last couple of years some key standards concerning DC distribution have been developed. ETSI (European Telecom Standards Institute) has developed a standard that has been submitted for approval. This standard concerns the requirements for the interface between telecommunication or data communication equipment and its power supply. The standard voltage range for these systems at the supply terminal is defined to be [1][25]:

- Minimum 260 V DC
- Maximum 400 V DC

The normal operating voltage is stated in [1] to be 354 V and 380 V, and the reference voltage is defined at:

$$U_T = \quad 265 \pm 15\, V \tag{4.1}$$

It is further on described in [1] that the PSU may be exposed to a interim variation in voltage within a range of 260 V - 400 V caused by boost charging, fault clearing, battery operation and voltage sags. However, the equipment will receive well regulated voltage ($380\, V\, DC\ \pm 1\,\%\ or\ 350\, V\, DC\ \pm 1\,\%$) [1].

Even though the requirements in the standard in [1] do not apply to installations in buildings directly, the requirements give some incentives, to where the voltage range should be defined for a DC distribution system supplying end load DC equipment in buildings.

In current regulations, the safety requirements for AC and DC distribution systems are equal. This implies that an LVDC distribution system must achieve the high safety standard that is required for AC distribution systems. In the Norwegian regulation applicable for low voltage electrical installations [2], the requirements for protection and protective measurement to ensure safe operation of the electrical distribution system is stated. Further on in [2], it is referred to a standard collection, *The Electrotechnical Standard Collection*, applicable in Norway [26]. The standard is constructed on the basis of international standards from IEC and CENELEC and the IEC 60364 series, and does not contain much regulations and guidelines relevant for DC systems, except for HVDC energy transmission. This shows that LVDC distribution systems are an area that is not included in the world standards yet. There is on-going work at this area, as IEC include several committees working on topics adjacent to LVDC systems, such as *Power Electronics for Electrical Transmission and Distribution System* and *Grid Integration of Large-capacity Renewable Energy (RE) Generation* [2][26][27].

Even though, there does not exist any standards that directly applies for a DC system in buildings, there exist regulations on *Electrolysis plant with operating voltage between 50 V DC and 1500 V DC, and with an output performance exceeding 500 kW* in [26], IEC 400-8-815. It is specified in [26] IEC 400-8-815.410.3.3: "For electrical equipment installed or used in a work zone, must be electrical isolated in accordance with IEC-400-4-41". These regulations set the focus on, that one does not come apart the galvanic separation that currently exists in converters.

The reason for not having standards regulating LVDC distribution systems with separate policy, is because an LVDC system has not been considered as an effective and appropriate system solution, except in some industrial processes, until now. This development has close relations to the expansion of Distributed Generator Sources (DGS), and the possibility of direct exploitation of DC [27].

Traditionally, consumer has been consumer, but a change is about to happen in terms of this. With the invention and development of DGS, it is now relevant to talk about prosumer, which consist of a producer and consumer, as the consumer will provide the network with surplus energy from its own distribution system. The Norwegian Electro Technical Comity has developed a strategy based on this [27].

Further on, the work has started globally to develop standards for the future energy grid. IEC is one of three organisations that are working with developing standards, globally. They are focusing on wind energy, intelligent control systems of power, Smart Meters and control of loads through their program *Road map for Smart Grid*. The European Union (EU) has set a mandate to promote focus on Smart Grid, Smart Meters and the Electrical Vehicle (EV). So hopefully some standards regarding LVDC distribution systems will be included in near future standards [28].

As an example of the development of standards for equipment applicable to DC, there has been developed a new USB-standard, USB PD (Power Delivery) that will be able to deliver 100 W DC, from 2014. A USB connection could be used for energy and data transmission. Until today, USB-devices have only been able to deliver 2.5 W and 4.5 W by USB 2.0 and USB 3.0 respectively. This invention will make it possible to deliver energy to all of the desktop equipment from one USB device. This development would in theory result in a computer being the only equipment that would need traditional connection to the AC distribution system with the current rectifier setup. Schneider Electric is positive to the invention but points out the doubt of the application going beyond the desktop, and mentions the development and popularity of having wireless devices [29].

A pioneering example is the development in the United States, where there has been promoted a 380 V DC standard applicable for data centres and commercial buildings by The Emerge Alliance. They have also established a standard for 24 V DC ceiling circuits resulting in a reduction of 15 % less energy consumed with having LED lighting connected with DC lines, than converting AC-DC [30]. In this case, there are developed a separate efficient system for lighting equipment at a voltage level of 24 V, in contrast to the result in [22], where it is concluded that it is not efficient with a DC system at a voltage level of 24 V supplying DC equipment. Furthermore, it is on-going work in Emerge to install DC power to desktops, avoiding the conversion from AC-DC when connecting office equipment [30].

4.1 Classification of Voltage Classes and Distribution Requirements

In Norway, *Regulations on Low Voltage Electrical Installations* (*Forskrift om Elektriske Lavspenningsanlegg*) has guidance to § 10 in reference to *the Norwegian Electrotechnical Norm* (*Norsk Elektroteknisk Norm),* which describes the following voltage values for AC in the range from 100 – 1000 V [2][26][31]:

Table 2: Presents the standard voltage level for AC systems [26].

230 V	230/400 V	400/690 V	1000 V

With two values specified, for example 230/400 V, it indicates that the line voltage is 400 V, while the neutral line is available and the phase voltage is 230 V. When there is only specified one value, for example 230 V, it means that only the line voltage is available and no neutral line [26][31].

IT-topology is used for purposes where the nominal voltage has a value up to 690 V AC in Norway, while the most widely used voltage level are 230 V AC [26][31]. The low-voltage distribution system transports the electrical energy from the distribution transformer to the end use equipment [31]. An IT-system is defined in *the Norwegian Electro Technical Commission* [26]: "IT-system, all live parts isolated from earth, or a point earthed through an impedance. Exposed parts of the installation are grounded separately or public, or to the system ground in accordance with Section 411.6 in IEC 400-4-41". However, in the majority of new commercial buildings the distribution system installed is TN-topology. A TN-topology is defined in The Norwegian Electro Technical Commission [26]: "TN-system has one point directly earthed at the power source and the exposed conductive parts connected to that point by protective conductors".

The most critical step of developing a DC distribution system is selecting the voltage level [25]. In [32] a part of the distribution system of the Department of Electric Power Engineering at Chalmers University of Technology (Gothenburg-Sweden) is evaluated in terms of supplying DC power. The limitation of the system is the impedance that is included in the system, which represents 20 m of 70 mm^2 three-phase cable between the substation transformer and the switch gear, with a requirement on the maximum allowed current 145 A and impedance 443 + j70 $\frac{\Omega}{m}$ at 20 ℃ [32].

The evaluation of different system voltage levels in a DC supply system is considered as part of the study [32]:

- **48 V DC:** A voltage level lower than 50 V is considered inherently safe. Therefore, a system of 48 V DC does not have any requirements on protection against direct contacts; that is contacts with live parts.
- **120 V DC:** With a voltage level of 120 V, it is possible to have a simple system as no protection or grounding arrangement is required against indirect contacts; that is contacts with exposed-conductive parts, which has become live under fault conditions.
- **230 V DC:** A voltage level of 230 V DC is equivalent to the RMS value of 230 V AC. This voltage level could therefore be applied to resistance equipment, such as heating and incandescent lighting, without changes.
- **326 V DC:** With a voltage level of 326 V DC applied, some modifications in the equipment must be made. In many of the electronic devices, there is an input diode rectifier, which gives the peak value of the 230 V AC voltages, equivalent to 326 V DC. With a standard voltage level of 326 V DC, these appliances could be used with some modifications; remove the input rectifier. The same cables could be applied, as the insulation should resist this voltage level.

A voltage level of 48 V DC has been applied to telecommunication equipment earlier. Therefore, devices applicable to 48 V DC exist on the market. These devices are expensive, due to high reliability requirements [21][32].

The results in [32] demonstrate that with a voltage level of 48 V DC, the power losses is too high for this voltage level to be considered as an effective solution compared to the existing 230 V AC system and the current exceeds the tolerated value of 145 A. The maximum voltage drop conditions limit the maximum current already at a cable length of 80 m, as represented in Figure 2.

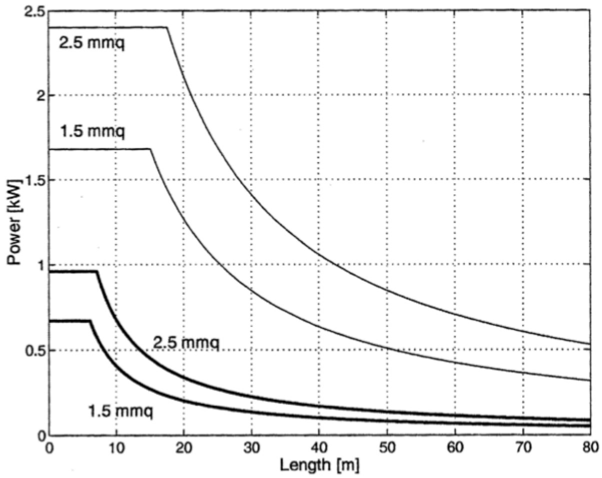


Figure 2: Represents the maximum power versus length for cables with cross section 1.5 and 2.5 mm^2 at rated voltage 120 V DC (thin line) and at 48 V DC (thick line) [32].

Therefore, it can be concluded that a voltage level of 48 V DC is not an effective voltage level for this application. DC systems for lower voltage levels are only used to limited extent, as traction systems and on board of ships [7][14].

The results in [32] regarding voltage levels of 120, 230 and 326 V DC demonstrates the possibility of using the same cables in the case of AC and DC systems. It also presents the results when measuring the current and voltage drop at these levels, and concluding that the limits is not exceeded except in some specific cases.

With a voltage level of 230 V DC, the power losses are measured to be lower than for 230 V AC, with exception of three-phase loads. This decrease is due to the increase in reactive power and decrease in power factor in the AC case [32].

In [32] it is observed that the voltage drop restriction may be a less constraining factor than the maximum current condition, depending on the voltage level and the cable length. Further on, the results in [32] indicate that the maximum power at 120 V DC is quite high, but the power delivered decreases fast with increased cable length. However, a standard voltage level of 230 V DC is proven to be sufficient for normal office loads, as long as the cable does not exceed 80 m, and for higher power loads up to 6.5 kW the voltage level has to be exceeded to 326 V DC for systems with a cable length of maximum 47 m and 2.5 mm^2 [32].

From these case study results, it is possible to conclude that for an LVDC system with one standard voltage level, it might be sufficient to supply 230 V DC as long as the existing AC distribution network supplies the loads that is dependent of higher power levels than normal office loads.

In [9] it is presented that an LVDC distribution system has increased transmission capacity compared to the existing AC distribution system, and it has the property of transmitting larger amount of power in cables with reduced cable-cross sections compared to the AC case. But, the effectiveness of transmission of DC in cables is largely dependent on the applied voltage level [9][32].

A low voltage distribution network that is applicable to DC power has to fulfil the same requirements and purpose as of the existing AC distribution system with respect to: standardization, maintenance and lifetime issues, and the environmental considerations [9].

It is specified in the European Union standard that the maximum supply limit for AC-DC converters are 1000 V AC and this also applies to LVDC networks [9].

4.2 Quality of Supply in DC Distribution Network

It is not defined much about DC systems in existing standards, but it is still expected to be supplied the same quality of power with a DC distribution system, as for the existing AC distribution system [27].

In a DC distribution system, the idea is to convert AC power from the main grid, to DC power to be supplied in the distribution network. The large challenge with having a DC system seems to be the AC-DC converter. If an advanced AC-DC converter was applied, that could transform the supplied AC voltage into a stabile DC voltage without transferring problems from the AC side to the DC side, the DC power would be applicable to a lot of equipment with significant reduction in power quality issues. According to [33]: “The voltage is considered stable when it does not change faster than 0.5 % of the agreed voltage level per second”.

The AC-DC converter needs to handle a variation in supplied voltage from + 10 % to – 15 %. With a converter at this standard, it would be possible to have a system that is less sensitive to voltage fluctuations, the RMS value, deviations in frequency and waveform. If the AC-DC converter were advanced to handle 50 % voltage drop in the system for 1/10 second, the system would be almost immune to frequency variations. The system would then be more resistant to voltage dips caused by short circuits in the network, automatic reclosures and connection of large loads (motors) in the distribution system. In Norway, voltage dips together with interruption are the disturbances causing the greatest overall economic loss to customers in the power grid [16][33].

A benefit with an advanced converter with these requirements of quality of supply is the reductions in immunity qualifications in apparatuses and electronic devices. Other advantages would be less damage on electrical equipment, increased lifetime, less malfunction and tripping incidents, and stable lighting output and power, due to the increased stability of the voltage supplied to the equipment. This indirectly reduces the fire hazard and increases the safety of the system. It is essential to value the importance of a great advanced AC-DC converter, to be able to gain an efficient and stable DC supply system [16][33].

In [34] three different circuit schemes have been proposed for realizing the conversion between the AC network and the local DC grid, and it has been concluded that an interface with an forced commutated inverter for the stabilization of the DC bus voltage, improvement of absorbed current waveform and the possibility to feed loads with two voltage levels, obtained the best results. This topology also have the opportunity of bidirectional power flow, this allows connected renewable power sources to be utilized efficiently by supplying power to the grid, in low demand periods in the LVDC system. It is further on stated that there is still work to be done and developments that needs to be made, before this is an optimal solution [34].

In the existing rectifier technology available today, the electronics is not good enough, therefore interference from the AC side will be transferred to the DC side in the rectifier process. Interference due to harmonics for example will be transformed from the AC side to the DC side, and a stabile power supply without disturbance will not be gained. Consequently, electronics in the rectifiers need to be improved, to be able to supply AC power from the grid and eventually DGS [18].

In [25] a study concerning AC distribution versus DC distribution performed by NTT Facilities has been described. The study views the benefits of AC distribution versus DC distribution with system reliability, see Figure 3.

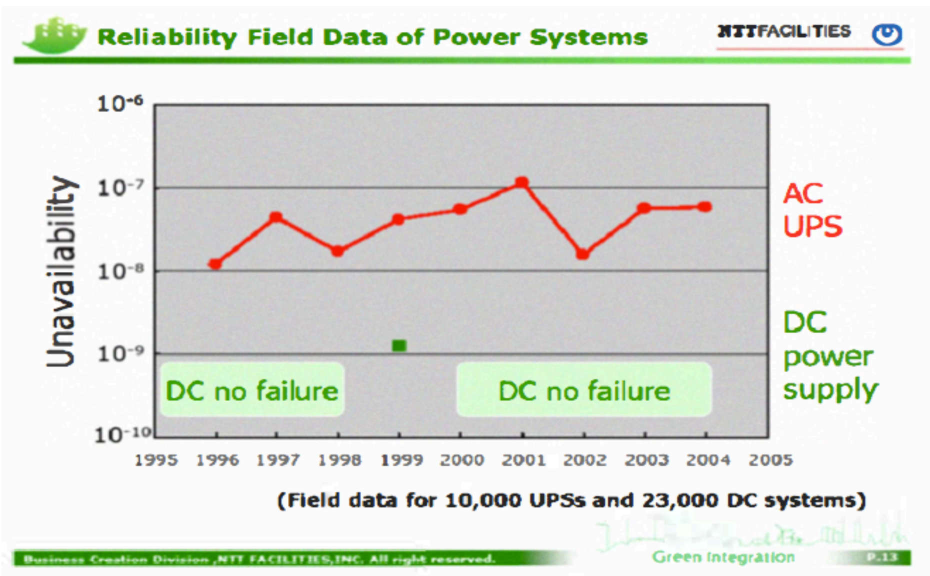


Figure 3: Describes system reliability in AC versus DC distribution system [8].

From Figure 3, it is therefore relevant to predict that an LVDC system could have a great impact on lighting, variable speed drives and Electrical Vehicle (EV) charging, due to the increased reliability. In the case of charging an EV with AC, it is required heavily large volume and expensive devices in the EV, with DC it could be directly charged [4][28].

Flicker in lighting is an example of the impact of bad quality of supply in the existing AC distribution network, which is a common and widespread problem. Flicker is defined in [35]: ”Impression of unsteadiness of visual sensation induced by a lighting stimulus whose luminance or spectral distribution fluctuates with time”. Flicker occurs due to variation in the supplied voltage level because of rapid load changes [33].

LED lighting equipment is applicable to DC power, and most of the LED equipment that exist today, consist of power electronics that transform the supplied AC power to DC power. The installed power electronics in devices are mainly poor, and not good enough to create a stable DC curve in the transformation. The result from the transformation is therefore often flickering in lighting devices. With an advanced converter that would be able to stabilize the converted DC power, it would reduce the number of problems connected to flickering [16].

5 Evaluating the Safety Aspects of a Supply System

In electrical distribution systems there are mainly two elements of risk, the danger of electric shock (current flow in a harmful level) and high temperatures that can cause fire, burns and other harmful effects [31].

The regulations and standards that applies for protection of electrical systems, mainly concerns the protection of humans and animals against injuries caused by dangerous current through the body, and the fire hazard and damage to buildings and other properties [31].

The safety aspect is maintained in electrical systems by the use of materials and equipment approved for the purpose and intended use. Besides personal safety and fire safety, reliability for the plant also need to be considered when dimensioning an installation [31].

5.1 Safety Aspects of a DC Supply System

An LVDC distribution system is a simpler system compared to the existing AC distribution system because of the reduction of AC-DC converters. This reduces the number of links and potential fault elements in the system. In today's AC distribution system, these converters represent heat losses that increase the fire risk of the system [9]. Further on, this simplification result in saved component costs, reduction of power conversion stages, increased system efficiency, and gives a less complex system compared to the existing system [7][11].

However, the LVDC system still has to have the DC-DC regulators that transform the applied power to the appropriate voltage level for the specific application. These regulators will represent fire hazards in the same way as for the AC system, but if a voltage level is chosen so that the supplied voltage level are consistent with some of the equipment, the DC-DC regulator will in principle be redundant. Nevertheless, the galvanic separation that is included in the regulator is still necessary, in order to obtain a safe system.

The protection of a low voltage DC network is a complex concept, as the DC supply system has to be compatible with the existing protection system for the AC network systems. A technical solution to this challenge is presented in [9], where it is proposed that the inverters short circuit current capability needs to fulfil utilized circuit breakers or fuse current requirements. This could be gained by over dimension the converter switch design [9].

ABB has started developing breakers and switches solutions applicable for LVDC applications [36]. Conventional automatic fuses can be applied at a voltage level up to 60 V DC and double pole automatic fuses up to 110 V DC. There also exist separate series of circuit breakers applicable up to 440 V DC. Ground fault circuit breakers can not be applied in a DC system. However, circuit breakers can be applied if they consist of thermal magnetic protection [37][38].

At present, it is not specified requirements for separate cables only applicable to DC in the existing standards. In [39] the results indicate that it will be benefitual to design specific cables only for DC application in the future.

6 Technical Challenges with an LVDC System

Today, AC power is supplied from the grid into the distribution system, where a rectifier before the equipment converts AC power to DC power because most of the consumer electronics used in domestic and commercial buildings, are equipment applicable to low voltage DC. These devices normally have an input transformer and a rectifier to transform and regulate the supplied power to the proper DC voltage level. Equipment comprising such components will produce losses during operation and are also representing losses when it is plugged in and in stand-by mode. This is due to the open-circuit current that is produced in the transformer, when the equipment is not utilized. In theory it would be possible to remove the input transformer and rectifier from the equipment and introducing a voltage regulator that would reduce these losses, and further efficient operation is gained when a proper voltage level is chosen and DC power applied directly [14][32]. It is described in [14] that: “In newer electronic equipment the single rectifier is supplied directly from the AC system and followed by a DC-DC regulator”. This makes it possible to reduce the conversion by one step if directly applying DC current.

Recent years IT equipment usually has a Power Supply Unit (PSU) converting the delivered AC power to an appropriate DC voltage level for the application, typically 12 V. Modifications to the PSUs represents an opportunity for advancement in efficiency. However, the study in [40] represents AC systems with an efficiency value of above 92 %, and also provides information on AC systems shipping in 2012, reaching efficiencies of 95 %. This results in only a hypothetical 5 % for a DC system being more advantageous at an efficiency of 100 % [40].

With the development of a separate DC system some reductions in components in the PSU can be obtained.

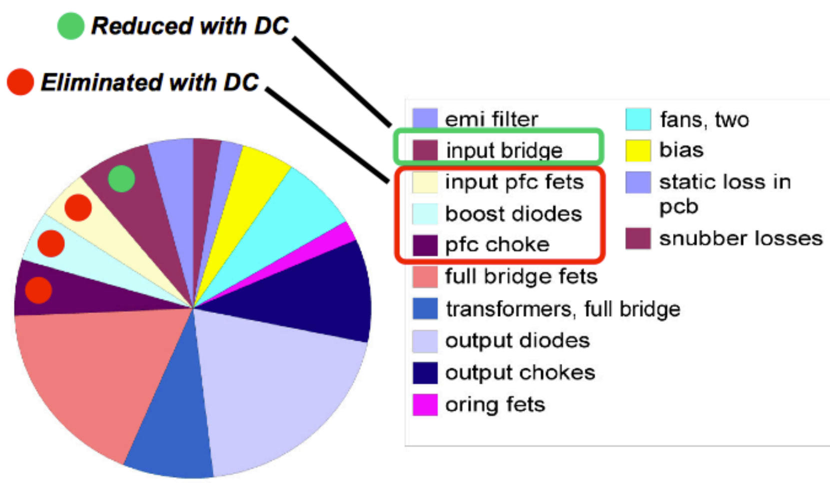


Figure 4: Represents the PSU separated into components, and which components the PSU is dependent on in terms of AC or DC supply [40[41].

In Figure 4, the items marked *Eliminated with DC* are component parts, which represent losses, that can be eliminated in a PSU supplied by DC, while the items marked *Reduced with DC* are component that still, to a certain extent, is required when converting to DC supply. This is to be able to maintain the standard requirements in terms of contact voltage. The galvanic separation in the PSU needs to be retained, or replaced with corresponding isolation having the same distinction. However, the losses represented by the components that can only be partly reduced, might represent a reduction of losses by half [40].

While, in electronic equipment such as heaters, there has not conventionally been integrated a transformer, and the equipment has been connected directly to the grid. However, in equipment such as radios, televisions, stereos, and computers, there has traditionally been integrated DC power supply. In this integrated solution, some of the equipment has a 50 Hz transformer, which provides a voltage adjustment from 230 V AC from the main grid to small voltage levels before rectification and DC regulation. This has particularly been the case for old equipment. In modern and new equipment such as computers, it is often used switched power supply working with a high-frequency transformer as part of the DC-DC regulator. This solution is chosen, because the 50 Hz transformers are heavy and expensive, and it is possible to save volume, costs and weight with this solution. The switched solution is also chosen to minimize energy loss compared to linear power supply [11][42].

The reason for integration of the electronics is not only the transformation of voltage for a particular application, but the integration is also for safety reasons. This is because, in electrical equipment a galvanic separation is required in order to safeguard existing security conditions in order for the equipment to be safe for humans and animals in contact with live parts.

In the case of an LVDC distribution system, where a standard voltage level is chosen, which in theory could be applied directly to equipment. The transformer, rectifier and in principle, the DC-DC regulator could be removed to reduce the losses. The DC-DC regulator represent a galvanic separation, and if it is removed, equivalent isolation then has to be integrated in the component in a way so the equipment fulfils the same safety requirements and replaces the safety function of the transformer. It might be possible to gain higher efficiency and reduce losses in this way, but it is not certain that the volume of the component would be any less than with today's solution.

With a separated DC system in addition to the existing AC system in buildings, it would be energy efficient to define a standard voltage level for the system and regulators, and adjust the voltage level in the equipment as in the existing AC distribution system. It is possible to imagine the case that:

- In some equipment, the voltage could be applied directly (but it is necessary with sufficient isolation in order to satisfy the safety requirements)

- In other low voltage equipment, a transformer and a DC-DC regulator might be necessary to gain the appropriate voltage level for the specific application

- The equipment that is dependent on high power delivered to fulfil its purpose, could keep the connection to the existing AC distribution grid

There have been performed studies earlier presenting the effectiveness of introducing a separate DC topology and supplying DC power directly. It is also conceivable that future apparatus for DC supply can be forced on the market by using standards, in that manufacturers will have to deal with the most energy efficient constructed equipment, if this proves to be DC.

With the development of technical apparatuses and the great use of electronic equipment in homes today, it is realistic to think that various DC facilities will be introduced on the market in the future.

7 Proposed System Solution

When introducing an LVDC system, it is important to evaluate the appropriate level of advance of the system solution and what level of advance will fit the purpose of the system.

In this project the main objective has been to look into the opportunities with having a simple LVDC system in addition to the existing AC system solution in buildings. The DC system is hypothetically intended to be supplied AC power from the main grid that is transformed to DC by a central advanced rectifier. The LVDC system has one standard voltage level that supplies all the equipment. Due to safety regulations, all the connected DC equipment needs to have a galvanic separation in the PSU, and DC-DC regulators is therefore integrated to obtain the safety requirements and to gain the correct voltage level of the specific load. The loads connected to this kind of system could be apparatuses such as computers, lighting system (LED) and different charging devices. The ideas is that valuable energy would be utilized instead of disappearing as heat loss in converters, and the system topology would be simplified.

If having an LVDC system reveals to be a good solution, the concept could be expanded to include substitution of Uninterruptible Power Source (UPS) with energy stored in rechargeable devices (a battery-block) and integrated DGS, such as wind and photovoltaic connected to the system topology, as they generate DC power directly [7][32].

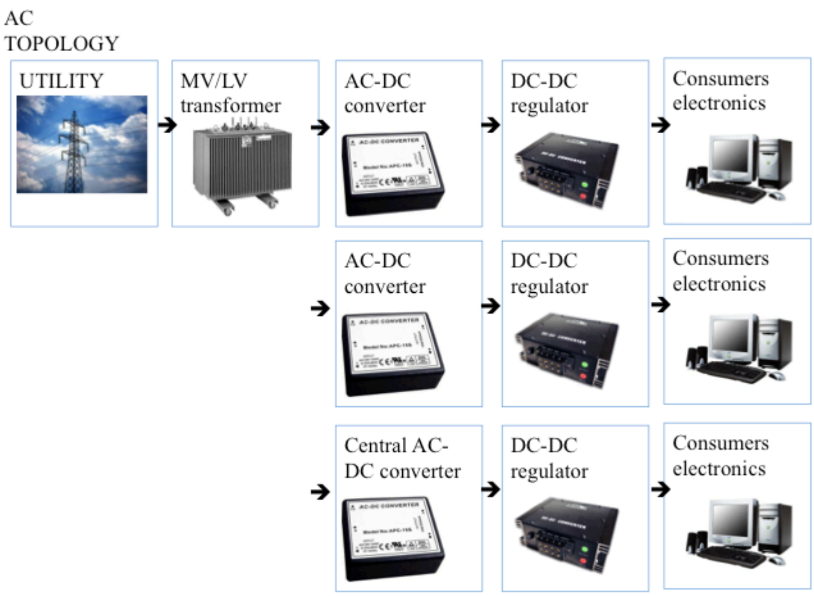


Figure 5: Illustration of the existing AC system solution [43]-[46].

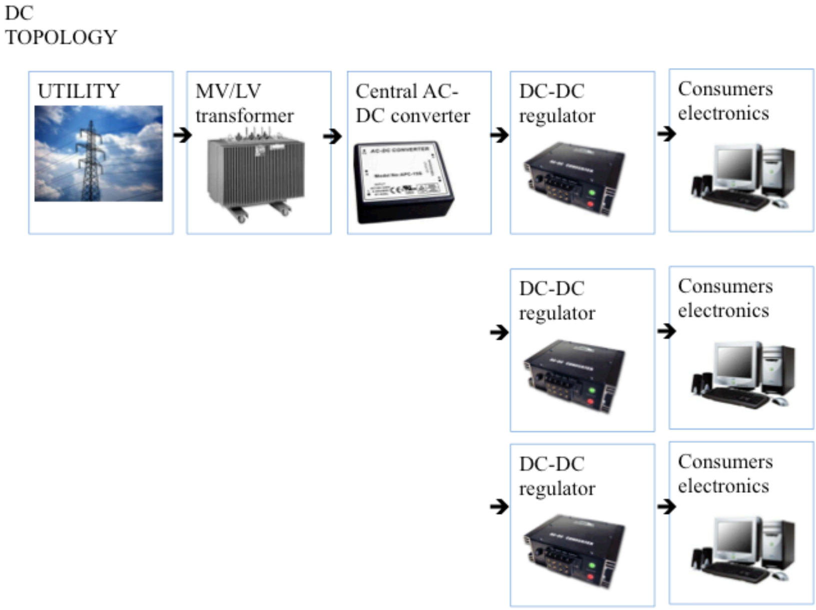


Figure 6: Schematic illustration of the proposed DC system solution [43]-[46].

When comparing Figure 5 and 6, it can be seen that the converters in front of each component in Figure 5 is replaced with one central converter to convert AC-DC in Figure 6. The DC-DC regulators would still be integrated in the equipment in order to sustain the same safety level.

7.1 General Characteristics of an LV Distribution Network

There are numerous different electrical loads, and the power required for each appliance varies accordingly. In an engineering phase, the connected loads affect the system dimensions. Thoroughly evaluations are performed in each phase of designing the electrical system in a building, in order to dimension the system correctly in terms of load analysis and the planned installed capacity.

Recently, the question of having an LVDC system in addition to the existing AC supply system has been raised, as the electrical loads also differ in whether they are DC or AC compatible loads, originally. Today, the standard is to supply AC power and to convert it to DC in case of a DC applicable load.

The energy demand in a commercial and residential building varies with the circadian rhythm of the working environment, in addition to the topology and weather condition in the vicinity.

Today, buildings are rehabilitated through the years. The modern installations have different structure than earlier, which affects the planning in designing the electrical structure of a building. Various companies have different needs in terms of energy and power delivered for the electrical system, which complicates the system solution when it comes to energy savings in the electrical system topology in a building. Further more, the uncertainty in the purpose of the building for later use (10-20 years) and the demand of energy in the building. It is therefore of vital importance to design an electrical system with flexible solutions to some extent, to be able to meet the needs for future utilization of the building and possible extensions of electrical loads in time. This is something that would be important to consider if introduction of a new system solution concept is appropriate.

For buildings, it is desirable to apply the most general guidelines for the distribution system structure, to make the system flexible and adaptable for different floor plans, since a buildings purpose and essential properties changes over time [31].

There are several factors that affect the design of the system topology in a building [31]:

- The location, type and size of the load
- The external power supply: voltage and feed point
- Potential internal power sources
- The building's design, size and available infrastructure routes

Traditionally, the distribution structure is designed in a hierarchical structure with electrical distribution at different levels, from a technical-economic and control technical criteria, see Figure 7. It is not unusual to combine different system topologies in the same supply network to gain an efficient system solution. The topology of a LV distribution grid mainly have radial structure, where the only protection encountered typically are simple overcurrent devices, most commonly fuses [31][47].

The division of distribution cables to the different loads varies with the aim of the building. In residential buildings, the division is mainly topographical, while it is affected by the type of the load to a greater extent in commercial buildings. This simplifies the task of any changes to the system retrospectively.

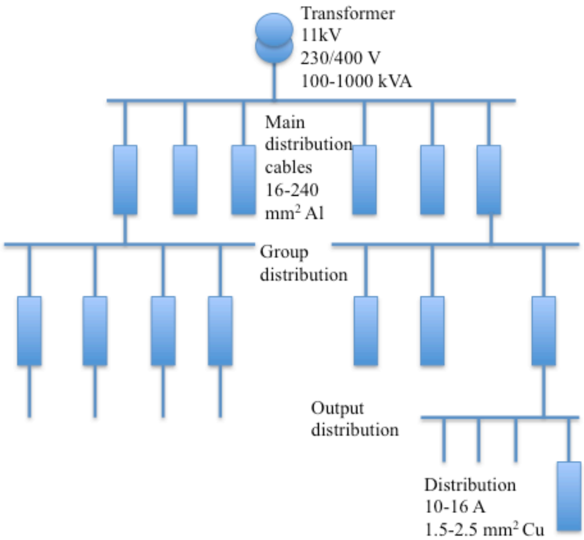


Figure 7: Schematically represents the existing AC distribution system [31].

7.2 New Proposed System Solution

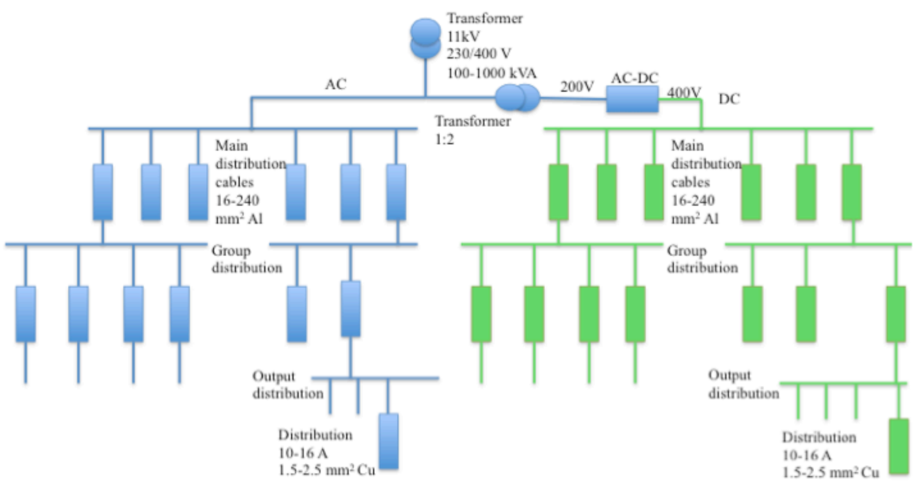


Figure 8: Schematically represents the new proposed system solution with an additional DC system supplying the original DC loads.

Figure 8 represents the new system solution proposed in this study, with an additional DC system supplying the original DC loads. The idea behind this system, with having a main central for AC-DC conversion, an Energy Control Centre (ECC), is to have a main control board that interconnects the AC utility grid to the DC system. With a centralized point of conversion, it is possible to ensure efficient transmission of the generated power [8][48].

The proposed solution in Figure 8 is designed in a way that disturbances could be transported from one voltage level to another through converters, it is proposed in earlier studies that these problems could be avoided by introducing control equipment, such as a Voltage Source Converter (VSC) with an IGBT interface, in combination with high frequency Pulse Width Modulation (PWM). The VSC also has the property of bidirectional power supply. The VSC is able to decouple the DC supply system from the AC grid in order to keep the voltage constant when it is influenced by disturbance, the system would then need a back-up system in order to work as supposed [14]. Introduction of a VSC improves the voltage control, and disturbances as voltage dips and fluctuations can be repaired, so they may be avoided in the operating voltage of the customer [9][14].

Earlier studies performed, have compared the existing AC system solution with system solutions for a DC system. However, none of the earlier studies found during research seemed to have tested the hypothetical system solution proposed in this study.

In this study, it is assumed that all of the loads in the DC system are single phase loads that are compatible with 230 V DC voltage. With these assumptions, it is possible to keep the existing cables as in the traditional system, as they will withstand this voltage level and problems with exceeded rated current in three-phase cables is avoided, because only two conductors are used [14].

The proposed system solutions include benefits such as:

- Reduction of converters, which result in increased system efficiency
- Reduction of components, which result in reduced cost
- Could reduce the power losses of the electrical system in buildings

The IEEE Power and Energy Society, is starting up a project regarding DC in homes, including a business case, use case and a standards and building code review, at the *IEEE PES General Meeting* in Vancouver, July 2014.

8 Theoretical Model of Simulation

In this part, the theoretical model of simulation is presented. The idea for the model is to include simulations on component level to be able to compare the losses in an AC and DC system later in the analysis.

Furthermore, the size of the LVDC system where determined by measurement performed on an example building.

8.1 Theoretical Model of Power Converters

The process of converting AC to DC power is separated into stages on an instantaneous basis by means of elements such as capacitors and inductors, which are capable of energy storage. Each power conversion stage are referred to as a converter [47].

The load connected to a system could be single phase or three phase, and being AC or DC compatible. The flow of power is generally from the utility input to the load output. There are exceptions to the general flow of power, with for example photovoltaic integrated in the utility system, where the power flow is in the opposite direction [47].

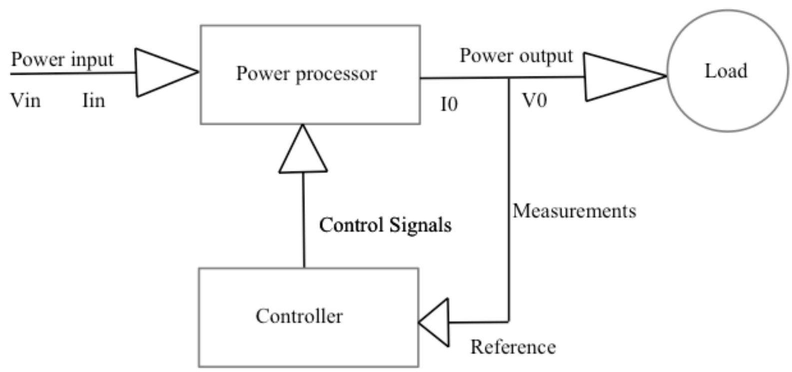


Figure 9: Represents a block diagram of a power electronic system [47].

In this study, AC-DC (a rectifier) and DC-DC converters will be given most weight, because they have the most relevance to the system solution proposed.

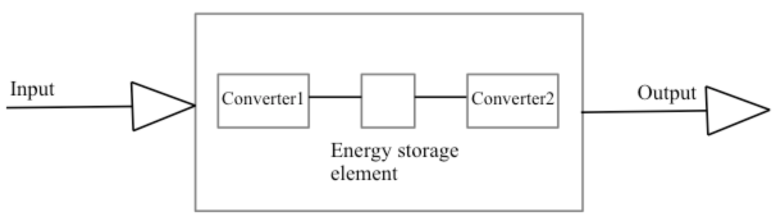


Figure 10: Represents a power processor block diagram [47].

8.2 Preview of Simulation Analysis

The main objective of this study is to outline and analyse a system solution for a specific building. There are still some key aspects that remains to be investigated before it could be drawn a more thoroughly conclusion about an LVDC system being a non-effective or effective distribution concept.

Therefore, the idea is to schematically, by using the simulation tool MATLAB with the toolboxes Simulink and SimPowerSystems, to simulate:

- The existing AC system solution in a building with connected loads, equivalent to the traditional system solution
- A new system solution concept, identical to the above mentioned system in terms of loads connected, but with an separate AC system supplying the high power required load and a separate DC system for low power required load (the loads that originally is applicable to DC), where the LVDC system is supplied converted DC power by a central rectifier at the feed-in from the main grid

The goal is to establish efficiency data in terms of the two different system solutions, by performing calculations that makes it possible to look detailed into energy losses, and the efficiency of the two different system solutions. In addition it would be aimed to try to estimate and calculate the energy loss or saving potential with an LVDC supply system and to look into in what extent of topology it is energy efficient to make use of an LVDC system.

8.3 Load Connected

A baseline load represents the load connected in the buildings system solution, which is typical for these installations. By choosing a baseline load, it is possible to provide this as a reference point in comparing the existing AC system solution, to the new concept of system solution with an additional DC system. This will not constrain the actual model of the building, as the efficiency curve varies with the load [40].

The power consumption is known from the load templates, see Appendix 17.1. For some of the loads, the daily power variation has been deducted from the results of measurements of voltages and currents. Where measurements where not available, an approximation has been made based on the principle of operation.

8.4 Computer Simulation of Power Electronic Converters and Systems

A computer model for simulations are developed during this study instead of using a set up in the laboratory, as it is usually easier to study the influence of specific parameters on the system behaviour in a computer system simulation. It is stated in [47] that; “In power electronics, computer simulation and a proof-of-concept hardware prototype in the laboratory are complementary to each other”.

The idea is to calculate and simulate the circuit waveforms, and steady state performance of the existing and new system solution, and the voltage and current ratings of various components. As the confidence of the simulation was developed, it was extended to simulations to include power loss calculations. For even more detailed measurements and calculations on the losses in the converters, it is possible to follow the methodology developed and used in [49][50].

There are numerous factors that make simulation of power electronics challenging. There are some properties that it is important that the simulation tool hold in order to gain a good simulation analysis and which also affect the difficulty of performing simulations [47]:

- Represent switching of states, as in diodes and thyristors large nonlinearities occur during switching from one state to another, during solid-state switches.
- In a power electronic system, the time constants, or the response time, will vary for different parts within the system. The simulation may therefore take a long time, and require the simulation to proceed with a very small time step to have the resolution to represent the smallest time constants.
- Accurate models are not always available, this is especially for power semiconductor devices and for magnetic components such as inductors and transformers.
- The controller of the device needs to be modelled along with the power converters.
- The simulation time may be long, even if only the steady-state values are of interest, due to unknown values of the initial circuit states at the start of the simulation.

In a computer system solution, there is no point in making the model so complex or “to good” such that the results be overwhelming, thus obscuring the phenomena of interest. Therefore, the best simulation is the simplest simulation that meets the immediate objective [47]. Due to this reasoning, the focus has been to develop a simple model and to look into the main focus areas, and a model that possibly can be expanded in future analysis if the results of a simple analysis result in a positive conclusion.

8.5 The Simulated Building: *Bjerke Upper Secondary School*

Figure 11: Presents *Bjerke Upper Secondary School* after the rehabilitation [51].

In order to have a realistic example of a building that could benefit from having a DC system, a representative building, *Bjerke Upper Secondary School (Bjerke Vidregående Skole)*, was chosen.

Bjerke Upper Secondary School, is a facility at Linderud that was originally built in the period 1964 - 1968, it was later rehabilitated to a modern installation with TN-S supply system in 2013. The school is located in Oslo, and consist of a main building A and B, and a sports hall. The building A consist of three floors and a basement, while building B only consist of two floors. Both of the main buildings (building A and B) involve administration, facilities for the staff, and education/teaching rooms [51].

In this study, the distributions focused on are two different sub distributions, one in each of the main buildings, A and B.

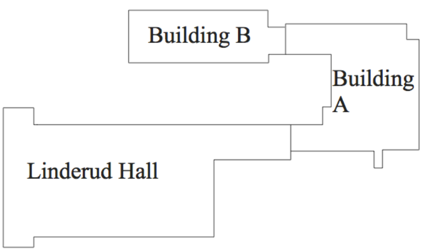


Figure 12: Represents the design of *Bjerke Upper Secondary School* [52].

The electrical installations are provided with ladder cables for each of the floors as follows radial network topology, that is, the cables are dimensioned for the load in the entire block and going all the way to the top of the installation, the distribution for each floor connected on the same cable [31], see Appendix 17.1 for more details on the topology of *Bjerke Upper Secondary School*.

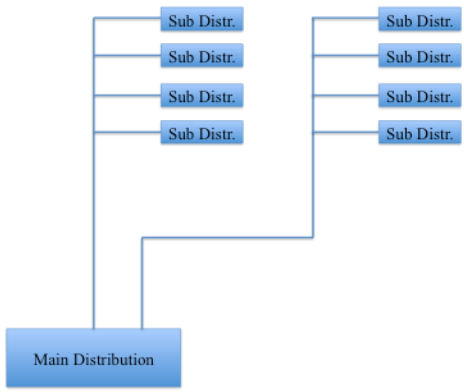


Figure 13: Schematically presents the topology of Radial Distribution System [31].

The electrical distribution system topology chosen at *Bjerke Upper Secondary School*, planned and designed by COWI, is a 230/400 V TN-S topology [52]. With a 230/400 V system, it indicates that the line voltage is 400 V, that is the voltage between two phases, and with 230 V phase voltage, that is the voltage between phase and neutral, while the neutral line is provided in the system [26][31].

Table 3: Represents the setup of the electrical system at *Bjerke Upper Secondary School* [52].

Voltage	230/400 V
Frequency	50 Hz
Distribution system	TN-S
Principal current	400 A
I_{sc} effective value	50 kA
Enclosing	IP2XC

9 Simulation Process

In this part, simulations on component level are presented in order to compare the losses in the AC and DC system later in the analysis.

Moreover, the size of the LVDC system where determined by estimates based on measurement results of an example building.

The simulation tool used was MATLAB, simulation and model-based design program, together with the toolboxes Simulink and SimPowerSystem.

9.1 Model Assumptions

For the simulation model a switching power supply was chosen, where the conversion of DC voltage at one level to another level is accomplished using a DC-DC conversion circuit. This conversion step was developed with solid-state devices, which is either operating in OFF or ON mode, comparable to a switch. These devices result in reduced power losses and increasing energy efficiency to a 70-90 % range compared to a linear power supply, as they are not required to operate in their active region. There are numerous factors that has affected the choice of having a switched power supply [53]:

- Increased switching speed
- Higher voltage and current ratings
- Lower cost of devices

The disadvantages of choosing switching supplies are the complexity of the device, and the introduction of increased EMI (Electromagnetic Interference) due to the high frequency switching [53].

The type of converters traditionally used in consumer electronics such as:

- Lighting equipment, LED
- Industrial IT
- Consumer electronics

are Flyback (derived from buck-boost converter) and Forward (derived from step down converter) converters, which are unidirectional core excitation devices. These converters are modified to provide electrical isolation by having a high frequency transformer, where the converters are regulated by PWM (Pulse Width Modulation) [53].

Further on, the converters need to be controlled within a specified tolerance band of $\pm1\%$ of its nominal value in DC switch-mode. This is gained by having negative-feedback control system, which response to changes in the output load and the input voltage [47]. The basic design structure model of the converters developed in the simulation is defined in [47].

9.2 AC System Design - Modelling and Designing the Converters

The development and design process of the converter models where performed in cooperation with Santiago A. Sanchez. During the design process, some lab measurements were performed to identify the waveform of a good and poor AC-DC converter, and to identify the type of equipment that have integrated a power factor corrector (PFC).

Table 4 present the lab equipment where the current and voltage waveforms where measured, in order to identify the behaviour of the converter models integrated in the equipment. Detailed results of the measured equipment can be seen in the digital attachments.

Table 4: Overview of lab equipment utilized during measurements of DC appliances.

Lab equipment utilized
AC voltage source, LUBCKE VARIAC: 234 V
Oscilloscope
Ampere meter
Voltage measuring analyser
Current clamp, FLUKE

The lab measurements in Table 6 where actively used when designing the converters as it was no point in making a *too good* converter, as that would not be representative as it is possible to see from the lab results that a lot of *traditional* equipment utilized has quite poor power factor corrector devices, see the digital attachments for the lab results.

The IEC (CENELEC) has set limits on acceptable limits for THD (Total Harmonic Distortion) for equipment. There are defined different classes of limits applicable to the different equipment. The classes that applies to the equipment in this study are Class C and D. Class C regulations applies to lighting equipment >= 25 W [54]. While Class D regulations applies to personal computer monitors and television receivers (power level up to 75 W and power levels not exceeding 600 W), IEC6100-3-2 [55]:

Table 5: represents the IEC6100-3-2; Class C limitations for THD, which applies to lighting equipment >= 25 W and Class D limitations for THD, which applies to personal computer monitors and television receivers [54][55].

Harmonic order n	**Class C Maximum Value [% of fundamental]**	**Class D Maximum Value [mA/W]**
3	$30 \cdot \lambda$	3.4
5	10	1.9
7	7	1.0
9	5	0.5
11 (Class C < n <= 39)	3	0.35
13		3.85/13

(λ is the circuit power factor)

Table 6: Overview of the equipment measured during the lab, see the digital attachments for the detailed results.

The equipment measured	
Equipment	**Result**
Mobile phone connected to a charger (Samsung)	Identified a curve shape, which indicate that a simple rectifier is installed in the charger, without a power factor corrector.
Fluorescent lighting (Energy saving lamp 30 W)	Identified a curve shape, which clearly indicates that a power factor corrector is installed in the device.
Laptop connected with charger (Dell)	Computer in on mode. Represents a curve form similar to the measurements for the mobile phone connected to a charger (Samsung).
LED lighting bulb (LEDON 6 W)	Represents a curve form indicating that no power factor corrector is installed in the device.
LED spot (MEGAMAN 20 W)	Represents a curve form indicating that no power factor corrector is installed in the device.
Stationary Computer (Dell OPTIPLEX990 Core17)	Identified a curve shape, which clearly indicates that a power factor corrector is installed in the device.
Stationary Computer (Dell OPTIPLEX990 Core17) connected to a screen (DELL)	Identified a curve shape, which clearly indicates that a power factor corrector is installed in the computer, and the curve affects the shape poorly and it indicates that a simple rectifier is installed in the screen, without a power factor corrector.
Stationary Computer (Dell OPTIPLEX990 Core17) connected to a screen (Dell)	Identified a curve shape, which clearly indicates that a power factor corrector is installed in the computer, and the curve affects the shape poorly and it indicates that a simple rectifier is installed in the screen, without a power factor corrector.
Computer screen (Dell)	Identified a curve shape, which indicate that a simple rectifier is installed in the charger, without a power factor corrector.
Model for a Dell stationary computer measured a 12 V point connected with a 12.6 and 1.9 ohms resistor	Identified a curve shape, which clearly indicates that a power factor corrector is installed in the computer, and the curve affects the shape poorly and it indicates that a simple rectifier is installed in the screen, without a power factor corrector.
Fluorescent siling lamp (OSRAM 36 W), 0.43 A, cos(phi) = 0.48	Represents a curve form indicating that no power factor corrector is installed in the device.

The Figures 14-16 represents measured equipment compared with the Class D requirement for THD:

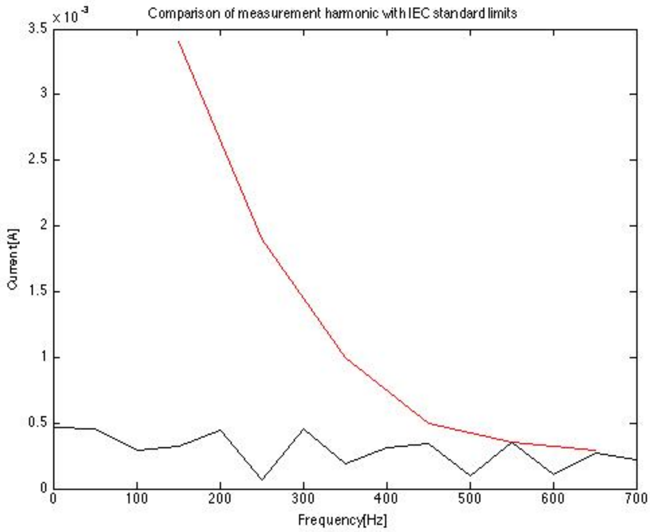


Figure 14: Presents the harmonics from measurements of a phone charger, 35 W, compared with the Class D limits, see the digital attachments for the lab results.

Figure 14, 15, and 16 are the results of lab measurements and clearly represent that the quality of the PFC installed in the equipment varies. Figure 15 show that the device violates the requirements for Class D equipment. Since the design of this device is not known, the design code could be different than the one chosen for this study. Still, it will be correct to design the simulated models within in the required THD limits, in order for the model to be realistic and approved by the IEC.

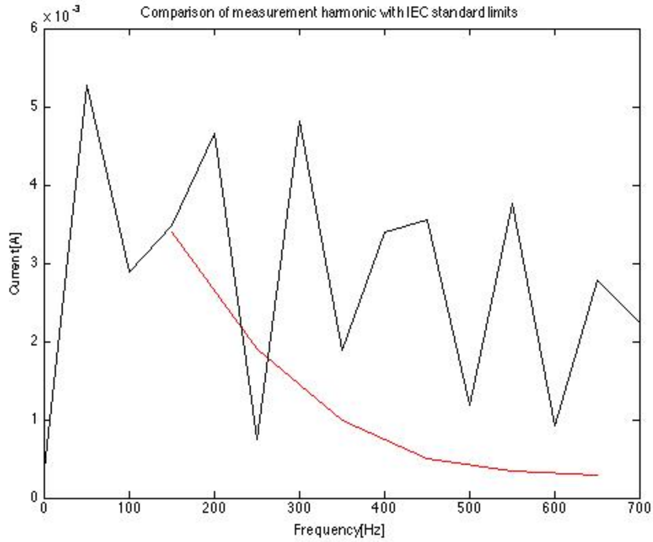


Figure 15: Presents the harmonics resulting from measurements of a Dell personal computer, 65 W, compared with the Class D limits, see the digital attachments for the detailed results.

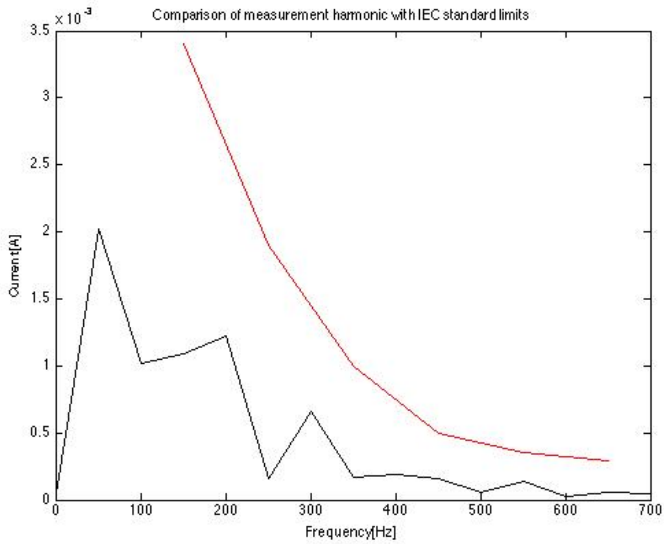


Figure 16: Presents the harmonics of a model for a stationary Dell computer, compared with the Class D requirements, see the digital attachments for the detailed results.

Further on, the idea for the AC simulation model (the existing system solution in buildings), is to design three types of converters:

1.) One converter simulating the AC-DC conversion process for lighting equipment < 25 W, LED
2.) One converter simulating the AC-DC conversion process for lighting equipment >= 25 W, LED
3.) One converter simulating the AC-DC conversion process for office equipment

The output voltage level of the simulated converters has to be controlled in order to gain a stable voltage level for the load. By using switched-mode converters, one or more switches transform the voltage level to the level appropriate for the appliance. The output voltage is then controlled by the t_{on} and t_{off} of the switch. By using Pulse Width Modulation (PWM) switching, the output voltage is controlled with constant frequency and by adjustment of the on duration of a switch [47].

In order to obtain the appropriate voltage level for the loads simulated, a step-down (Buck) converter was designed. The converter was designed in continuous conduction mode, where the voltage output varies linearly with the duty ratio of the switch for a given input voltage [47].

9.3 Designing PFC's

In this study, the focus when developing and designing converters has been to build models with basic and universal structure. This is to achieve a general impression and overview of a converter model and the losses in AC-DC converters, as the design code has small variations when it comes to structure and selected parameter values in the different converters implemented in the equipment. The design code for existing converters is not very accessible, and is often kept secret by the manufacturers. However, it would not give a representative model of the losses in a converter if a specific design from one manufacturer where chosen to be the model analysed in the study.

First, a model for a universal 20 W Power Factor Controller was designed, in order to understand the design process and to have the opportunity to measure equipment at this power level. Furthermore, it was helpful to compare the harmonics of the model with the measured equipment and the IEC requirements before expanding the PFC model to higher power levels.

Designing Universal 20 W Power Factor Corrector (PFC)

In the process of designing a universal 20 W PFC for LED equipment, the design codes [47], [54] and [56] was actively used.

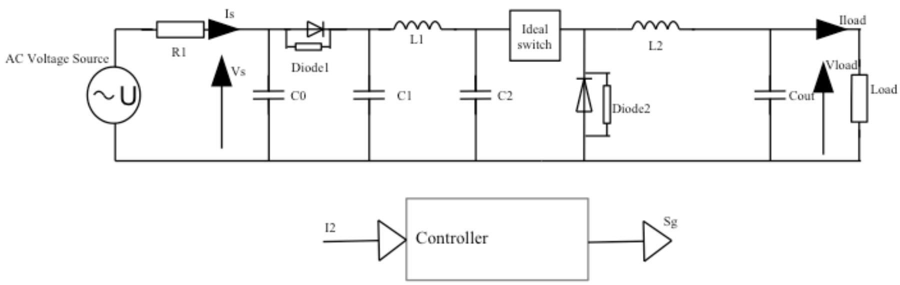


Figure 17: Schematic simplified model of the designed 20 W PFC in MATLAB, see Appendix 17.2 and the digital attachments for the original MATLAB model.

The topology of the design is chosen to be a controller at low cost, variable frequency and with Flyback topology, as this is the best choice of controller or converter in low power LED applications. I/S isolation is included in the topology for the application of solid-state lighting [54][56].

Table 7: represents the parameter value for the key specifications [54][56].

Defined key specifications	
Minimum input voltage (V_{acLL})	85 V_{ac}
Maximum input voltage (V_{acHL})	265 V_{ac}
Line frequency (f_{LINE})	50 Hz
Output Voltage (V_{out})	400 V
Maximum output voltage ($V_{out(max)}$)	415 V
PFC maximum output power (P_{out})	270 W
Minimum switching frequency ($f_{sw(min)}$)	65 kHz
Output voltage ripple ($V_{ripple(p-p)}$)	20 V
Hold-up time ($t_{hold-up}$)	16 ms
Estimated efficiency (η)	93 %
• Small size • Low cost • Good line regulation • High efficiency • Overload and short circuit protection	

In the PFC, passive filter design has been implemented. The idea behind having a passive filter design is to include inductors and capacitors together with the diode rectifier bridge to reduce the input current distortion and improve the current waveform applied from the utility grid. In this design the input current waveform is improved by having a circuit arrangement as represented in Figure 19, where the C_{d1} is small relatively to C_d which give the opportunity of having a larger ripple in V_{d1} and by this improving the waveform of I_s. The low-pass filter consisting of L_d and C_d filter the ripple of V_{d1}. This arrangement was the one closed to the detected forms in the LED equipment measured during the lab. However, this approach for equipment increases the cost, size, losses, and the power drawn by the load with a great dependence of V_d [47].

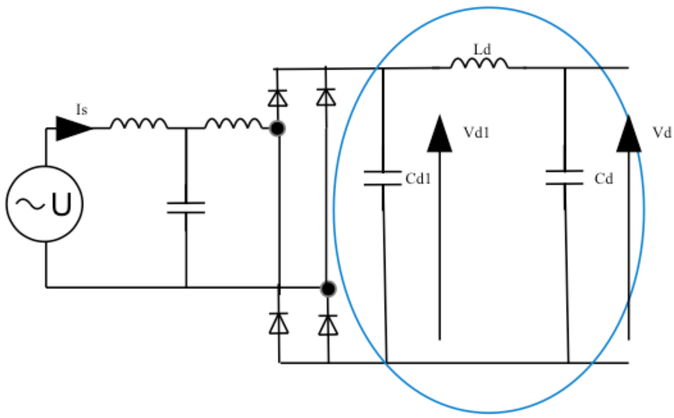


Figure 18: Schematically representation of the passive filter, inductor and capacitors in conjunction with the diode rectifier [47].

The model parameters in the PFC design are decided by the design of DN06040/D [56], see the digital attachments for detailed MATLAB script for initializing the parameters of the model.

Further on, some special considerations had to be taken into account for the LED PFC, as the applications where integrated in a 230 V AC system. At high voltage levels, small strings of LED's driven result in very narrow duty cycles. It takes up to 200-400 ns before the switching controllers senses the current. In order to solve this challenge, a half wave rectified input circuit was introduced to reduce the switching frequency to an operational level and to keep the voltage level at a minimum [54].

IEC (CENELEC) has set limits on acceptable limits for THD (Total Harmonic Distortion) for lighting equipment. These regulations applies to lighting equipment >= 25 W [54]. In order to satisfy these requirements, a PFC had to be included in the model. Since the PFC < 25 W, it was not necessary to include THD modifications, however, the model was designed to satisfy the regulations by comparing the harmonics of the simulated device with the limitations given by IEC.

The input line harmonics for a 6 W LED device measured and compared to the Class C requirements for lighting equipment, IEC61000-3-2:

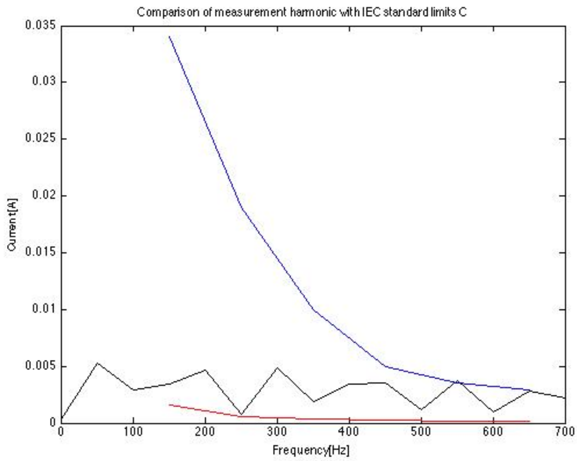


Figure 19: The graphical representation of measuring the current of a 6 W LED (black), plotted together with the IEC standardization limits, Class C (red), and Class D (blue), see digital attachments for the measurement results.

Figure 19 and 20 represents the input line harmonics for a 20 W LED device measured and compared to the Class C requirements for lighting equipment, IEC61000-3-2.

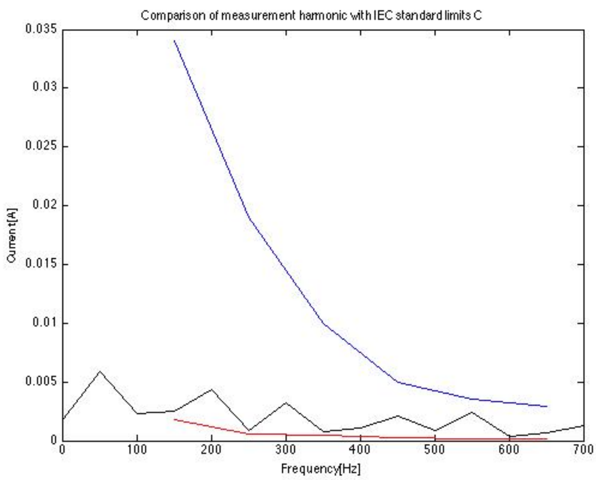


Figure 20: The graphical representation of measuring the current of a 20 W LED (black), plotted together with the IEC standardization limits, Class C (red) and Class D (blue), see digital attachments for the measurement results.

The input line harmonics for a 20 W PFC device designed in MATLAB and compared to the Class C requirements for lighting equipment, IEC61000-3-2:

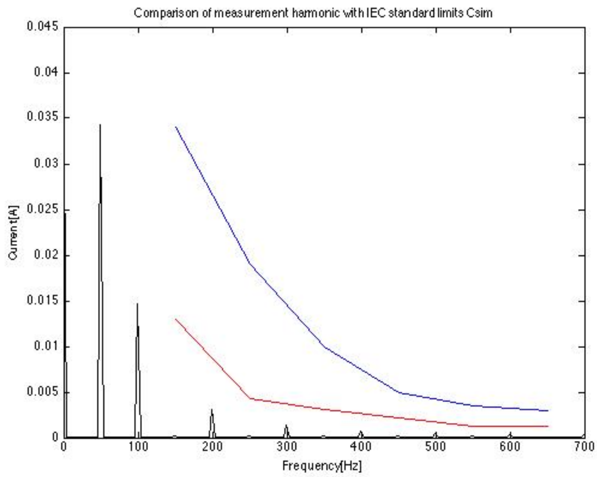


Figure 21: The graphical representation of the simulated model for a 20 W PFC for LED applications (black), plotted together with the IEC standardization limits, Class C (red) and Class D (blue), see digital attachments for the measurement results.

Comparing Figure 19, 20, and 21, it is possible to see in Figure 19 and 20 that the measured devices for appliances < 25 W does not have a PFC, and does not satisfy the IEC limits for Class C equipment. However, the standard only applies for appliances >= 25 W, and it is possible to see that the THD for the devices does not exceed the Class D requirements.

Further on, it is possible to detect that the simulated converter is designed in a way that is within the IEC standardization limits defined. It can therefore be concluded that the converter simulated satisfies the standardization requirement (even though is does not need to, because it is not >= 25 W).

The difference of the lab measurement devices and the simulated PFC is the fulfilment of the limitations of harmonics. The lab measurement devices < 25 W, that means that the devices are not required to obtain the Class C requirement for THD.

Design of LED PFC for 100 W Applications

The models schematic layout and basic model of the PFC has been developed and key specifications decided by using [27], [57], and NCP1607 [58]. During the design process some modifications where performed by using [59], adding a filter and defining the filter parameters.

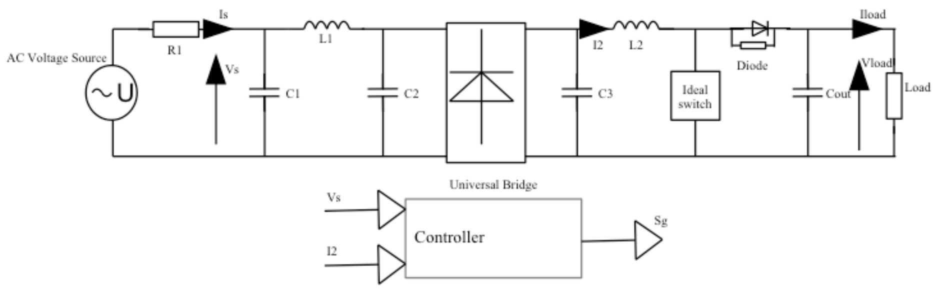


Figure 22: Schematic model of the designed 100 W PFC, see Appendix 17.3 and the digital attachments for the original MATLAB model.

Figure 22 give a schematic representation of the designed model in MATLAB, where I_s and V_s represent the current and voltage at the AC side of the converter, while I_{load} and V_{load} represent the current and voltage at the DC side of the converter, respectively. The controller ensures a controlled current and voltage output at the load, represented as a block in Figure 22, more details of the converter model design can be seen from Appendix 17.3 and the digital attachments.

Table 8: Overview of defined key specifications in the modulation of the 100 W PFC, see digital attachments for the script used for initialising in MATLAB.

Defined key specifications	
Minimum input voltage (V_{acLL})	88 V_{ac}
Maximum input voltage (V_{acHL})	264 V_{ac}
Line frequency (f_{LINE})	50 Hz
Output Voltage (V_{out})	400 V
Maximum output voltage ($V_{out(max)}$)	415 V
PFC maximum output power (P_{out})	100 W
Minimum switching frequency ($f_{sw(min)}$)	65 kHz
Output voltage ripple ($V_{ripple(p-p)}$)	20 V
Hold-up time ($t_{hold-up}$)	16 ms
Estimated efficiency (η)	93 %

The specifications defined in Table 8 where written in a MATLAB script used for initializing the parameters in the converter model, see digital attachments.

The PFC coil (Boost inductor) was then defined by using the equations described below:

The peak current in the inductor is calculated by the equation [57]:

$$I_{coil,pk}(\max) = \frac{\sqrt{2} \cdot P_{out}}{\eta \cdot V_{acLL}} \tag{9.1}$$

The rms current then follows by the equation:

$$I_{coil,rms}(\max) = \frac{I_{coil,pk}(\max)}{\sqrt{6}} \tag{9.2}$$

The peak-to-peak ripple current is then calculated by the following equation:

$$I_{ppri} = \frac{0.45 \cdot I_{coil,pk}(\max)}{2} \tag{9.3}$$

The current ratio can then be calculated by:

$$I_{ratio} = \frac{I_{ppri}}{1.225 \cdot I_{cpmax}} \tag{9.4}$$

The inductor design in the boost converter is calculated by using the formula [59]:

$$L_d = \frac{\sqrt{2} \cdot V_{acLL}}{f_{sw} \cdot 0.45 * I_{coil,pk(max)}} \cdot \left(1 - \frac{\sqrt{2} \cdot V_{acLL}}{V_{out}}\right) \tag{9.5}$$

The forward voltage is given by the factor:

$$V_f = 1.4 \tag{9.6}$$

$$P_{bridge} = \frac{4 \cdot \sqrt{2} \cdot V_f \cdot P_{out}}{V_{acLL} \cdot pi \cdot \eta} \tag{9.7}$$

The current in the Mosfet is defined by:

$$I_{Mrms} = \frac{P_{out}}{\eta \cdot V_{acLL}} \cdot \sqrt{1 - \frac{8 \cdot \sqrt{2} \cdot V_{acLL}}{3 \cdot pi \cdot V_{out}}} \tag{9.8}$$

The conduction losses in the converter is defined by:

The forward resistance for 600 V increased at 80 % temperature

$$R_{dson} = 0.19 \tag{9.9}$$

$$P_{con} = I_{Mrms}^2 \cdot R_{dson} \cdot 1.8 \tag{9.10}$$

And the switching capacitor (turned on) losses are defined in [60]:

$$C_{oss} = 780 \cdot 10^{-12} \tag{9.11}$$

Assume

$$f = \frac{f_{sw}}{2} \tag{9.12}$$

and

$$D_{high} = \frac{(\frac{V_{out}}{V_{acLL}} - 1)}{(\frac{V_{out}}{V_{acLL}})} \tag{9.13}$$

$$D_{low} = \frac{(\frac{V_{out}}{V_{acLL}} - 1)}{(\frac{V_{out}}{V_{acLL}})} \tag{9.14}$$

Calculating the mean of (9.13) and (9.14):

$$D_{mean} = \frac{D_{low} + D_{high}}{2} \tag{9.15}$$

The frequency can then be calculated as:

$$f = f_{sw} \cdot D_{mean} \tag{9.16}$$

The switching losses:

$$P_{swcap} = \frac{2}{3} \cdot C_{oss} \cdot 5 \cdot V_{out}^{1.5} \cdot D_{mean} \cdot f_{sw} \tag{9.17}$$

The critical conduction mode operates by having a fixed time interval over the line cycle. The maximum time is defined by the time the maximum energy has to be transferred to the output, and can be calculated by the equation below:

$$T_{ON} = \frac{2 \cdot L \cdot P_{out}}{\eta \cdot V_{acLL}^2} \tag{9.18}$$

Further on, the capacitor design value is decided by:

$$C_{out} = \frac{P_{out}}{2 \cdot pi \cdot f \cdot V_{ripple,(p-p)} \cdot V_{out}} \tag{9.19}$$

The capacitor current is then calculated:

$$I_{crms} = \sqrt{\frac{(32 \cdot \sqrt{2} \cdot P_{out}^2)}{9 \cdot pi \cdot V_{acLL} \cdot V_{out} \cdot \eta^2} - (\frac{P_{out}}{V_{out}})^2} \tag{9.20}$$

And the second converter is defined by:

$$C_{out2} = \frac{t_{hold-up} \cdot 2 \cdot P_{out}}{V_{out}^2 - 0.85 \cdot V_{out}^2} \tag{9.21}$$

The filter parameters are calculated to have these values:

$$C_{filter} = 0.1 \cdot 10^{-6}$$

$$C_{ac} = 0.47 \cdot 10^{-6}$$

IEC (CENELEC) has defined the harmonics Class C, which applies to lighting equipment, IEC6100-3-2 [55]. The input line harmonics for the simulated model compared to the IEC61000-3-2 standard limits (Class C) for harmonics:

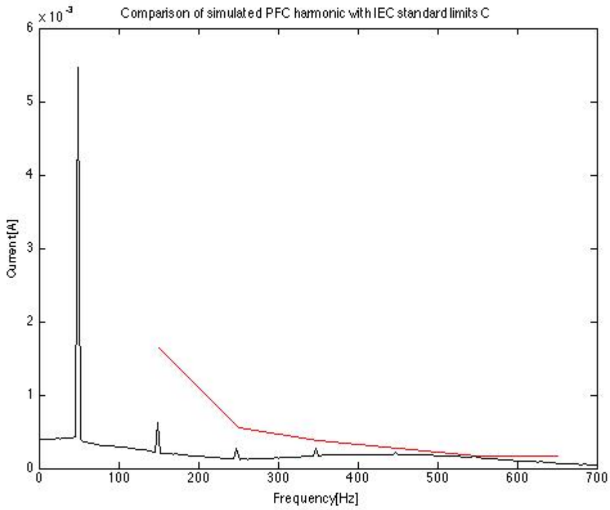


Figure 23: Represents the input line harmonics for the simulated PFC in comparison with the standardization limits, see digital attachments for the MATLAB script.

In order to for the simulated PFC to satisfy the IEC standardization requirements, and reduce the THD, the inductor in the model had to be increased, see the digital attachments for the script initialising the MATLAB model.

Designing 270 W Critical Conduction Mode (CrM) Power Factor Corrector (PFC)

The model has been developed and key specifications decided by using [47], [57], and NCP1607 [58].

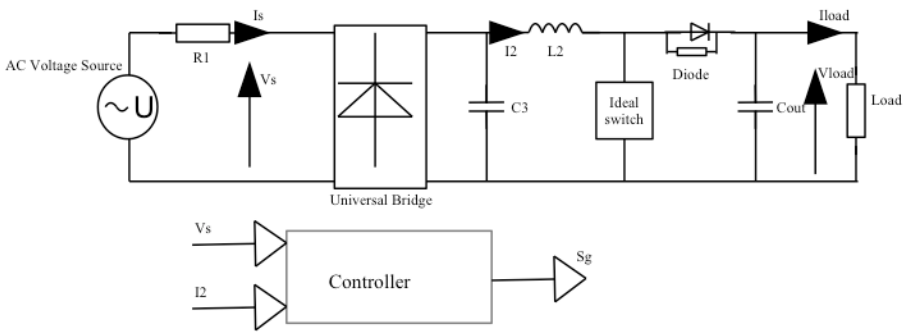


Figure 24: Schematic model of the designed 270 W PFC, see Appendix 17.4 and the digital attachments for the original MATLAB model.

Figure 24 give a schematic representation of the designed model in MATLAB. The idea is to present the points of measurements of the model for calculation of the power loss of the converter. I_s and V_s represent the current and voltage at the AC side of the converter, while I_{load} and V_{load} represent the current and voltage at the DC side of the converter, respectively. The controller ensures a controlled current and voltage output at the load, represented as a block in Figure 24, more details of the converter model design can be seen from Appendix 17.4 and the digital attachments.

Table 9: Overview of defined key specification in the modulation of the 260 W PFC, see the digital attachment for the MATLAB script initialising the parameters.

Defined key specifications	
Minimum input voltage (V_{acLL})	88 V_{ac}
Maximum input voltage (V_{acHL})	264 V_{ac}
Line frequency (f_{LINE})	50 Hz
Output Voltage (V_{out})	400 V
Maximum output voltage ($V_{out(max)}$)	415 V
PFC maximum output power (P_{out})	270 W
Minimum switching frequency ($f_{sw(min)}$)	65 kHz
Output voltage ripple ($V_{ripple(p-p)}$)	20 V
Hold-up time ($t_{hold-up}$)	16 ms
Estimated efficiency (η)	93 %

The specifications defined in Table 9 where written in a MATLAB script used for initializing the parameters in the converter model, see the digital attachments for the details.

The PFC coil (Boost inductor) was then defined by using the equations (9.1)-(9.21) described in the above section.

The IEC (CENELEC) has defined the harmonics Class D, which applies to personal computer monitors and television receivers (power level up to 75 W and power levels not exceeding 600 W), IEC6100-3-2 [55].

The input line harmonics for the measured model for a stationary computer compared to the IEC61000-3-2 standard limits (Class D) for harmonics:

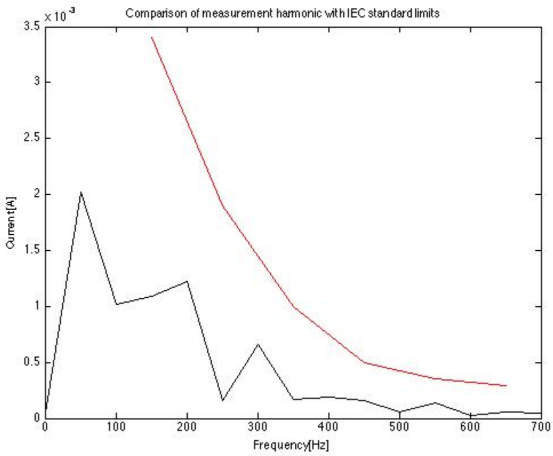


Figure 25: The graphical representation of measuring the current of a model for a Dell stationary computer (black), plotted together with the IEC standardization limits (red), see the digital attachments for detailed results.

From Figure 25 it is possible to detect that the measured model of a Dell stationary computer meets the criteria of Class D for harmonics defined by IEC.

The input line harmonics for the simulated converter for office equipment applications compared to the IEC61000-3-2 standard limits (Class D) for harmonics:

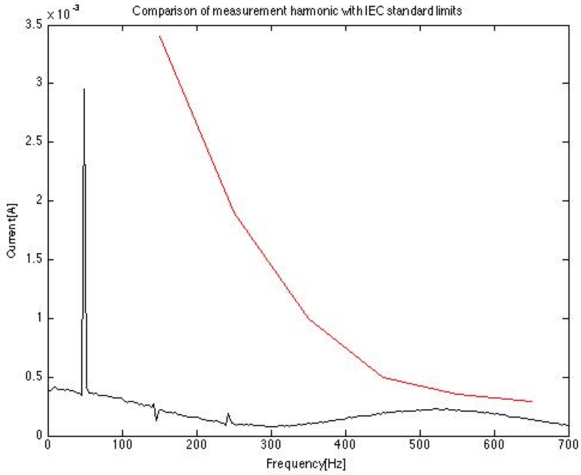


Figure 26: The graphical representation of the current of the simulated model for a converter for office equipment (black), plotted together with the IEC standardization limits (red), see the digital attachments for the details of the model.

Comparing Figure 25 and 26 it is possible to detect that the simulated converter is designed in a way that is within the IEC standardization limits defined, and the current path of the simulated converter has common peaks and shape of the current curve of the real equipment existing today. It can therefore be concluded that the converter simulated satisfies the standardization requirement and are representative in the model for a real converter.

The representation of harmonics in the above section show that the even harmonics are not zero, however, it is not the main component either. This will not affect the results too much later in the analysis, as the designed models satisfy specified limits and requirements.

9.4 Power Loss Calculation

For calculation of the power in the converters, this relation was used [61]:

$$P = V \cdot I \tag{9.22}$$

For calculation of the power loss in the converters, the equation below was used:

$$P_{loss} = P_{ACinput} - P_{DCoutput} \tag{9.23}$$

MATLAB Simulation – Calculation of Power Losses

PFC 100 W

Table 10: Represent extracts from the results measuring the current, I_s, and voltage, V_s, at the AC side, and the current, I_{load}, and the voltage, Vl_{oad}, at the DC side of the 100 W PFC, see Appendix 17.5.

V_s (V_{AC}) Relative to fundamental	I_s (A) Relative to fundamental	V_{load} (V_{DC}) DC component	I_o (A) DC component	Power loss (W)
230	0.6	390	0.2	46

From Table 10, it can be seen that the power loss in the 100 W PFC is approximately 46 W. This is an unrealistic high loss for a 100 W conversion process. It is therefore concluded that there are a source in the simulation model causing the large error, see Appendix 17.5 for the simulated voltage and current results relative to the fundamental and DC component.

PFC 270 W

Table 11: Represent extracts from the results measuring the current, I_s, and voltage, V_s, at the AC side, and the current, I_{load}, and the voltage, V_{load}, at the DC side of the 270 W PFC, see Appendix 17.6.

V_s (V_{AC}) Relative to fundamental	I_s (A) Relative to fundamental	V_{load} (V_{DC}) DC component	I_o (A) DC component	Power loss (W)
230	1	390	0.7	50

From Table 11, it can be seen that the power loss in the 270 W PFC is approximately 50 W. This is an unrealistic high loss for a 270 W conversion process. It is therefore concluded that there are a source in the simulation model causing the large error, see Appendix 17.6 for the simulated voltage and current results relative to the fundamental and DC component.

Simulation of the converter models designed and modelled in MATLAB, gave graphical models satisfying the IEC requirement classes for harmonics, and the graphical representation of the current and voltage waveforms gave the desired values for the system. However, placing current and voltage measurements in the model for calculation of the power losses in the converter result in very high losses. It was therefore concluded that something is wrong with the model. The source of the large errors is difficult to detect, when the current and voltage are at the appropriate level and the controller working good. It was therefore tried to measure over all parts of the model separately in order to search for possible sources of error, but none of the devices seems to be the source of the large losses, see the digital attachments for the MATLAB scripts used for error searching in the model. It was therefore concluded that the source of the large error probably was caused by:

- The implemented and designed controller
- The solver algorithm implemented in the simulation tool used, MATLAB, Simulink with the toolbox SimPowerSystem

The reasons for concluding that the large losses most likely result from the implemented solver algorithm in MATLAB, is that, when a test of copying the parameter values calculated and resulting from running the model built and designed in MATLAB into a identical pre-built example *Boost power factor correction (PFC) circuit* [62], calculation from the resulted simulation gave the expected and realistic values for the power losses in the device.

PSIM is a simulation program great for power conversion and control [62]. It is particularly efficient in simulating converter systems, one has therefore subsequently seen that it could have been advantageous to use PSIM from the beginning of the simulation.

The model applied in PSIM was a model that was predefined and implemented in the simulation tool together with the installation of the program [62]. The model in PSIM was identical to the model built and designed in MATLAB in terms of the components included in the model, the only "physical" difference in the two models are the controller. The controller built in MATLAB is as good as it can be implemented in this simulation tool, and the controller predefined in PSIM is a bit different. It is not possible to implement an identical device as this in MATLAB. It is hard to tell if this is the source of the large losses. Since the two simulation programs both give good curves of the voltage and current, and the controller seems to work in both cases. The remaining difference in the two models is the different algorithms implemented in the different simulation programs solver. It could therefore be that the solver implemented in MATLAB being the source of the errors, as the exact same parameters used in the PSIM model as in the MATLAB model give realistic results.

The losses from the running the MATLAB program and implementing it in to the pre-defined model in PSIM gave losses that are realistic and in the same range as the resulting losses from the design code that the devices are built up of, see [47], [57], and NCP1607 [58], which are indicative. For example, in the design code in [57], for a 270 PFC device:

Table 12: The performance results for a 270 W PFC based on NCP1607 [58].

V_{in} (V_{AC})	**P_{in} (W)**	**V_o (V)**	**I_o (A)**	**Output Power (W)**	**Power Loss (W)**	**Efficiency**	**Error**
230	275.5	387.1	0.699	270.63	4.85	98.25 %	1.77 %

For calculation of the efficiency, this relation was applied:

$$\eta = (1 - \frac{P_{in} - P_{output}}{P_{in}}) \cdot 100 \quad (9.24)$$

9.5 PSIM Simulation

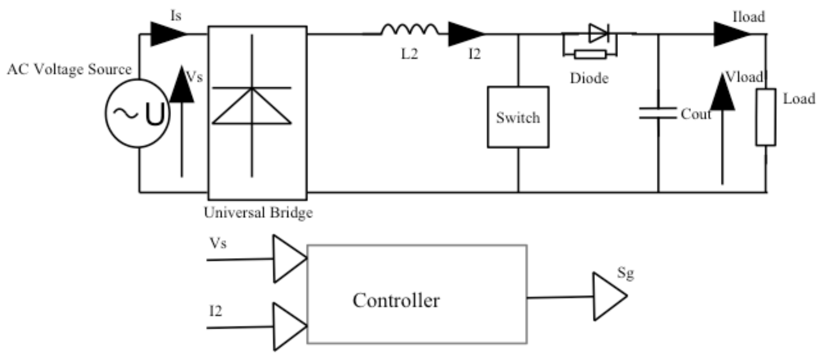


Figure 27: Schematically model of the predefined model of the Boost Power Factor Correction Circuit, see Appendix 17.7 and the digital attachments for the original PSIM model [62].

Figure 27 represents the predefined model in PSIM [62], where modifications where done to the parameter values in order for the simulation model to represent a 100 W and 270 W PFC. The parameters used in the model are calculated in MATLAB by using [47][57], and the design code for NCP1607 [58], see Appendix 17.7 and the digital attachments.

Comparison of the Harmonics of the PSIM Model and the IEC Requirements

In order to utilize the predefined model of the PFC in PSIM, it has to be tested that the PFC satisfies the IEC requirements for THD (Total Harmonic Distortion) for Class C and D.

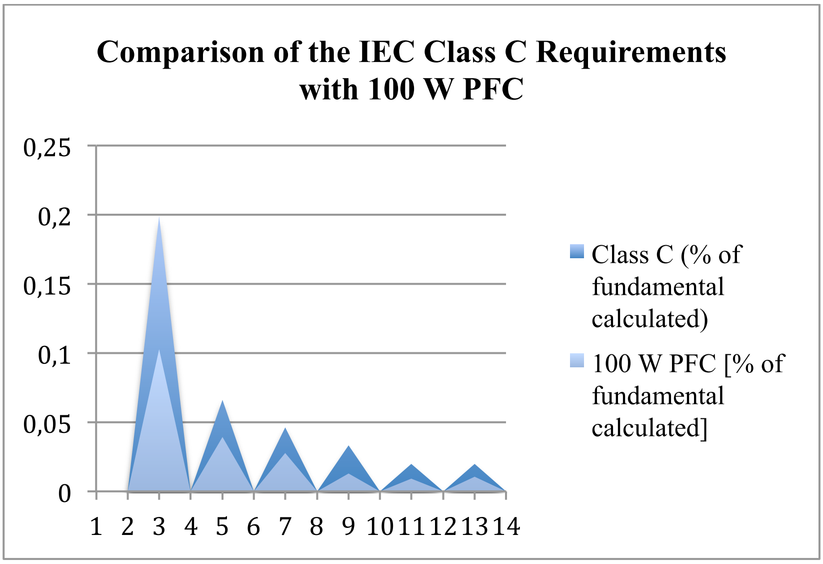


Figure 28: Represents the comparison between the IEC Class C requirements and the 100 W PFC, see Appendix 17.8, 17.9, and the digital attachments.

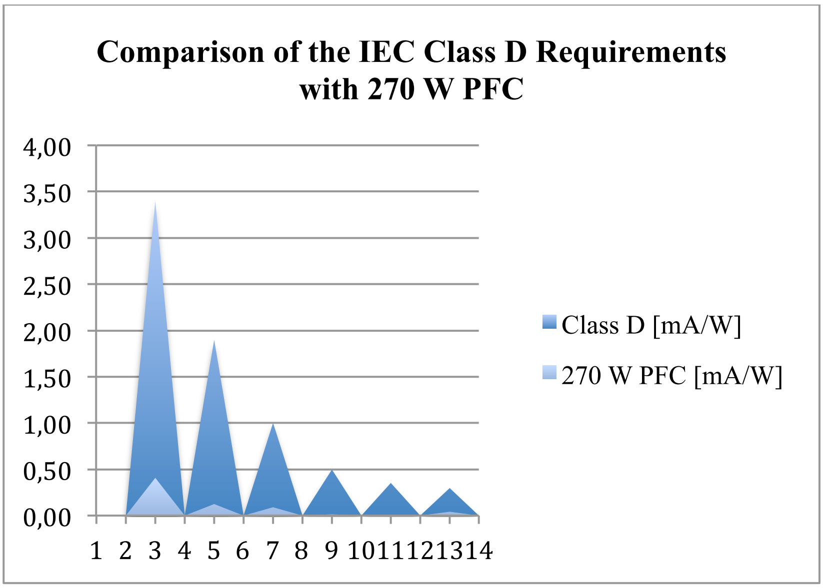


Figure 29: Represents the comparison between the IEC requirements and the 270 W PFC, see Appendix 17.8, 17.9, and the digital attachments.

From Figure 28 and 29 it is possible to see that the PFC for 100W and for 270 W modelled in PSIM satisfies the IEC Class C and the Class D requirements for THD, respectively.

Calculation of Power Losses

PFC 100 W

Table 13: Represent extracts from the results when measuring the current I_s, and voltage, V_s, at the AC side, and the current I_{load}, and the voltage, V_{load}, at the DC side of the 100 W PFC, see Appendix 17.10 for the measurement results.

V_s ($V_{ACpk\text{-}pk}$) Relative to fundamental	I_s ($A_{pk\text{-}pk}$) Relative to fundamental	V_{load} (V_{DC}) DC component	I_o (A) DC component	Power loss (W)	Error
325	0.67	409	0.26	3	3.0 %

The relation used to calculate the error:

$$Error = \frac{Inupt\ power_{AC} - Output\ power_{DC}}{Input\ power_{AC}} \cdot 100\% \qquad (9.25)$$

From Table 13, it can be seen that the power loss in the 100 W PFC is approximately 3 W. This is a realistic loss for a 100 W conversion process, see Appendix 17.10 for the simulated voltage and current results relative to the fundamental and DC component.

PFC 270 W

Table 14: Represent extracts from the results of measuring the current, I_s, and voltage, V_s, at the AC input side, and the current, I_{load}, and voltage, V_{load}, at the DC side of the 270 W PFC, see Appendix 17.11 for the measurement results.

V_s ($V_{ACpk\text{-}pk}$) Relative to fundamental	I_s ($A_{pk\text{-}pk}$) Relative to fundamental	V_{load} (V_{DC}) DC component	I_o (A) DC component	Power loss (W)	Error
325	1.70	400	0.67	7	2.5 %

In Table 14, the relation (9.25) are used to calculate the error. Moreover from Table 14, it can be seen that the power loss in the 270 W PFC is approximately 7 W. This is a realistic loss for a 270 W conversion process, see Appendix 17.11 for the simulated voltage and current results relative to the fundamental and DC component.

The loss of power measured in the PSIM converter model for 270 W has a bit higher losses than the design code represented in [57] with a power loss of approximately 5 W. This is not unexpected as losses will vary slightly from design to design, and the controller implemented in the model has a great influence on the resulting losses.

9.6 DC System Design – Voltage Source Converter (VSC)

To be able to interconnect an AC and DC grid, a power electronics three phase voltage source converter (VSC) is needed in order to have the opportunity to control and convert power from AC-DC and reverse [63]. Assumptions in the VSC model:

- It is only looked into the AC grid supplying the DC grid, and no power flow in the reverse direction, as no DGS are connected in this study
- An ideal AC grid is supplying the DC grid

Santiago A. Sanchez, has earlier, using MATLAB, Simulink and the toolbox SimPowerSystem, developed a model of a three-phase VSC. The VSC device is basically a rectifier, converting AC-DC, in order to connect an AC and DC system. This pre-developed model was utilized in this project, in order to measure the power loss of the conversion process when having one single rectifier. The modelling and equations describing the VSC connected at the DC side to a grid and to an ideal AC system are based on [64]-[67]:

$$\frac{di_d}{dt} = \frac{E_{sd} - v_d + wL_q - ri_d}{L} \tag{9.26}$$

$$\frac{di_q}{dt} = \frac{E_{sq} - v_q - wLi_d - ri_q}{L} \tag{9.27}$$

$$\frac{dv_{dc}}{dt} = \frac{i_{dc} + i_{grid}}{C} \tag{9.28}$$

$$i_{dc} = \frac{3}{2} \cdot (s_{gd} i_d + s_{gq} i_q) \tag{9.29}$$

where $E_{s,k}$ with k {d,q} is the voltage of the AC grid in the direct quadrant axis, i_k is the current in the filter inductance L, and the voltage at the switch terminals of the converter is v_k, the DC voltage is v_{dc}, and the current at the DC side of the converter is i_{dc}, the switching commands are s_{gk}, and the current flowing from the DC grid is i_{grid}. The internal part of the controller system was designed by the set of equations given in [68]-[71]:

$$v_d = -k_p\left(i_{refd} - i_d\right) - k_i\gamma_d + \omega Li_q + \alpha e^{-\alpha t}E_{sd} \tag{9.30}$$

$$v_q = -k_p\left(i_{refq} - i_q\right) - k_i\gamma_q + \omega Li_d + \alpha e^{-\alpha t}E_{sq} \tag{9.31}$$

$$\gamma_d = i_{refd} - i_d \tag{9.32}$$

$$\gamma_q = i_{refq} - i_q \tag{9.33}$$

$$s_{gk} = \frac{v_k}{v_{dc}} \tag{9.34}$$

The external part of the controller, controlling the DC side of the system, was designed by the set of equations given in [68]-[72]:

$$e_v t_{em} = K_{pv}(e_v + k_i i_{ev}) \tag{9.35}$$

$$i_{dref} = e_v t_m - i_{lo} \tag{9.36}$$

$$e_v = V_{dcref} - V_o = \frac{d\gamma_{dc}}{dt} \tag{9.37}$$

This can be written as:

$$K_{pdc} e_v + K_{i,dc} \int e_v dt = i_{dc} - i_{lo} \tag{9.38}$$

Reordering (9.38) and then get:

$$i_{dc} = \left(K_{p,dc} + K_{i,dc}\right) \frac{d\gamma_{dc}}{dt} + \mathrm{i}_{lo} \tag{9.39}$$

$$i_{dc} = \frac{3}{2}(S_{gd} i_d + S_{gq} i_q) \tag{9.40}$$

where $S_{gq} i_{dc} = i_q = 0$ and $S_{gd} dc = i_d$. This will then result in:

$$i_{dref} = \frac{3}{2} S_{gd} i_d \tag{9.41}$$

The above equations defined for the VSC is represented in the block diagram in Figure 30.

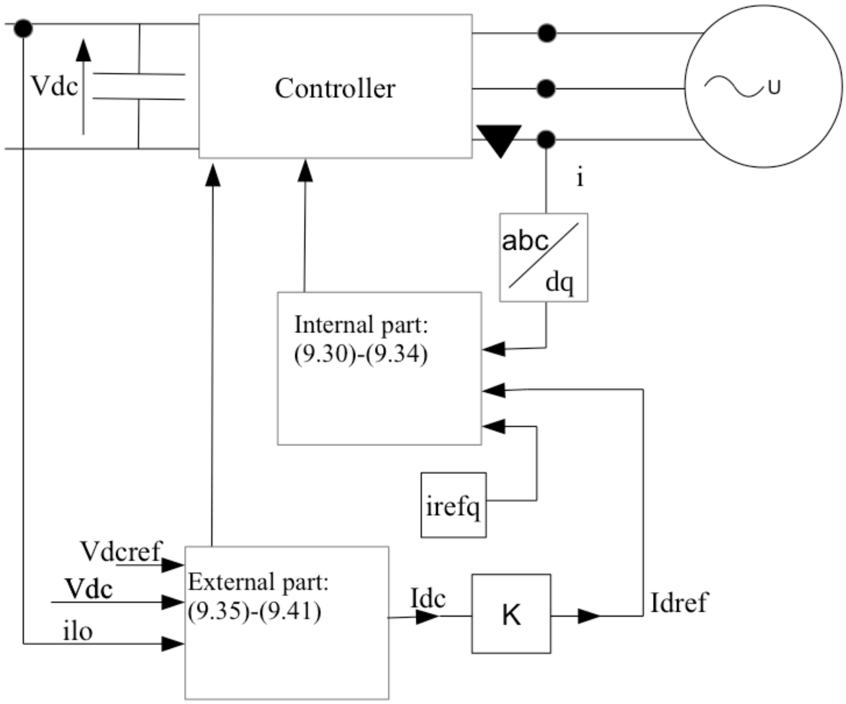


Figure 30: Block diagram representing the equations of the VSC, see the digital attachments for the original model designed in MATLAB.

In order to exploit the model of the VSC, some modifications where done in the parameters of the VSCs controller to control the voltage and current to the desired value. The parameters used specifying the VSC and VSCs controller can be seen in the script attached in the digital attachments.

By performing some modifications to the predefined model of the VSC, the VSC is converting three-phase 230 V AC into single-phase 230 V DC from the AC grid to the DC system solution. It is then possible to utilize the converted power in a DC system.

9.6.1 Mapping the Energy Consumption of the DC grid

When projecting and planning a DC system supplied by using a central VSC connected to the existing AC grid, a main factor deciding the architecture of the VSC is the necessary energy supplied to the system. The required energy supplied into the DC system is dependent on the systems associated loads power demand and load image. The daily energy picture of a building will vary throughout the day, and are affected by numerous factors. The energy demand in a system is complicated and challenging to predict because it changes more frequently than every minute. However, in order to get a overview of the changing loads daily demand and behaviour, there where performed measurements at *Bjerke Upper Secondary School*.

Measurements of Existing System Solution - Method

The methods and measuring equipment utilized to perform measurements at *Bjerke Upper Secondary School* are described in this section. The measurements where performed in cooperation with Morten Halten Eggen at COWI, and the measurement equipment used are owned by COWI. A risk analysis were performed prior to the measurements, see Appendix 17.12 and the digital attachment for the detailed analysis.

The measurements where performed to gain sufficient data for comparison purposes in this analysis, there were performed measurements with a data logger for the total supply of the building over a period from Monday until Thursday afternoon, with a data logger over a period of 24 hours over specific loads, and instantaneous measurements on specific DC loads with nearly constant power use when turned on. The instantaneous measurements where performed in order to assure that the description of the sub distribution boards resembled with what was installed in the building, the results from this can be seen in Appendix 17.13.

The current in the different conductors were measured by using current clamps, while the voltage was measured to 230 V for the single-phase load (voltage between one phase and neutral). The measurements where performed with different measuring equipment, by the need for the resulting measurements.

Instantaneous Measurements

Instantaneous measurements were performed with FLUKE 41 Power Harmonics Analyser in a period during a peak load period Monday 24 February (12:30-14:30) for the different loads that are originally DC loads, see Appendix 17.14 for detailed description of the measurement equipment. The background for taking instantaneous measurements, was to check that the sub distributions had the installed equipment as projected, so that it was clear what kind of equipment that was measured. These measurements gave an incentive of the active efficiency (P) the various DC loads are dependent on to work properly, see Appendix 20.13 for the results.

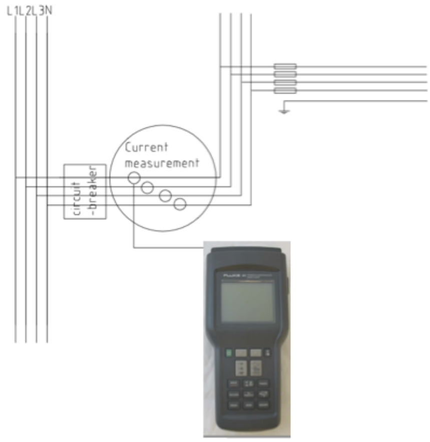


Figure 31: Wiring diagram for current measurements [73], see Appendix 17.14 for details on the measuring equipment.

Figure 31 describes the connection of the measuring equipment to be able to quantify the different loads power dependency.

Measurements with a Data Logger

There were performed 4 different measurements with a data logger, Power Guide 4400, where 4 different measuring points over a period of 24 hours was repeated in two series, see Appendix 17.14 for description of the measurement equipment utilized. These selected measuring points behaviour was studied and saved for each minute.

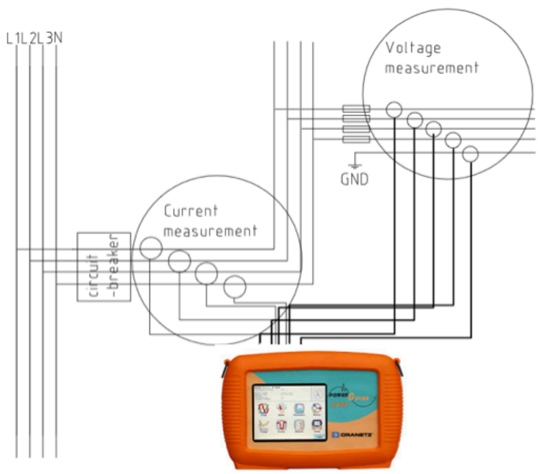


Figure 32: Represents the connection of measuring equipment to detect the power consumed by each load over a period of time [75], see Appendix 17.14.

The equipment was utilized to data log measurements of an interval of each minute for a period of 24 hours over the chosen sub distributions to detect the daily load picture with variations over specific DC loads at *Bjerke Upper Secondary School*.

Selection of Measuring Points

In the measurements performed, different points in the system topology were measured. The focus of the measurements were to gain an overview of the efficiency and energy use of loads connected that originally are DC loads, where it is possible to supply DC directly. A selection of possible DC loads was made for the measurements, and the priority was mainly sockets with connected computer equipment and lighting fixtures. There were performed instantaneous measurements and data logging measurements over a period of time at specific loads, and the total load picture of *Bjerke Upper Secondary School* where measured. All the different measurements represent the measurements of the phases at the inlet of the distribution. The overview of selected measuring points for the instantaneous measurements can be seen in Appendix 20.16, and the measuring points for data logging for 24 hours are given in Table 15.

Table 15: Selection of data logging measuring points over a 24 hours period, at *Bjerke Upper Secondary School* [52].

Building	Distribution	Description	Number	Line
Building A, Basement	+01=433.22	Lighting (along hall) U1052	F-110	L1
		Lighting U1072, U1073, U1074, U1075, U1078	F-103	L2
		Lighting U1052 Hall	F-109	L3
		Efficiency lighting Hall U1052 LED +=563.021-XY001.21A LED +=563.021-XY001.21B LED +=563.021-XY001.21C	F-115 F-115.2 F-115.3 F-115.4	L1
		Lighting U1044 Hall	F-110	L2
Building B, first floor	+01=433.30	Socket offices room 01085-88	F-507	L1
		Socket offices room 01081-85	F-508	L2
		Socket offices room 01076-80	F-509	L3

Results From Measurements

In this part, the results of the measurements are presented. The instantaneous measurements where performed on the loads described in Appendix 17.13, and the data logging measurements over a 24 hour period was performed on the loads described in Table 15. Some of the sockets measured have unspecified socket load, which typically consist of office equipment or socket outlets. The distribution points described as lighting mainly are mounted rigidly lightning fixtures.

The results from the data logging measurements are described by graphs to get a better visualization of the results, as measurements for a load each minute in 24 hours result in 1140 measurement values for each load. The reason for choosing a time period of 24 hours is to represent the flow of energy on a daily basis and to easier see when the peak period occurs, in order to make a survey of the power required for the loads to fulfil its function during the peak periods. The results for the instantaneous measurements are represented in Appendix 17.13, and the results from the data logging measurements are presented below and in the digital attachments. The results from the data logging measurements where plotted in the program DRAN-VIEW by Trinergi [74], and all the results can be seen in the digital attachments.

There were performed 3 series á 24 hours over 6 different loads that originally are DC loads. Current and voltage probes where used to make a survey of the measurements.

Further on, there were performed measurements to outline a survey of the total energy use of *Bjerke Upper Secondary School* from Monday until Friday in March 2014, see the digital attachments for all the results.

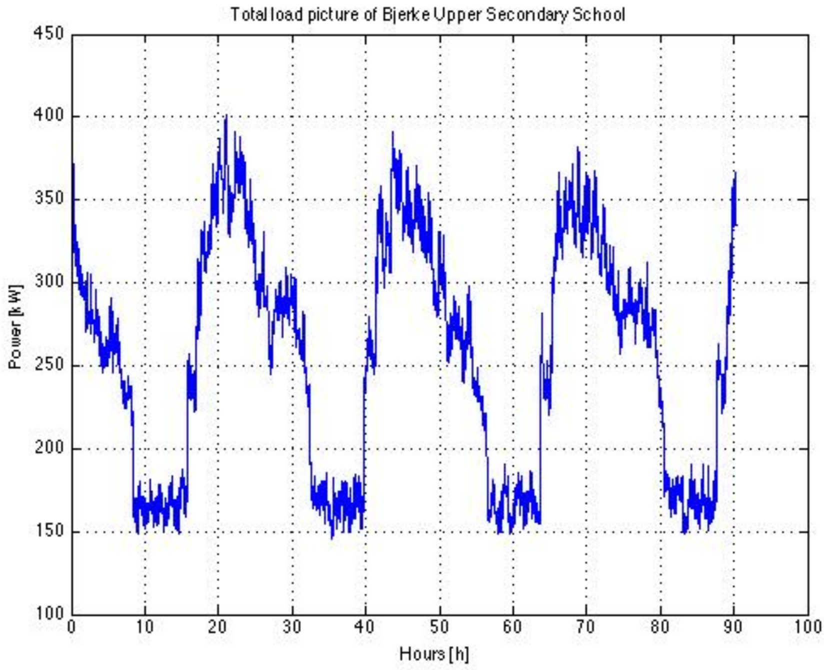


Figure 33: Represents the total load picture of *Bjerke Upper Secondary School*, see the digital attachments for the original signal results.

Figure 33 clearly represents that the power required for the loads in total need much higher power delivered than it would be efficient to provide with a DC system. The efficiency of a system is represented by efficiency curves, and not a single value, as the efficiency of a system will vary in terms of the applied load [49]. It is therefore only looked into the loads that original is applicable to DC, and in the range of power required where it would be efficient to replace AC supply with DC supply.

9.7 Parameterizing of the VSC by Utilizing Measurement Results

Performing measurements at Bjerke Upper Secondary School resulted in load profiles with measurements for each minute. In order to gain a better visualization of the load profiles of the measured loads, the data was plotted using the simulation tool MATLAB.

In a future DC grid it is assumed that all fluorescent lighting can be replaced with LED lighting, in order to fully utilize the concept of a DC system solution. Therefore three fluorescent distributions power consumption where measured, the resulted load profiles can be seen in Figure 34:

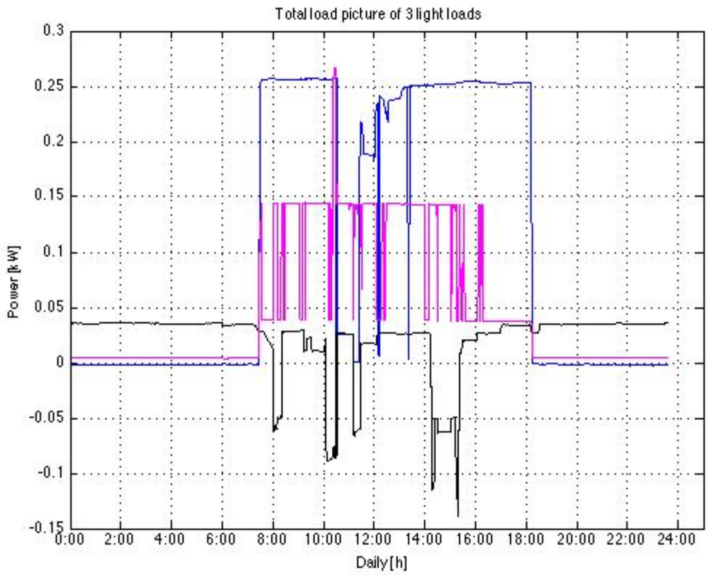


Figure 34: Represents the varying load of three distributions supplying lighting equipment at *Bjerke Upper Secondary School*, see the digital attachments for the measurement results.

The loads that are represented in Figure 34 are:

- Represents lighting in room U1052: lighting equipment of 0,628 kW
- Represents lighting in room U1072-U1075, U1078: lighting equipment of 0,620 kW
- Represents lighting in hall way U1052: lighting equipment of 0,182 kW

In order to replace the function of the fluorescent lights with LED, LED lighting which complements the same function have to be introduced. Assuming that the loads measured could be representative load profiles for all the lighting equipment installed, typically for one floor there could be lighting devices such as:

- 11 loads acting as of profile blue
- 11 loads acting as of profile black
- 12 loads acting as of profile magneta

Resulting of a total power demand of 5 kW, this can be seen from the total load profile for the devices plotted using MATLAB in Figure 35.

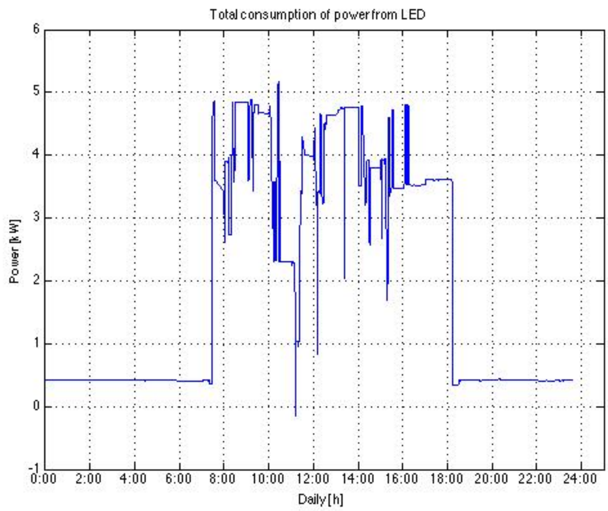


Figure 35: Representing the daily power consumption from LED lighting, see the digital attachments for the measurement results.

Further on, three office load distributions where measured, the resulted load profiles can be seen in Figure 36:

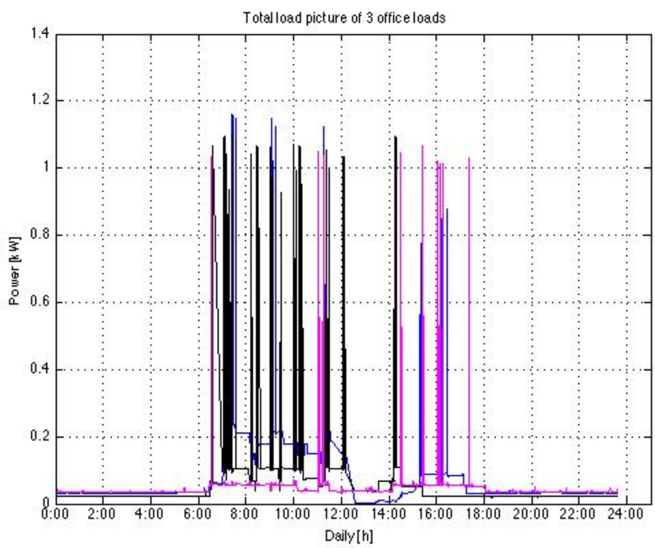


Figure 36: Represent the varying load of three distributions supplying office equipment at *Bjerke Upper Secondary School*, see the digital attachments for the measurement results.

The loads that are represented in Figure 36 are:

- Loads connected to socket in room 01085-88: Office equipment of 1620 kW
- Loads connected to socket in room 01081-85: Office equipment of 1620 kW
- Loads connected to socket in room 01089-91, 01095: Office equipment of 1620 kW

Assuming that the loads measured could be representative load profiles for all the office loads installed, typically for one floor there could be office loads such as:

- 11 loads acting as of profile blue
- 11 loads acting as of profile black
- 12 loads acting as of profile magneta

Resulting of a total power demand of approximately 15 kW, this can be seen from the total load profile for the devices plotted using MATLAB.

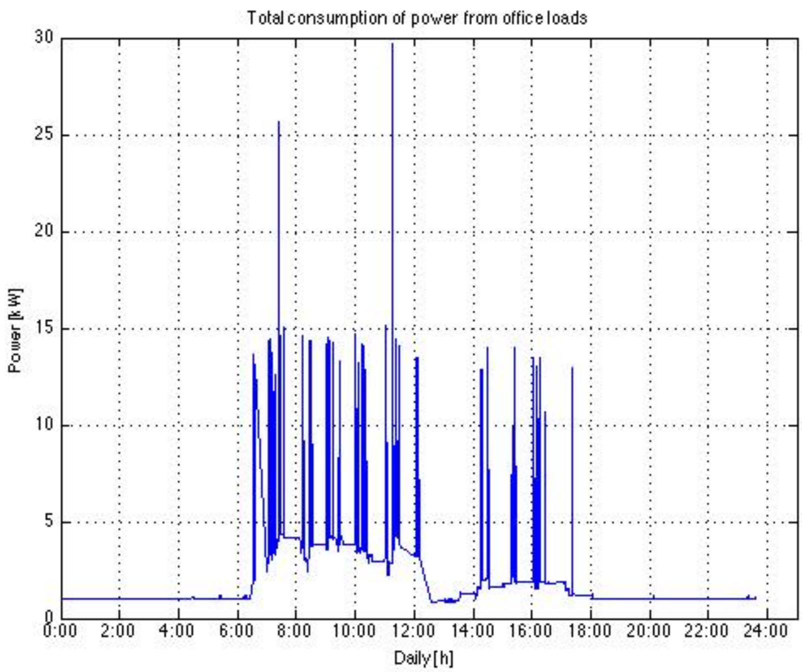


Figure 37: Represents the daily power consumption from office loads, see the digital attachments for the measurement results.

In the term *office loads* included are devices such as servers, stationary and personal computers, additional screens and mobile phone chargers.

From Figure 34 and 36 it is possible to detect that the load curve for each load, does not necessarily include as much power as the devices installed are resulting in. This could be a result of not all the devices being turned on during the 24 hour measuring period, and/or the devices not operating at full load.

This result in a demand of 20 kW for the DC system when operating at full load.

Technical Data Utilized

The technical data utilized in this project for the central VSC performance specifications, was a model for a 20 kW IGBT converter, developed by SINTEF Energy Research AS. The IGBT converter is designed as a generally useful building block for DC-DC converters, AC-DC converters and motor controls [75].

Table 16: The parameter description for the 20 kW IGBT converter [75], see the digital attachments for the datasheet specifying the parameters.

Parameter	Value		
Inductor	2 mH	50 A	Siemens
Resistor	0.2 Ω		
Converter on DC-side	3300 μF	47 kΩ	

In the performance calculated, defined below in Table 16, the inverter functions included are [75]:

- Associated power circuit
- Switching logic
- Galvanic isolation
- Generation of down time
- Protection functions

Properties such as regulation and modulation of the power are not part of the converter, but are included in the control system implemented by using [68]-[72].

Table 17: The calculated performance of the 20 kW IGBT [75], see the digital attachments for the datasheet specifying the parameters.

<table>
<tr><th colspan="4">Performance (Calculated)</th></tr>
<tr><td>DC Voltage</td><td colspan="3">0 – 650 V</td></tr>
<tr><td>Switching frequency</td><td colspan="2">0 – 25 kHz</td><td>0 – 100 % Pulse Width Modulation</td></tr>
<tr><td>Capacitor bank</td><td colspan="2">3300 μF</td><td>700 V</td></tr>
<tr><td rowspan="4">Power capacity per user branch;
• DC operation
• Loss limited
• Dissipated efficiency at 500 W</td><td>25 A</td><td>500 V DC</td><td>20 kHz switching</td></tr>
<tr><td>50 A</td><td>500 V DC</td><td>10 kHz switching</td></tr>
<tr><td>70 A (Measured 67 A without disconnection of temperature)</td><td>300 V DC</td><td>10 kHz switching</td></tr>
<tr><td>105 A</td><td>500 V DC</td><td>2 kHz switching</td></tr>
</table>

As there are not specified parameters for the device at a voltage level of 230 V, the parameters closest to this voltage level, 300 V, was used. Even though the voltage level can be increased to 500 V for the device, it does not imply that the power level of the device can be increased. This is a result of the inductor limitations in the device, with a current limitation of 50 A.

$$i_{ac,RMS} = 50\ A \qquad V_{ac,RMS} = \frac{200}{\sqrt{2}} = 141.42\ V \qquad S_{3\varphi} = 3 \cdot V_{ac,RMS} \cdot i_{ac,RMS}$$

By calculation these relations result in: $S_{3\varphi} \approx 21\ kW$.

Simulations with variable switching frequency was performed, to see the influence of a lower or higher switching frequency. It was clear that the switching signals where greatly affected by the switching frequency, and that with reduced switching frequency the losses in the device increased, and conversely. By testing these variations, it was apparent that the switching frequency was important in controlling the power in the VSC.

As a result of measurements at *Bjerke Upper Secondary* School and limitations in devices available for the purpose, the power delivered by a DC system considered in this case is a 20 kW system.

Power Loss Calculation in the VSC

By measuring at the input (AC side) and output (DC side) of the converter, the power in the VSC in simulation, the loss of power can be calculated.

Table 18: Represent extracts from the results measuring the current, input power and the output power at the 20 kW VSC, see Appendix 17.15 for the measurement results from the scope.

Input Power, AC (kW)	Output Power, DC (kW)	Power loss (kW)	Efficiency	Error
22.8	20.95	1.85	92 %	8 %

The efficiency of the VSC was calculated by the relation (9.24) and the percentage error was calculated by the relation (9.25). An efficiency of a VSC of 92 % was detected.

10 Comparison of Simulated AC and DC System Solution

As the models for conversion of power that are integrated in equipment today are simulated and meet required standards, it is time to consider the energy loss and energy saving potential with an AC versus an DC system solution.

10.1 Energy Considerations

From the simulation in MATLAB and PSIM it was occurred an instantaneous power loss of 5 W and 7 W, respectively for the 100 W and 270 W PFC. The term instantaneous power indicate; *that at one instant of time, the loss of power resulting from the PFC being loaded with a specific resistivity* [61].

The power losses in the converter devices designed in this study are considered by using the measurement results from *Bjerke Upper Secondary School* as a base on how the load image can vary throughout the day, assuming all of the fluorescent lighting devices installed in the building could be replaced with LED lamps. From the waveform in Figure 38 for lighting equipment, and Figure 39 for office equipment, the power loss could be calculated.

To simplify the energy considerations, it is only concerned that the system consists of lamps (LED) and office equipment (stationary computers) in the further considerations of an LVDC system.

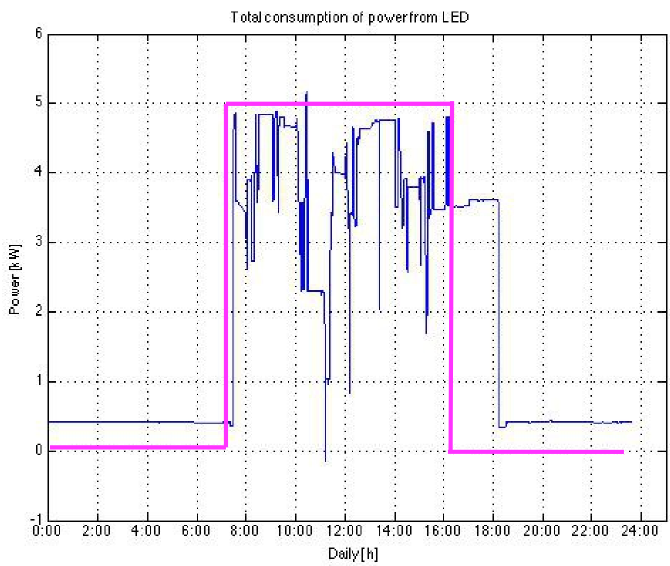


Figure 38: Represents the total consumption of power from LED (blue), and the approximate curve (magneta), see the digital attachments for the measured results.

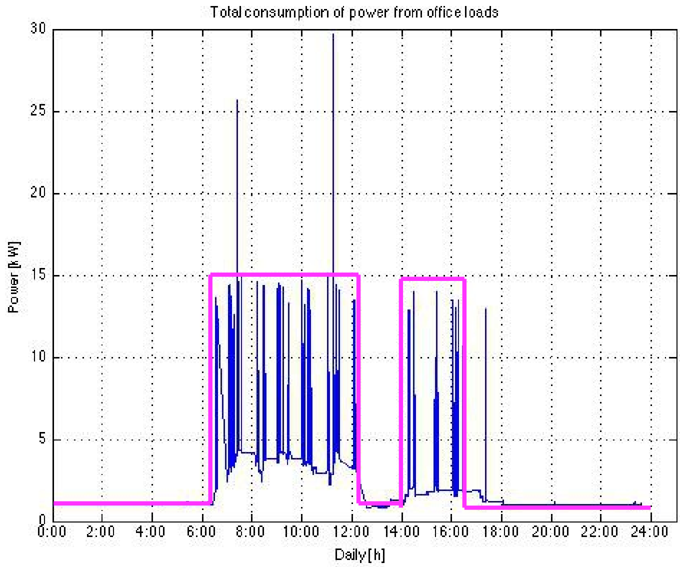


Figure 39: Represents the total consumption of power from office loads (blue), and the approximate curve (magneta), see the digital attachments for the measured results.

Assuming the equipment is in ON mode, the instantaneous energy loss for a device with a 100 W and 270 W PFC, respectively, can be calculated from the simulation results.

100 W PFC

$$Energy\ [kWh] = 3 \cdot 10^{-3} [kW] \cdot 1[h] = 0.003\ [kWh]$$

270 W PFC

$$Energy\ [kWh] = 7 \cdot 10^{-3} [kW] \cdot 1[h] = 0.007\ [kWh]$$

Furthermore, considering a AC system supplying the equipment connected by AC-DC converters, as the existing system solution:

From Figure 38 it can be concluded that the lighting equipment are ON in approximately t_{270W} = 8.5 hours per day, from 07:30-16:00, with a power consumption of respectively 5 kWh.

This corresponds to 50 LED lamps à 100 W, which would result in a loss of energy of:

$$E_{loss,\mathrm{LED}} = 0.003kW \cdot 50 \cdot 8.5h = 1.3\ [kWh]$$

While it from Figure 39 can be concluded that the office equipment are ON in approximately t_{270W} = 7.5 hours per day, from 07:00-12:00 and 14-16:30, with a power consumption of respectively 15 kWh.

This corresponds to 56 stationary computers à 270 W, which would result in a loss of energy of:

$$E_{loss,comp.} = 0.007kW \cdot 56 \cdot 7.5h = 2.9\ [kWh]$$

The total loss for 20 kW load for one day is then **4.2 kWh**, by utilizing the relation:

$$E_{total,loss} = E_{loss,LED} + E_{loss,comp.} \tag{10.1}$$

From Figure 38 and 39 it can be seen that when the equipment are ON, it can be approximated to have constant load, and in a period where the load is not constant and operating at full load the power output to the DC side can be calculated by the relation:

$$P_{out,dc} = \eta \cdot P_{in,ac} \tag{10.2}$$

The total energy loss for these devices can then be calculated for a week or a longer time period, assuming that the load behaves equally as the load profile each day.

Moreover, considering a DC system supplying the equipment connected, as the new proposed system solution:

20 kW VSC

Calculating the total energy loss of the 20 kW VSC. The average time when the devices are in ON mode, $t_{average} = 8h$. Calculated by the relation:

$$t_{average} = \frac{t_{100W} + t_{270W}}{2} \tag{10.3}$$

From the simulations a performance of η = 92 % was detected, resulting in a instantaneous power loss of 1.85 kW. The total energy loss for one day, 8 h can then be calculated:

$$E_{loss,92\%} = 1.85kW \cdot 8h = 14.8\ [kWh]$$

The resulting energy loss of the VSC is **14.8 kWh**, which is much higher than the energy loss for the identical system without a central converter, the existing AC system solution.

Further calculations has therefore been performed, in order to see at what performance the VSC need to operate in order for it to be a more energy efficient solution instead of the existing AC system, see Table 19.

Table 19: Represents the resulting calculations of energy loss with varying performance of the VSC.

Performance (%)	**Power loss (kW)**	**Daily [h]**	**Energy loss [kWh]**
95 %	1.1	8	9.1
95.5 %	0.9	8	7.2
96 %	0.8	8	6.4
97 %	0.7	8	5.5
97.6 %	0.6	8	4.4
97.7 %	**0.5**	**8**	**4.1**
98 %	**0.4**	**8**	**3.6**

From Table 19 it can be concluded that the loss of energy is reduced by having a VSC with a performance **> 97.7 %,** when comparing with the energy loss of 4.2 kWh from the existing AC system.

Traditionally, the performance of converters has had the performance distribution:

Table 20: The traditional deviation of size of converts versus performance [42].

Power converter	**Performance (%)**
100 W	80 %
1 kW	90 %
20 kW	95 %
10 MW	98 %

Eltek, a company that specializes in direct current equipment with one of the world´s highest efficiency converter products, concentrates especially with converters in the range 1-2 kW. In datasheets for their most efficient rectifier products, the performance are > 95 % at 30-70 % loads and also performance > 96 % in some of the products [76]-[81]. Specialists on converters believe that since it is possible to have an efficiency of above 95 % for converters at a power level of 1-3 kW it will be possible for the great electric manufacturers to create 20 kW converters at a performance of 97-98 % [42]. It might also be possible to create converters for a bigger system at a bit higher power level, and then for the converters to supply a larger system than 20 kW [32].

10.2 Comments On Results

In real time, devices power consumption will vary and therefore the amount of energy consumed depends on factors such as:

- The load profile of the appliance; how many hours per day the equipment is in ON mode
- Variable voltage and current delivered

- Disturbance from the grid forwarded into the device as a result from the converter process, making it necessary to introduce filters which result in additional power losses
- The energy consumption of the device
- Depends on how good the electronic components are in the device at variable load, and the control systems switching frequency

These considerations are included in the model to some extent, and it will be benefitual for further considerations of introducing a DC system to evaluate the impact of this on the simulation models. Moreover, it was a challenge met in this study, to find a simulation program where the details of the converter design could be designed, in addition to being able to run a simulation with a varying load image, without having temporal long simulation time. It was therefore chosen to emphasize the converter design, so that it was possible to thoroughly consider the loss they provide and constitute, and then look into the opportunity of possible energy saved with introducing a central rectifier, instead of one in each equipment device. One of the shortcomings of the model presented in this study, are that the results are current for a full load picture of the system, which in reality will vary as seen in the load profiles from the measurements performed at *Bjerke Upper Secondary School*. So this study represents the potential of energy savings in a system solution working at full load.

11 Wiring Losses in AC versus DC Systems

In cooperation with Morten Halten Eggen at COWI, there was developed a FEBDOK analysis for two sub distributions at *Bjerke Upper Secondary School*: +01=433.22 and +01=433.30 [50]. The original DC loads in the distributions were designed in FEBDOK, were information about the cable cross sections, the power drawn from each load, the voltage level and the type of supply system was specified. There were performed two FEBDOK analysis, where the two different types of power supply source where introduced, respectively an AC and a DC source, see Appendix 17.16 and the digital attachments for the designed system and detailed sub distribution content for the analysis in FEBDOK.

The background for performing an analysis in FEBDOK, is due to the wiring losses influence on the system efficiency, as wiring represent electrical losses. The losses in the wiring are influenced by the cross-sectional area, the length of the wire, and especially the operating current of the system [40].

Furthermore, the idea was to confirm the results from earlier studies, that one can use existing cables for a DC system with a voltage level of 230 V as for an AC system, and still maintain the standard [26]. For instance, in [32] there have been performed a study concluding that a DC system at 230 V at cable length up to 80 m for normal office loads, result in less losses than for the same system with AC, and that the voltage drop restriction might be a less constraining factor than the maximum current condition.

Moreover, in [14] it has been concluded that the current are lower in a single-phase DC system than a single-phase AC system delivering the same amount of power, due to the power factor. The power factor is defined as [57]:

$$PF = \cos\varphi = \frac{|P|}{|S|} \tag{11.1}$$

where P is the active power, S is the apparent power, and φ is the angle between current and voltage.

In an AC system, the power factor has a value between 0 and 1. This is a result of stored energy in the load returning to the source, or it could be a consequence of non-linear loads interrupting the waveform of the current (drawn from the source) and this will give increased apparent power (larger than the active power). This can be seen by the relation [82]:

$$S = P + jQ \tag{11.2}$$

In an electrical system, a load with low power factor will have a higher current than a load with high power factor, for the same amount of power delivered [14]. With increased current, the losses will increase resulting in increased cable cross sections to maintain the standard requirements [26].

Furthermore, in a DC system with only DC loads connected, in $cos\varphi = 1$. This is due to the fact that no loads introduce reactive power to the system, and the apparent power would therefore be equal to the active power.

Moreover, it is concluded in [14] that it is possible to use existing cables for all single phase DC loads at 230 V DC.

In [31] it is stated that the current-heat-loss in a cable for AC is larger than the loss for the same cable supplied by DC. This is a result of AC current not distributing evenly throughout the cable cross-section.

11.1 Results From the FEBDOK Calculations

The architecture of the systems where designed equally in both the AC and DC system case, in terms of cable cross sections and load connected, with only loads that originally are DC applicable connected, and some equal loads with different cable length and cross section, in order to look into if the system satisfies the requirements in [26]. The AC system was defined as a three-phase system while the DC system was defined as a single-phase system, due to the fact that the comparison of the losses and applicable cables would be the result of an analysis of the existing system solution up against the proposed system solution.

The standard requirements to the voltage drop defined in [26]:

- Notification threshold voltage drop in total: 4 %
- Notification threshold voltage drop to the “last” distribution: 2 %

This are the voltage drop to distributions calculated on the basis of the designed load current in the distribution. Moreover, IEC has defined 230/400 V as the standard voltage level for electrical systems with a voltage drop tolerance of $\pm$ 10 %. In [26] the voltage drop limits are discussed, and the recommended voltage drop between the installation´s feed point and the electrical equipment is recommended to not exceed the limit of 3 % for lighting equipment, while the suggested voltage drop for other equipment is a voltage drop of 5 % [4][26][31].

Table 21: Presents the definition of parameters in the systems, see Appendix 17.16 and the digital attachments for the FEBDOK report.

Definition of System Parameters	
Distribution System	TN-S
System voltage	400 V
Calculations starts from	Distribution
System frequency	50 Hz
Voltage drop is calculated from distribution	Starting point

From the analysis performed in FEBDOK, the voltage drop over the cables in the different sub distributions is calculated, which result in equal voltage drops in the AC and DC system. While, the load current for equal loads is different for the AC and DC system, respectively. Consequently, the loss of power in the cables will also differ in the two different systems.

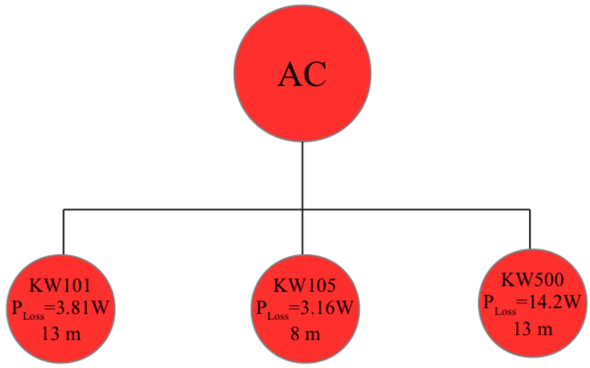


Figure 40: Presents the extracts from the analysis in FEBDOK for the AC system, see Appendix 17.16 and the digital attachments for the detailed analysis of the system.

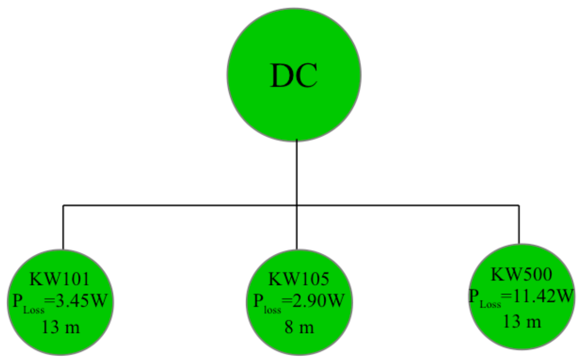


Figure 41: Presents the extracts from the analysis in FEBDOK for the DC system, see Appendix 17.16 and the digital attachments for the detailed analysis of the system.

In Figure 40 and 41 extracts from the FEBDOK analysis are presented, with equal loads with different supply system together with the losses of the cable supplying the specific load, where KW101 and KW105 are LED lighting, and KW500 are a socket with office load connected.

Table 22: Presents the $\cos\varphi$ planning values in the two different systems, AC and DC, respectively [52][83], see Appendix 17.16 and the digital attachments for the detailed analysis of the system.

Power Factor		
System	**$\cos\varphi$, planning value**	
AC	0.9	General planning value for AC systems
	0.95	High efficient planning value for LED
DC	1.0	General planning value for DC systems

There exist LED drivers for fluorescent lighting with certain differences in quality. A LED drive of bad quality could have a power factor = 0.4, while a LED drive of good quality typically could be corrected to a power factor = 0.95 [83][84]. Moreover, this will cause the difference in the losses in cables for the supply of AC versus DC to be smaller. However, DC will still result in minimum loss, as can be seen in Figure 40 and 41.

On the basis of the FEBDOK analysis, it can be concluded that the same cables can be used in AC and DC systems, for the voltage level of 230 V. It has not been looked detailed into whether the efficiency of using DC instead of AC affects the efficiency of the cables as it does not seem to be a crucial factor in terms of energy loss/saved with having a new system solution. Although, the results of the simple analysis performed in FEBDOK represented potential of decreased power loss in cables in a single-phase DC system.

Moreover, the results in [14] represents that it is more efficient to use DC instead of AC for normal office loads as long as the cable length does not exceed 80 m. It can be seen from the FEBDOK analysis that with exceeding cable length over 80 m, the crucial element is the cable´s cross section of the cable, which has to be increased in order to satisfy the IEC requirements [26], see Appendix 17.16 and the digital attachments for the detailed analysis of the system in FEBDOK.

With the FEBDOK analysis as a basis, in addition to the results of [14], [32] and [40], it can be concluded that using DC result in reduced power losses in the cables. However, there exist electrical losses from the wiring in a system, the wiring losses does not constitute the major difference in the choice of having an AC or DC system solution. The wiring losses for an AC and DC system are nearly equal, but with some cases of higher losses in system supplied by AC.

12 Future Opportunities with an LVDC System

Considering the climate changes the world is in today, it is important to try to reduce the consumption of non-renewable energy sources for generation of electrical energy. With the possible invention of a future LVDC system in buildings, a spectrum of opportunities follows.

An LVDC system gives opportunities for direct exploitation of DC with connection to Renewable Energy Sources (RES) or Distributed Generator Sources (DGS). With the invention of Smart Grids in cooperation with Smart Meters and the integration of an LVDC system in buildings, it might be that future buildings could be self-sufficient with energy, achieve greater energy efficiency and result in minimal losses. These concepts could also be integrated together with fast charging of EV's (Electrical Vehicles) by having a local battery charged by energy produced by RES and DGS integrated in a building, as the case in [85]. This idea makes it possible to avoid the main grid and introduction of imbalances to the system caused by fast charging an EV [85].

Moreover, an LVDC system allows for new solutions and inventions in terms of Uninterruptible Power Supply (UPS) for sensitive loads.

These future opportunities with LVDC system has not been the main focus in this study. However, these potential possibilities are important to mention in the content of a DC system. This is due to the fact that an LVDC system might not outperform the existing AC system in terms of only energy efficiency, although these opportunities with DC might weight up the arguments for an LVDC system.

12.1 LVDC System with Connection of RES

DGS could be integrated in an LVDC network, as they produce DC power directly. The DGS would need a conversion step from DC-AC to be able to deliver power to the grid and a conversion step from DC-AC to connect to the distributed AC network. With an LVDC network in addition to the AC distribution network, one conversion stage could be removed and result in decreased losses and increased energy efficiency [14]. The standardization process of having DC Microgrids with connection to DGS is in the initial phase, however the ISO-95 standard proposed deals with the integration enterprise and control system of the system solution [86].

There are many benefits with having DGS and Renewable Energy Sources (RES) integrated in a separate DC system; no AC losses, no reactive power issues (the applications are mainly loads/resistances), no need for power-factor correction, and no frequency synchronization issues if the system is disconnected from the AC grid [8].

DGS and RES supply variable amount of power depending on factors such as weather conditions and type of renewable. The amounts of power the DGS and RES are able to supply are therefore hard to predict, and less stable than the power from the main grid [7]. The result of these variations are fast load changes, decreased reliability and stability of the system due to high-frequency oscillations, which wear and tear the connection between the out-dated current grid and the DGS. These variations affect the lifetime of especially the mechanical equipment, which tend to wear out before the static electronic devices. This phenomenon influences the maintenance cost and the efficiency of the system [8].

The infrastructure of the existing grid needs to be modified to be able to operate by stable and efficient conditions with the connection of an increased level of DGS and RES [8]. The system depending on DGS are in need of back-up solutions because they mainly rely on renewables, unlike AC systems, which have more reliant capacity [7].

In [8], the requirements necessary to ensure an energy efficient DC system with connection to renewables is having an Energy Control Centre (ECC) with these properties listed:

- Bidirectional power flow operation
- Dynamics decoupling of interfaced systems
- Bidirectional fault current interrupt capability
- Metering and communication functions

The idea of having DGS and RES connected to the distribution network, are known as the concept Smart Grid. The sense is to connect different sources of distributed generators of renewables on the supply side, and utilize the concept of demand-side-management. It is desirable that microgrids will gain higher reliability by being well designed, and more efficient, environmental friendly, flexible and more immune to power issues taking place in the network compared to the existing distribution system. It is still a challenge in investigating how the connection of Distributed Energy Sources (DES) could impact the stability of the main grid and the technical integration of a variable source of generation and the need for cost efficient back up supply [25][63].

If the concept of Smart Grid is successfully integrated in domestic and commercial buildings in the future, integrated building automation with lighting, IT equipment, cooling system of sources as wind and solar energy could make an optimized solution with a DC system, compared to the AC solution applied today. An example of the increased efficiency with introducing DC systems are according to ENIAC 2011; "a DC supply for Variable Speed Drive (VSD) motors with a central rectifier will significantly increase adoption of these drives, resulting in energy savings of more than 10 %", [87].

12.2 Uninterruptible Power Supply System AC versus DC

In recent years, companies such as Intel, Schneider Electric, and Sun Microsystems participated in technology-based development projects to identify the advantages of DC power distribution for supplying UPS systems [40].

Schneider Electric performed a study focusing on the comparison of high efficiency AC UPS versus DC UPS power distribution for Data Centres with assumed 50 % load. The data applied in the AC distribution system are numbers based on actual equipment that can be purchased today. The values used in the DC distribution system are on the other hand based on preliminarily manufacturer´s data, estimates, and calculations [40]. A conceptual 380 V DC distribution system is proposed, as a possible solution to the inefficiency problem based on the possibility of building a DC UPS that is more efficient than the AC UPS. Further considerations in the model [40]:

- The elimination of the power distribution unit (PDU) transformers will reduce electrical losses
- The possibility of perhaps improve the efficiency of IT equipment power supply beyond the improvements possible in an AC bus system
- That the supplied IT equipment has been modified to accept DC

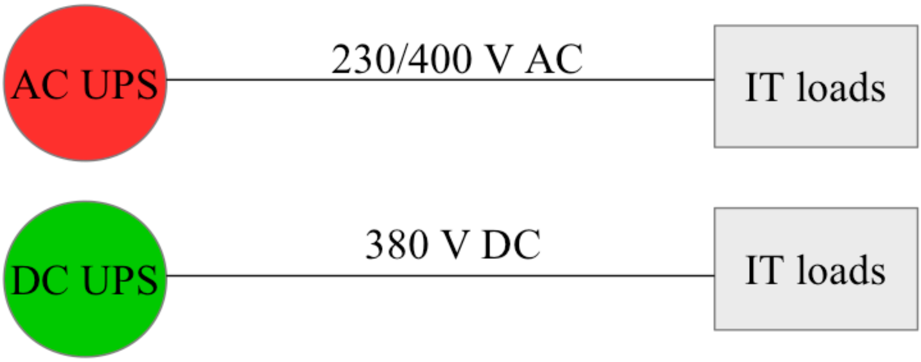


Figure 42: Represents the architecture of the systems modelled trying to identify opportunities with high efficiency AC UPS distribution and high efficiency DC UPS distribution (hypothetical).

In recent years, inefficiencies of 30 % and less have been detected in operating data centres. The inefficiencies is primarily due to factors such as [40]:

- Inefficient IT device power supplies
- Inefficient transformer-based power distribution units (PDUs)
- Inefficient UPS system
- Operation and loads well below the design rating of the system, which enhances all of the above losses

In [40] it is performed a calculation on the potential benefits with introduction of DC UPS, by the use of the equation:

$$\begin{aligned}\Delta\eta = \eta' - \eta = (1 - loss') - \eta &= \big(1 - (1-\eta)\cdot(1 - PSLR)\big) - \eta \\ &= (\eta + PSLR - \eta \cdot PSLR) - \eta \\ &= PSLR \cdot (1 - \eta)\end{aligned} \tag{12.1}$$

In (12.1), η represent the AC power supply efficiency, η' represents the efficiency with modifications in the PSU and DC supply, and PSLR is the power supply loss reduction as a result of the conversion to DC supply. By using the highest detected efficiency of a DC system of 95 %, and assumes reductions in losses in the PSU by 20 % as expected in [41] with conversion to DC supply, the resulting benefit of efficiency is only 1.0 % [40]. This result of only 1 % improvement with conversion of system supply system is greatly affected by the efficiency of the PSU in the first place. In the case of data centres, as these results are calculated for in [40], the efficiency is high in the base case. So, the conversion to a DC system could result in greater efficiency improvements in systems with power supplies with lower efficiency.

Moreover, it is presented in [40] that the latest development of AC UPS reduce the losses by 5 times as much compared with earlier developments of AC UPSs, and it is also stated that: “there is no longer any evidence that a DC UPS of greater efficiency can be created”.

It is concluded in [40] that the existing AC UPS power distribution system today already achieves correspondingly the same efficiency as a hypothetical DC UPS power distribution system would gain in the future. Figure 43 indicates that the efficiency for the Symmetra MW 1000 kVA delta-conversion UPS has an efficiency rating of 96.2 % and the Symmetra PX double-conversion UPS has an efficiency rating of 96.3 % at 50 % load (these ratings are with the output regenerated and conditioned by the on-line output converter, a UPS eco-mode greatly increases the efficiency) [40][88].

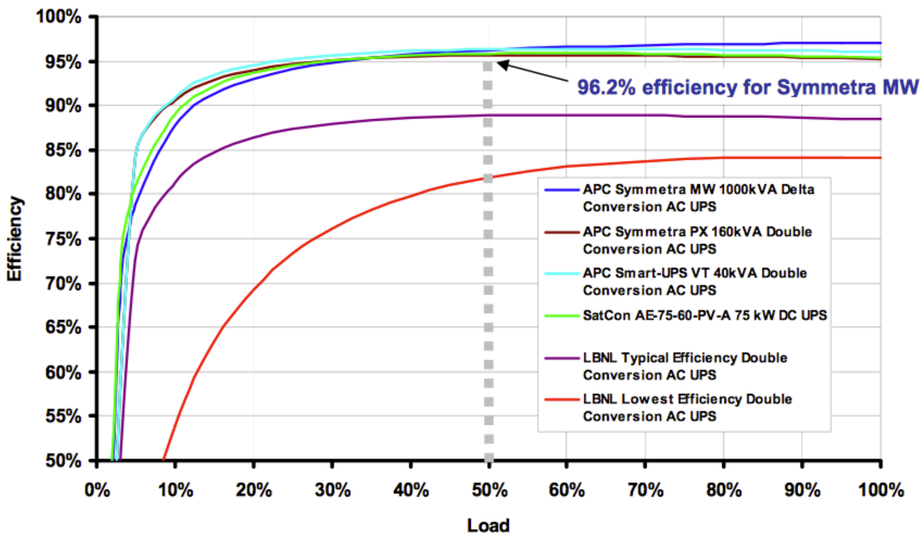


Figure 43: represents a comparison of efficiency of several commercially available AC and DC UPS systems [40][88].

The DC UPS efficiency values are hypothetical, as appliances applicable to DC with standard specifications are not available on the market yet. However, Emerson was able to give The Green Grid data, that describes a DC UPS efficiently (at a 50 % load) as 95.1 % and Delta Electronics an efficiency of 97.7 % for a DC UPS, (the architecture of the DC UPS from Delta Electronics does not satisfy the grounding standard of the ETSI 300 international standard) [40]. As a standard for DC telecommunication rectifiers is under development by the US EPA, the EPA published data of the efficiency of DC telecom rectifiers for DC rectifiers for 48 V telecom plants, that it is possible to adjust for 380 V DC use. The data reveals that it is possible to create DC UPS that are as efficient as around 95.5 %, and this result in an increase in efficiency compared to the first generation DC UPS systems with an efficiency of 95.1 % [40]. Still, the greatest 380 V DC UPS plants that meet the international standards safety requirements are 95.0 % efficient [40].

Table 23: Represents the potential efficiency improvements in AC and DC UPS's.

UPS Potential efficiency improvement	
AC	**DC**
• In the next few years, it is not expected introduced efficiency improvements, as the efficiency today is 96.3 %.	• Currently, the efficiency values which formed the basis for this analysis were values based on the highest performance data submitted to the EPA, and there is no DC UPS with improved efficiency that also meet the safety regulations. • By reasoning the opportunities with DC UPS it is conceivable that it could gain an greater efficiency.

It can therefore be concluded from [40], that it is not energy efficient to replace todays existing AC UPS's with DC UPS's. Despite these results, in 2013 ABB launched a pioneer project within the world of electricity by introducing a 380 V DC-powered datacentre at the Green datacentre Zürich West. This pioneering concept is now concluded to be an energy efficient system and an option to the AC system [36].

The system solution that was challenged in [36] was the traditional solution of having AC UPS technology, which frequently use double conversion UPS running in economy mode in order to obtain increased operating efficiency. During this mode, the AC UPS is principally bypassing the AC-DC and DC-AC converters to obtain reduced switching losses. The proposed DC system solution had one AC-DC conversion point and the DC power would then be directly distributed to the servers by using a DC-PDU (Power Distribution Unit) having less electrical switchgear, cable and parallel modules. The end use equipment would still be able to obtain the same reliable system and uptime, but with reduction of components [36].

12.3 Datacenters

In electrical systems for datacenters, the conversion from AC-DC constitute of a great amount of energy dissipation. Normally, AC delivered from the grid, has to be stepped down in order to obtain an appropriate voltage level for building equipment. Further on, the AC is converted to DC and fed into an UPS. The DC power from the UPS is then again converted to AC to be transported in the installed cables, and at the end use equipment the power is again converted into DC. This result in four conversion stages, which can be avoided by introducing a DC system [36].

In [45] it is proposed to convert AC-DC at the in-feed-point in the building, and then distribute DC in the building. Introducing a DC system would result in 25-40 % less square footage than by having a AC system, due to the possibility of having IT equipment directly connected to back-up batteries. By applying a DC system solution to a datacenter, the utility bills is reduced by 10-20 %, according to Trent Warehouse, the VP of marketing for power electronics at General electric [36].

Table 24: Represents the results of introducing DC to a datacentre [36].

Results of introducing DC to a datacentre	
Increased energy efficiency	10 % [kWh]
Capital cost reduction	15 % [$]
Space savings	25 % [m^2]

The introduction of a DC datacenter has resulted in an increase of 10 % in energy efficiency compared to an AC datacenter, at 40-60 % server load "from grid to chip". Further on, the capital costs is reduced with 15 % for the electrical infrastructure, and saving space of 25 % m^2 compared to the traditional AC supply system [36].

In [36] ABB's head of Low Voltage Production division, Said Tarak Mehta, is quoted: "Across all our business areas, customers are asking for improved reliability and energy efficiency, and DC power is an effective solution".

12.4 Economic Evaluation of Opportunities with DC

In [9] it has been performed an economical evaluation of comparing the traditional AC distribution system with an LVDC system, without connection to renewables and sensitive loads with back-up power supply. It is assumed that the network structure in an AC and DC system are equal and that all cables are installed by ploughing. The results indicate that choosing a bipolar system solution, due to decrease in cable cross-sections and number of transformers reduces the network costs.

However, it is further discussed that an LVDC distribution network will introduce new power electronic devices. These devices introduce increased costs due to their short lifetime, which is estimated to be ¼ of the traditional devices, and result in additional maintenance costs and costs of converters [9].

Still it is concluded that the total costs of the LVDC distribution network decreases by 12 %, but the investment costs has increased with 46 % in the new system solution, compared to the existing AC system. In the analyse these expenditures has been considered:

- Network investment costs
- Power electronic devices, investment
- Network power loss costs

- Power losses in power electronic devices costs
- Outages
- Maintenance and repair

These results indicate that the economic evaluation of a simple LVDC system is benefitual. The earth fault protection for an LVDC system is not considered in this analyse, and is something that has to be weighted up against this result, because earth fault protection for LVDC systems are more expensive than the protection equipment utilized in AC distribution systems [18].

In [32] an economic analyse is also considered, in terms of replacing the traditional UPS system for back-up supply with battery blocks. An example is evaluated, where the expenses for connecting 44 computers consuming 180 W for 10 minutes back-up, to either a UPS system or to a battery block, respectively. The lowest-price UPS at rated power 180 W and 10 minutes back-up time represents a cost of \$ 87.5 for each UPS. This result in an expense of \$ 3850 for having one UPS connected to each sensitive load. The expenditures for a corresponding back-up supply system using a battery-block is lower, even in the worst case (120 V), where the expenses decreases with \$ 1400 and has six times the capacity in back-up time, when considering a 230 V system in both the AC and the DC case [32].

Furthermore, in [36] a DC system solution versus AC system solution are considered supplying data centres, where it is concluded that the capital costs are reduced by 15 % in the case of introducing a DC system.

It can be seen from these earlier case studies, that on the economic side, an LVDC distribution system seems benefitual in the case of a simple and advance LVDC system solution.

The economic benefits and disadvantages considering LVDC system with connection to DGS and RES have not been evaluated, and is a very complex system solution to consider. There exist numerous factors that will affect this economical evaluation, such as:

- Predicting weather conditions
- Utilizing “free-green-energy”
- The technical costs with installations and maintenance
- The costs of the stabilization effects on the main grid
- Cost of having back-up supply during peak periods and periods of the DGS and RES not being able to supply enough power to cover the demand
- The environmental benefits

However, this is an evaluation that should be performed before this connection is considered energy efficient and cost effective, and an economic evaluation of an LVDC system should be considered where the costs of sufficient protection for the system is included.

13 Discussion

13.1 Requirements, Technical Challenges & Safety Aspects

In summary, it is convenient to look into having an LVDC network because the end use equipment are mainly original DC loads, and does not represent high power loads.

It has been seen from reviewed studies, that the efficiency of DC power reduces significantly with increased cable length, especially for low voltage levels. It could therefore be efficient to supply a standard voltage level in the LVDC system and to have DC-DC regulators in the end use equipment that control the required DC voltage for the application.

As of this writing, no separate standard has been developed for DC electrical distribution systems in buildings. In current regulations, the safety requirements for AC and DC distribution systems are equal: "ensure safe operation of the electrical distribution system" [2]. There is on-going work on the area of developing DC standards, and it is one of the largest challenges and crucial factors in introducing a new system solution.

In [26] it is stated: "For electrical equipment installed or used in a work zone, must be electrical isolated in accordance with IEC-400-4-4.1". These regulations set the focus on, that one does not come apart the galvanic separation that currently exists in converters. This means that with an introduction of a DC system at a voltage level that could be directly applied to the equipment, DC-DC regulators still has to be integrated in order to obtain the requirements for a galvanic separation or sufficient isolation.

In short, a low voltage distribution network that is applicable to DC power has to fulfil the same requirements and purpose as of the existing AC distribution system with respect to; standardization, maintenance and lifetime issues, and the environmental considerations [9].

From earlier studies, [14], and the analysis performed in this study in FEBDOK, it can be concluded that the existing cables can be utilized in an LVDC system at a voltage level of 230 V DC with decreased losses compared to the existing AC system solution. The selection of voltage level is therefore important. With a voltage level of 230 V DC, the power losses are measured to be lower than for the 230 V AC system, with exception of three phase loads. Earlier studies detect that a standard voltage level of 230 V DC is sufficient for normal office loads, as long as the cable length does not exceed 80 m. For higher power loads up to 6.5 kW, the voltage level has to be increased to 326 V DC (equivalent to the peak value of 230 V AC) for systems with a cable length of maximum 47 m and 2.5 mm^2 [32].

One of the largest challenges with introduction of a DC system, is having a central AC-DC converter. The device needs to handle a variation in supplied voltage from + 10 % to – 15 %. In the existing rectifier technology today the electronics is not good enough therefore interference from the AC side will be transported to the DC side. Interference due to harmonics, for example, will be transferred, and a stabile power supply without disturbance will not be gained. Consequently, electronics in rectifiers need to be improved, to be able to supply AC power to the DC side, and eventually integrate DGS to the DC grid [18].

In electrical distribution systems the two main elements of risk are:

- Danger of electric shock (Current flow in harmful level)
- High temperatures that can cause fire, burns and other harmful effects

With DC there are potential for increased safety and reduction of the fire hazard, due to the possibility of reduction in the number of links and components in the system, and again potential fault elements. Furthermore, saved component costs, reduction of conversion stages, increased system efficiency, and a less complex system [7][11]. Even though DC-DC regulators has to be integrated.

Moreover, all electrical installations provide a fire risk to a certain extent. At present, there is no reason to believe that the fire risks associated with DC equipment are greater than those associated with any other electrical equipment. There already exist protection equipment preventing fire caused by DC arcs for photovoltaic for example [89].

Although, with new technologies, new risks are also introduced. It is therefore important to map out the risks and to implement guidance for dealing with fires involving DC systems [90][91]. Also, there are different opinions among professionals on the highest fire risk in electrical systems, if it is the arcs or the heating of equipment [92].

With introduction of a DC system, it is possible to imagine that:

- In some equipment, the voltage could be applied directly (necessary with sufficient isolation in order to satisfy the safety requirements)
- In other low voltage equipment, a transformer and a DC-DC regulator might be necessary to gain the appropriate voltage level for the specific application
- The equipment that is original AC loads, could keep the connection to the existing AC distribution grid

With the development of technical apparatuses and the great use of electronic equipment in homes today, it is realistic to think that various DC facilities will be introduced on the marked in the future. Moreover, it is conceivable that future apparatuses for DC supply can be forced on the market by using standards, in that manufacturer will have to deal with the most energy efficient constructed equipment, if it proves to be DC.

The disadvantage of applying DC is the non-existence of natural zero crossing, to be able to break the power, DC-DC contactors are applied. DC-DC contactors are more expensive and the volume of the component is increased, compared to AC automatic breakers [21]. However, the development of breakers and switches solutions for DC application has started, and some conventional equipment can also be utilized for DC [36][37][38].

13.2 Proposed System Solution

The DC system is hypothetically intended to be supplied AC power from the main grid that is transformed to DC by a central rectifier. The LVDC system has one standard voltage level that supplies all the equipment. Due to safety regulations and to gain the correct voltage level for the appliance, all the equipment must have a galvanic separation integrated in the PSU (Power Supply Unit).

It is desirable to apply the most general guidelines for the distribution system structure, to make the system flexible and adaptable for different floor plans, since a buildings purpose and essential properties changes over time [31]. This is also an argument for choosing a standard voltage level, and having DC-DC regulators in the equipment instead.

In the proposed system solution, a central rectifier, Energy Control Centre (ECC), are supplying the DC system. With an ECC, a main control board is introduced, making it possible to interconnect the AC grid to the DC system. With a centralized point of conversion, it is possible to ensure efficient transmission of generated power [8][48].

In this study, it is assumed that all the loads in the DC system are single phase loads that are compatible with 230 V DC voltage. With these assumptions, it is possible to keep the existing cables as in the traditional system. DC-DC regulators are not integrated in the equipment that would need it, as the loss would be equal in a DC and AC system, and not represent a difference in terms of energy efficiency.

13.3 Simulation on Component Level

The process of converting AC to DC is separated into stages on an instantaneous basis. Therefore, schematically, by using MATLAB with the toolboxes Simulink and SimPowerSystems, and PSIM there were simulated:

- The conversion points of the AC system
- The central conversion point of the DC system

with connected loads.

The focus in the study was to develop a simple model and to look into the main focus areas. The model where thought to possibly be expanded in the future analysis if the results of a simple analysis give a positive conclusion about introducing an LVDC system. *Bjerke Upper Secondary School* was chosen as an example for measurements of a building that could possibly benefit from introducing a DC system in the future.

The AC System Design

Three types of converters where designed in the presentation of the AC system solution that exist today:

- One converter for application < 25W
- One converter for application >= 25W
- One converter for office equipment

The modelling and design process of the converters where characterized by trying to make the design with universal structure, to achieve a general impression and overview of a converter model and the losses in the AC-DC converters. The design codes for converters have variations from one manufacturer to another. And detailed design codes are often kept secret by the manufacturers, and are not very available.

Due to this reasoning, a 20 W universal PFC was designed as a base model, before this model was expanded with other design codes in order to obtain a 100 W and 270 W converter for LED and office loads, respectively.

The power losses resulting from the simulations performed, detected that the converter models designed and modelled in MATLAB, gave graphical models satisfying the IEC requirement classes for harmonics, and the graphical representation of the current and voltage waveforms gave the desired values for the system. However, placing current and voltage measurements in the model for calculation of the power losses in the converter result in very high losses. It was therefore concluded that something is wrong with the model. The source of the large errors was difficult to detect, when the current and voltage were at the appropriate level and the controller working good. It was therefore concluded that the source of the large error probably was caused by:

- The implemented and designed controller
- The solver algorithm implemented in the simulation tool used, MATLAB, Simulink with the toolbox SimPowerSystem

The reasons for concluding that the large losses most likely result from the implemented solver algorithm in MATLAB, is that, when a test of copying the parameter values calculated and resulting from running the model built and designed in MATLAB into a identical pre-built example *Boost power factor correction (PFC) circuit (boost, pfc.sch)* [62], calculation from the resulted simulation gave the expected and realistic values for the power losses in the device.

PSIM is a simulation program great for power conversion and control [62]. It is particularly efficient in simulating converter systems, one has therefore subsequently seen that it could have been advantageous to use PSIM from the beginning of the simulation.

The model applied in PSIM was a model that was predefined and implemented in the simulation tool together with the installation of the program [62]. The model in PSIM was identical to the model built and designed in MATLAB in terms of the components included in the model, the only "physical" difference in the two models are the controller. The controller built in MATLAB is as good as it can be implemented in this simulation tool, and the controller predefined in PSIM is a bit different. It is not possible to implement an identical device as this in MATLAB. It is hard to tell if this is the source of the large losses. Since the two simulation programs both give good curves of the voltage and current, and the controller seems to work in both cases. The remaining difference in the two models are the different algorithms implemented in the simulation programs solver. It could therefore be that the solver implemented in MATLAB being the source of the errors, as the exact same parameters used in the PSIM model as in the MATLAB model give realistic results.

The losses from the running the MATLAB program and implemented into the pre-defined model in PSIM gave losses that are realistic and in the same range as the resulting losses from the design code that the devices are built up of, see [47], [57], and NCP1607 [58], which are indicative. However, the PSIM simulation resulted in losses of 3 W for the 100 W converter, and 7 W for the 270 W converter. From the basis of converters, suggesting that converters around 100 W having a efficiency of 80 % [42], while the results from the simulation performed here gained a efficiency of 97 %, is something that need to take under consideration when evaluating the results. It could be that the gained efficiency in the PSIM simulation of the converters is a bit better theoretically than actually is the result in practice. So, the conversion to a DC system could result in greater efficiency improvements in systems with power supplies with lower efficiency.

Moreover, one of the shortcomings of the model presented in this study, are that the results are for a full load picture of the system, which in reality will vary as seen in the load profiles from the measurements performed at *Bjerke Upper Secondary School*. So this study represents the potential of energy saving in a system working at full load.

From a retrospective point of view, it would have been benefitual to perform further lab measurements to check the validation of the simulated models of 100 W and 270 W AC-DC converters gave realistic results in terms of performance and power losses. For instance by measuring over a stationary computer both the AC and DC side will have to be measured. At the DC side, where the DC side split into different cables with differing voltage levels. It will therefore be difficult to measure the loss when one must measure the current and voltage over each cable at the same instant in time, as the wires also will draw different power affected by the operation of the computer. The measurement of old equipment versus new technology will probably have large variation in terms of the performance of the converter. Due to limited time and new equipment to measure, this where not performed. In addition, perhaps by DC supply, if it is created a standard for DC systems, it might be possible to create a new supply solution for stationary computers where this is considered with one supply cable as for personal computers.

In addition, the validate of the study would possibly been strengthened by building a converter from the start to get a valid source for the performance of the converters, as well as being able to confirm the weakness of the simulations model in MATLAB. This would also have strengthened the conclusion of the study.

The DC System Design

The DC system is presented with an central point of conversion, a VSC, converting three phase AC voltage into single phase 230 V DC. The model utilized was a predefined model developed by Santiago A. Sanchez, where modifications where done to the model to make it work for the chosen voltage level and purpose. In order to map the energy consumption of a DC grid, measurements at *Bjerke Upper Secondary School* where performed.

The measurements performed at *Bjerke Upper Secondary School* gave realistic values that was comparable and gave a good indication on the power utilized by a load that originally is a DC load. The limitation in measuring equipment, limits the broadness of the measurement, therefore a lot less of the electrical installations that was originally DC loads was measured. It was still considered that the measured results could be used to present the load picture of a device, as the original DC loads measured was loads that one could generalize, since many of the measured loads are repeated in buildings.

The measurements was limited to one point of distribution and limited loads, this affects the reliability of the measurements. It can be discussed, if it would have been ought to perform more detailed measurements over each original DC load in the same point of distribution to gain a higher reliability of the measurements. In some of the points of distribution it differs what kind of loads the distribution are supplying, and it can therefore be discussed in what extent the measurements are reliable. However, for the purpose of the measurement results, parameterize the VSC, it was concluded that the measurements was representative.

In summary, the size of the DC system for supplying DC loads of one floor is 20 kW, it might be benefitual with a larger VSC if the building have more DC loads as long as the cable lengths does not exceed 80 m. If so, it might be most efficient to increase the voltage level or having a VSC supplying the DC grid at each floor.

The performance of the VSC was measured to be 92 % from the simulation model, which resulted in a much higher power loss than the power loss for having one converter in each device for the same amount of power delivered in the existing AC system. This could be due to “to good” performance in the 100 W and 270 W simulation, in what is actually the case in real examples. But, using the simulation as the basis, it is clear from calculation that the performance of the VSC has to be increased to > 97.7 % in order for it to be more energy efficient with a DC system supplying the original DC loads, than the existing system. From datasheets at Eltek and experts point of view, it is envisaged that there is possible to make a converter model for 20 kW at a performance > 97.7 %, which make DC an energy efficient replacement of the AC system. Experts believe that it is possible to gain this performance in the future based on Eltek´s products performance for smaller converters developed so far [42], [76]-[81].

Moreover, in [40] calculations has been performed, to see if the efficiency of a system is influenced by variation in load, in the analysis the efficiency of the PSU within IT equipment is included. In [40] it is concluded that the effect of the variation of load (IT equipment) on the system efficiency is so small that the effect does not make a significant difference in the case of supplying AC or DC.

13.4 Comparison of AC and DC System

The reason for alternate power most likely being preferred over direct power, in transmission and distribution in the future, is due to characteristics such as [30]:

- Easy conversion from one voltage level to another, resulting in grid efficiency and reduced losses in the system
- Easy to control and to interrupt in switching and fault situations

Moreover, the dominant loads in a building (power wise) are AC loads, and it may therefore be difficult to avoid not building both AC and DC distribution architecture. This could be costly, but the costs may be equal to the energy saved over time. In addition, in AC systems another aspect that has to be considered, is that the heat loss produced in an AC system has to be compensated with for example cooling, and in these cases if it is possible to avoid the cooling system by introducing a DC system, it would save much more energy than just the savings from the converter process.

For example, it is stated in [30] that: “One estimate says 5 % of all electricity used in the typical US home is lost to conversion of AC to DC power to run DC devices”. This statement could be compared with the results gained from the losses from the simulation of 100 and 270 W PFC, and the 20 kW VSC; considering a system of 20 kW converting AC-DC for supplying original DC loads, with a loss of 5 % will result in a loss of 1 kW. Based on Table 20 and a 5 % loss of power in the conversion process from AC-DC, the performance of the VSC only has to be > 95.5 % in order to be more energy efficient than the existing AC system.

Further on, there might be improvements possible to perform to the simulation models in order to make the 100 W and 270 W PFC with higher losses (if that's the case in real life) and to gain higher efficiency in the VSC. However, in conclusion, the main factor for it being energy efficient to introduce an LVDC system is how achievable increased performance of the VSC is.

For instance, it is good indications that DC equipment with high performance is under development; HVDC systems it has also been represented trends and solutions of “HVDC Brick by Power”, DC-DC regulators, where the input is 330-390 V DC and the output 12V/66A/1800 W with efficiency up to 98 % [36]. In [36] it is described that solutions for 200/400/800 W are planned.

In addition to the importance of performance, is the electrical losses that exist from the wiring in a system, the wiring losses does not constitute the major difference in the choice of having an AC or DC system solution. The wiring losses for an AC and DC system seen from the FEBDOK analysis are nearly equal, but with some cases of higher losses in IT equipment in the AC case.

Although, a theoretical LVDC distribution system would be greatly benefitual, there will still be devices that are much more efficient operating, maintained and built as AC applicable [30]. It therefore realistic to forecast a future system in buildings with a mixed system solution divided in an AC and DC applicable part.

In the United States pioneering projects introduced by The Emerge Alliance detect reduction of 15 % less energy consumed with having LED lighting connected with DC lines, than converting AC-DC [30]. This result detect that a DC system at 24 V only supplying LED lighting are energy efficient. This kind of system solution has not been considered in this study, as these results where detected late in the study. However, this is a concept that should be considered more closely in the future for electrical systems in buildings.

In addition to the development of DGS and the introduction of Smart Grids, the customers are both consumers and prosumers in the energy grid. This will result in customers being able to provide the network with surplus energy from its own distribution system and utilizing green energy from DGS directly in the DC system. This introduction of green energy could increase the profit by introducing a DC system, as “free” energy is utilized. Moreover, it is expected to be supplied the same quality of power with a DC distribution system, as for the existing AC distribution system [27].

These future opportunities with LVDC system has not been the main focus in this study. However, these potential possibilities are important to mention in the content of a DC system. This is due to the fact that an LVDC system might not outperform the existing AC system in terms of only energy efficiency, although these opportunities with DC might weight up the arguments for an LVDC system.

For instance, in China, some facilities largely dependent on DC are developing DC-microgrids; self-containing electrical grid connected to solar panels linked to computer servers and LED lighting systems. This is also the case in Japan, where large centralized converters distribute 380 V DC, reducing power consumption by 15 % compared to the traditional AC system solution [30].

The economical benefits and disadvantages considering an LVDC system with connection to DGS and RES have not been evaluated in this study, and is a very complex system solution to consider. There exist numerous factors that will affect this economical evaluation, such as predicting weather conditions, utilizing “free-green-energy”, the technical costs with installations and maintenance, the costs of the stabilization effects on the main grid, cost of having back-up supply during peak periods and periods of the DGS and RES not being able to supply enough power to cover the demand, and the environmental benefits. However, this is an evaluation that should be performed before this connection is considered energy efficient and cost effective, and an economic evaluation of an LVDC system should be considered where the costs of sufficient protection for the system is included.

There are differing opinions on AC and DC UPS´s, in addition to the supply of DC to UPS´s [40][36]. In [40] it is concluded that it is not energy efficient to replace todays existing AC UPS´s with DC UPS`s. This is due to the theoretically attainable greatest DC UPS that satisfies the international standards safety requirements have a performance of 95 %, while the AC UPS´s gain a performance of 96.3%. Despite these results, ABB launched a pioneering project by introducing a 380 V DC powered data centre at the Green data centre at Zürich West. This pioneering concept is now concluded to be an energy efficient system and an option to the AC system [36]. The introduction of a DC data center has resulted in an increase of 10 % in energy efficiency compared to an AC data center, at 40-60 % server load “from grid to chip”. Furthermore, the capital costs are reduced with 15 % for the electrical infrastructure, and saving space of 25 % m^2 compared to the traditional supply system [36].

13.5 Experts Point of View

In [30] seven different experts within the IEEE Smart Grid has stated their opinion on the future of the distribution system, AC versus DC. It is discussed that in developing countries, where the primary source of electricity most probably will be renewables producing DC, it is likely to think that future village systems will be DC-based.

However, the specialists also consider development of applicable standards and building codes that cover DC distribution in buildings as a crucial factor in making DC distribution systems a reality. Due to the fact that wiring practices, distribution panel ratings, grounding practices, and circuit breaker devices practices will all be affected.

Furthermore, a necessity is the need for an energy router or an advanced central rectifier, in order to connect the DC system in buildings with the AC distribution grid. An energy router would have the property of being able to convert DC from DGS to AC feeding the grid, and also convert distributed AC power to DC for supplying the DC system in buildings. Energy routers are still in early research and development stage [30].

Moreover, it is stated in [30] that: “It might be that the right answer is to use a mixed delivery system in homes and businesses moving forward”.

14 Conclusion

In this study different aspects regarding introduction of an LVDC distribution system are considered, and it can be concluded from the presented research and designed simulation models that:

- Original DC loads will benefit from having a separate DC system in terms of power loss at a voltage level of 230 V DC
- AC loads require high power delivered and it will be most energy efficient to keep the connection to the existing AC system
- An LVDC system of 20 kW size is realistic in the future supplying a floor in a building with DC loads
- An LVDC system supplied by a central VSC converting power from the AC grid is an energy efficient system solution compared to the existing AC system solution, largely depending on the performance of the VSC

Simulations and calculations resulted in a requirement of a performance > 97.7 % of the VSC in order for it to be more energy efficient with a DC system instead of the existing AC system solution with AC-DC converters in each link with a performance of approximately 97 %. Experts believe that it is possible to gain this performance in the future based on manufactures products performance for smaller converters developed so far.

Further on, it can be summarised that:

- An LVDC system might outperform the existing AC system in the future, due to the possibilities with direct exploitation of DC with connection to RES, DGS, and new solutions in terms of UPS for sensitive loads.
- From earlier case studies, on the economic side, an LVDC distribution system seems benefitual in the case of a simple and more advanced LVDC system solution.

A dependent factor with the development of a DC system in buildings is the introduction of building codes and standards regulating the proposed system solution. At present, one does not come apart DC-DC regulators in equipment, due to the galvanic separation that is needed to fulfil the safety requirements. In addition, it will be important to develop a VSC with great performance so an LVDC system is competitive in terms of power loss.

For future systems in buildings it can be concluded that the possibility of a mixed supply system, AC and DC, is realistic and energy efficient.

15 Future Work

There are many important aspects that remain to be considered regarding introduction of an LVDC system in buildings. Due to that fact that this is one of the first analyses conducted at this field, with the proposed system solution, it would be benefitual to continue on the same track to gain reliable results. It will then be important to perform lab measurements of existing PSU's to validate the losses in the converters in different equipment, in addition to the development of a VSC with great performance. It will also be essential to look more detailed into having a separate DC system only supplying LED equipment, as the study in [30] conclude that is an energy efficient solution.

Moreover, it will be central to develop building codes, map out the possibilities of protection equipment and grounding for a DC system in more detail. As well as looking detailed into the connection of DGS and RES in conjunction with the concept of an LVDC system in buildings, in terms of energy supply, energy efficiency and an economic evaluation.

16 References

[1] European Standard, "ETSI EN 300 132-3-1 V2.1.1" [Online]. *ETSI Technical Committee Environmental Engineering (EE)*, France. October, 2011.Available: http://www.etsi.org/deliver/etsi_en/300100_300199/3001320301/02.01.01_40/en_3001320301v020101o.pdf

[2] Direktoratet for Samfunnssikkerhet og Beredskap (DSB)., "Forskrift om elektriske lavspenningsanlegg" [Online]. Justis- og beredskapsdepartementet, 2005.

[3] Ironlaw., (2011, February 22), "AC and DC current: Fundamental differences and a simple explanation," [Online]. Available: http://vr-zone.com/articles/ac-and-dc-current-fundamental-differences-and-a-simple-explanation/11194.html

[4] International Electrotechnical Comission, "LVDC" [Online]. IEC SMB (Standardization Management Board) SG (Strategy Group), e-tech, July, 2011. Available: http://www.iec.ch/etech/2011/etech_0711/tech-4.htm

[5] Diffen LLC., (2013), "Alternating Current vs. Direct Current" [Online]. Available: http://www.diffen.com/difference/Alternating_Current_vs_Direct_Current

[6] Amin M.; Arafat Y.; Lundberg S.; Mangold S., "An efficient appliance for low voltage DC house," [Online]. *Electrical Power and Energy Conference (EPEC), 2011 IEEE*, 5th October 2011. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6070221

[7] Keon-Woo Park; Jae-Bong Kim; Dong-Zoon Lee, "Applying the DC Distribution System Constructed Commercial Buildings," [Online]. *Renewable Energy Research and Applications (ICRERA), 2012 International Conference, KD Power Co., Ltd Seoul Korea,* November 2012. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6477372&isnumber=6477238

[8] Dong D.; Cvetkovic I.; Boroyevich D.; Zhang W.; Wang R.; Mattavelli P., "Grid-Interface Bidirectional Converter for Residential DC Distribution Systems – Part One: High-Density Two-Stage Topology," [Online]. *IEEE Transactions on Power Electronics*, Vol.28, No.4, April 2013. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6263309&isnumber=6341145

[9] Salonen P.; Kaipia T.; Nuutinen P.; Peltoniemi P.; Partanen J., "An LVDC Distribution System Concept," [Online]. *Department of electrical engineering, Lappeenranta University of Technology,* IEEE, June 2008,. Available: https://aaltodoc.aalto.fi/bitstream/handle/123456789/809/urn011603.pdf?sequence=1

[10] Sandstad J., (2009, February 15), "Vekselstrøm," [Online]. Available: http://snl.no/vekselstrøm

[11] Norum, L.E., NTNU (2013, September 24, November 14, November 20). Personal conversation and mail conversation.

[12] Bianconi A., "Switches AC VS DC," [Online]. *EAA Membership Honor Roll 2005,* Staten Island, NY. Available: http://www.eaa.org/sportaviationmag/2005/0502_switches.pdf

[13] Store Norske Leksikon., (2009, February 14), "Likestrøm," [Online]. Available: http://snl.no/likestrøm

[14] Nilsson D.; Sannino A., "Efficiency analysis of low- and medium- voltage DC distribution systems," [Online]. *Power Engineering Society General Meeting, 2004. IEEE*, Vol.2, June 2004. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1373299

[15] Kuffel, E., Kuffel, J., Zaengk, W.S., *High Voltage Engineering Fundamentals*. Oxford, USA: Newnes, 2nd edition 2000. ISBN: 978-0-7506-3634-6

[16] Seljeseth, H. SINTEF/NTNU (2013, October 28). Personal conversation.

[17] Electrical Installation Wiki; "Effects of harmonics – Disturbances affecting sensitive loads" [Online]. Schneider Electric, 2013. Available: http://www.electrical-installation.org/enwiki/Effects_of_harmonics_-_Disturbances_affecting_sensitive_loads

[18] Strømsnes, A. Siemens (2013, November 4). Personal conversation and mail conversation.

[19] Blix B., (July 2010), "Er PC-en din et strømsluk?" [Online]. Available: http://www.dinside.no/846628/er-pc-en-din-et-stromsluk

[20] European Commission, Low Voltage Directive, LVD 2006/85/EC. European Union Directive, Brussels 2006.

[21] Ljøkelsøy, K. SINTEF/NTNU (2013, October 15). Personal conversation.

[22] Paajanen P., Kaipia T., Jarmo P., "DC supply of low-voltage electricity appliances in residential buildings," *Electricity Distribution – Part 1, 2009. CIRED 2009. 20th International Conference and Exchibition,* 2009. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5255644&isnumber=5255237

[23] Bjørset, H.H. and Hansen E.H., *LYSTEKNIKK*. The Norwegian University of Science and Technology, Trondheim, 2006.

[24] Hansen, E.H. NTNU (2013, November 12). Personal conversation.

[25] Becker D.J.; Sonnenberg B.J., "DC Microgrids in Buildings and Data Centers," [Online]. Telecommunications Energy Conference (INTELEC) 2011, IEEE 33rd International, Emerson Network Power , Energy Systems, Warrenville Illinois USA, Oct. 2011. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6099725&isnumber=6099710

[26] Norsk Elektroteknisk Norm, “Elektriske lavspenningsanlegg - installasjoner (400)”, NEK normkomité 64, 2010.

[27] Aanensen, L.T. NEK (2013, September/October/November). Personal conversation and mail conversation.

[28] Norsk Elektroteknisk Komite., “Smarte energinett” [Online]. Strategi for standardisering (dialogdokument), NEK SmartGrid forum, 2013. Available: http://www.standard.no/no/Fagomrader/Elektro/SmartGrid/

[29] Godske, B., “Ny USB-standard kan levere 100 W jævnstrøm i hele hjemmet” [Online]. Ingeniøren, El, 7 november, 2013. Available: http://ing.dk/artikel/ny-usb-standard-kan-levere-100-w-jaevnstroem-i-hele-hjemmet-164008?utm_medium=email&utm_source=ing.dk&utm_campaign=tipenven

[30] Houseman, D., Sciacca, S., Abi-Samra, N., McDonald, J., Imhoff, C.,Amin, M.; ”IEEE Smart Grid Experts Roundup: AC vs. DC Power,” [Online]. Several IEEE Smart Grid Experts provide their input on the topic, IEEE Smart Grid. Available: http://smartgrid.ieee.org/questions-and-answers/902-ieee-smart-grid-experts-roundup-ac-vs-dc-power

[31] Hansen E.H., “3 Lavspente fordelingssystemer,” in Elektroinstallasjoner, 2010 Edition, The Norwegian University of Science and Technology, Ch.3, Sec.3.2-3.4, pp.10-15.

[32] Sannino A.; Postiglione G.; Bollen M.H.J., “Feasibility of a DC network for commercial facilities,” [Online]. *IEEE Transactions on Industry Applications*, Vol.39, No.5, September-October 2003. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1233614

[33] Sand, K., “Supply voltage variations – causes – consequences – solutions” [Online]. Lecture foil in ELK10 Quality of supply in electrical power systems, NTNU, 2003.

[34] Brenna M.; Tironi E.; Ubezio G., “Proposal of a local DC distribution network with distributed energy resources,” [Online]. *Harmonics and Quality of Power, 2004. 11th International Conference,* 12-15 September, 2004. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1409388

[35] Norges vassdrags- og energidir., “Forskrift om leveringskvalitet i kraftssystemet” [Online]. Olje- og energidepartementet (OED), 2007.

[36] Schärer, A.; “Likestrømsløsninger for datasentre” [Online]. ABB Datasenterdagene, March 13. 2014. Available: http://new.abb.com/about/technology/data-centers/powerdistribution/dc-datacenters

[37] Halten-Eggen, M., COWI AS (2014, February, March & May). Cooperation with measurements and personal&mail conversation.

[38] Holdhus, M., ABB (2014, March). Mail conversation.

[39] Gunvaldsen I., (2009, February 14), “Likeretter,” [Online]. *Store Norske Leksikon*. Available: http://snl.no/likeretter

[40] Rasmussen, N.; Spitales, J., ”A Quantitative Comparison of High Efficiency AC vs. DC Power Distribution for Data Centers” [Online]. *White Paper 127, Revision 3,* Schneider Electric – Data Center Science Center, 2012. Available: http://www.apcdistributors.com/white-papers/Power/WP-127%20A%20Quantitative%20Comparison%20of%20High%20Effeciency%20AC%20vs.%20DC%20Power%20Distribution%20for%20Data%20Centers.pdf

[41] Bushue, M., “DC Data Center Stakeholders Meeting” [Online]. Sun Microsystems Presentation, hosted by Lawrence Berkely National Labs, 2007, July 12. Available: http://hightech.lbl.gov/presentations/dc-powering/dc-stakeholders/1-Voltage.pdf

[42] Undeland, T.M., NTNU (2013, November 14. 2014, January & May). Personal conversation.

[43] *Choice of MV/LV transformer* [Online, Picture]. Available: http://www.electrical-installation.org/enwiki/Choice_of_MV/LV_transformer

[44] *Sunpower* [Online, Picture]. Available: http://www.sunpower-uk.com/product/5W-Dual-15V-Output-Encapsulated-AC-DC-Converter/APC-15D/default.htm

[45] Digilog Systems, *DC-DC Converter* [Online, Picture]. Available: http://www.digilogsystems.com/power-supplies.html

[46] Consumers electronics, *Office Equipment* [Online, Picture]. Available at: http://www.a1aaudiovisual.com/OfficeEquipment.html

[47] Mohan, N.; Undeland, T.M.; Robbins, W.P., *Power Electronics – Converters, Applications and Design*. University of Minnesota, Minnapolis, Minnesota and Norwegian University of Science and Technology (NTNU), Trondheim, Norway, John Wiley & Sons, Inc., third edition 2003. USA ISBN: 978-0-471-22693-2.

[48] Wicks F., “Evaluating Alternatives for Integrating Distributed DC Generation with AC Power Systems,” [Online]. *Energy Conversion Engineering Conference and Exhibit, 2000. (IECEC) 35th Intersociety*, Vol.2, 2000. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=870872&isnumber=18862

[49] Ruiz, A. G.; “Design, Operation and Control of Series-Connected Power Converters for Offshore Wind Parks”. Doctoral theses at the Norwegian University of Science and Technology (NTNU), Faculty of Information Technology, Mathematics and Electrical Engineering, Department of Electric Power Engineering, “Chapter 3 Proposed Energy Conversion System – 3.5 Methodology for losses calculation”, p.58, 2012.

[50] Eguchi, N.; Itoh, J.-I.; Kodachi, H.; Odaka, A.; Ohguchi, H.; Sato, I.; Umida, H.; "Analysis of loss and junction temperature in power semiconductors of the matrix converter using simple simulation methods," [Online]. *Industry Applications Conference, 2004. 39th IAS Annual Meeting. Conference Record of the 2004 IEEE* ,

vol.2, no., pp.850,855 vol.2, 3-7 Oct. 2004. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1348512&isnumber=29650

[51] *Nye Bjerke Videregående Skole fra August 2013* [Online, Picture].Available: http://www.bjerke.vgs.no/skolen/Nye_Bjerke/Nye_Bjerke.html

[52] COWI AS, "Bjerke Videregående Skole", construction drawing, 2011.

[53] Bauer P.; Weldemariam, L.E.; Raijen, E., "Stand-alone Microgrids" [Online]. *Telecommunications Energy Conference (INTELEC), 2011 IEEE 33rd International, vol., no.,* 13 October, 2011. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6099837&isnumber=6099710

[54] Weir, B.; "High Brightness LED Driver Solutions for General Lightning" [Online]. ON Semiconductor. Available: http://www.onsemi.com/pub_link/Collateral/TND345-D.PDF

[55] Abidin, M. N. Z.; "IEC 61000-3-2 Harmonics Standards Overview" [Online]. Schaffner EMC Inc., Edison, NJ, USA. Available: http://www.teseq.cn/pdfinfo/05_AN_IEC61000-3-25.pdf

[56] ON Semiconductor; "DN06040/D, Universal Input, 20 W, LED Ballast" [Online]. Design Note, Rev.2, September 2008. Available: http://www.datasheetarchive.com/dl/Datasheet-081/DASF0035483.pdf

[57] ON Semiconductor, "Power Factor Correction (PFC) Handbook, Choosing the Right Power Factor Controller Solution" [Online]. Rev.4, February 2011. Available: http://www.onsemi.com/pub_link/Collateral/HBD853-D.PDF

[58] ON Semiconductor; "NCP1654, Power Factor Controller for Compact and Robust, Continuous Conduction Mode Pre-Converters" [Online]. Available: http://www.onsemi.com/pub_link/Collateral/NCP1654-D.PDF

[59] Fairchild Semiconductor Corporation; "AN-9731 LED Application Design Guide Using BCM Power Factor Correction (PFC) Controller for 100W Lighting System," [Online]. Fairchild Semiconductor Corporation, Rev.1.0.0, 24 March 2011. Available: http://www.fairchildsemi.com/an/AN/AN-9731.pdf

[60] Fairchild Semiconductor, "FCB20N60F_F085 N-CHANNEL MOSFET 600V, 20A, 190 mOhm" [Online]. Datasheet, December 2013. Available: http://www.fairchildsemi.com/ds/FC/FCB20N60F_F085.pdf

[61] Hyperphysics, "DC Electric Power," [Online]. Available: http://hyperphysics.phy-astr.gsu.edu/hbase/electric/elepow.html

[62] POWERSIM, "Application Examples, Boost power factor correction (PFC) circuit (boost pfc.sch)," [Online]. Pre-built examples provided together with the software, PSIM. Available: http://powersimtech.com/support/application-examples/

[63] Sanchez, S.A.; Molinas, M.M.C., Zanchetta, P.; Degano, M., “Stability evaluation of a DC micro-grid and future interconnection to an AC system”. Renewable Energy, vol.62, September 17, 2013.

[64] Liu, J.; Feng, X.; Lee, F.C; Borojevich, D., “Stability margin monitoring for DC distributed power systems via current/voltage perturbation,” [Online]. *Applied Power Electronics Conference and Exposition, APEC 2011, Sixteenth Annual IEEE,* vol. 2, 2001. Available:
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=912453&isnumber=19694

[65] Liu, J.; Feng, X.; Ye Z.; Lee, F.C; Borojevich, D., “Stability Monitoring Using Voltage Pertubation for DC Distributed Power Systems,” [Online]. *Center for Power Electronics Systems, Virginia Polytechnic Institute and State University, USA*, 2002. Available:
http://www.cpes.vt.edu/_media/annual_reports/2002/Report/VolumeIIPartII/1DPS/19.pdf

[66] Danielsen, S.; Molinas, M.; Toftevaag, T.; Fosso, O.B., “Constant power load characteristic´s influence on the low-frequency interaction between advanced electrical rail vehicle and railway traction power supply with rotary converters,” [Online]. *Modern Electric Traction, 9th International Conference, Poland*, September 2009. Available:
http://www.elkraft.ntnu.no/eno/Papers2009/Steinar_Molinas-gdansk.pdf

[67] Areerak, K-N..; Bozhko, S.V.; Asher, G.M.; De Lillo, L.; Thomas, D.W.P., “Stability Study for a Hybrid AC-DC More-Electric Aircraft Power System,” [Online]. *IEEE Transactions on Aerospace and Electronic Systems,* vol.48, no.1, January 2012. Available:
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6129639&isnumber=6129613

[68] Sun, J., “Small-Signal Methods for AC Distributed Power Systems-A Review,” [Online]. *IEEE Transactions on Power Electronics*, November 2009. Available:
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5204172&isnumber=5338051

[69] Sun, J.M Karimi, K.J., “Small-signal input impedance modelling of line-frequency rectifiers,” [Online]. *IEEE Transactions on Aerospace and Electronic Systems,* vol.44, no.4, October 2008. Available:
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4667724&isnumber=4667706

[70] Sun, J.; Chen, M., “ Analysis and mitigation of interactions between PFC converters and the AC Source,” [Online]. *Power Electronics and Motion Control Conference, 2004. IPEMC, 2004. The 4th International Conference*, vol.1, August 2004. Available:
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1377791&isnumber=30072

[71] Chen, M.; Sun, J., “ Low-Frequency Input Impedance Models for Boost Single-Phase PFC Converters,“ [Online]. *IEEE Transactions on Power Electronics Specialists*

Conference, June 2005. Available:
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1581760&isnumber=33408

[72] Areerak, K-N..; Bozhko, S.V.; Asher, G.M.; De Lillo, L.; Thomas, D.W.P., "DQ-transformation approach for modelling and stability analysis of AC-DC power system with controlled PWM rectifier and constant power loads," [Online]. *Power Electronics and Motion Control Conference, 2008. EPE-PEMC 2008, 13th*. Available:
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4635567&isnumber=4635237

[73] *Eènfasige merk Fluke: Powermeter* (2014) [Online, Picture]. Available:
http://docweb.khk.be/IIBT_Elektrotechniek/WebLabo/vermogenmeting_digitaal.htm

[74] Trinergi ab, *DRAN-VIEWI*, Lisens: COWI AS. www.trinergi.se.

[75] Kolstad, H.; Ljøkelsøy, K., "20 kW IGBT Omforme. Beskrivelse". *SINTEF Energiforskning AS, Energisystemer,* Prosjektnr. 12X127.03, 20 september, 2002.

[76] Eltek, "Datasheet – Flatpack2 380 V Rectifier" [Online]. Available:
http://www.eltek.com/detail_products.epl?id=2096375&cat=24671&k1=&k2=25515&k3=&k4=&close=1

[77] Eltek, "Datasheet - Flatpack2 HE Front End 48V/3000W Rectifier Module" [Online]. Available:
http://www.eltek.com/detail_products.epl?id=2122623&cat=24671&k1=&k2=25515&k3=&k4=&close=1

[78] Eltek, "Datasheet - Flatpack2 48V HE Rectifiers-2.pdf" [Online]. Available:
http://www.eltek.com/detail_products.epl?id=1123903&cat=24671&k1=&k2=25515&k3=&k4=&close=1

[79] Eltek, "Datasheet - Flatpack2 48-60_2000 HE-2.pdf" [Online]. Available:
http://www.eltek.com/detail_products.epl?id=1123903&cat=24671&k1=&k2=25515&k3=&k4=&close=1

[80] Eltek, "Datasheet – Flatpack2 220V Rectifiers-2.pdf" [Online]. Available:
http://www.eltek.com/detail_products.epl?id=1123912&cat=24671&k1=&k2=25515&k3=&k4=&close=1

[81] Eltek, "Datasheet – Flatpack2 24_1800 HE-2.pdf" [Online]. Available:
http://www.eltek.com/detail_products.epl?id=1123906&cat=24671&k1=&k2=25515&k3=&k4=&close=1

[82] Electrical Technology.; "Active, Reactive, Apparent and Complex Power. Simple explanation with forumlas" [Online]. Available:
http://www.electricaltechnology.org/2013/07/active-reactive-apparent-and-complex.html

[83] Sylte, G., GLAMOX (2014, May). Mail conversation.

[84] OSRAM, "OPTOTRONIC FIT" [Online]. Datasheet *OT FIT 35/220…240/700 CS L ZMP_1123347.pdf*, 2014. Available: http://www.osram.de/osram_de/produkte/elektronik/innen-evg-fuer-led-module-und-dimmer/linear-area-konstantstrom-nicht-dimmbar/optotronic-fit/index.jsp

[85] Garathun, M.G.; "SMARTHUS" [Online]. Teknisk Ukeblad Bygg, 2014. Available: http://www.tu.no/bygg/2014/06/04/fremtidens-smartbolig-kan-hurtiglade-elbilen-fra-eget-batteri#cxrecs_s

[86] Guerrero, J.M.; Vasquez, J.C.; Teodorescu, R., "Hierarchical control of droop-controlled DC and AC microgrids – a general approach towards standardization" [Online]. *Industrial Electronics,* 2009. IECON'09. *35th Annual Conference of IEEE, vol., no., 3-5 November, 2009.* Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5414926&isnumber=5414636

[87] Patterson B., "Improved Efficiency & Renewable Energy Adoption via LVDC Microgrid Power Distribution". *NEMA LVDC Workshop 2011*, Washington.

[88] Symmetra MW. TUV Test Report Number 21113774_010, September 26, 2005. Symmetra PX – TUV Test Report IS-EGN-MUC/ed, June 12, 2007.

[89] Wieland; "Overspenningsbeskyttelse WIETAP GM YPV SCI1000FM" [Online]. Products datasheet. Available: https://eshop.wieland-electric.com/products/no/overspenningsbeskyttelse-wietap-gm-ypv-sci1000fm/84.995.2515.0?vendorProductId=84.995.2515.0&navigate=0

[90] Jøransen, S.; "Elektrisitet & Brannyrket" [Online]. Oslo Brannvesen, 2011. Available: http://www.brannmannen.no/arkiv/fag-og-presentasjoner.aspx?PID=40&M=NewsV2&Action=1&NewsId=140

[91] Bre Global; "Fire Safety and photovoltaic systems" [Online]. Bre Global, Building Research Establishment, 2014. Available: http://www.bre.co.uk/page.jsp?id=3210

[92] Seehusen, J.; "SERIELYSBUER" [Online]. Teknisk Ukeblad Bygg, 2014. Available: http://www.tu.no/bygg/2014/03/05/siemens--lysbuer-er-en-viktig-brannarsak.-sintef--varmgang-er-viktigere

[93] Winter S. Associates., (2013, April 09), "Net Zero Energy Buildings" [Online]. Available: http://www.wbdg.org/resources/netzeroenergybuildings.php

[94] Molinas, M.M.C., NTNU (2013, November 20). Mail conversation.

[95] Gunvaldsen I., (2009, February 15), "Vekselretter," [Online]. *Store Norske Leksikon*. Available: http://snl.no/vekselretter

[96] Gunvaldsen I., (2009, February 14), "Kraftelektronikk," [Online]. *Store Norske Leksikon*. Available: http://snl.no/kraftelektronikk

[97] Byeon G.; Lee H.; Yoon T.; Jang G.; Chae W.; Kim J., "A research on the characteristics of fault current of DC distribution system and AC distribution system," [Online]. *Power Electronics and ECCE Asia (ICPE & ECCE), 2011 IEEE 8th International Conference*, May-June 2011. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5944603

[98] Gytri, A., NTNU (2014, January 23). Personal and mail conversation.

[99] D'arco, S., SINTEF (2014, January 24 & 27). Mail conversation.

[100] Årdal, A.R., SINTEF (2014, January 24 & 27). Mail conversation.

[101] Klubicka, V., NTNU (2014, January 27). Personal conversation.

[102] European Standard (EN), "Operated by rectified current source, alternating current source of direct current source up to 400 V". *Sub-part 1: Direct current source up to 400 V*, ETSI EN 300 132-3-1 v.2.1.1 (2011-10).

[103] Lawrence Berkely National Labs report: "High Performance Buildings: Data Center – Uniterruptible Power Supplies (UPS)". Figure 17, December, 2005.

[104] Lawrence Berkely National Labratory: "High Performance Buildings: Data Center – Server Power Supplies". December, 2005.

[105] Papathanassiou, S.; Hatziargyriou N.; Strunz, K., "A Benchmark Low Voltage Microgrid Network". Presented at the CIGRE Symposium *Power systems with dispersed generation: technologies, impacts on development, operation and performances*, Athens, Greece, April 2005.

[106] Sanchez, S.A., NTNU (2014, January 31). Personal and mail conversation.

[107] Barote, L.; Marinescu, C., "Renewable hybrid system with battery storage for safe loads supply" [Online]. *PowerTech, 2011 IEEE Trondheim*, vol.no., 19-23 June, 2011. Available: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6019274&isnumber=6019147

[108] Ranheim, K. Noratel (2014, February 13). Mail conversation.

[109] Halten-Eggen, M., COWI AS (2014, February-May). Personal an mail conversation.

[110] Krok, T., COWI AS (2014, March). Personal and mail conversation.

[111] Ruskin, A.W.; *Electric Utility, Is Electricity a product?* [Online, Picture]. *Toxic Tort Litigation Blog*, September 3, 2008. Available: http://www.toxictortlitigationblog.com/2008/09/articles/toxic-tortproduct-liability-li/is-electricity-a-product/

[112] Zainal Abidin, M.N.; "SCHAFFNER, safety for electronic systems, IEC 61000-3-2 Harmonics Standards Overview" [Online]. Schaffner EMV AG Corporate Headquarters, Edison, NJ, USA, May 2006. Available: http://www.teseq.cn/pdfinfo/05_AN_IEC61000-3-25.pdf

[113] ON Semiconductor; "NCP1651, Single Stage Power Factor Controller" [Online]. Available: http://www.onsemi.com/pub_link/Collateral/NCP1651-D.PDF

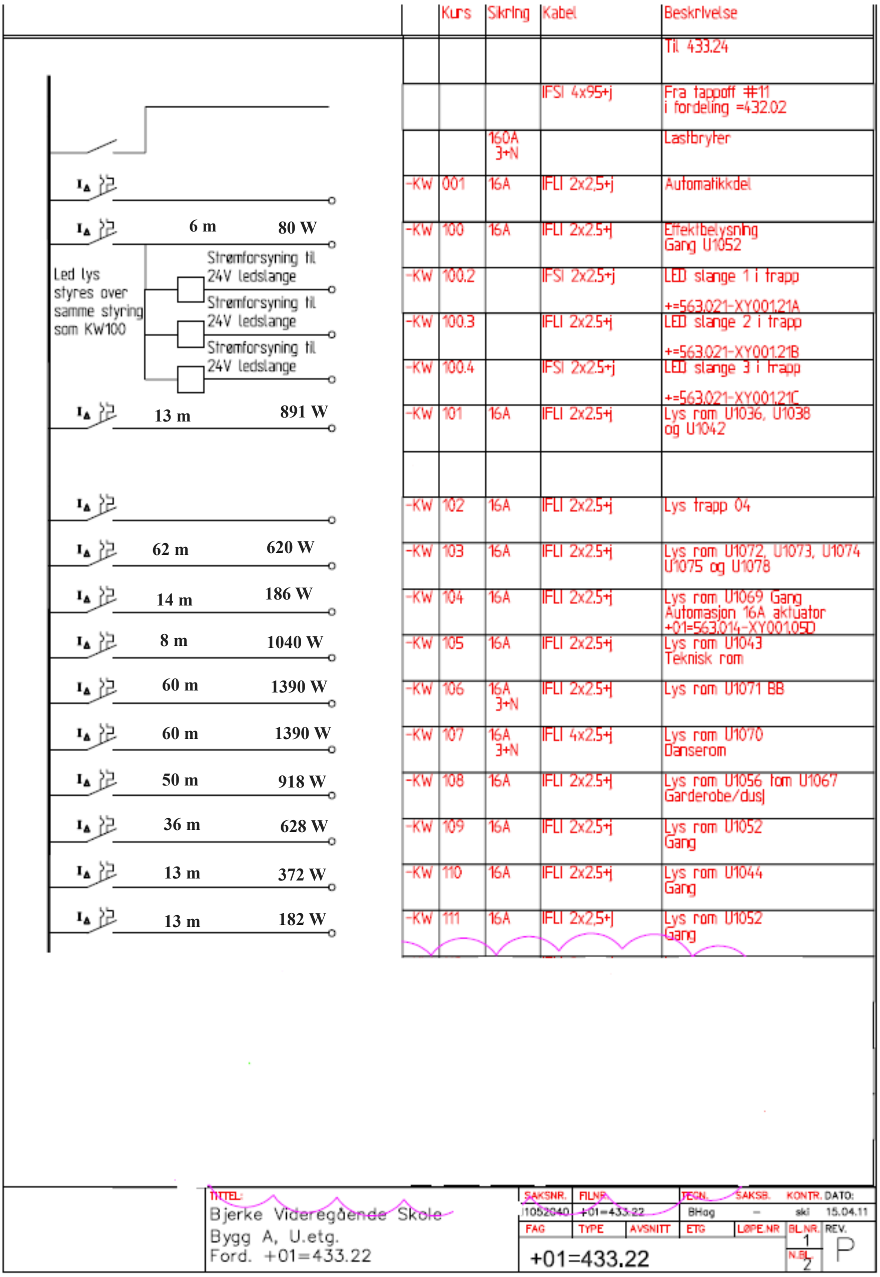
[114] *Gycom* (2014) [Online, Picture]. Available: http://www.gycom.com/no/produkter/maleinstrument/stromtenger-til-instrument

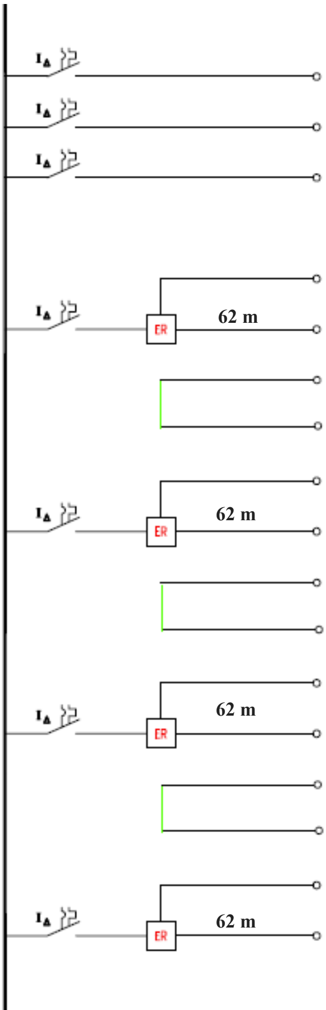
[115] FLUKE Corporation, Model 41 Power Harmonics Analyzer, February 1994. Available: http://faculty.cincinnatistate.edu/paul/7154/manuals/Fluke41.pdf

[116] Dranetz (2014) [Online, Picture]. Available: http://dranetz.com/portable/powerguide-4400

17 Appendices

17.1 Overview of sub distributions measured at Bjerke Upper Secondary School



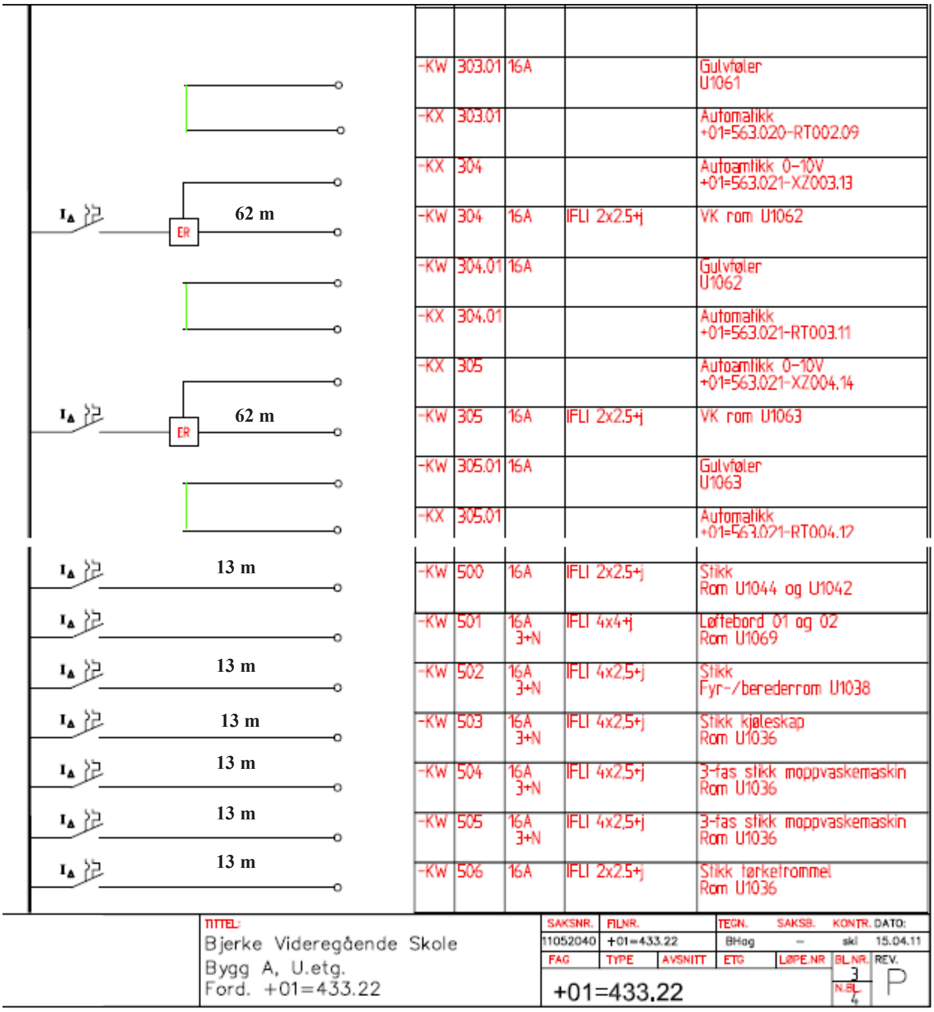


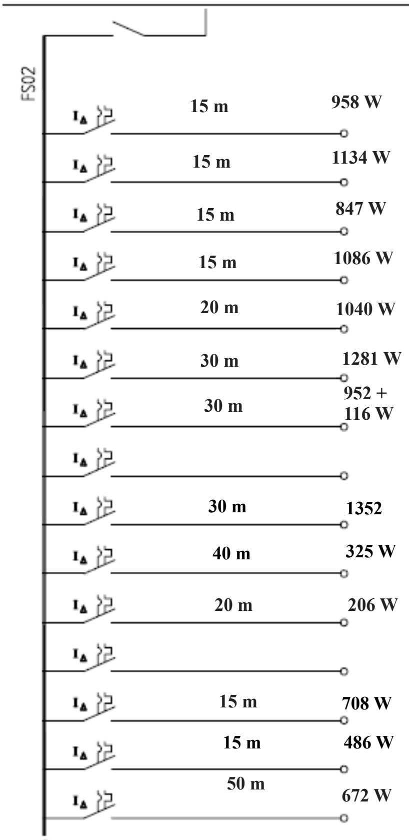
-KW	120	10A 1+J	IFLI 2x1,5+j	Styrestrøm til VV-beredere
-KW	121	25A 3+N	IFLI 4x6+J	Varmtvannsbereder 14kW
-KW	122	25A 3+N	IFLI 4x6+J	Varmtvannsbereder 14kW
-KX	300			Autoamtikk 0-10V +01=563.020-XZ002.13
-KW	300	16A	IFLI 2x2,5+j	VK rom U1078
-KW	300.01	16A		Gulvføler U1078
-KX	300.01			Automatikk +01-563.020-RT002.08
-KX	301			Autoamtikk 0-10V +01=563.020-XZ001.07
-KW	301	16A	IFLI 2x2,5+j	VK rom U1074
-KW	301.01	16A		Gulvføler U1074
-KX	301.01			Automatikk +01=563.020-RT001.06
-KX	302			Automatikk 0-10V +01=563.020-XZ001.11
-KW	302	16A	IFLI 2x2,5+j	VK rom U1056
-KW	302.01	16A		Gulvføler U1056
-KX	302.01			Automatikk +01-563.020-RT001.10
-KX	303			Autoamtikk 0-10V +01=563.020-XZ002.12
-KW	303	16A	IFLI 2x2,5+j	VK rom U1061

TITTEL:
Bjerke Videregående Skole
Bygg A, U.etg.
Ford. +01=433.22

SAKSNR.	FILNR.	TEGN.	SAKSB.	KONTR.	DATO:
11052040	+01=433.22	BHag	–	ski	15.04.11

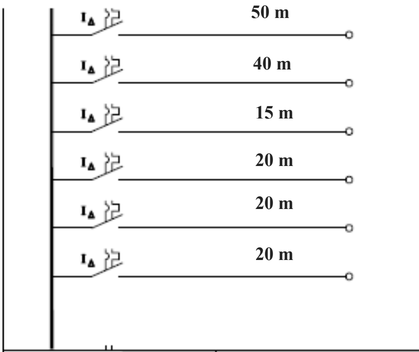
FAG	TYPE	AVSNITT	ETG	LØPE.NR	BL.NR.	N.BL.	REV.
+01=433.22					2	3	P


62 m
ER
62 m
ER
13 m
13 m
13 m
13 m
13 m
13 m
-KW 303.01 16A Gulvføler U1061
-KX 303.01 Automatikk +01=563.020-RT002.09
-KX 304 Autoamtikk 0-10V +01=563.021-XZ003.13
-KW 304 16A IFLI 2x2.5+j VK rom U1062
-KW 304.01 16A Gulvføler U1062
-KX 304.01 Automatikk +01=563.021-RT003.11
-KX 305 Autoamtikk 0-10V +01=563.021-XZ004.14
-KW 305 16A IFLI 2x2.5+j VK rom U1063
-KW 305.01 16A Gulvføler U1063
-KX 305.01 Automatikk +01=563.021-RT004.12
-KW 500 16A IFLI 2x2.5+j Stikk Rom U1044 og U1042
-KW 501 16A 3+N IFLI 4x4+j Løftebord 01 og 02 Rom U1069
-KW 502 16A 3+N IFLI 4x2.5+j Stikk Fyr-/berederrom U1038
-KW 503 16A 3+N IFLI 4x2.5+j Stikk kjøleskap Rom U1036
-KW 504 16A 3+N IFLI 4x2.5+j 3-fas stikk moppvaskemaskin Rom U1036
-KW 505 16A 3+N IFLI 4x2.5+j 3-fas stikk moppvaskemaskin Rom U1036
-KW 506 16A IFLI 2x2.5+j Stikk tørketrommel Rom U1036
TITTEL:
Bjerke Videregående Skole
Bygg A, U.etg.
Ford. +01=433.22
SAKSNR. 11052040
FILNR. +01=433.22
TEGN. BHag
SAKSB. –
KONTR. skl
DATO: 15.04.11
FAG
TYPE
AVSNITT
ETG
LØPE.NR
BL.NR. 3
N.BL. 4
REV. P
+01=433.22



	Kurs	Sikring	Kabel	Beskrivelse
		125A 3+N		Fordeling 433.30
-KW	100	16A	IFLI 2x2.5+j	Belysning korridor Rom 01093 og 01094
-KW	101	16A	IFLI 2x2.5+j	Belysning allrom, Idrett-MDD Rom 01099
-KW	102	16A	IFLI 2x2.5+j	Belysning rom 01102 – 01108 dusj, garderober
-KW	103	16A	IFLI 2x2.5+j	Belysning kontorer Rom 01086 - 01091, 01095 – 01097
-KW	104	16A	IFLI 2x2.5+j	Belysning teknisk rom Rom 01109
-KW	105	16A	IFLI 2x2.5+j	Belysning dusj, garderober, Auditorium Rom 01110 – 01119
-KW	106	16A	IFLI 2x2.5+j	Belysning korridor, Resepsjon Rom 01075, 01092
-KW	107	16A	IFLI 2x2.5+j	Belysning vestibyle Rom 01075
-KW	108	16A	IFLI 3x2.5+j	Belysning gang Rom 01076
-KW	109	16A	IFLI 2x2.5+j	Belysning kopi/rekvisiter/arkiv Rom 01077 - 01080
-KW	110	16A	IFLI 2x2.5+j	Belysning i heis
-KW	111	16A	IFLI 2x2.5+j	Belysning felles uten DAU Automatikk: Styres fra aktuator +01=563.024-XY001.16A
-KW	112	16A	IFLI 2x2,5+j	Relysning korridor 01100
-KW	113	16A	IFLI 2x2,5+j	Belysning rom 01101 kondisjon
-KW	114	16A	IFLI 2x2,5+j	Belysning kontor Rom 01081 - 01085

TITTEL:	SAKSNR.	FILNR.		TEGN.	SAKSB.	KONTR.	DATO:
Bjerke Videregående Skole Bygg B, 1.etg. Ford. +01=433.30	11052040	+01=433.30		BHog	–	ski	15.04.11
	FAG	TYPE	AVSNITT	ETG	LØPE.NR	BL.NR. 1 N.BL. 2	REV. M
	+01=433.30						



	Kurs	Sikring	Kabel	Beskrivelse
-KW	502	16A	IFLI 2x2,5+j	Stikk kopi, printer Rom 01077
-KW	503	16A	IFLI 2x2,5+j	Stikk i kanal resepsjon Rom 01092
-KW	504	16A	IFLI 2x2,5+j	Stikk og nedføringsstav Rom 01100 og 01101
-KW	505	16A	IFLI 2x2,5+j	Stikk gard/idrett, WC, gang Rom 01102,-106,-108,-093,-096
-KW	506	16A 3+N	IFLI 4x2,5+j	Stikk 1-fas og 3-fas teknisk Teknisk rom 01109
-KW	507	16A 3+N	IFLI 4x2,5+j	Stikk i kanal kontorer Rom 01085,-086,-087,-088

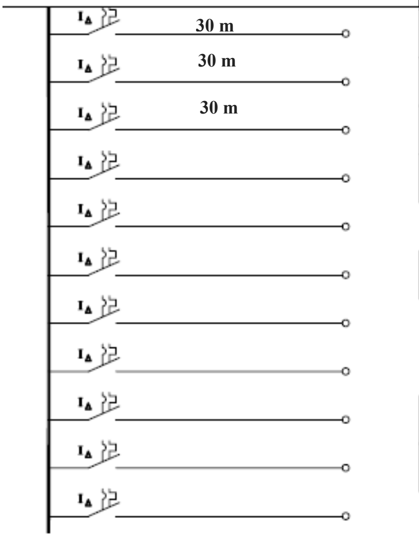
M

TITTEL:
Bjerke Videregående Skole
Bygg B, 1.etg.
Ford. +01=433.30

SAKSNR.	FILNR.	TEGN.	SAKSB.	KONTR.	DATO:
11052040	+01=433.30	BHag	–	ski	15.04.11

FAG | TYPE | AVSNITT | ETG | LØPE NR | BL.NR. 3 | N.BL. 4 | REV. M

+01=433.30



	Kurs	Sikring	Kabel	Beskrivelse
-KW	508	16A 3+N	IFLI 4x2,5+j	Stikk i kanal kontorer Rom 01081,-082,-083,-084,-085
-KW	509	16A 3+N	IFLI 4x2,5+j	Stikk gang, rekvisita, arkiv Rom 01076,-078,-079,-080
-KW	510	16A 3+N	IFLI 4x2,5+j	Stikk og nedføringsstav møte, gruppe, hvilerom Rom 01089,-090,-091,-095
-KW	511	16A	IFLI 2x2,5+j	Stikk i rom 01099
-KW	512	16A 3+N	IFLI 4x2,5+j	Stikk atrium Rom 01119
-KW	513	16A 3+N	IFLI 4x2,5+j	Romkontroll +01=563.025 og +01=563.027
-KW	514	16A	IFLI 2x2,5+j	Oppvaskmaskin rom 01076
-KW	515	16A	IFLI 2x2,5+j	Stikk på benk minikjøkken Rom 01076
-KW	516	16A 3+N	IFLI 4x2,5+j	Stikk garderobe personal, WC og HCWC Rom 01114, 01118, 01110
-KW	517	16A	IFSI 2x2,5+j	Stikk Rom 01075 Vestibyle
-KW	518	16A	IFLI 2x2,5+j	Romkontroll +01=563.026 og +01=536.024

M

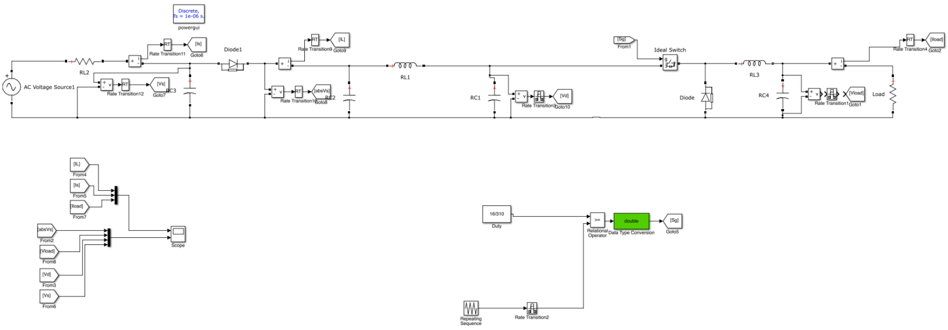
TITTEL:
Bjerke Videregående Skole
Bygg B, 1.etg.
Ford. +01=433.30

SAKSNR.	FILNR.	TEGN.	SAKSB.	KONTR.	DATO:
11052040	+01=433.30	BHag	–	ski	15.04.11

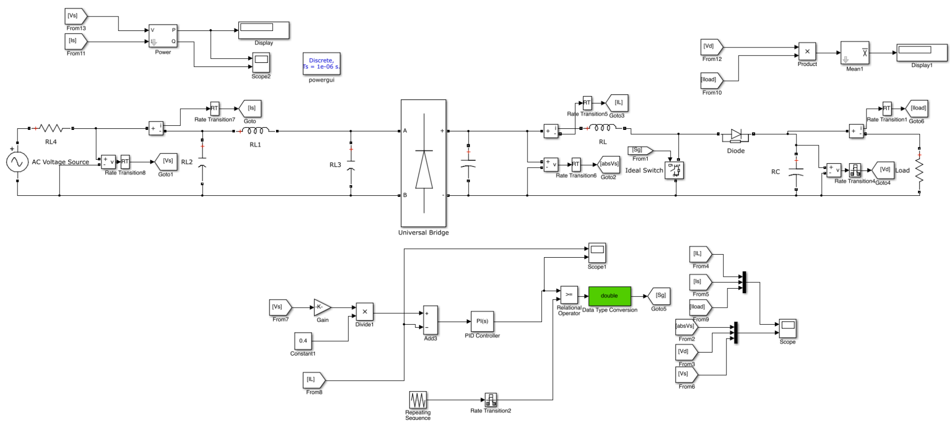
FAG | TYPE | AVSNITT | ETG | LØPE NR | BL.NR. 4 | N.BL. – | REV. M

+01=433.30

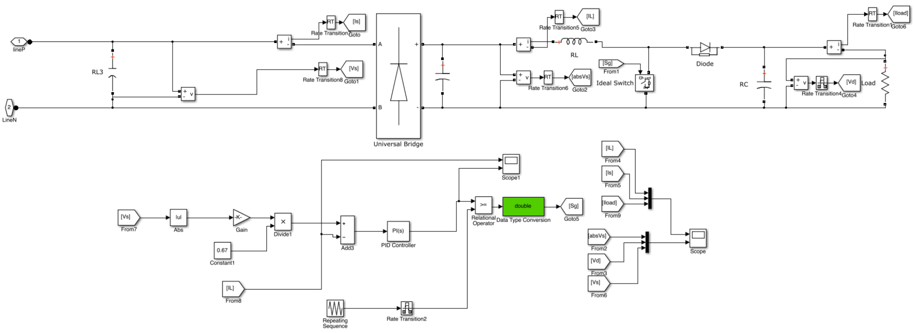
17.2 MATLAB: Schematic model of the designed 20 W PFC



17.3 MATLAB: Schematic model of the designed 100 W PFC

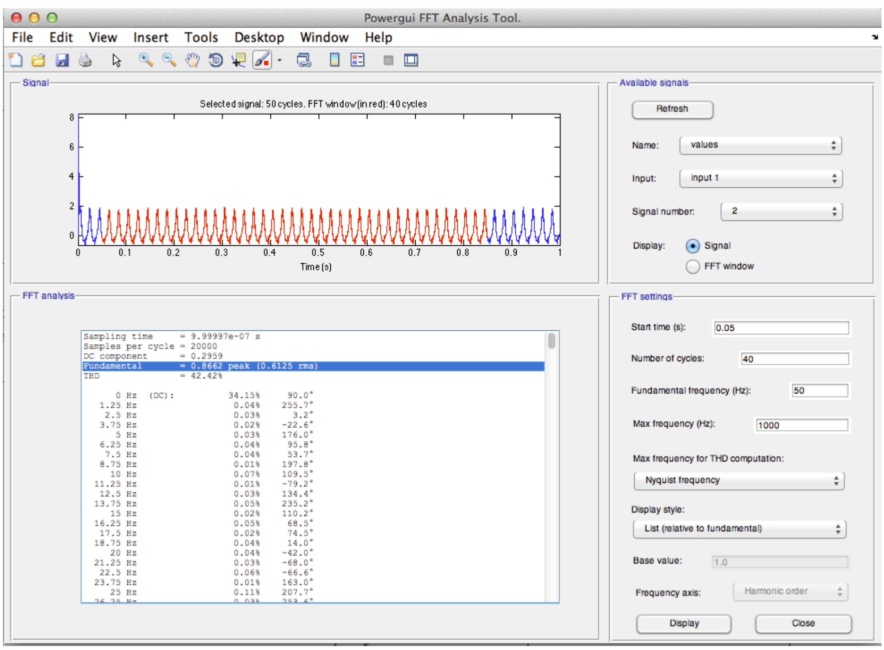


17.4 MATLAB: Schematic model of the designed 270 W PFC

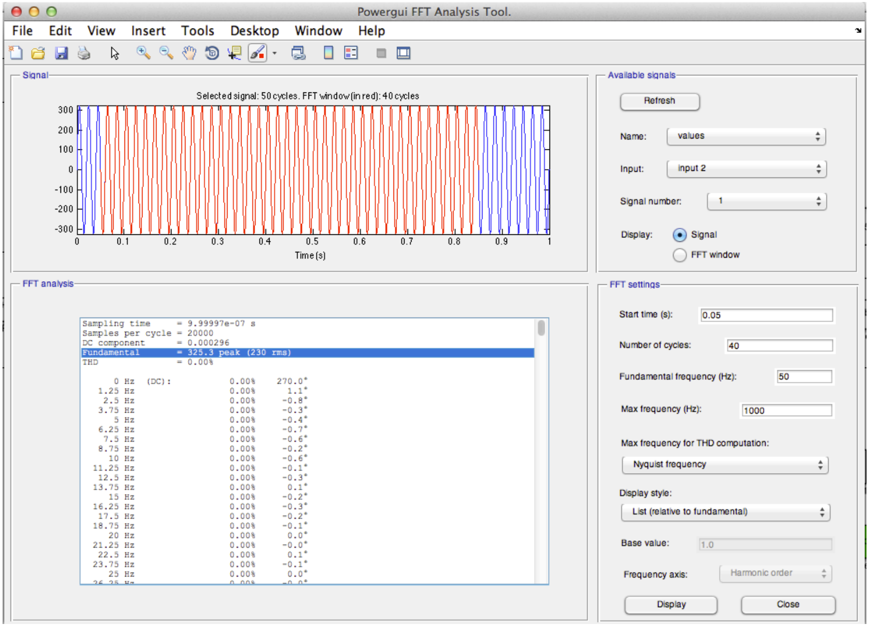


17.5 MATLAB: Simulation results for running the PFC 100 W model with Simulink and the toolbox SimPowerSystem

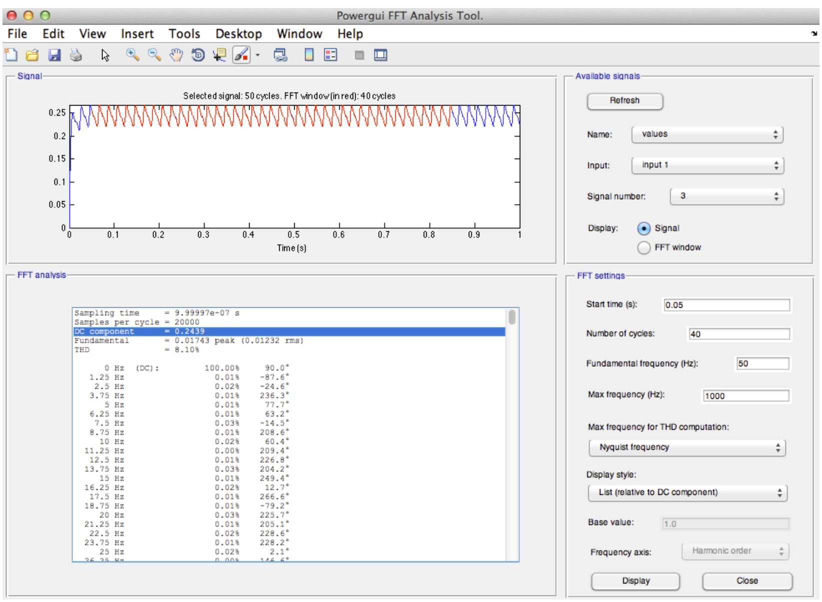
Represent extracts from the results measuring the current, I_s, at the AC input side of the 100 W PFC.



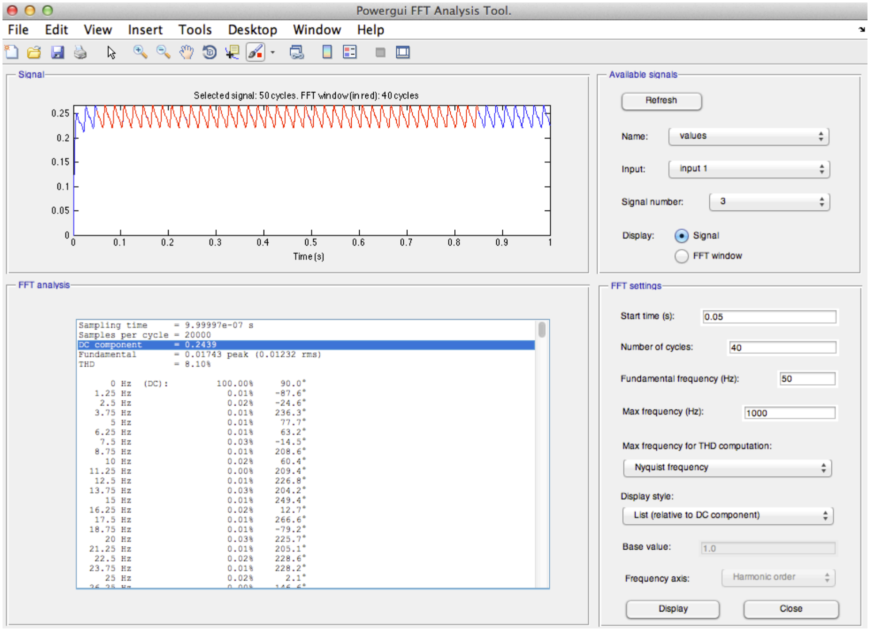
Represent extracts from the results measuring the voltage, V_s, at the AC input side of the 100 W PFC.



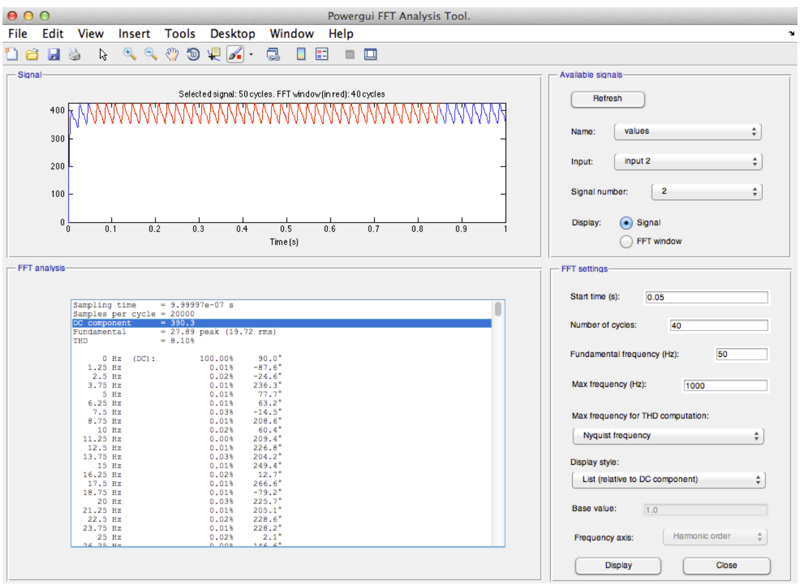
Represent extracts from the results measuring the current, Iload, at the DC load side of the 100 W PFC.



Represent extracts from the results measuring the current, Iload, at the DC load side of the 100 W PFC.

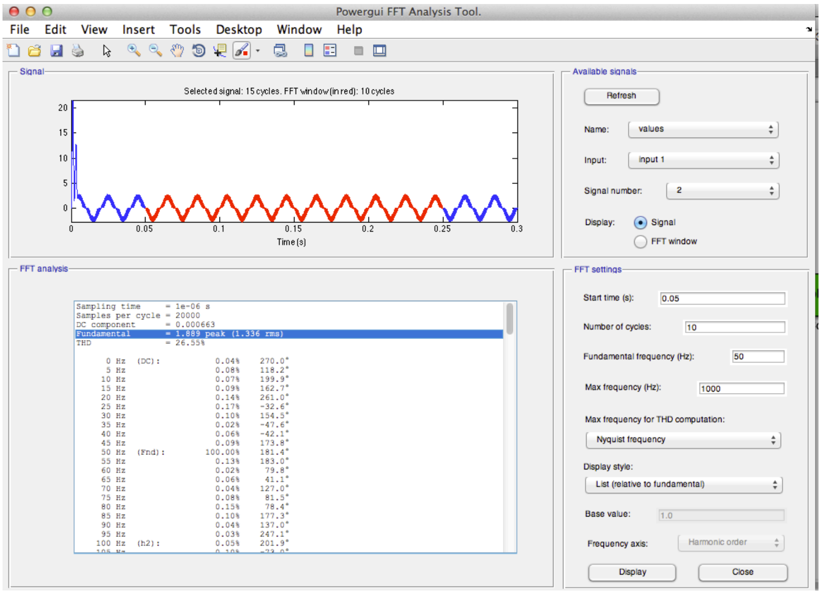


Represent extracts from the results measuring the voltage, V_{load}, at the DC load side of the 100 W PFC.

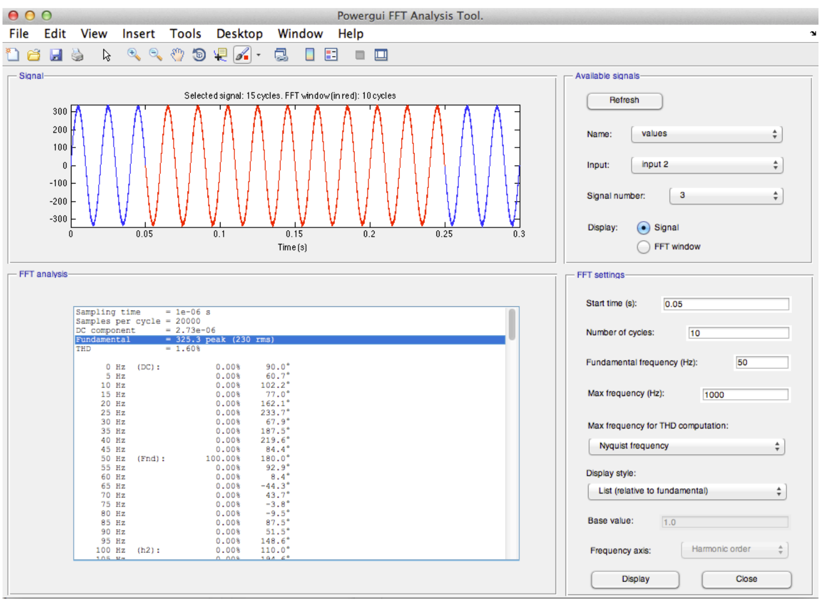


17.6 MATLAB: Simulation results for running the PFC 270 W model with Simulink and the toolbox SimPowerSystem

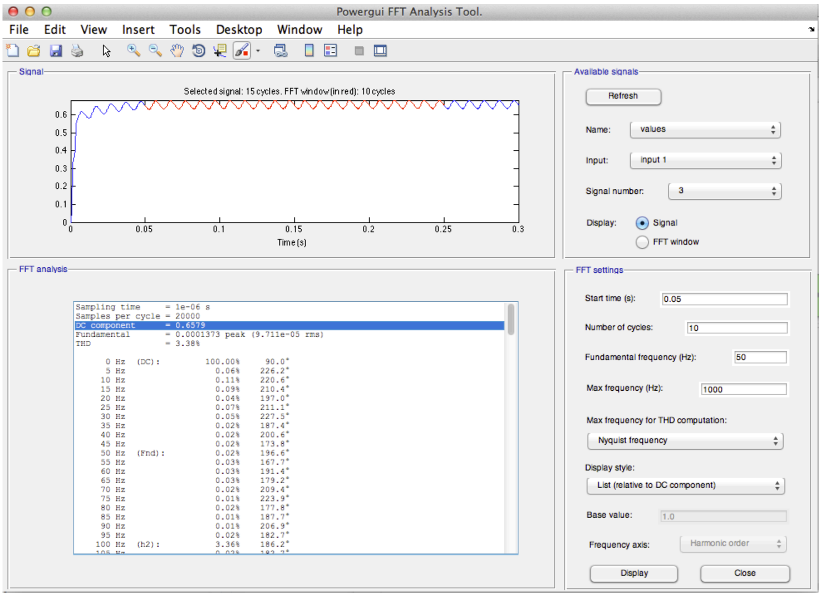
Represent extracts from the results measuring the current, I_s, at the AC side of the 270 W PFC.



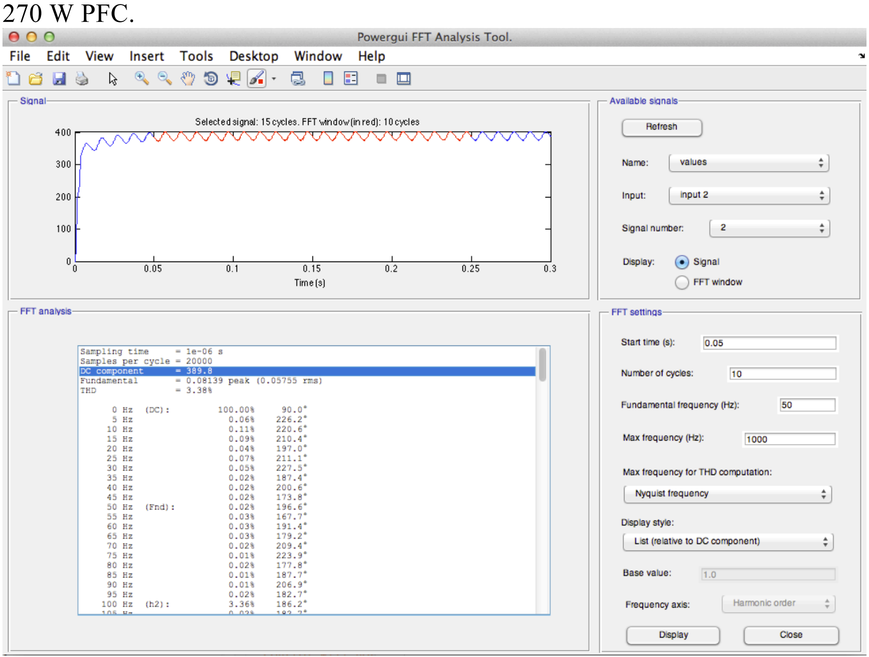
Represent extracts from the results measuring the voltage, V_s, at the AC side of the 270 W PFC.



Represent extracts from the results measuring the current, I_{load}, at the DC load of the 270 W PFC.

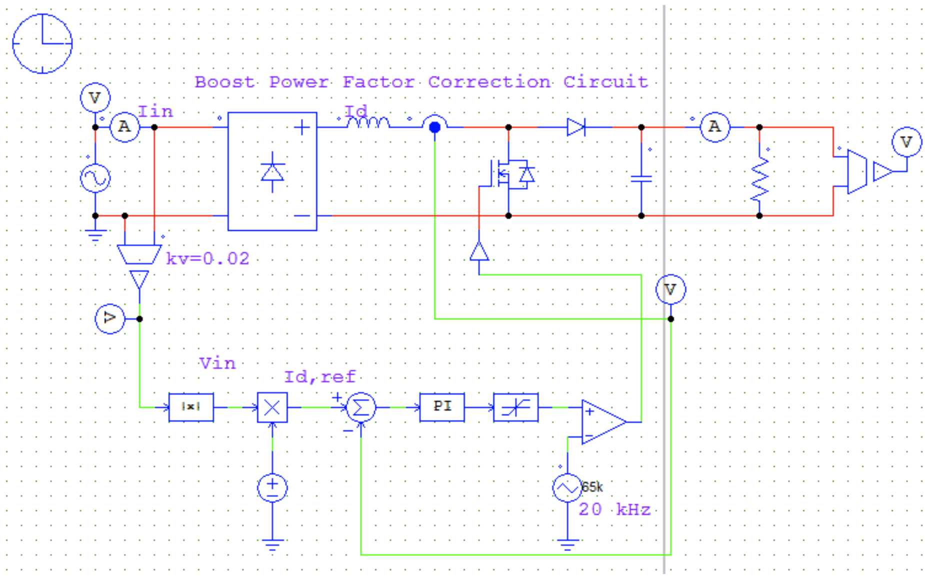


Represent extracts from the results measuring the voltage, V_{load}, at the DC load of the 270 W PFC.



17.7 PSIM: Schematic model of the predefined PFC model

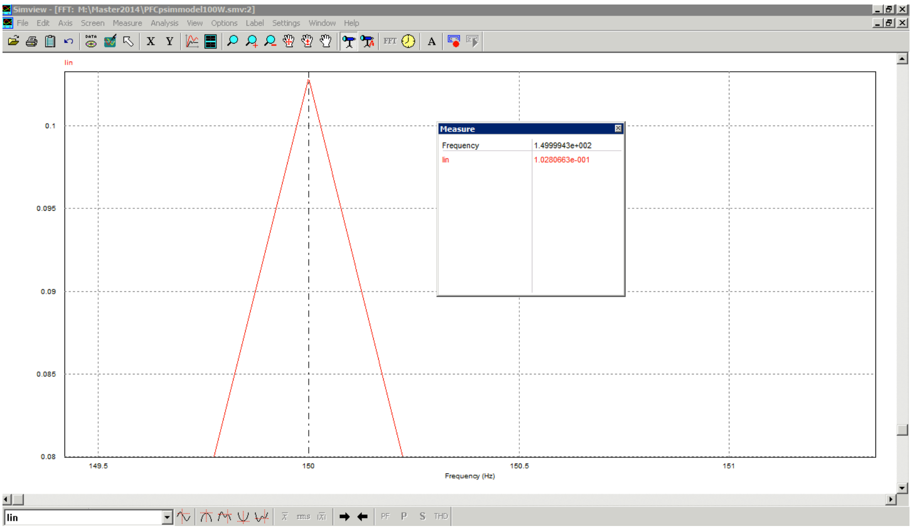
Presents the predefined model of the Boost Power Factor Correction Circuit [62].



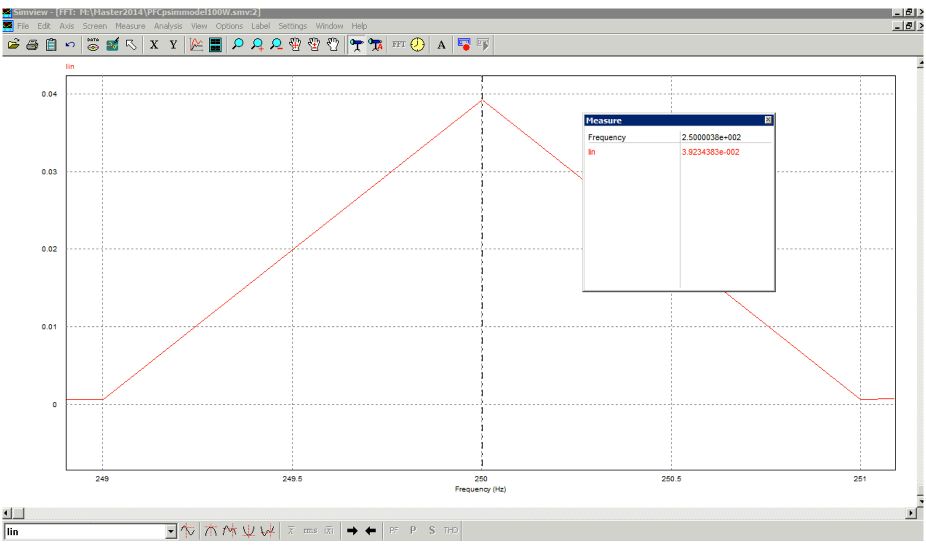
17.8 PSIM: Simulation results for running the PFC 100 W model with specified parameters from MATLAB

Simulation results for running the PFC 100 W model in PSIM, measuring the harmonics 3-13 in order to compare with the IEC requirements.

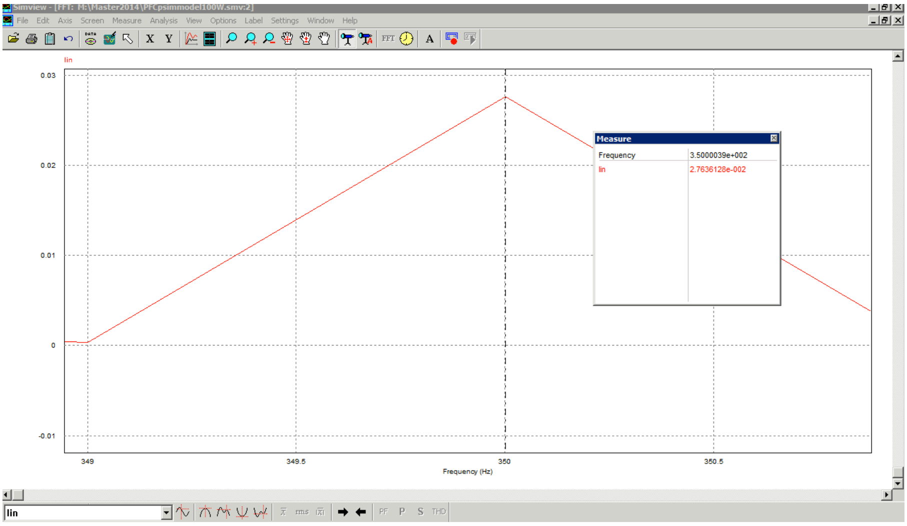
Measuring the In at the third harmonic in PSIM.



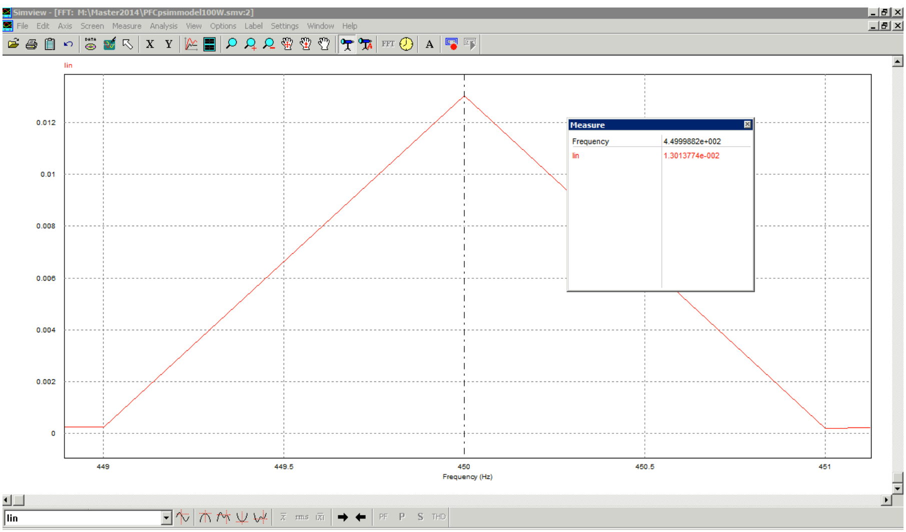
Measuring the In at the 5th harmonic in PSIM.



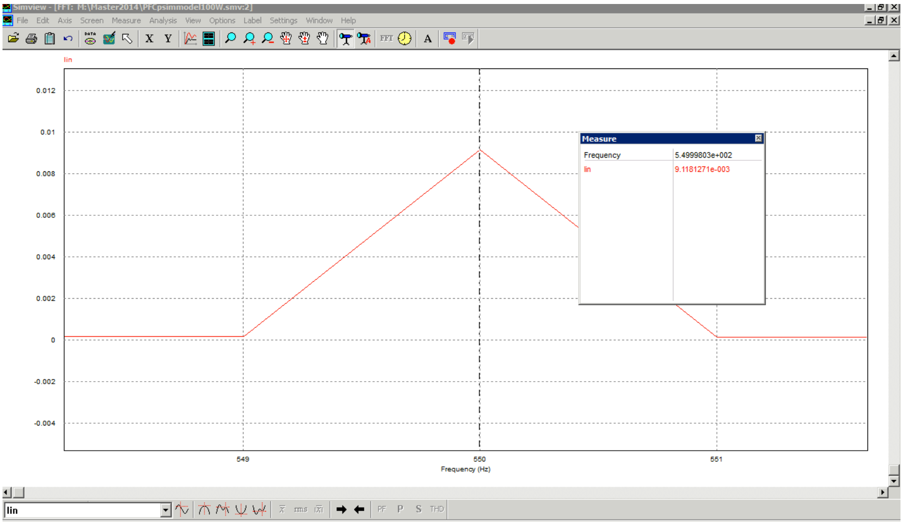
Measuring the In at the 7th harmonic in PSIM



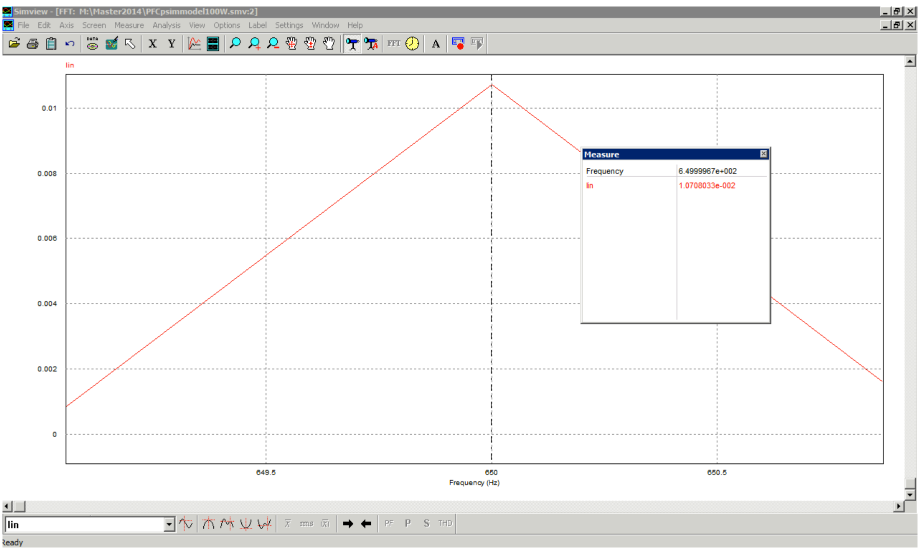
Measuring the In at the 9th harmonic in PSIM.



Measuring the In at the 11th harmonic in PSIM.



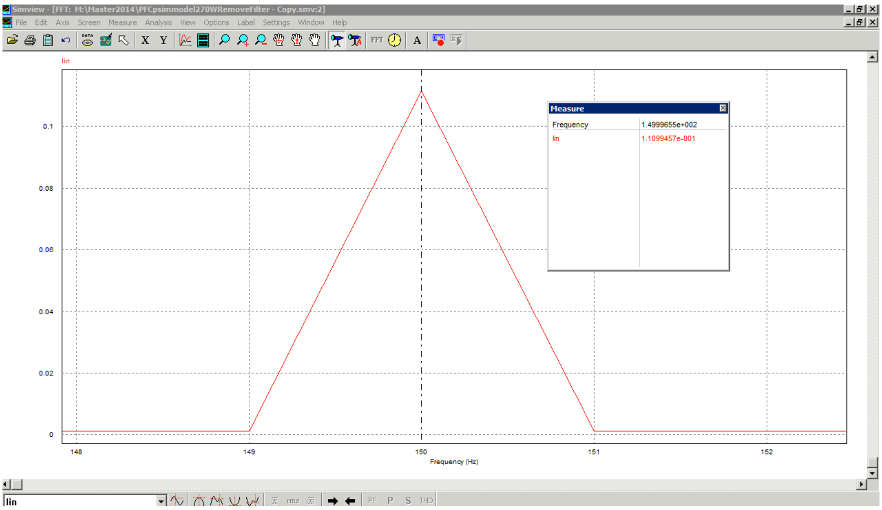
Measuring the In at the 13th harmonic in PSIM.



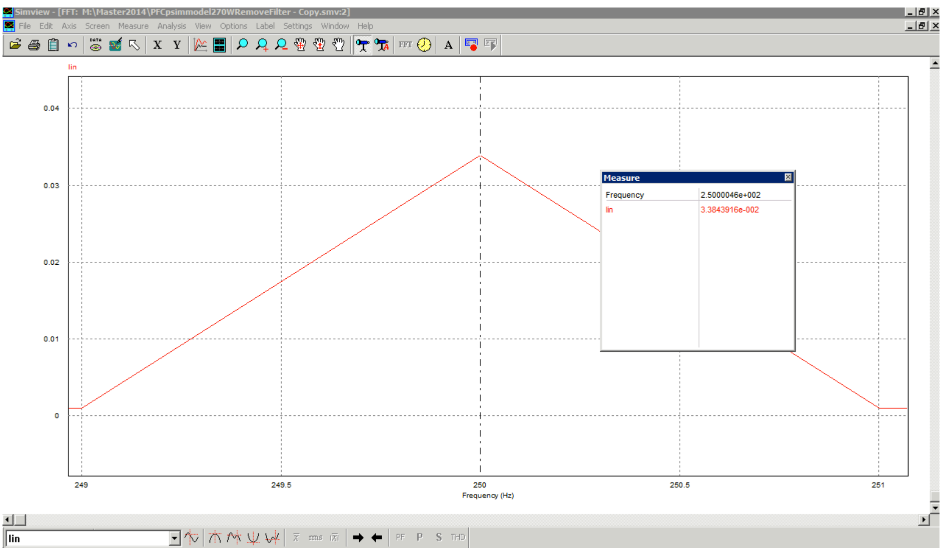
17.9 PSIM: Simulation results for running the PFC 270 W model with specified parameters from MATLAB

Simulation results for running the PFC 270 W model in PSIM, measuring the harmonics 3-13 in order to compare with the IEC requirements.

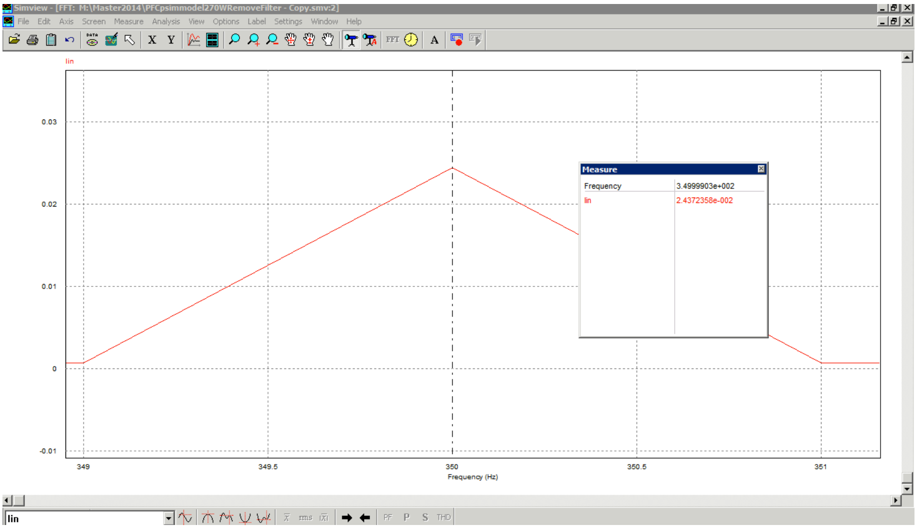
Measuring the In at the third harmonic in PSIM.



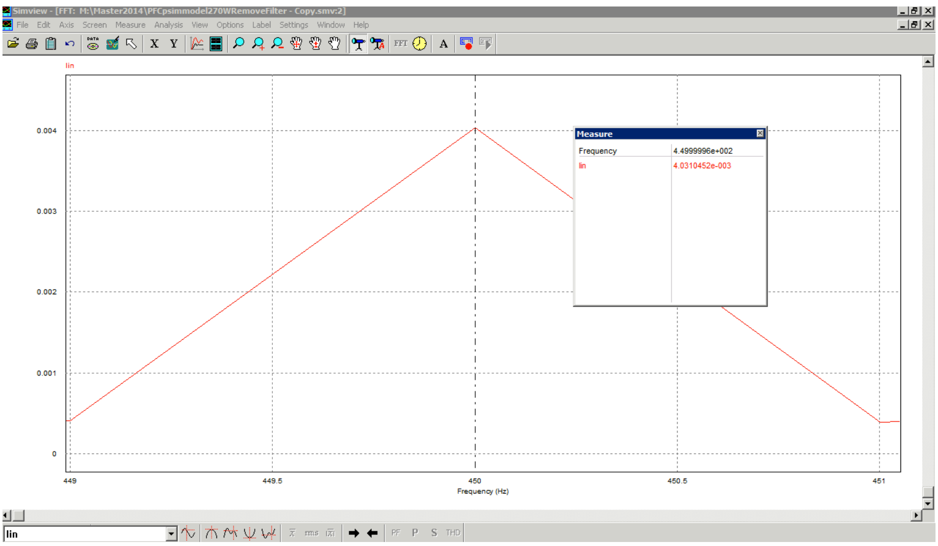
Measuring the In at the 5th harmonic in PSIM.



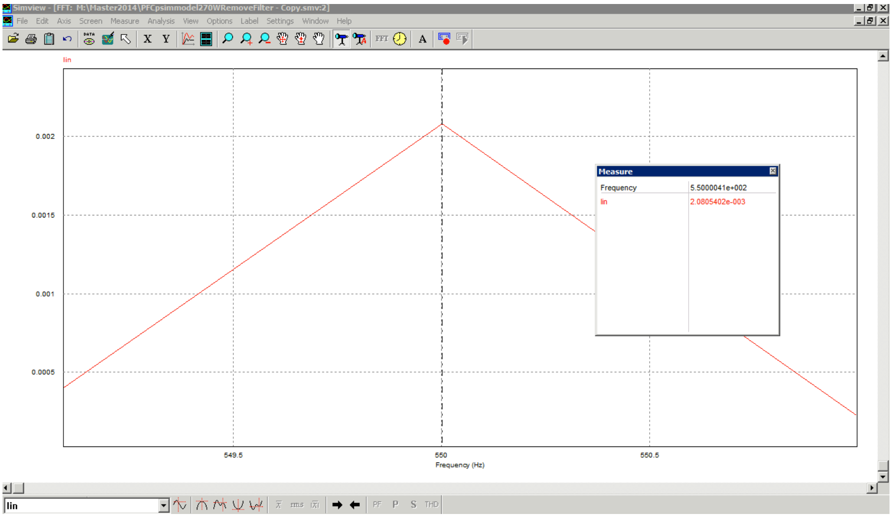
Measuring the In at the 7th harmonic in PSIM.



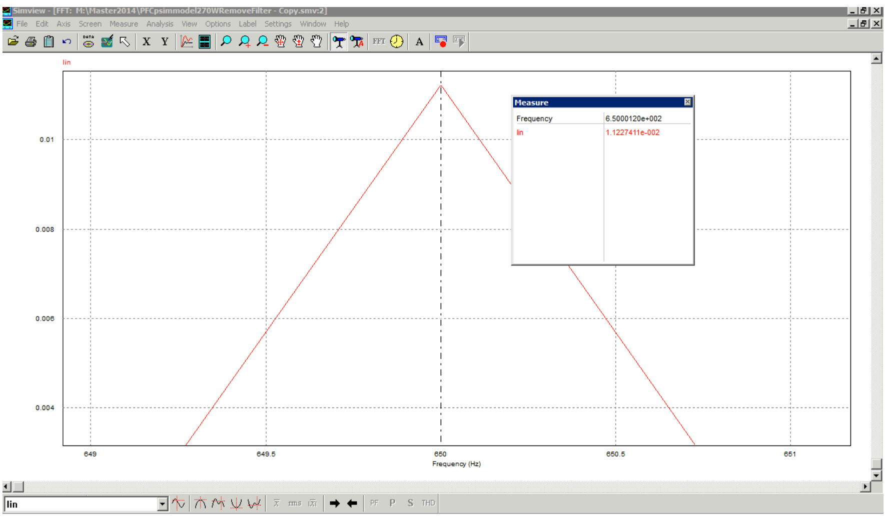
Measuring the In at the 9th harmonic in PSIM.



Measuring the In at the 11th harmonic in PSIM.



Measuring the In at the 13th harmonic in PSIM.



In order to utilize the predefined model of the PFC in PSIM, it has to be tested that the PFC satisfies the IEC requirements for THD (Total harmonic distortion) for Class C and D.

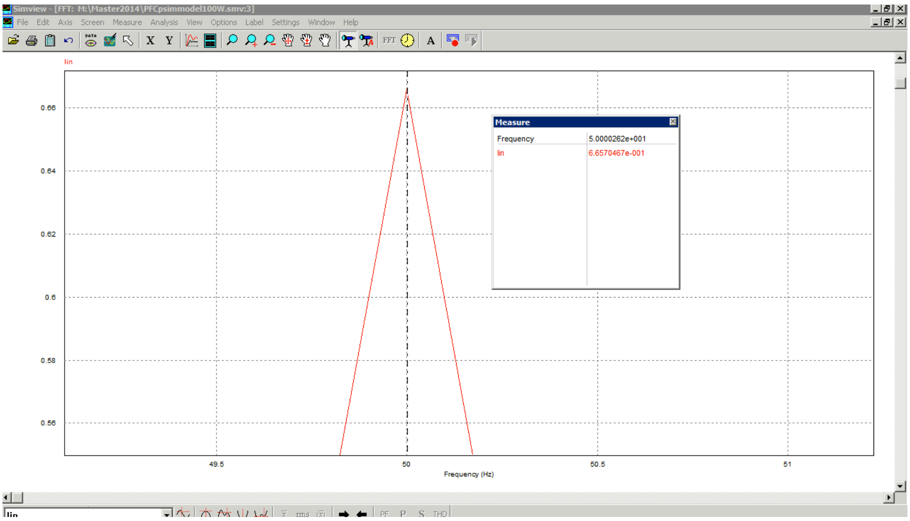
The table below Presents the IEC Class C and D requirements, compared with the values for the harmonics n, PFC 100 and 270 W.

Harmonic order n	Class C		Class D	100 W PFC	270 W PFC	
	[% of fundamental]	[% of fundamental calculated]	[mA/W]	[% of fundamental calculated]	[A]	[mA/W]
3	$30 \cdot \lambda$	0.199113	3.4	0.10280663	0.1109945 7	0.411091
5	10	0.066371	1.9	0.039234383	0.0338439 16	0.125347837
7	7	0.0464597	1.0	0.027636128	0.0243723 58	0.0902679925 9
9	5	0.0331855	0.5	0.013013774	$4.0310452 \cdot 10^{-3}$	$1.492979704 \cdot 10^{-2}$
11	3	0.0199113	0.35	0.009118127 1	$2.0805402 \cdot 10^{-3}$	$7.705704444 \cdot 10^{-3}$
13	3	0.0199113	3.85/13	0.01078033	$1.1227411 \cdot 10^{-2}$	0.0415830037

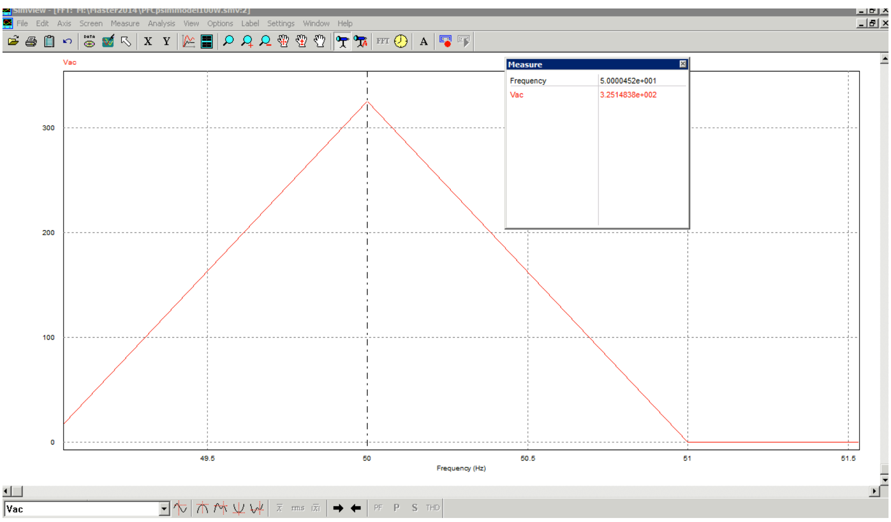
(λ is the circuit power factor)

17.10 PSIM: Simulation results for running the predefined PFC 100 W model in PSIM with the calculated parameters from the MATLAB, Simulink with the toolbox SimPowerSystem model.

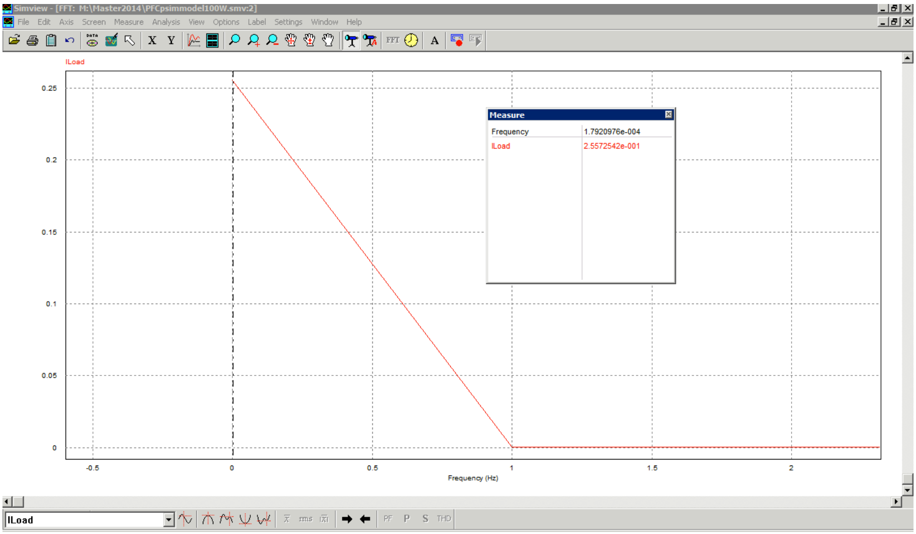
Represent extracts from the results measuring the current, I_s, at the AC side of the 100 W PFC.



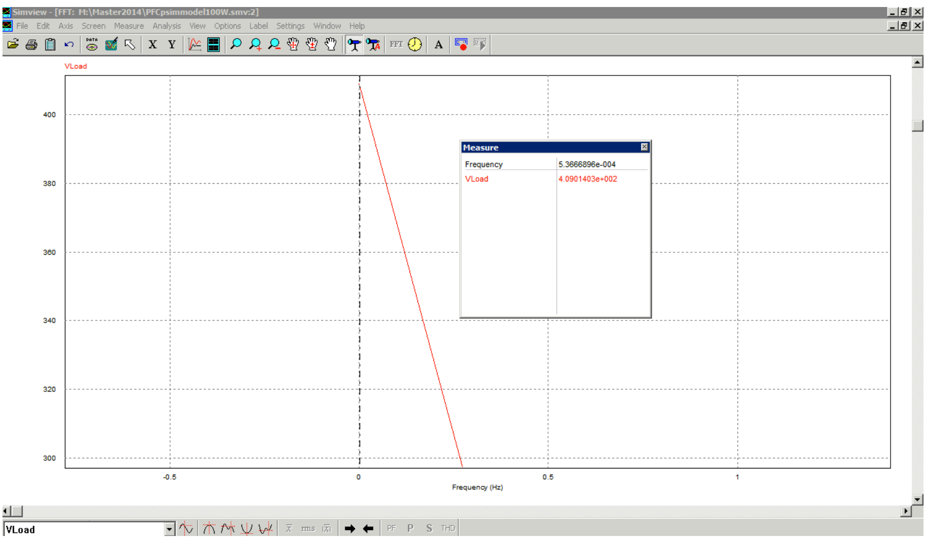
Represent extracts from the results measuring the voltage, V_s, at the AC side of the 100 W PFC.



Represent extracts from the results measuring the current, I_{load}, at the DC load side of the 100 W PFC.



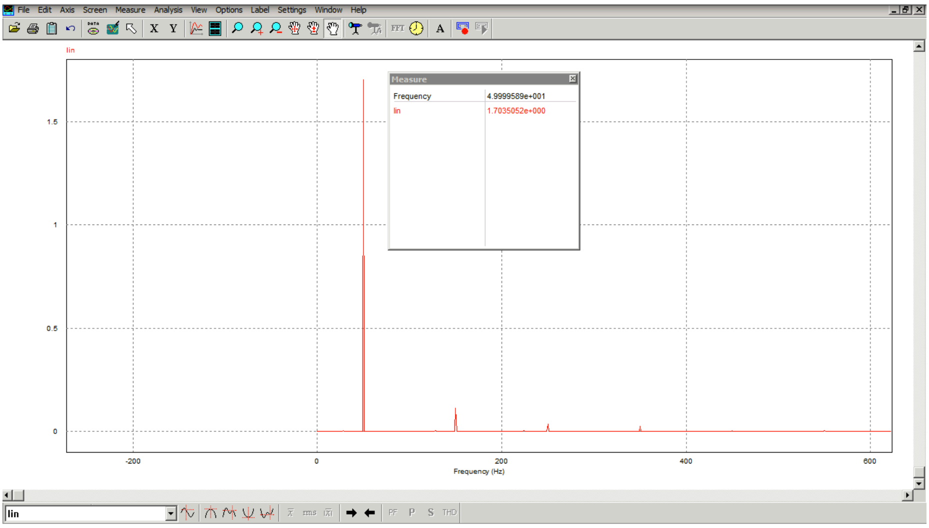
Represent extracts from the results measuring the voltage, V_{load}, at the DC load side of the 100 W PFC.



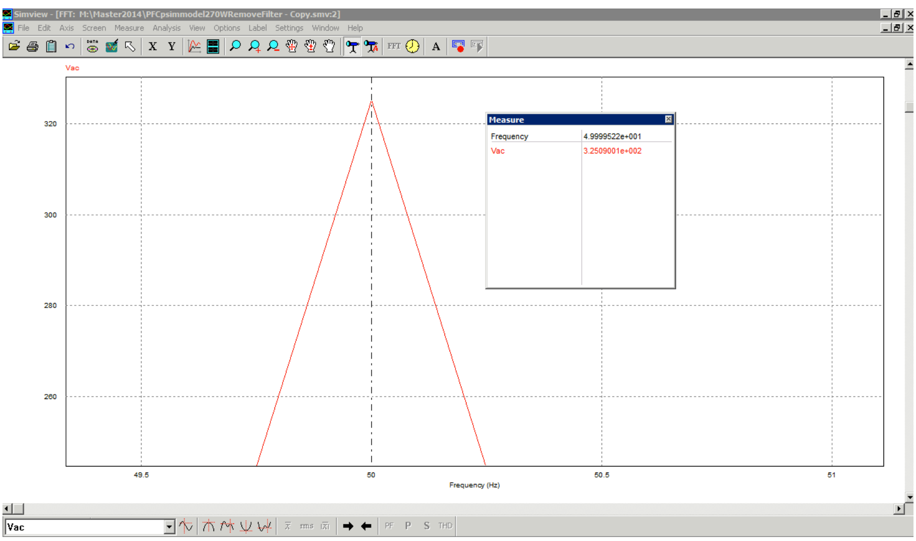
17.11 PSIM: Simulation results for running the predefined PFC 270 W model in PSIM with the calculated parameters from the MATLAB, Simulink with the toolbox SimPowerSystem model.

Simulation results for running the predefined PFC 270 W model in PSIM with the calculated parameters from the MATLAB, Simulink with the toolbox SimPowerSystem model.

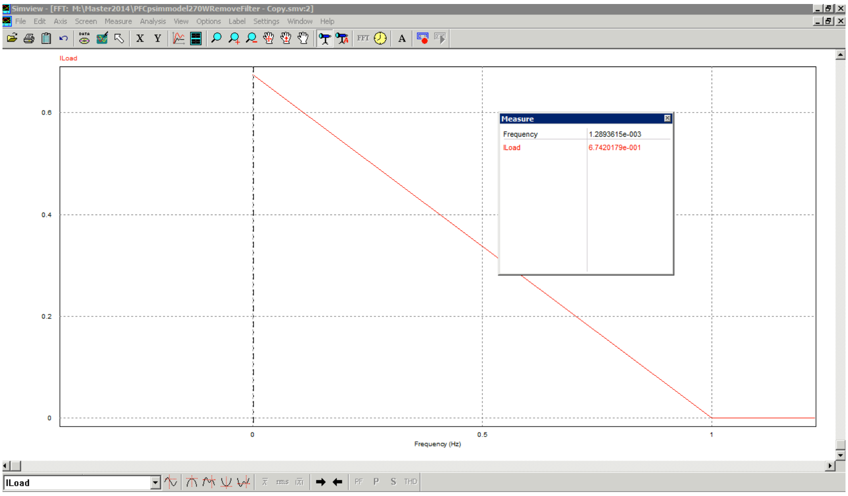
Represent extracts from the results measuring the current, I_s, at the AC side of the 270 W PFC.



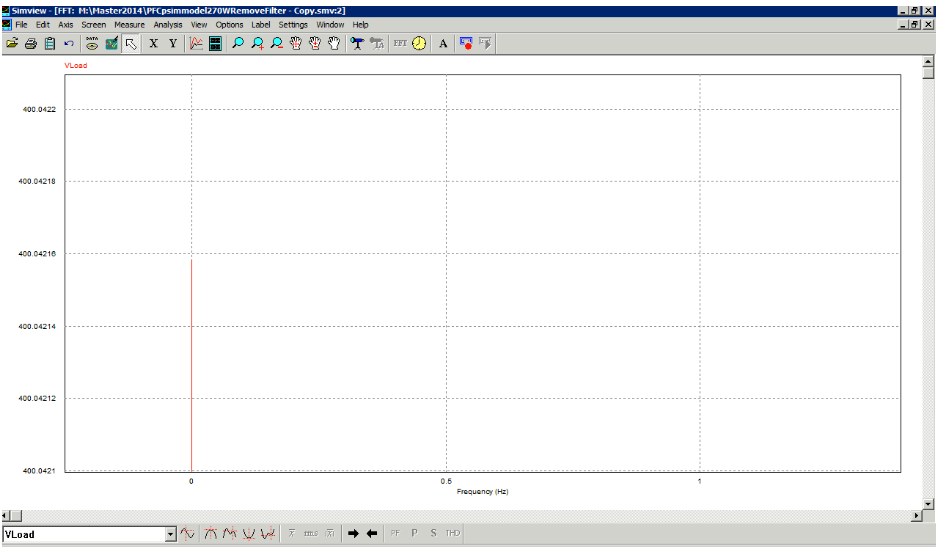
Represent extracts from the results measuring the voltage, V_s, at the AC side of the 270 W PFC.



Represent extracts from the results measuring the current, I_{load}, at the DC load side of the 270 W PFC.



Represent extracts from the results measuring the voltage, V_{load}, at the DC load side of the 270 W PFC.



17.12 Risk Analysis performed for the measurements performed at *Bjerke Upper Secondary School*

FELTKORT FOR DELTAKER

Navn: Aurora Bøhle Foss **Mob. nr.:** 98090840

Bostedsadresse: Brøsetveien 119 D 7046 Trondheim

Forsikringsselskap: Tryg Forsikring (tidligere Vesta) evt. *Studenter er forsikret gjennom folketrygden*

Nærmeste pårørende (navn, adresse og telefonnummer):

Steven Foss Buerstadveien 35 3135 Torød
Mob.nr.: 92201608

OPPLYSNINGER OM FELTARBEIDET

Feltarbeidets navn/type: Målinger i forbindelse med master: *DC forsyning til bygningsinstallasjoner*
Måling skal utføres ved Bjerke VGS, Statsråd Mathiesens vei 25, 0594 Oslo i samarbeid med COWI AS
Bedriftsbesøk: COWI AS, Grenseveien 86, 0663 Oslo, Sentralbord: 02694
Kontaktperson: Morten Halten-Eggen, Direkte: 48298396 Olav Økern, Direkte: 90590968

Navn på leder av målinger: Morten Halten-Eggen, Direkte: 48298396

Feltområde/arbeidssted: Bjerke VGS, Statsråd Mathiesens vei 25, 0594 Oslo i samarbeid med COWI AS, **arbeidssted for uken vil være:** COWI AS, Grenseveien 86, 0663 Oslo,

Varighet Fra: 24.02.2014 Til: 28.03.2014

Evt. personlig reiserute: Jeg planlegger å reise ned noen dager i forkant, fly ned til Sandefjord Torp torsdag 20.02.2014, og returnerer fra Gardemoen (OSL) flyplass til Værnes flyplass søndag 02.03.2014
Dersom du planlegger en privat reise i tilknytning til feltarbeidet, kan dette beskrives her.

Jeg bekrefter at jeg har lest NTNUs retningslinje; Feltarbeid – for deg som deltar.

Jeg bekrefter at jeg vil rette meg etter de sikkerhetsrutiner som gjelder for feltarbeidet, og at jeg vil opptre slik at min og andres sikkerhet ivaretas under feltarbeidet.

17.13 Results of the instantaneous measurements performed at *Bjerke Upper Secondary School*

Description	Number	Result [A]	Voltage level [V]	Calculated efficiency [W]
Distribution: +01=433.20				
Lighting room U1013 and U1015 U1021	F-101	1,49	230	342,7
Lighting room U1011, U1012 and U1014	F-102	3,4	230	782
Lighting room U1006, U1007, U1008 and U1010	F-103	1,82	230	418,6
Lighting room U1002, U1003, U1005 and U1009	F-104	2,75	230	632,5
Lighting room U10222, U1023, U1024 and U1026	F-105	2,96	230	680,8
Lighting room U1027 Technical room	F-106	0,1	230	23
Lighting room U1028, U1029, U1030 and U1031	F-107	0,14	230	32,2
Lighting kitchen	F-108	2,2	230	506
Lighting room U1080 Auditorium	F-109	0,68	230	156,4
Lighting hall room U1030, U1001 and U1081a	F-111	1,39	230	319,7
Outside Lighting is controlled by actuator	F-112	1,04	230	239,2

Heating cabling room U1021 Bathroom	F-300	5,59	230	1285,7
Heating cabling U1003 Bathroom	F-301	7,05	230	1621,5
Heating cabling scraper strip entrance	F-302	0,06	230	13,8
Selfregulating Heating cabling Basement 57 m	F-303	0,12	230	27,6
Heating cabling in room U1002 meeting room	F-304	0,12	230	27,6
Socket in canal room U1018	F-500	0,61	230	140,3
Socket room U1013, U1014, U1019, U1020, U1021 and U1022	F-502	0,81	230	186,3
Socket room U1003, U1005, U1009, U1011, U1012 and U1026	F-503	0,04	230	9,2
Charging station wheelchair room U1026	F-510	0,1	230	23
Socket charging station wheelchair room U1026, Without connection of wheelchair, with toy on wall	F-561	0,08	230	18,4
Socket charging station wheelchair room U1026, With connection of wheelchair, without	F-561	0,03	230	6,9

toy on wall				
Distribution: +01=433.23				
Portable PC Dell 1, AC/DC adapter DA90PM111	F-508	0,25	230	57,5
Portable PC Dell 2, Dell 65W AC adapter	F-508	0,45	230	103,5
Stationary PC+library lighting	F-508	0,85	230	195,5
Library Lighting	F-508	0,4	230	92
Stationary PC	F-508	0,45	230	103,5
Distribution: +01=433.26				
L1		3,02	230	694,6
L2		2,61	230	600,3
L3		2,9	230	667
N		1,75	230	402,5
SUM EFFICIENCY UPS=	2364,4	1,75	230	402,5
Emergency Lighting central	F-500	0,28	230	64.4
Fire central	F-501	0,48	230	110,4
Parallel control	F-502	0,65	230	149,5
Forced entry	F-503	1,30	230	299
Access control	F-504	0,27	230	62,1

17.14 Appendix: Overview of Measurement Equipment

Measuring equipment

When performing measurements to an electrical system, there exist numerous different measurement equipment that can be applied. The equipment chosen for the measurements in this study was determined by the focus of the measurements. The aim of these measurements was to measure power consumption of different loads, which originally are DC loads, over a period of time. Therefore, it was important to choose measuring equipment that could store data and that had the property of being able to take measurements over a period of time.

Current Clamp [114]

To be able to measure the current at numerous measuring points, current clamps where utilized. Current clamps are based on measuring the magnetic fields produced around the conductors when they are energized [72]. The current clamps were used together with the FLUKE 41 Power Harmonics Analyser.

FLUKE 41 Power Harmonics Analyser [73]

FLUKE 41 Power Harmonics Analyser is an advanced measurement equipment device that is able to give good measuring results and give the opportunity to measure numerous factors, such as harmonics, flicker and unbalance for single phase loads [74].

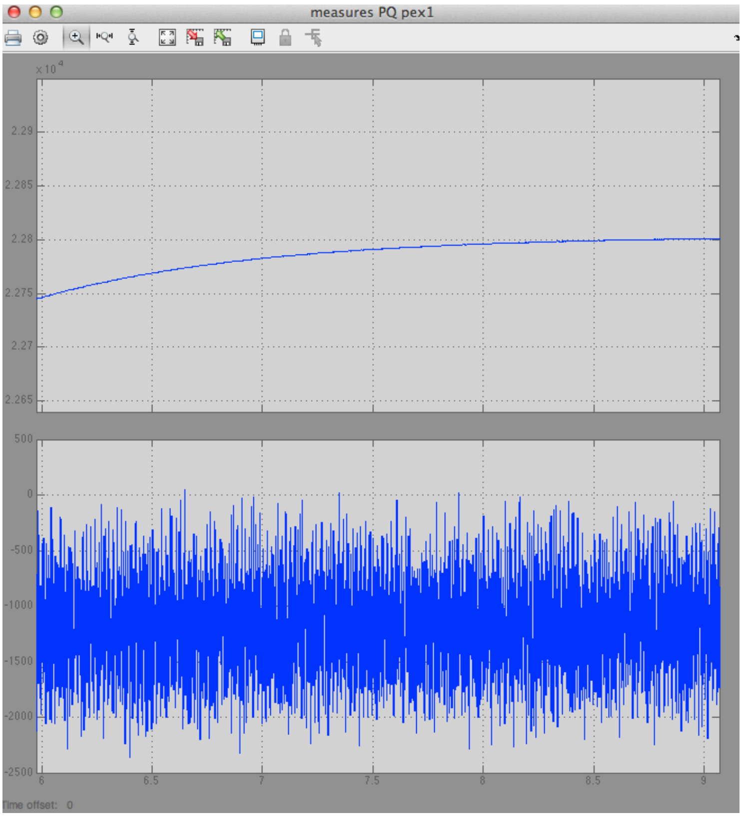
Power Guide 4400 [116]

The Power Guide 4400 is able to take 3-phase measurement by an automatic setup to provide instant detection of circuits and configurations to collect data. Users can select the length and mode of data collection, including troubleshooting, data logging, power quality surveys, energy and balancing loading, as the instrument is equipped with 8 independent channels [116]. The equipment was utilized to data log measurements of an interval of each minute for a period of 24 hours over each sub distribution measured to detect the total power consumption of Bjerke Upper Secondary School and the daily variations.

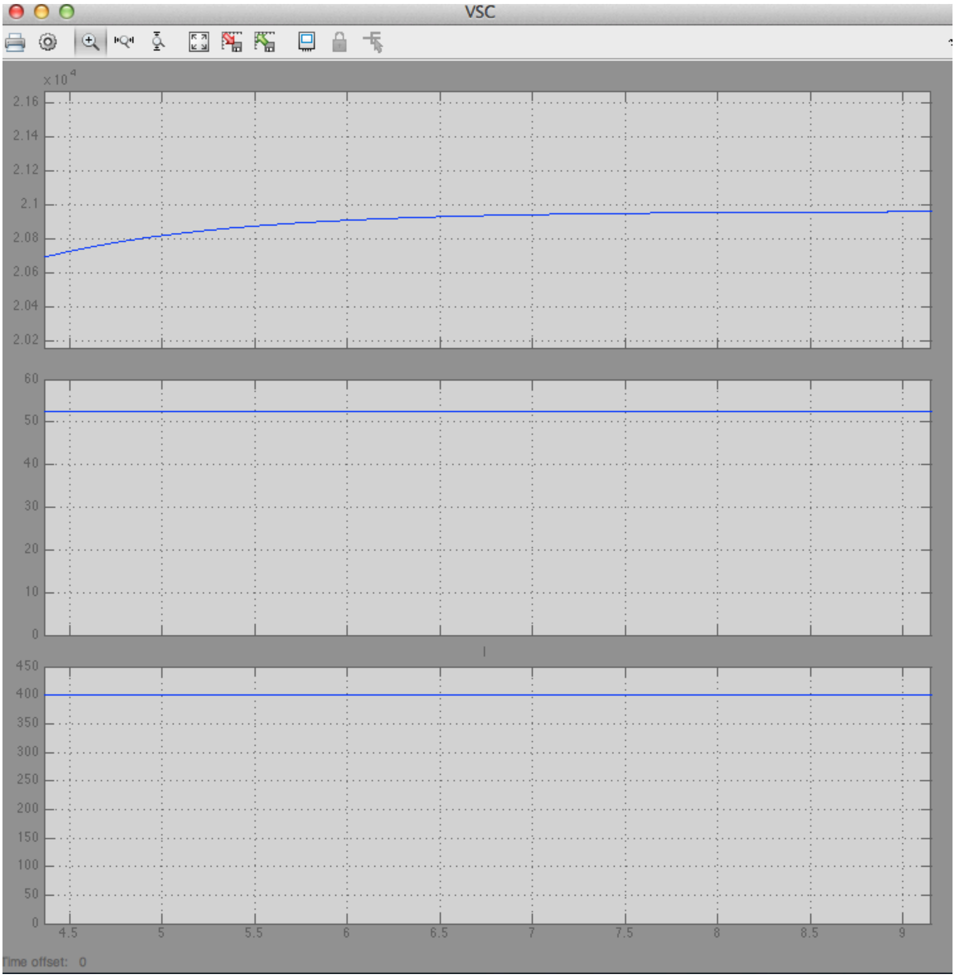
17.15 VSC: Represents extracting graph from measuring the power loss of the 20 kW VSC

The losses in the VSC are found by looking at the scope at the AC side and DC side for the measured power.

Presenting the power at the input of the AC side of the VSC, from scope in MATLAB. The simulation of the VSC give a input power of $P_{in,ac} = 22.8\ kW$.



Presents the power at the DC output, by measurements of the VSC running the simulation in MATLAB. The simulation of the VSC give a input power of $P_{out,dc} = 20.95\ kW$.



17.16 FEBDOK: Extracts from documentation of the DC and AC model

Dokumentasjon for anlegget

Bjerke vg. skole - Likestrøm

Anleggsadresse	**Kunde, eier**
Undervisningsbygg - Oslo Kommune Statsråd Mathisensvei 25 0594 OSLO	COWI AS Grensevn. 88 0605 OSLO Tel: 02694

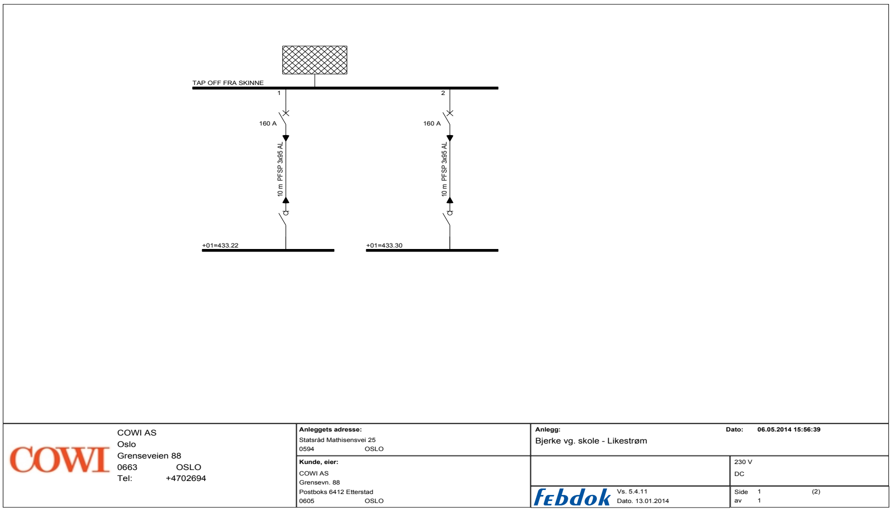
COWI

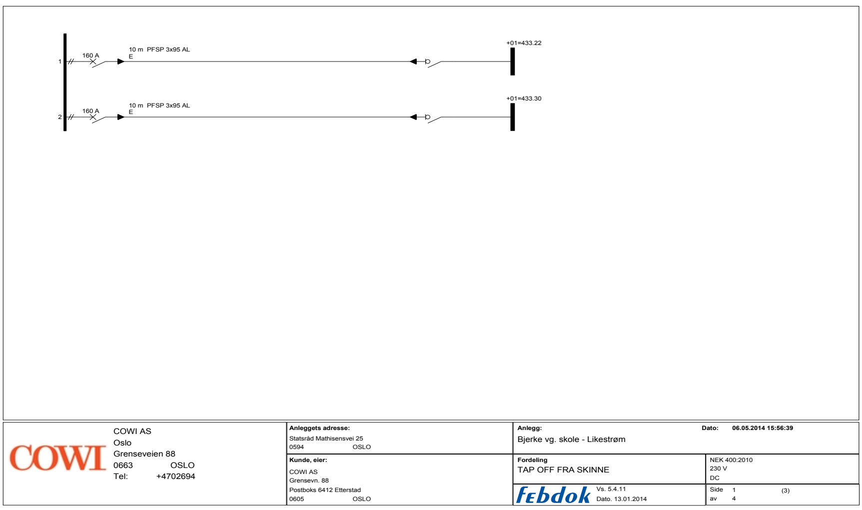
Utarbeidet av:
COWI AS
Oslo
Grenseveien 88
Postboks 6412 Etterstad, 0605 Oslo
0663 OSLO

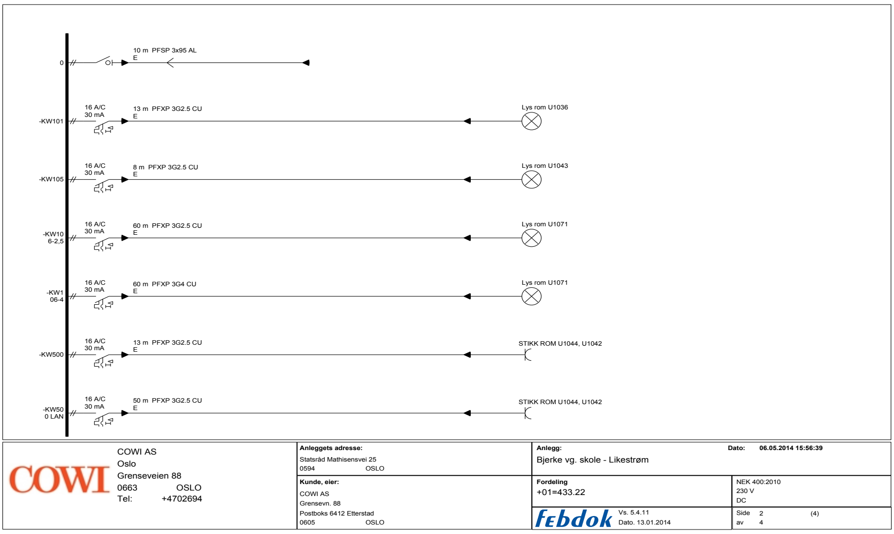
Tel: +4702694

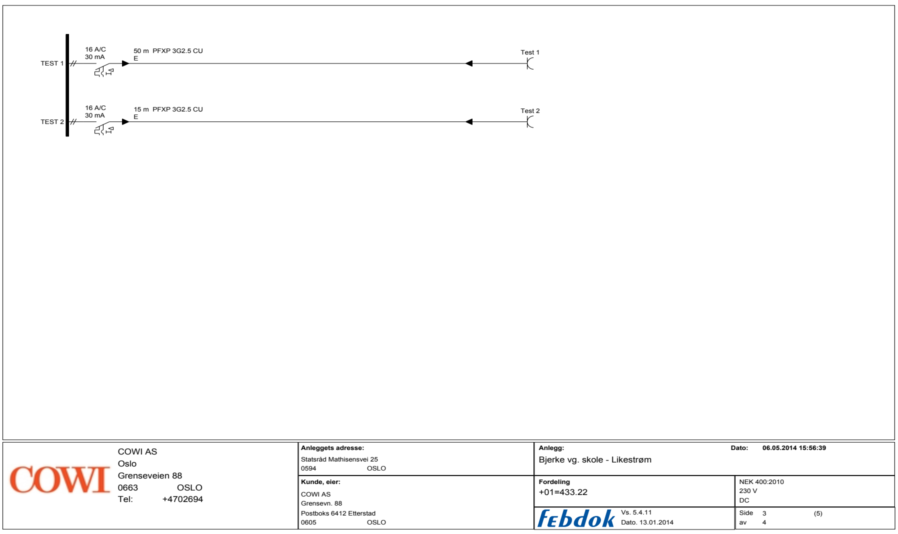
1

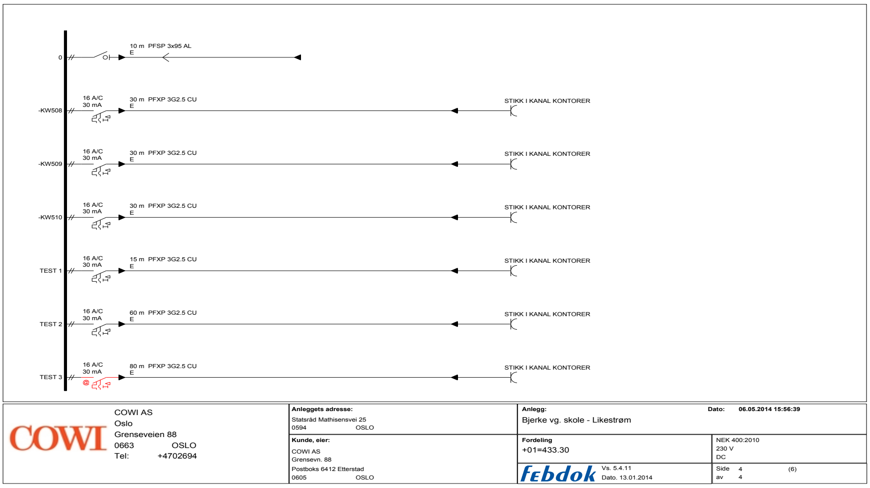
febdok


TAP OFF FRA SKINNE
1
2
160 A
160 A
10 m PFSP 3x95 AL
10 m PFSP 3x95 AL
+01=433.22
+01=433.30
COWI
COWI AS
Oslo
Grenseveien 88
0663 OSLO
Tel: +4702694
Anleggets adresse:
Statsråd Mathisensvei 25
0594 OSLO
Kunde, eier:
COWI AS
Grensevn. 88
Postboks 6412 Etterstad
0605 OSLO
Anlegg:
Bjerke vg. skole - Likestrøm
Dato: 06.05.2014 15:56:39
230 V
DC
febdok
Vs. 5.4.11
Dato. 13.01.2014
Side 1 (2)
av 1


1
2
160 A
160 A
10 m PFSP 3x95 AL
E
10 m PFSP 3x95 AL
E
+01=433.22
+01=433.30
COWI
COWI AS
Oslo
Grenseveien 88
0663 OSLO
Tel: +4702694
Anleggets adresse:
Statsråd Mathisensvei 25
0594 OSLO
Kunde, eier:
COWI AS
Grensevn. 88
Postboks 6412 Etterstad
0605 OSLO
Anlegg:
Bjerke vg. skole - Likestrøm
Dato: 06.05.2014 15:56:39
Fordeling
TAP OFF FRA SKINNE
NEK 400:2010
230 V
DC
febdok
Vs. 5.4.11
Dato. 13.01.2014
Side 1 (3)
av 4


0
10 m PFSP 3x95 AL
E
-KW101
16 A/C
30 mA
13 m PFXP 3G2.5 CU
E
Lys rom U1036
-KW105
16 A/C
30 mA
8 m PFXP 3G2.5 CU
E
Lys rom U1043
-KW10
6-2,5
16 A/C
30 mA
60 m PFXP 3G2.5 CU
E
Lys rom U1071
-KW1
06-4
16 A/C
30 mA
60 m PFXP 3G4 CU
E
Lys rom U1071
-KW500
16 A/C
30 mA
13 m PFXP 3G2.5 CU
E
STIKK ROM U1044, U1042
-KW50
0 LAN
16 A/C
30 mA
50 m PFXP 3G2.5 CU
E
STIKK ROM U1044, U1042
COWI
COWI AS
Oslo
Grenseveien 88
0663 OSLO
Tel: +4702694
Anleggets adresse:
Statsråd Mathisensvei 25
0594 OSLO
Kunde, eier:
COWI AS
Grensevn. 88
Postboks 6412 Etterstad
0605 OSLO
Anlegg:
Bjerke vg. skole - Likestrøm
Dato: 06.05.2014 15:56:39
Fordeling
+01=433.22
NEK 400:2010
230 V
DC
febdok
Vs. 5.4.11
Dato. 13.01.2014
Side 2 (4)
av 4


TEST 1
16 A/C
30 mA
50 m PFXP 3G2.5 CU
E
Test 1
TEST 2
16 A/C
30 mA
15 m PFXP 3G2.5 CU
E
Test 2
COWI
COWI AS
Oslo
Grenseveien 88
0663 OSLO
Tel: +4702694
Anleggets adresse:
Statsråd Mathisensvei 25
0594 OSLO
Kunde, eier:
COWI AS
Grensevn. 88
Postboks 6412 Etterstad
0605 OSLO
Anlegg:
Bjerke vg. skole - Likestrøm
Dato: 06.05.2014 15:56:39
Fordeling
+01=433.22
NEK 400:2010
230 V
DC
febdok
Vs. 5.4.11
Dato. 13.01.2014
Side 3 (5)
av 4


0
10 m PFSP 3x95 AL
E
-KW508
16 A/C
30 mA
30 m PFXP 3G2.5 CU
E
STIKK I KANAL KONTORER
-KW509
16 A/C
30 mA
30 m PFXP 3G2.5 CU
E
STIKK I KANAL KONTORER
-KW510
16 A/C
30 mA
30 m PFXP 3G2.5 CU
E
STIKK I KANAL KONTORER
TEST 1
16 A/C
30 mA
15 m PFXP 3G2.5 CU
E
STIKK I KANAL KONTORER
TEST 2
16 A/C
30 mA
60 m PFXP 3G2.5 CU
E
STIKK I KANAL KONTORER
TEST 3
16 A/C
30 mA
80 m PFXP 3G2.5 CU
E
STIKK I KANAL KONTORER
COWI
COWI AS
Oslo
Grenseveien 88
0663 OSLO
Tel: +4702694
Anleggets adresse:
Statsråd Mathisensvei 25
0594 OSLO
Kunde, eier:
COWI AS
Grensevn. 88
Postboks 6412 Etterstad
0605 OSLO
Anlegg:
Bjerke vg. skole - Likestrøm
Dato: 06.05.2014 15:56:39
Fordeling
+01=433.30
NEK 400:2010
230 V
DC
febdok
Vs. 5.4.11
Dato. 13.01.2014
Side 4 (6)
av 4

Beregningsresultater

Kurs nr. 1

Det er angitt at kursen ikke behøver å være beskyttet av et strømstyrt jordfeilvern

Inntak/fordeling	: +01=433.22		Fordelingstype	: DC
Beskrivelse	: +01=433.22			
Merkespenning	: 230 V		Antall faser	: 2
Laststrøm	: 86,9 A		Fasekobling	: L1-L2
Cos phi	: 1		Temperatur i fordeling	: 30 °C
Merkeeffekt, Pn	: 20,0 kW		Kurs nr innmating	: 0
Merkeytelse, Sn	: 20,0 kVA			:
Sammenlagret strøm	: L1: 38,9 A	L2: 38,9 A		
Sum nedstrøms tap	: 0,1 [kW]			
	:			

Spenningsfall totalt	: 0,7 V	0,3 %	Klemmespenning	: 229.3
...til siste fordeling	: 0,0 V	0,0 %		
...over Kabel	: 0,7 V	0,3 %	Maksimal lengde	: 68,8 m

Kabel	:			
Kabeltype/-lederløsning	: PFSP 3x95 AL			
Ref. inst. met.	: E			
Omgivelsetemperatur	: 30,0 °C			
Kabellengde	: 10,0 m		Annen korreksjonsfaktor	0.7
Tap i kabel	: 58,07 W	5,81 W/m		
Strømføringsevne	: 147,00 A			

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** TAP OFF FRA SKINNE febdok Ver. 5.4.11 Dato. 13.01.2014	NEK 400:2010 230 V DC Side 1 (13) av 18

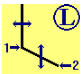
Beregningsresultater

Kurs nr. 1

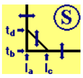
Kombinert vern, merking :

Fabrikat	: ABB SACE	Artikkel nummer	:
Bryterenhet	: XT2 Iru: 160 A / N	EAN-nummer	:
Utløserenhet	: EKIP LSI	Bryteevne	: 65,00 kA Ics
Merkestrøm	: 160,00 A	I2-verdi	: 208,00 A
		I5-(Im-) verdi	: 1760,00 A

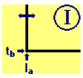
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer : 271,8 m



	Min tillatt	Max tillatt	Instillt verdi
I1	: 0,560 / 89,6 A	0,880 / 140,8 A	0,880 / 140,8 A
t1	: 12,000 s	36,000 s	36,000 s



	Min tillatt	Max tillatt	Instillt verdi
I2	: 1,500 / 240,0 A	8,000 / 1280,0 A	3,500 / 560,0 A
t2	: 0,10 s	0,40 s	0,10 s



	Min tillatt	Max tillatt	Instillt verdi
I3	: 3,500 / 616,0 A	10,000 / 1600,0 A	6,500 / 1040,0 A

	Kombinert vern				
	Ik [kA]	cos phi	î [kA]	Kabel $t=k^2S^2/I^2$ [s]	t utkobling [s]
Ik2p max	8,660	1,00	12,492	0,695	0,020
Ik2p max ende	7,043	1,00	10,160	1,051	0,020
Ik2p min	1,424	1,00	2,054	25,707	0,020

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40	
COWI — COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** TAP OFF FRA SKINNE	NEK 400:2010 230 V DC	
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 2 (14) av 18	

Beregningsresultater

Kurs nr. **2**

Det er angitt at kursen ikke behøver å være beskyttet av et strømstyrt jordfeilvern

Inntak/fordeling	: +01=433.30		Fordelingstype	: DC
Beskrivelse	: +01=433.30			
Merkespenning	: 230 V		Antall faser	: 2
Laststrøm	: 86,9 A		Fasekobling	: L1-L2
Cos phi	: 1		Temperatur i fordeling	: 30 °C
Merkeeffekt, Pn	: 20,0 kW		Kurs nr innmating	: 0
Merkeytelse, Sn	: 20,0 kVA			:
Sammenlagret strøm	: L1: 42,2 A	L2: 42,2 A		
Sum nedstrøms tap	: 0,2 [kW]			
	:			

Spenningsfall totalt	: 0,7 V	0,3 %	Klemmespenning	: 229.3
...til siste fordeling	: 0,0 V	0,0 %		
...over Kabel	: 0,7 V	0,3 %	Maksimal lengde	: 68,8 m

Kabel	:			
Kabeltype/-lederløsning	: PFSP 3x95 AL			
Ref. inst. met.	: E			
Omgivelsetemperatur	: 30,0 °C			
Kabellengde	: 10,0 m		Annen korreksjonsfaktor	0.7
Tap i kabel	: 58,07 W	5,81 W/m		
Strømføringsevne	: 147,00 A			

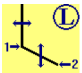
Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** **Dato:** **06.05.2014 15:56:40** Bjerke vg. skole - Likestrøm	
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** TAP OFF FRA SKINNE	NEK 400:2010 230 V DC
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 3 (15) av 18

Beregningsresultater

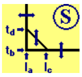
Kurs nr. 2

Kombinert vern, merking	:		
Fabrikat	: ABB SACE	Artikkel nummer	:
Bryterenhet	: XT2 Iru: 160 A / N	EAN-nummer	:
Utløserenhet	: EKIP LSI	Bryteevne	: 65,00 kA Ics
Merkestrøm	: 160,00 A	I2-verdi	: 208,00 A
		I5-(Im-) verdi	: 1760,00 A

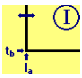
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer : 271,8 m



	Min tillatt	Max tillatt	Instillt verdi
I1	: 0,560 / 89,6 A	0,880 / 140,8 A	0,880 / 140,8 A
t1	: 12,000 s	36,000 s	36,000 s



	Min tillatt	Max tillatt	Instillt verdi
I2	: 1,500 / 240,0 A	8,000 / 1280,0 A	3,500 / 560,0 A
t2	: 0,10 s	0,20 s	0,10 s



	Min tillatt	Max tillatt	Instillt verdi
I3	: 3,500 / 616,0 A	10,000 / 1600,0 A	6,500 / 1040,0 A

	Kombinert vern				
	Ik [kA]	cos phi	î [kA]	Kabel $t=k^2S^2/I^2$ [s]	$t_{utkobling}$ [s]
Ik2p max	8,660	1,00	12,492	0,695	0,020
Ik2p max ende	7,043	1,00	10,160	1,051	0,020
Ik2p min	1,424	1,00	2,054	25,707	0,020

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40
COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** TAP OFF FRA SKINNE	NEK 400:2010 230 V DC
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 4 (16) av 18

Beregningsresultater

Kurs nr. **-KW101**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Fast belastning	: LYS ROM U1036		
Beskrivelse	: Lys rom U1036		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 3,87 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 0,9 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 0,9 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 1,6 V	0,7 %	Klemmespenning	: 228.4
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 0,9 V	0,4 %	Maksimal lengde	: 124,3 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 13,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 3,45 W 0,27 W/m		
Strømføringsevne	: 21,00 A		

Kortslutningsvern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 68,2 m

	Kortslutningsvern				
	Ik [kA]	cos phi	î [kA]	Kabel $t=k^2S^2/I^2$ [s]	$t_{utkobling}$ [s]
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	1,054	1,00	1,520	0,074	0,010
Ik2p min	0,565	1,00	0,815	0,259	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
\# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 230 V DC
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 5 (17) av 18

Beregningsresultater

Kurs nr. **-KW105**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Fast belastning	: LYS ROM U1043		
Beskrivelse	: Lys rom U1043		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 4,52 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 1,0 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,0 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 1,3 V	0,6 %	Klemmespenning	: 228.6
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 0,6 V	0,3 %	Maksimal lengde	: 106,4 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 8,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 2,90 W 0,36 W/m		
Strømføringsevne	: 21,00 A		

Kortslutningsvern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 68,2 m

	Kortslutningsvern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel t=k²S²/I² [s]**	**$t_{utkobling}$ [s]**
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	1,559	1,00	2,249	0,034	0,010
Ik2p min	0,734	1,00	1,059	0,153	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40
COWI — COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 230 V DC
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 6 (18) av 18

Beregningsresultater

Kurs nr. **-KW106-2,5**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Fast belastning	: LYS ROM U1071		
Beskrivelse	: Lys rom U1071		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 6,04 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 1,4 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,4 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 7,1 V	3,1 %	Klemmespenning	: 222.9
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 6,4 V	2,8 %	Maksimal lengde	: 79,6 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 60,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 38,81 W 0,65 W/m		
Strømføringsevne	: 21,00 A		

Kortslutningsvern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 68,2 m

	Kortslutningsvern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel t=k²S²/I² [s]**	**t $_{utkobling}$ [s]**
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	0,260	1,00	0,375	1,223	0,010
Ik2p min	0,179	1,00	0,258	2,580	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40
COWI — COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 230 V DC
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 7 (19) av 18

Beregningsresultater

Kurs nr. **-KW106-4**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Fast belastning	: LYS ROM U1071"		
Beskrivelse	: Lys rom U1071		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 6,04 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 1,4 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,4 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 4,7 V	2,0 %	Klemmespenning	: 225.3
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 4,0 V	1,7 %	Maksimal lengde	: 128,0 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G4 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 60,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 24,15 W 0,40 W/m		
Strømføringsevne	: 28,00 A		

Kortslutningsvern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 109,6 m

	Kortslutningsvern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel t=k²S²/I² [s]**	**t $_{utkobling}$ [s]**
Ik2p max	6,647	1,00	9,588	0,005	0,010
Ik2p max ende	0,409	1,00	0,590	1,265	0,010
Ik2p min	0,267	1,00	0,385	2,968	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40	
COWI — COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 230 V DC	
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 8 (20) av 18	

Beregningsresultater

Kurs nr. **-KW500**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: STIKK ROM U1044		
Beskrivelse	: STIKK ROM U1044, U1042		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,04 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,6 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 2,3 V	1,0 %	Klemmespenning	: 227.7
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 1,6 V	0,7 %	Maksimal lengde	: 68,3 m

Kabel	:			
Kabeltype/-lederløsning	: PFXP 3G2.5 CU			
Ref. inst. met.	: E			
Omgivelsetemperatur	: 30,0 °C			
Kabellengde	: 13,0 m		Annen korreksjonsfaktor	0.7
Tap i kabel	: 11,42 W	0,88 W/m		
Strømføringsevne	: 21,00 A			

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 68,2 m

	Kombinert vern				
	Ik [kA]	cos phi	î [kA]	Kabel $t=k^2S^2/I^2$ [s]	$t_{utkobling}$ [s]
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	1,054	1,00	1,520	0,074	0,010
Ik2p min	0,565	1,00	0,815	0,259	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO		**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** **06.05.2014 15:56:40**
COWI	COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 230 V DC
		febdok Ver. 5.4.11 Dato. 13.01.2014	Side 9 (21) av 18

Beregningsresultater

Kurs nr. **-KW500 LAN**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: STIKK ROM"		
Beskrivelse	: STIKK ROM U1044, U1042		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,04 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,6 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 6,9 V	3,0 %	Klemmespenning	: 223
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 6,2 V	2,7 %	Maksimal lengde	: 68,3 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 50,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 43,94 W 0,88 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 68,2 m

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel t=k²S²/I² [s]**	**t utkobling [s]**
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	0,310	1,00	0,447	0,860	0,010
Ik2p min	0,209	1,00	0,301	1,892	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
\# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40	
COWI — COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 230 V DC	
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 10 av 18	(22)

Beregningsresultater

Kurs nr. **TEST 1**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: TEST 1		
Beskrivelse	: Test 1		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 2,17 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 0,5 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 0,5 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 2,6 V	1,1 %	Klemmespenning	: 227.4
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 1,9 V	0,8 %	Maksimal lengde	: 221,7 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 50,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 4,17 W 0,08 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 68,2 m

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel t=k²S²/I² [s]**	**$t_{utkobling}$ [s]**
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	0,310	1,00	0,447	0,860	0,010
Ik2p min	0,209	1,00	0,301	1,892	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
\# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40
COWI — COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 230 V DC
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 11 (23) av 18

Beregningsresultater

Kurs nr. **TEST 2**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: TEST 2		
Beskrivelse	: Test 2		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 2,17 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 0,5 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 0,5 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 1,3 V	0,5 %	Klemmespenning	: 228.7
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 0,6 V	0,3 %	Maksimal lengde	: 221,7 m

Kabel	:			
Kabeltype/-lederløsning	: PFXP 3G2.5 CU			
Ref. inst. met.	: E			
Omgivelsetemperatur	: 30,0 °C			
Kabellengde	: 15,0 m		Annen korreksjonsfaktor	0.7
Tap i kabel	: 1,25 W	0,08 W/m		
Strømføringsevne	: 21,00 A			

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 68,2 m

	Kombinert vern				
	Ik [kA]	cos phi	î [kA]	Kabel $t=k^2S^2/I^2$ [s]	$t_{utkobling}$ [s]
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	0,933	1,00	1,346	0,095	0,010
Ik2p min	0,518	1,00	0,747	0,308	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO		**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40
COWI	COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 230 V DC
		febdok Ver. 5.4.11 Dato. 13.01.2014	Side 12 (24) av 18

Beregningsresultater

Kurs nr. **-KW508**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: STIKK I KANAL KONTOR		
Beskrivelse	: STIKK I KANAL KONTORER		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,04 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,6 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 4,4 V	1,9 %	Klemmespenning	: 225.5
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 3,8 V	1,6 %	Maksimal lengde	: 68,3 m

Kabel	:			
Kabeltype/-lederløsning	: PFXP 3G2.5 CU			
Ref. inst. met.	: E			
Omgivelsetemperatur	: 30,0 °C			
Kabellengde	: 30,0 m		Annen korreksjonsfaktor	0.7
Tap i kabel	: 26,36 W	0,88 W/m		
Strømføringsevne	: 21,00 A			

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 68,2 m

	Kombinert vern				
	Ik [kA]	cos phi	î [kA]	Kabel t=k²S²/I² [s]	$t_{utkobling}$ [s]
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	0,502	1,00	0,724	0,328	0,010
Ik2p min	0,317	1,00	0,457	0,823	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40	
COWI — COWI AS, Grenseveien 88, 0663 OSLO, Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 230 V DC	
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 13 av 18	(25)

Beregningsresultater

Kurs nr. **-KW509**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: STIKK I KANAL'		
Beskrivelse	: STIKK I KANAL KONTORER		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,04 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,6 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 4,4 V	1,9 %	Klemmespenning	: 225.5
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 3,8 V	1,6 %	Maksimal lengde	: 68,3 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 30,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 26,36 W 0,88 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 68,2 m

	Kombinert vern				
	Ik [kA]	cos phi	î [kA]	Kabel $t=k^2S^2/I^2$ [s]	$t_{utkobling}$ [s]
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	0,502	1,00	0,724	0,328	0,010
Ik2p min	0,317	1,00	0,457	0,823	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25, 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40
COWI — COWI AS, Grenseveien 88, 0663 OSLO, Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010, 230 V DC
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 14 (26) av 18

Beregningsresultater

Kurs nr. **-KW510**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: STIKK I KANAL"		
Beskrivelse	: STIKK I KANAL KONTORER		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,04 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,6 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 4,4 V	1,9 %	Klemmespenning	: 225.5
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 3,8 V	1,6 %	Maksimal lengde	: 68,3 m

Kabel	:			
Kabeltype/-lederløsning	: PFXP 3G2.5 CU			
Ref. inst. met.	: E			
Omgivelsetemperatur	: 30,0 °C			
Kabellengde	: 30,0 m		Annen korreksjonsfaktor	0.7
Tap i kabel	: 26,36 W	0,88 W/m		
Strømføringsevne	: 21,00 A			

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 68,2 m

	Kombinert vern				
	Ik [kA]	cos phi	î [kA]	Kabel $t=k^2S^2/I^2$ [s]	$t_{utkobling}$ [s]
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	0,502	1,00	0,724	0,328	0,010
Ik2p min	0,317	1,00	0,457	0,823	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 230 V DC
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 15 (27) av 18

Beregningsresultater

Kurs nr. **TEST 1**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: TEST 1'		
Beskrivelse	: STIKK I KANAL KONTORER		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,04 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,6 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 2,5 V	1,1 %	Klemmespenning	: 227.4
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 1,9 V	0,8 %	Maksimal lengde	: 68,3 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 15,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 13,18 W 0,88 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A

Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer : 68,2 m

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel $t=k^2S^2/I^2$ [s]**	**$t_{utkobling}$ [s]**
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	0,933	1,00	1,346	0,095	0,010
Ik2p min	0,518	1,00	0,747	0,308	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25, 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40
COWI — COWI AS, Grenseveien 88, 0663 OSLO, Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010, 230 V DC
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 16 (28) av 18

Beregningsresultater

Kurs nr. **TEST 2**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last : TEST2'
Beskrivelse : STIKK I KANAL KONTORER

Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,04 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,6 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 8,2 V	3,5 %	Klemmespenning	: 221.8
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 7,5 V	3,3 %	Maksimal lengde	: 68,3 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 60,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 52,73 W 0,88 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A

Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer : 68,2 m

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel t=k²S²/I² [s]**	**$t_{utkobling}$ [s]**
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	0,260	1,00	0,375	1,223	0,010
Ik2p min	0,179	1,00	0,258	2,580	0,010

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 230 V DC
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 17 (29) av 18

Beregningsresultater

Kurs nr. **TEST 3**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: TEST 3'		
Beskrivelse	: STIKK I KANAL KONTORER		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,04 A	Fasekobling	: L1-L2
Cos phi	: 1		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,6 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 10,7 V	4,6 %	Klemmespenning	: 219.3
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 10,0 V	4,3 %	Maksimal lengde	: 68,3 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 80,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 70,31 W 0,88 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:	**Vernet tilfredsstiller ikke alle krav i forskrift/norm**	
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A

Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer : 68,2 m

	Kombinert vern				
	Ik [kA]	cos phi	î [kA]	Kabel t=k²S²/I² [s]	$t_{utkobling}$ [s]
Ik2p max	6,647	1,00	9,588	0,002	0,010
Ik2p max ende	0,197	1,00	0,284	2,130	0,010
Ik2p min	0,138	1,00	0,199	4,340	@ 10,166

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Likestrøm	**Dato:** 06.05.2014 15:56:40
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 230 V DC
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 18 (30) av 18

Dokumentasjon for anlegget

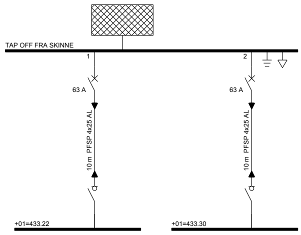
Bjerke vg. skole - Vekselstrøm

Anleggsadresse	**Kunde, eier**
Undervisiningsbygg - Oslo Kommune Statsråd Mathisensvei 25 0594 OSLO	COWI AS Grensevn. 88 0605 OSLO Tel: 02694

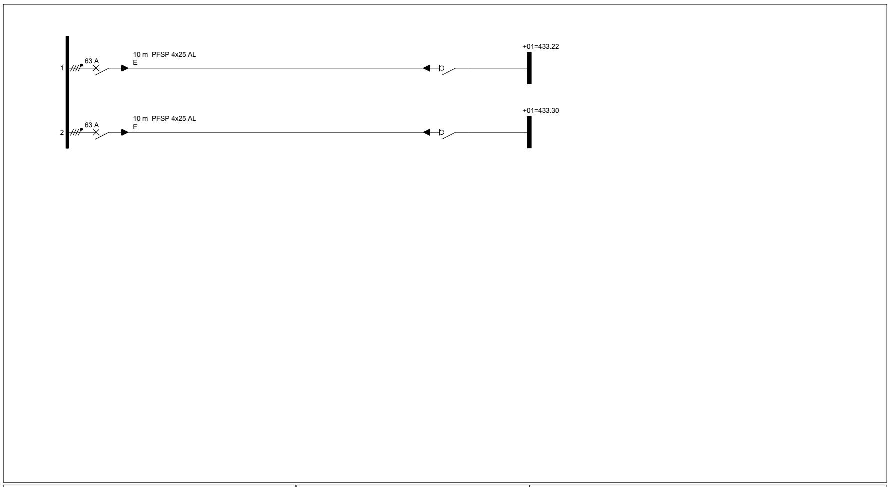
Utarbeidet av:
COWI AS
Oslo
Grenseveien 88
Postboks 6412 Etterstad, 0605 Oslo
0663 OSLO

Tel: +4702694

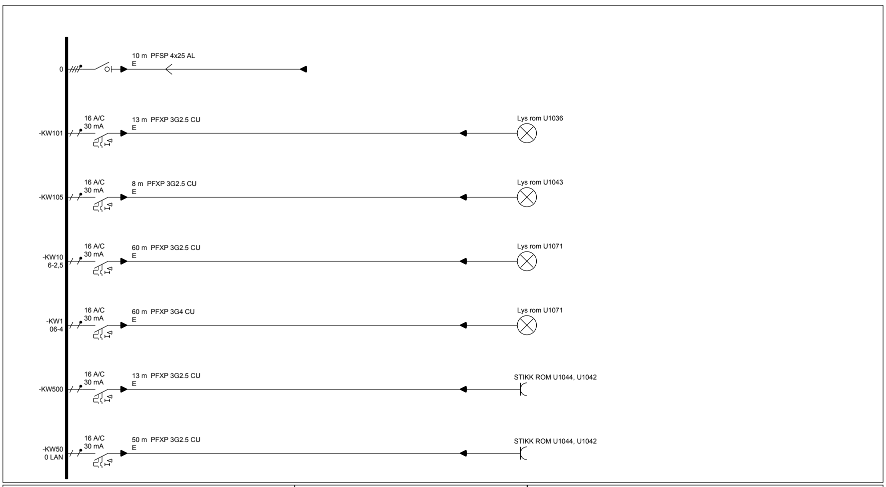
1



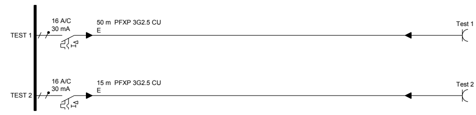
COWI AS Oslo Grenseveien 88 0663 OSLO Tel: +4702694	**Anleggets adresse:** Statsråd Mathisensvei 25 0594 OSLO	**Anlegg:** Bjerke vg. skole - Vekselstrøm	**Dato:** 21.05.2014 12:13:42
	Kunde, eier: COWI AS Grensevn. 88 Postboks 6412 Etterstad 0605 OSLO		400 V TN-S
		febdok Vs. 5.4.11 Dato. 13.01.2014	Side 1 (2) av 1



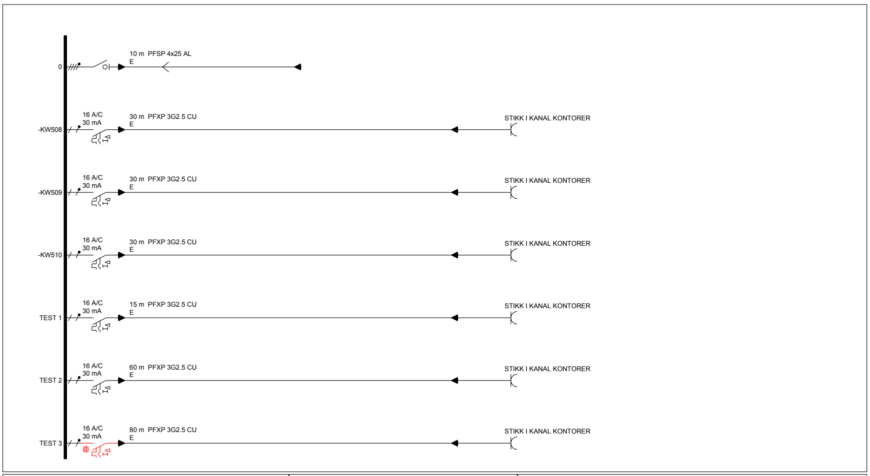
COWI AS Oslo Grenseveien 88 0663 OSLO Tel: +4702694	**Anleggets adresse:** Statsråd Mathisensvei 25 0594 OSLO	**Anlegg:** Bjerke vg. skole - Vekselstrøm	**Dato:** 21.05.2014 12:13:43
	Kunde, eier: COWI AS Grensevn. 88 Postboks 6412 Etterstad 0605 OSLO	**Fordeling** TAP OFF FRA SKINNE	NEK 400:2010 400 V TN-S
		febdok Vs. 5.4.11 Dato. 13.01.2014	Side 1 (3) av 4



COWI AS Oslo Grenseveien 88 0663 OSLO Tel: +4702694	**Anleggets adresse:** Statsråd Mathisensvei 25 0594 OSLO	**Anlegg:** Bjerke vg. skole - Vekselstrøm	**Dato:** 21.05.2014 12:13:43
	Kunde, eier: COWI AS Grensevn. 88 Postboks 6412 Etterstad 0605 OSLO	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
		febdok Vs. 5.4.11 Dato. 13.01.2014	Side 2 (4) av 4



COWI AS Oslo Grenseveien 88 0663 OSLO Tel: +4702694	**Anleggets adresse:** Statsråd Mathisensvei 25 0594 OSLO	**Anlegg:** Bjerke vg. skole - Vekselstrøm	**Dato:** **21.05.2014 12:13:43**
	Kunde, eier: COWI AS Grensevn. 88 Postboks 6412 Etterstad 0605 OSLO	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
		febdok Vs. 5.4.11 Dato. 13.01.2014	Side 3 (5) av 4



COWI AS Oslo Grenseveien 88 0663 OSLO Tel: +4702694	**Anleggets adresse:** Statsråd Mathisensvei 25 0594 OSLO	**Anlegg:** Bjerke vg. skole - Vekselstrøm	**Dato:** **21.05.2014 12:13:43**
	Kunde, eier: COWI AS Grensevn. 88 Postboks 6412 Etterstad 0605 OSLO	**Fordeling** +01=433.30	NEK 400:2010 400 V TN-S
		febdok Vs. 5.4.11 Dato. 13.01.2014	Side 4 (6) av 4

Beregningsresultater

Kurs nr. 2

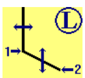
Det er angitt at kursen ikke behøver å være beskyttet av et strømstyrt jordfeilvern

Inntak/fordeling	: +01=433.30		Fordelingstype	: TN-S	
Beskrivelse	: +01=433.30				
Merkespenning	: 400 V		Antall faser	: 3	
Laststrøm	: 50,1 A		Fasekobling	: L1-L2-L3-N	
Cos phi	: 1		Temperatur i fordeling	: 30 °C	
Merkeeffekt, Pn	: 34,7 kW		Kurs nr innmating	: 0	
Merkeytelse, Sn	: 34,7 kVA			:	
Sammenlagret strøm	: L1: 15,6 A	L2: 15,6 A	L3: 15,6 A	N: 0,0 A	
Sum nedstrøms tap	: 0,3 [kW]				
	:				

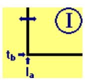
Spenningsfall totalt	: 1,3 V	0,3 %	Klemmespenning	: 398.7
...til siste fordeling	: 0,0 V	0,0 %		
...over Kabel	: 1,3 V	0,3 %	Maksimal lengde	: 63,9 m

Kabel	:			
Kabeltype/-lederløsning	: PFSP 4x25 AL			
Ref. inst. met.	: E			
Omgivelsetemperatur	: 30,0 °C			
Kabellengde	: 10,0 m		Annen korreksjonsfaktor	0.7
Tap i kabel	: 108,57 W	10,86 W/m		
Strømføringsevne	: 54,60 A			

Kombinert vern, merking	:		
Fabrikat	: ABB SACE	Artikkel nummer	:
Bryterenhet	: XT2 Iru: 160 A / N	EAN-nummer	:
Utløserenhet	: EKIP LS/I	Bryteevne	: 36,00 kA Ics
Merkestrøm	: 63,00 A	I2-verdi	: 81,90 A
		I5-(Im-) verdi	: 693,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 815,9 m



	Min tillatt	Max tillatt	Instillt verdi
I1	: 0,800 / 50,4 A	0,840 / 52,9 A	0,840 / 52,9 A
t1	: 12,000 s	36,000 s	36,000 s



	Min tillatt	Max tillatt	Instillt verdi
I3	: 1,000 / 69,3 A	10,000 / 630,0 A	5,500 / 346,5 A

Beregningsresultater

Kurs nr. 2

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel $t=k^2S^2/I^2$ [s]**	**$t_{utkobling}$ [s]**
Ik3p max	10,000	0,80	14,679	0,036	0,020
Ik3p max ende	6,917	0,90	10,001	0,075	0,020
Ik3p min	1,564	0,92	2,258	1,476	0,020
Ik2p max	8,660	0,80	12,712	0,048	0,020
Ik2p max ende	5,990	0,90	8,660	0,101	0,020
Ik2p min	1,355	0,92	1,957	1,966	0,020
Ik1p max	3,499	0,80	5,136	0,295	0,020
Ik1p max ende	2,678	0,88	3,878	0,503	0,020
Ik1p min	0,890	0,92	1,285	4,558	0,020
Ij max	3,499	0,80	5,136	0,162	0,020
Ij max ende	2,532	0,90	3,661	0,310	0,020
Ij min	0,867	0,92	1,251	2,645	0,020

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** **Dato: 22.05.2014 13:30:16** Bjerke vg. skole - Vekselstrøm	
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** TAP OFF FRA SKINNE	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 4 (16) av 32

Beregningsresultater

Kurs nr. **-KW101**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Fast belastning	: LYS ROM U1036		
Beskrivelse	: Lys rom U1036		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 4,08 A	Fasekobling	: L1-N
Cos phi	: 0.95		
Merkeeffekt, Pn	: 0,9 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 0,9 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 1,6 V	0,7 %	Klemmespenning	: 228.3
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 0,9 V	0,4 %	Maksimal lengde	: 124,1 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 13,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 3,81 W 0,29 W/m		
Strømføringsevne	: 21,00 A		

Kortslutningsvern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A

Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer : 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16	
COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S	
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 5 av 32	(17)

Beregningsresultater

Kurs nr. **-KW101**

	Kortslutningsvern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel t=k²S²/I² [s]**	**t $_{utkobling}$ [s]**
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	0,878	0,99	1,267	0,107	0,010
Ik1p min	0,469	0,98	0,677	0,376	0,010
Ij max	2,532	0,90	3,661		
Ij max ende	0,859	0,99	1,239		
Ij min	0,461	0,98	0,665		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO		**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** **22.05.2014 13:30:16**
COWI	COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
		febdok Ver. 5.4.11 Dato. 13.01.2014	Side 6 (18) av 32

Beregningsresultater

Kurs nr. **-KW105**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Fast belastning	: LYS ROM U1043		
Beskrivelse	: Lys rom U1043		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 4,74 A	Fasekobling	: L2-N
Cos phi	: 0.95		
Merkeeffekt, Pn	: 1,0 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,1 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 1,4 V	0,6 %	Klemmespenning	: 228.6
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 0,7 V	0,3 %	Maksimal lengde	: 106,8 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 8,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 3,16 W 0,40 W/m		
Strømføringsevne	: 21,00 A		

Kortslutningsvern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 7 (19) av 32

Beregningsresultater

Kurs nr. **-KW105**

	Kortslutningsvern				
	Ik [kA]	cos phi	î [kA]	Kabel t=k²S²/I² [s]	$t_{utkobling}$ [s]
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	1,194	0,98	1,722	0,058	0,010
Ik1p min	0,575	0,97	0,829	0,250	0,010
Ij max	2,532	0,90	3,661		
Ij max ende	1,159	0,98	1,672		
Ij min	0,564	0,97	0,814		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO		**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16
COWI	COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
		febdok Ver. 5.4.11 Dato. 13.01.2014	Side 8 (20) av 32

Beregningsresultater

Kurs nr. **-KW106-2,5**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Fast belastning	: LYS ROM U1071		
Beskrivelse	: Lys rom U1071		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 6,35 A	Fasekobling	: L3-N
Cos phi	: 0.95		
Merkeeffekt, Pn	: 1,4 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,5 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 7,1 V	3,1 %	Klemmespenning	: 222.8
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 6,7 V	2,9 %	Maksimal lengde	: 79,7 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 60,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 42,55 W 0,71 W/m		
Strømføringsevne	: 21,00 A		

Kortslutningsvern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 9 (21) av 32

Beregningsresultater

Kurs nr. **-KW106-2,5**

	Kortslutningsvern				
	Ik [kA]	cos phi	î [kA]	Kabel $t=k^2S^2/I^2$ [s]	$t_{utkobling}$ [s]
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	0,249	1,00	0,359	1,333	0,010
Ik1p min	0,169	1,00	0,244	2,894	0,012
Ij max	2,532	0,90	3,661		
Ij max ende	0,248	1,00	0,358		
Ij min	0,168	1,00	0,242		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** **Dato:** **22.05.2014 13:30:16** Bjerke vg. skole - Vekselstrøm	
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 10 (22) av 32

Beregningsresultater

Kurs nr. **-KW106-4**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Fast belastning	: LYS ROM U1071"		
Beskrivelse	: Lys rom U1071		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 6,35 A	Fasekobling	: L1-N
Cos phi	: 0.95		
Merkeeffekt, Pn	: 1,4 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,5 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 4,7 V	2,0 %	Klemmespenning	: 225.2
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 4,2 V	1,8 %	Maksimal lengde	: 127,9 m

Kabel	:			
Kabeltype/-lederløsning	: PFXP 3G4 CU			
Ref. inst. met.	: E			
Omgivelsetemperatur	: 30,0 °C			
Kabellengde	: 60,0 m		Annen korreksjonsfaktor	0.7
Tap i kabel	: 26,47 W	0,44 W/m		
Strømføringsevne	: 28,00 A			

Kortslutningsvern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 102,8 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16
COWI — COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 11 (23) av 32

Beregningsresultater

Kurs nr. **-KW106-4**

	Kortslutningsvern				
	Ik [kA]	cos phi	î [kA]	Kabel $t=k^2S^2/I^2$ [s]	$t_{utkobling}$ [s]
Ik1p max	2,678	0,88	3,878	0,030	0,010
Ik1p max ende	0,381	1,00	0,550	1,458	0,010
Ik1p min	0,245	0,99	0,353	3,525	0,010
Ij max	2,532	0,90	3,661		
Ij max ende	0,378	1,00	0,545		
Ij min	0,243	0,99	0,351		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** **22.05.2014 13:30:16**	
COWI	COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
		febdok Ver. 5.4.11 Dato. 13.01.2014	Side 12 (24) av 32

Beregningsresultater

Kurs nr. **-KW500**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: STIKK ROM U1044		
Beskrivelse	: STIKK ROM U1044, U1042		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,83 A	Fasekobling	: L2-N
Cos phi	: 0.9		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,8 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 2,3 V	1,0 %	Klemmespenning	: 227.6
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 1,8 V	0,8 %	Maksimal lengde	: 68,3 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 13,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 14,02 W 1,08 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 13 (25) av 32

Beregningsresultater

Kurs nr. **-KW500**

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel $t=k^2S^2/I^2$ [s]**	**$t_{utkobling}$ [s]**
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	0,878	0,99	1,267	0,107	0,010
Ik1p min	0,469	0,98	0,677	0,376	0,010
Ij max	2,532	0,90	3,661		
Ij max ende	0,859	0,99	1,239		
Ij min	0,461	0,98	0,665		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO		**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** **22.05.2014 13:30:16**
COWI	COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
		febdok Ver. 5.4.11 Dato. 13.01.2014	Side 14 (26) av 32

Beregningsresultater

Kurs nr. **-KW500 LAN**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: STIKK ROM"		
Beskrivelse	: STIKK ROM U1044, U1042		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,83 A	Fasekobling	: L3-N
Cos phi	: 0.9		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,8 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 6,9 V	3,0 %	Klemmespenning	: 223
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 6,9 V	3,0 %	Maksimal lengde	: 68,3 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 50,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 53,92 W 1,08 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16
COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 15 (27) av 32

Beregningsresultater

Kurs nr. **-KW500 LAN**

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel $t=k^2S^2/I^2$ [s]**	**$t_{utkobling}$ [s]**
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	0,294	1,00	0,424	0,956	0,010
Ik1p min	0,196	1,00	0,283	2,152	0,010
Ij max	2,532	0,90	3,661		
Ij max ende	0,292	1,00	0,421		
Ij min	0,194	1,00	0,280		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** **Dato:** **22.05.2014 13:30:16** Bjerke vg. skole - Vekselstrøm	
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 16 (28) av 32

Beregningsresultater

Kurs nr. **TEST 1**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: TEST 1		
Beskrivelse	: Test 1		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 2,41 A	Fasekobling	: L1-N
Cos phi	: 0.9		
Merkeeffekt, Pn	: 0,5 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 0,6 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 2,6 V	1,1 %	Klemmespenning	: 227.3
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 2,1 V	0,9 %	Maksimal lengde	: 221,9 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 50,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 5,11 W 0,10 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16
COWI — COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 17 (29) av 32

Beregningsresultater

Kurs nr. **TEST 1**

	Kombinert vern				
	Ik [kA]	cos phi	î [kA]	Kabel t=k²S²/I² [s]	$t_{utkobling}$ [s]
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	0,294	1,00	0,424	0,956	0,010
Ik1p min	0,196	1,00	0,283	2,152	0,010
Ij max	2,532	0,90	3,661		
Ij max ende	0,292	1,00	0,421		
Ij min	0,194	1,00	0,280		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 18 (30) av 32

Beregningsresultater

Kurs nr. **TEST 2**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: TEST 2		
Beskrivelse	: Test 2		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 2,41 A	Fasekobling	: L2-N
Cos phi	: 0.9		
Merkeeffekt, Pn	: 0,5 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 0,6 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 1,3 V	0,6 %	Klemmespenning	: 228.7
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 0,6 V	0,3 %	Maksimal lengde	: 221,9 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 15,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 1,53 W 0,10 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 19 (31) av 32

Beregningsresultater

Kurs nr. **TEST 2**

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel t=k²S²/I² [s]**	**t $_{utkobling}$ [s]**
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	0,794	0,99	1,145	0,131	0,010
Ik1p min	0,436	0,98	0,629	0,435	0,010
Ij max	2,532	0,90	3,661		
Ij max ende	0,778	0,99	1,122		
Ij min	0,430	0,98	0,620		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** **Dato:** **22.05.2014 13:30:16** Bjerke vg. skole - Vekselstrøm	
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.22	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 20 (32) av 32

Beregningsresultater

Kurs nr. **-KW508**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: STIKK I KANAL KONTOR		
Beskrivelse	: STIKK I KANAL KONTORER		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,83 A	Fasekobling	: L1-N
Cos phi	: 0.9		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,8 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 4,5 V	1,9 %	Klemmespenning	: 225.5
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 4,1 V	1,8 %	Maksimal lengde	: 68,3 m

Kabel	:			
Kabeltype/-lederløsning	: PFXP 3G2.5 CU			
Ref. inst. met.	: E			
Omgivelsetemperatur	: 30,0 °C			
Kabellengde	: 30,0 m		Annen korreksjonsfaktor	0.7
Tap i kabel	: 32,35 W	1,08 W/m		
Strømføringsevne	: 21,00 A			

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A

Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer : 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25, 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16	
COWI — COWI AS, Grenseveien 88, 0663 OSLO, Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010, 400 V TN-S	
	febdok Ver. 5.4.11, Dato. 13.01.2014	Side 21 (33) av 32	

Beregningsresultater

Kurs nr. **-KW508**

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel $t=k^2S^2/I^2$ [s]**	**$t_{utkobling}$ [s]**
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	0,460	1,00	0,664	0,391	0,010
Ik1p min	0,286	0,99	0,413	1,011	0,010
Ij max	2,532	0,90	3,661		
Ij max ende	0,455	1,00	0,656		
Ij min	0,283	0,99	0,408		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25, 0594 OSLO		**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16
COWI	COWI AS, Grenseveien 88, 0663 OSLO, Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010, 400 V TN-S
		febdok Ver. 5.4.11 Dato. 13.01.2014	Side 22 (34) av 32

Beregningsresultater

Kurs nr. **-KW509**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: STIKK I KANAL'		
Beskrivelse	: STIKK I KANAL KONTORER		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,83 A	Fasekobling	: L2-N
Cos phi	: 0.9		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,8 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 4,5 V	1,9 %	Klemmespenning	: 225.5
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 4,1 V	1,8 %	Maksimal lengde	: 68,3 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 30,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 32,35 W 1,08 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A

Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer : 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16
COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 23 (35) av 32

Beregningsresultater

Kurs nr. **-KW509**

	Kombinert vern				
	Ik [kA]	cos phi	î [kA]	Kabel $t=k^2S^2/I^2$ [s]	$t_{utkobling}$ [s]
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	0,460	1,00	0,664	0,391	0,010
Ik1p min	0,286	0,99	0,413	1,011	0,010
Ij max	2,532	0,90	3,661		
Ij max ende	0,455	1,00	0,656		
Ij min	0,283	0,99	0,408		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	Beregningsresultater for anlegget: Bjerke vg. skole - Vekselstrøm	Dato: 22.05.2014 13:30:16
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	Fordeling +01=433.30	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 24 (36) av 32

Beregningsresultater

Kurs nr. **-KW510**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: STIKK I KANAL"		
Beskrivelse	: STIKK I KANAL KONTORER		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,83 A	Fasekobling	: L3-N
Cos phi	: 0.9		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,8 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 4,5 V	1,9 %	Klemmespenning	: 225.5
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 4,1 V	1,8 %	Maksimal lengde	: 68,3 m

Kabel	:			
Kabeltype/-lederløsning	: PFXP 3G2.5 CU			
Ref. inst. met.	: E			
Omgivelsetemperatur	: 30,0 °C			
Kabellengde	: 30,0 m		Annen korreksjonsfaktor	0.7
Tap i kabel	: 32,35 W	1,08 W/m		
Strømføringsevne	: 21,00 A			

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** **22.05.2014 13:30:16**
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 25 (37) av 32

Beregningsresultater

Kurs nr. **-KW510**

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel $t=k^2S^2/I^2$ [s]**	**$t_{utkobling}$ [s]**
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	0,460	1,00	0,664	0,391	0,010
Ik1p min	0,286	0,99	0,413	1,011	0,010
Ij max	2,532	0,90	3,661		
Ij max ende	0,455	1,00	0,656		
Ij min	0,283	0,99	0,408		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:**	**22.05.2014 13:30:16**
COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 400 V TN-S	
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 26 (38) av 32	

Beregningsresultater

Kurs nr. **TEST 1**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: TEST 1'		
Beskrivelse	: STIKK I KANAL KONTORER		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,83 A	Fasekobling	: L1-N
Cos phi	: 0.9		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,8 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 2,6 V	1,1 %	Klemmespenning	: 227.4
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 2,1 V	0,9 %	Maksimal lengde	: 68,3 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 15,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 16,17 W 1,08 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A

Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer : 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** **22.05.2014 13:30:16**
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 27 (39) av 32

Beregningsresultater

Kurs nr. **TEST 1**

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel $t=k^2S^2/I^2$ [s]**	**$t_{utkobling}$ [s]**
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	0,794	0,99	1,145	0,131	0,010
Ik1p min	0,436	0,98	0,629	0,435	0,010
Ij max	2,532	0,90	3,661		
Ij max ende	0,778	0,99	1,122		
Ij min	0,430	0,98	0,620		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** **Dato:** **22.05.2014 13:30:16** Bjerke vg. skole - Vekselstrøm	
COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 28 (40) av 32

Beregningsresultater

Kurs nr. **TEST 2**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: TEST2'		
Beskrivelse	: STIKK I KANAL KONTORER		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,83 A	Fasekobling	: L2-N
Cos phi	: 0.9		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,8 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 8,2 V	3,6 %	Klemmespenning	: 221.8
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 8,3 V	3,6 %	Maksimal lengde	: 68,3 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 60,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 64,70 W 1,08 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:		
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** **Dato: 22.05.2014 13:30:16** Bjerke vg. skole - Vekselstrøm	
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 29 (41) av 32

Beregningsresultater

Kurs nr. **TEST 2**

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel $t=k^2S^2/I^2$ [s]**	**$t_{utkobling}$ [s]**
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	0,249	1,00	0,359	1,333	0,010
Ik1p min	0,169	1,00	0,244	2,894	0,012
Ij max	2,532	0,90	3,661		
Ij max ende	0,248	1,00	0,358		
Ij min	0,168	1,00	0,242		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** **Dato:** **22.05.2014 13:30:16** Bjerke vg. skole - Vekselstrøm	
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 30 (42) av 32

Beregningsresultater

Kurs nr. **TEST 3**

Det er angitt at kursen skal være beskyttet av et strømstyrt jordfeilvern

Variabel last	: TEST 3'		
Beskrivelse	: STIKK I KANAL KONTORER		
Merkespenning	: 230 V	Antall faser	: 2
Laststrøm	: 7,83 A	Fasekobling	: L3-N
Cos phi	: 0.9		
Merkeeffekt, Pn	: 1,6 kW	Utnyttelsegrad	: 1
Merkeytelse, Sn	: 1,8 kVA	Samtidighetsfaktor	: 1

Spenningsfall totalt	: 10,6 V	4,6 %	Klemmespenning	: 219.3
...til siste fordeling	: 0,7 V	0,3 %		
...over Kabel	: 11,0 V	4,8 %	Maksimal lengde	: 68,3 m

Kabel	:		
Kabeltype/-lederløsning	: PFXP 3G2.5 CU		
Ref. inst. met.	: E		
Omgivelsetemperatur	: 30,0 °C		
Kabellengde	: 80,0 m	Annen korreksjonsfaktor	0.7
Tap i kabel	: 86,26 W 1,08 W/m		
Strømføringsevne	: 21,00 A		

Kombinert vern, merking	:	**Vernet tilfredsstiller ikke alle krav i forskrift/norm**	
Fabrikat	: ABB STOTZ	Artikkel nummer	:
Bryterenhet	: DS200M C	EAN-nummer	:
Utløserenhet	: DDA 200 C	Bryteevne	: 10,00 kA Ics
Merkestrøm	: 16,00 A	I2-verdi	: 23,20 A
Merkeutløsestrøm jordfeil	: 30	I5-(Im-) verdi	: 160,00 A
Kabel, største lengde som vil gi elektromagnetisk utkobling av alle feilstrømmer			: 63,9 m

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** 22.05.2014 13:30:16
COWI COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 400 V TN-S
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 31 (43) av 32

Beregningsresultater

Kurs nr. **TEST 3**

	Kombinert vern				
	Ik [kA]	**cos phi**	**î [kA]**	**Kabel t=k²S²/I² [s]**	**$t_{utkobling}$ [s]**
Ik1p max	2,678	0,88	3,878	0,012	0,010
Ik1p max ende	0,191	1,00	0,276	2,266	0,010
Ik1p min	0,133	1,00	0,192	4,673	@ 10,792
Ij max	2,532	0,90	3,661		
Ij max ende	0,190	1,00	0,274		
Ij min	0,132	1,00	0,190		

@ = Vernet tilfredsstiller ikke alle krav i forskrift/norm
# = Ikke forskriftsstridig, men vær oppmerksom på løsningen

Anleggets adresse: Statsråd Mathisensvei 25 0594 OSLO	**Beregningsresultater for anlegget:** Bjerke vg. skole - Vekselstrøm	**Dato:** **22.05.2014 13:30:16**	
COWI AS Grenseveien 88 0663 OSLO Tel: +4702694	**Fordeling** +01=433.30	NEK 400:2010 400 V TN-S	
	febdok Ver. 5.4.11 Dato. 13.01.2014	Side 32 (44) av 32	

18 Overview of the Digital Attachments

- MATLAB model and scripts for the 20 W PFC
- MATLAB model and scripts for the 100 W PFC
- MATLAB model and scripts for the 270 W PFC
- Lab measurements
- Error searching for the MATLAB model
- PSIM model script for the 100 W PFC
- PSIM model script for the 270 W PFC
- MATLAB model and scripts for the 20 kW PFC
- Measurements at *Bjerke Upper Secondary School*
- Risk analysis performed for the measurements at *Bjerke Upper Secondary School*
- FEBDOK analysis for two sub distributions at *Bjerke Upper Secondary School*, AC and DC system solution