NTNU – Trondheim
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Micro Power Plant at Marangu Hotel, Kilimanjaro

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Master of Science in Mechanical Engineering
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MASTER THESIS

for

Student Kristin Gjevik

Spring 2014

Micro power plant at Marangu Hotel, Kilimanjaro

Mikrokraftverk for Marangu Hotel Kilimanjaro

Background and objective

The Marangu Hotel is situated near the mountain of Kilimanjaro. The hotel has access to water from a near by river through a channel originally used for irrigation. The flow is sufficient for producing electricity in the range og 10-20 kW. The head is about 20 m. A small turbine design by the Waterpower Laboratory is available. The planned power plant shall be able to work alone; hence it is necessary to include a sufficient control system based on dump load system.

The objective is to design a micro power plant with purpose to supply the Marangu Hotel with electricity.

The work will imply collaborator with Arusha Technical College.

The following tasks are to be considered:

1 Measure the flow and head available through the irrigation channel at Marangu Hotel
2 Design the power plant, complete with reservoir, penstock, valves and control system
3 Suggest improvements of the dump load system, with reference to the candidates own project work

Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Risk assessment of the candidate's work shall be carried out according to the department's procedures. The risk assessment must be documented and included as part of the final report. Events related to the candidate's work adversely affecting the health, safety or security, must be documented and included as part of the final report. If the documentation on risk assessment represents a large number of pages, the full version is to be submitted electronically to the supervisor and an excerpt is included in the report.

Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☒ Field work

Department of Energy and Process Engineering, 14. January 2014

Olav Bolland
Department Head

Torbjørn K. Nielsen
Academic Supervisor

Research Advisor: Anders Austegard, SINTEF

Abstract

Development of micro-hydropower schemes in rural areas of developing countries is largely depended on simple and affordable systems. The contra-rotating pipe turbine, produced by GreenEnergy is a one-piece and easily operated turbine, designed as the Rolls-Royce of turbines with good operational qualities. Suitable for low head sites, this turbine is easily installed in existing plants, for minimum passage flows or independent schemes supplying electricity to rural areas.

The contra-rotating prototype will now be donated to a site in a developing country and the river Una, near Marangu Hotel in Tanzania has been chosen as a potential site. Thereby the turbine could produce clean and needed electricity, and at the same time test its versatility and easy operation.

Field work was performed in Tanzania in February, to gain necessary groundwork for this thesis. A proper site review was conducted with a focus on head and distance measurements of the potential scheme. An introduction to the local conditions, both technically and socially was also in focus.

The contra-rotating prototype was tested in the Waterpower Laboratory, to assess the condition after the generator upgrades performed by BEVI. Results showed a disappointingly increase of efficiency at design operation. This might imply an inaccurate position of the runner and generator hubs.

A full scheme design is presented with all components necessary in addition to an economical review and evaluation local conditions. Designed scheme has a goal of easy operation and minimum maintenance demand, which has been ensured by installation of a Coanda intake and simple control system.

Hydrological data of the area has been assessed from data of a nearby area, from a PhD thesis on the hydrological study of the area. This turned out to be one of the large uncertainties presented in this project. The adapted data gave a low expected river discharge, compared to what would secure a sustainable installation.

Further progress is now dependent on the partners involved, especially GreenEnergy. Eventual future activities will require thorough discharge measurements from Una.

Sammendrag

Den økende utbyggingen av små-skala vannkraftverk i rurale områder i utviklingsland, er i stor grad avhengig av enkle, rimelige og vedlikeholdsfrie løsninger. Den kontraroterende rørturbinen, produsert av GreenEnergy er en enkel turbin, bestående av turbin og generator i ett. Konseptet er basert på at den skal være vedlikeholdsfri og robust, med gode driftsegenskaper. Spesielt er den aktuell ved minstevannsføring og isolerte nettsystemer, der turbinen kan levere strøm til distriktene.

Denne kontraroterende turbinen skal nå doneres til et utviklingsland, og Marangu Hotell i Tanzania har blitt valgt som potensiell lokasjon. Dette vil samtidig gi GreenEnergy en mulighet til teste dens allsidighet og driftsegenskaper.

Feltarbeid i Tanzania ble utført i februar, for skaffe nødvending grunnlag for prosjektering. Hovedsakelig gikk arbeidet ut på å samle inn informasjon og gjennomføre nødvendige feltmålinger.

Den kontraroterende turbinprototypen ble testet på Vannkraftlaboratoriet for å vurdere driftsegenskapene, etter de nylig gjennomførte reparasjonene hos BEVI. Resultatene levde ikke opp til forventningene, og viste kun en svak økning av effektivitet i forhold til tidligere testing. Dette kan innebære en unøyaktig posisjon på roterende deler i rørturbinen.

Et enkelt og lite vedlikeholdskrevende kraftverksdesign er presentert i denne oppgaven. Økonomisk vurdering og sosiale konsekvenser er også inkludert. I tillegg har det hydrologiske grunnlaget for området blitt vurdert. Dette viste seg å være en stor usikkerhet for systemet, og ble basert på data fra nærområdet og en PhD-oppgave gjennomført om det hydrologiske grunnlaget i området. De tilpassede måledataene i denne oppgaven ga en svært lav forventet strømning i elven, for at dette skal være en bærekraftig installasjon.

Eventuell videreføring av dette prosjektet ved Marangu Hotell, må avgjøres av samarbeidspartnerne i prosjektet, og i hovedsak GreenEnergy. Ved videre satsning må det gjennomføres grundige måleundersøkelser for den aktuelle elven.

Preface

This Master's thesis is written at the Waterpower Laboratory, Department of Energy and Process Engineering at the Norwegian University of Science and Technology (NTNU) during the spring of 2014. The aim of this work has been to perform a feasibility study for a potential micro-hydropower plant at Marangu Hotel in Tanzania. A suggested design of the plant is also included. Field work was performed in Tanzania in February, and the turbine of interest has been tested at the Waterpower Laboratory. In addition to the technical solutions, this thesis concentrates on the local adaptations that would make this a successful and sustainable project, considering the local conditions.

I would like to thank my supervisor Torbjørn K. Nielsen for engaging me in such an interesting project with his company GreenEnergy. Together with Johnny Røyrvik and Bjarte Skår, they have been of great help and shown me the professional side of theoretical and practical engineering.

Special thanks also go to Professor Daniel Ngoma at Arusha Technical College for his time, hospitality and our great discussions during my stay in Arusha and Marangu. I would also like to thank Marangu Hotel for their hospitality and for answering all my many questions. I am sure I will come back to visit soon.

Employees and PhD-candidates at the Waterpower Laboratory have been of great help, both during the lab testing of the contra-rotating pipe turbine and questions in general. They also deserve credit for creating such a positive and inspiring working environment at the lab. Finally a big thank to all my fellow students, it has been a true pleasure finishing my Master's degree with this project at the Waterpower Laboratory.

Kristin Gjevik

Trondheim, June 10, 2014

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Abbreviations

NTNU	=	Norwegian University of Science and Technology
NVE	=	Norwegian Water Resources and Energy Directorate
ATC	=	Arusha Technical College
TANESCO	=	Tanzanian Electrical Supply Company Limited
NGO	=	Non-Governmental Organization
ELC	=	Electric Load Controller
PV	=	PhotoVoltaic
PE	=	PolyEthylene
PVC	=	PolyVinyl Cloride
PP	=	PolyPropylene
NOK	=	Norwegian Krone

Nomenclature

L	Length of pipe	[m]
D	Diameter of pipe	[m]
Q	Volume flow	[m^3/s]
H	Head	[m]
C	Velocity of water	[m/s]
g	Gravitational force	[$9.81\ m/s^2$]
P	Generated effect	[W]
Re	Reynolds number	[-]
ε	Surface roughness	[mm]
ρ	Water density	[kg/m^3]
f	Darcy friction factor	[-]
λ	Friction coefficient	[-]
ζ	Friction coefficient	[-]
η	Efficiency	[-]
$cos(\phi)$	Phase displacement	[-]

Chapter 1

Introduction

Clean energy access is one of the major challenges in order to ensure sustainable socio-economic growth in developing countries. However an extensive use of fossil fuels and biofuel for energy has severe impacts on environment and global warming. Many developing areas are experiencing an increased vulnerability for these climatic changes, in addition to volatile energy prices, reducing the potential to rise up out of poverty (Agency, 02.06.2014).

In Tanzania, the electricity situation is highly unreliable, and only 15 % is reported to have access to electricity according to the governmental Rural Energy Agency (Agency, 02.06.2014). In rural areas the conditions are worse with coverage of only 2 % of the population. Accordingly, there are large investments and technological development to be made, both on grid systems and small- and regular scale power generation. An increased knowledge on how to implement clean energy sources on a small-scale level is an important step to bring isolated communities out of poverty.

Scope of this thesis is developed and defined throughout the work. Original tasks, including measurements of channel flow will be replaced with assessment of available hydrological data in accordance with supervisor, Torbjørn K. Nielsen. The originally planned dump-load system is replaced with frequency conntroller with capacitor batteries. This replace the planned dump-load solution and the concept is therefore presented briefly in Chapter 0.9.

This thesis is set apart from the regular research theses published at the Waterpower Laboratory. The objective includes project planning, performed through a feasibility study and a proposal of scheme design for the potential site. Field work performed at the selected location at Marangu Hotel in Tanzania will be foundation for the prospect and design. Main focus will be on combining all necessary disciplines needed for implementation of this turbine in the Marangu scheme. Design proposal will be based on sustainability and creation of an affordable and easily operated system.

It is important that this thesis is comprehensible for all potential partners, including owners of Marangu Hotel, with little or no previous background within micro-hydropower. Previous work and an introduction of all partners involved is presented in Chapter . Following, Chapter 0.5 offers an introduction to basic theory and the system insight necessary for this project. Some assumptions and simplifications are made throughout the site presentation in Chapter 0.11, and as the final scheme is presented in Chapter 0.15. Discussion of chosen site design and local conditions is reviewed in Chapter 0.22 prior to the presented conclusion, found in Chapter 0.28.

Chapter 2

Background

The contra-rotating axial pipe turbine has been developed based on an idea of creating a maintenance-free and easily operated turbine. With support from the Norwegian Water Resources and Energy Directorate (NVE) a prototype was made in 2007 and the company GreenEnergy was formed by concept developers Johnny Røyrvik and Torbjørn Nielsen. With them they also got Bjarte Skår from Brødrene Dahl, a Norwegian pipe supply company.

The turbine has been operated for over 3100 hours, both in lab and installed at a Norwegian power plant. Next step of development would be to install the prototype turbine at a more challenging site, in order to test its versatility, flexibility and low maintenance requirements. This site would preferably be a rural site in a developing country, where it could provide electricity to a small community. Such a site was found at Marangu Hotel, in the Kilimanjaro area of Tanzania.

Discovery of Marangu Hotel made this a realistic plan, as a big challenge was the level of security that could be maintained at the chosen site. The choice of location opened for a potential cooperation with Arusha Technical College, a previous collaboration partner of Torbjørn Nielsen. This would offer the project an educational aspect and a valuable exchange of experience.

2.1 Previous work

Since 2005 there have been written three Master's theses on this turbine prototype, to improve its mechanical and hydraulic design. Ramdal (2005) worked on optimization of prototype design, Lundekvam (2006) tested the on turbine performance during operation, while Haugli (2010) investigated possible improvements for future new prototypes.

During the spring of 2006, the turbine prototype was tested by Lundekvam at the Waterpower laboratory, and installed at Tevla for eight months during the fall of 2006. Throughout the last year, the turbine has been upgraded at BEVI, a Swedish company for supply and service of electrical equipment (Andersson, 2014). Improvements included a soft-start and frequency control system, and were funded through the NVE project. This improved turbine prototype will now be assessed for installed at Marangu Hotel.

Two trips to Marangu have been performed by GreenEnergy during the last years, to check the suitability and engage the owners of Marangu Hotel. At this point, a thorough feasibility study is needed, in order to check if the site is suitable for installation.

2.2 The study area

Tanzania is a green and diverse country with nature ranging from savannahs and jungle, tropical beaches and snow-capped mountains. Mount Kilimanjaro towers over the north-eastern parts of Tanzania, and reaches Africa's highest point with a height of 5895 masl (CIA, 09.06.2014).

Located near the equator, the area is provided with two distinct rainy seasons. The main rainy season lasts from March to May while the shorter one is in November. The area around Mount Kilimanjaro is known as green and fertile and holds an important role as a catchment area for Tanzania and Kenya. Although often assumed, the Kilimanjaro ice cap is not the main source of the fertile land, however the montane forest between 1600 and 3100 masl provides most of the water to Pangani River Basin (Røhr, 2003).

2.3 Electricity situation in Tanzania

The electricity grid in Tanzania is covered by the state owned company TANESCO, Tanzanian Electrical Supply Company Limited, also supplying all electricity. Power generation is based on 57 % hydroelectricity, while the rest is mainly thermal based generation (TANESCO, 20.05.2014). The grid is poor and unreliable, with regular blackouts. Some are shorter disconnections, while other will disconnect the grid for several days. Due to this, most hotels, businesses and those who can afford are highly dependent on diesel generators to have secure electricity availability. This is a motivation for implementation of smaller-scale hydropower, as it can offer an environmentally friendly and available energy.

2.4 Marangu Hotel

Located at the foot of Kilimanjaro, Marangu Hotel has since 1910 been a prime location for tourists and travellers wanting to climb Africa's tallest mountain. The hotel is run by three Irish siblings Desmund, Seamus, and Fennulah Brice-Bennett, who grew up at the hotel area themselves. In the local Chagga language, Marangu means 'full of water', suitable for its green and fertile areas of Kilimanjaro and nearby river Una. Along the west side of the hotel area, there is an old channel bringing some water through the hotel area. Though now used for irrigation, the channel once held a small hydropower turbine at the river bend, supplying the hotel with electricity in the 1930s (Brice-Bennett, 2014).

2.5 Arusha Technical College

Arusha Technical College, known as ATC or Technico, is an autonomous institution training technicians and engineers within several fields of study. The college was established in 1978 as a collaboration between the government of Tanzania and Federal Republic of Germany (Ngoma, 2014). Collaboration with one of the professors of mechanical engineering, Daniel Ngoma, was initiated through this project. His background within renewable engineering, and a Master's degree from Germany, made him an important resource for the work.

At ATC, Ngoma develops and produces several cross-flow turbines, together with his students. One of the cross-flow prototypes produced, was installed in a scheme at the campus, as a visual example. ATC and Professor Ngoma have valuable previous experience from small-scale hydropower projects. Amongst several projects, they have installed a 750 W cross-flow turbine in Makumira village outside Arusha. This was done in cooperation with the University of Dar es Salaam, and funded by an Italian non-governmental organization (NGO) (Ngoma, 2014).

Chapter 3

Theoretical Basis and System Insight

3.1 The Contra-Rotating Axial Pipe Turbine

This turbine concept is based on an easily handled one-piece turbine, that can be installed with low cost and low maintenance requirements. As an alternative to reduction valves or installed in the minimum passage flow systems, this turbine can utilize otherwise dissipated energy.

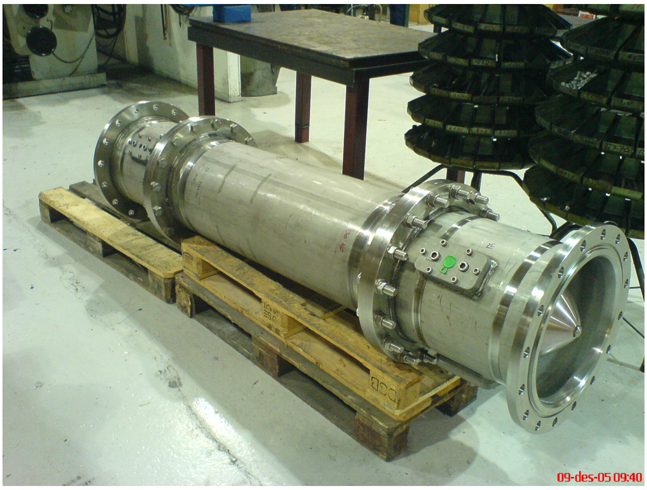

Figure 3.1: The contra-rotating axial pipe turbine. (Lundekvam, 2006)

The easily handled turbine consists of two internal generators one at each of the two independent contra-rotating stages. Concept drawing is shown in Figure 2.

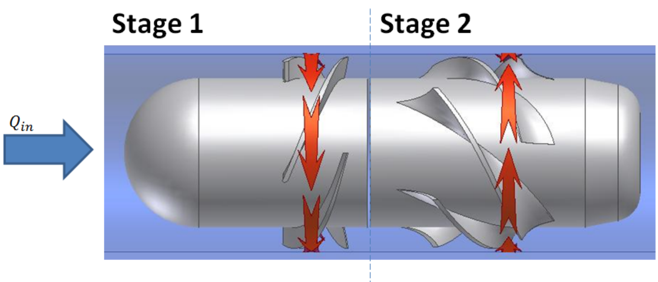

Figure 3.2: Turbine stage I and II. (Nielsen et al., 2006)

As illustrated in Figure 2, the flow enters the turbine at the first stage, where energy is retracted as the water meets the runner vanes, and is given a spin. First stage therefore also functions as guide vanes for the second stage, where the flow with spin meets the contra-rotating runner vanes of second stage. At this stage the spin will be converted into mechanical energy to the shaft, leaving the exit water out of stage II with no rotation. This is shown in the velocity diagrams in Figure 3.

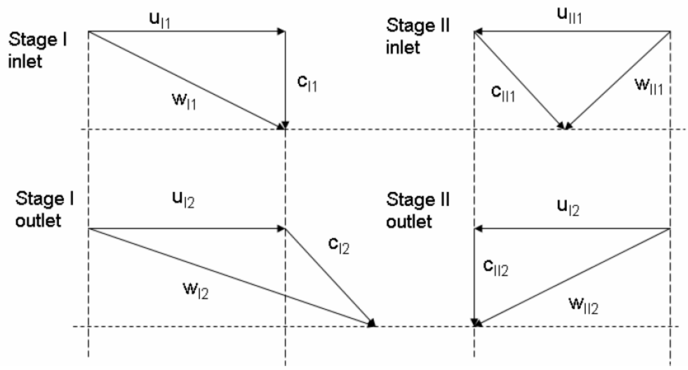

Figure 3.3: Velocity diagrams through stages I and II. (Haugli, 2010)

Two asynchronous generators are located inside stage I and II of the runner hubs. Consequently, the stator is located along the shaft. while the rotor rotates along with the runner blades on the inner side of the hub. These generators are run independently with a nominal rotational speed of $n = 750\ rpm$. During the last upgrade of the turbine BEVI installed a soft-start system for the two generators. This will connect the turbines to the grid when the rotational speed is correct, simplifying the start-up and inspections during operation.

Original design characteristics included a 40 kW output, at a design head of 15 m and volume flow of 200 L/s, however lab testing in 2006 showed different results. Student Atle Lundekvam performed his Master's thesis on testing this early prototype, and found the following characteristics (Lundekvam, 2006).

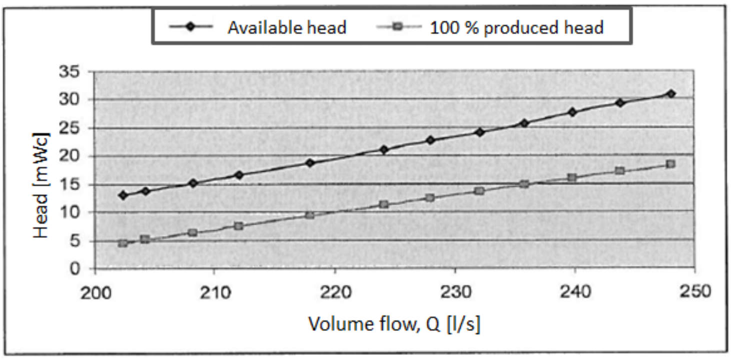

Figure 3.4: Head-discharge curve. (Lundekvam, 2006)

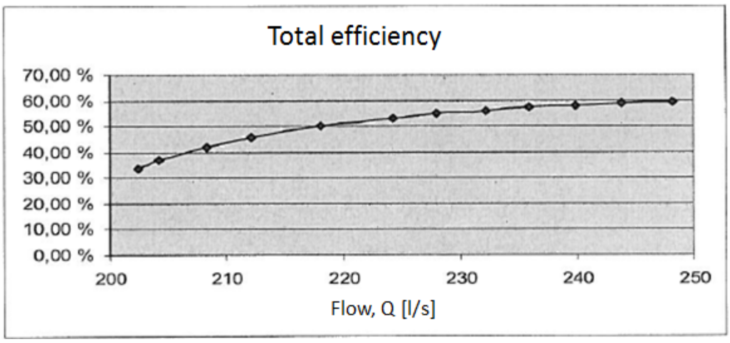

Figure 3.5: Total efficiency with ranging volume flow, Q. (Lundekvam, 2006)

The graph in Figure 4 shows an unused capacity, and the efficiency curve in Figure 5 refer to a point of best efficiency with a higher flow than the design flow of 200 L/s. Lundekvam also points out that the head is almost twice that of the original design head.

During Lundekvam's testing of runaway speed in the laboratory, in the spring of 2006, the turbine was short-circuited due to a defect in the generator. Testing was therefore abruptly stopped, and the turbine was sent to BEVI for maintenance and repair. A winding fault, and contact between stator and rotor was discovered in each generator (Lundekvam, 2006).

The turbine has since then, been installed at a Norwegian site Tevla, where it replaced a previous reduction valve. It was operated for 6 months until it experienced a large extent of drag, and friction causing low efficiency and noise.

After the short circuit and many operational difficulties the turbine has been recoiled and cast in epoxy by BEVI. Improvements on the cooling system and internal drainage were also performed. These improvements are considered significant to a generators performance and the turbine might therefore be considered with a new set of operational characteristics. This must be verified by lab testing.

3.2 Hydrology

A vital part of a feasibility study is mapping of the hydrology. Thorough work should be made on whether there are sufficient amounts of water in the area to cover the volume flow of the turbine and other potential environmental requirements.

Data can be found from gauging stations and studies of relevant duration curves. By including rainfall, watershed, groundwater recharge, evaporation and glacier run-off, a hydrological basis of the area and river can be established. This data is often gathered for decades by governmental water authorities, and a obvious challenge is the usual lack of data in rural and less developed areas.

Another general challenge with estimation of hydrology in such areas, is the high use of water for irrigation. Large portions of the water is therefore drawn from the rivers, so large rivers investigated at one location might be non-existing at a lower level, as it is separated into undefined irrigation use.

Fortunately hydrological background can instead be given from the work of NTNU professor Ånund Killingstad and PhD Paul Christen Røhr. Røhr has written a PhD-thesis on the hydrology in the southern slopes of Mt Kilimanjaro, in where Marangu and this site is located. The study ”A hydrological study concerning the southern slopes of Mt. Kilimanjaro, Tanzania” was a cooperation between the Norwegian University of Science and Technology and the University of Dar es Salaam (Røhr, 2003).

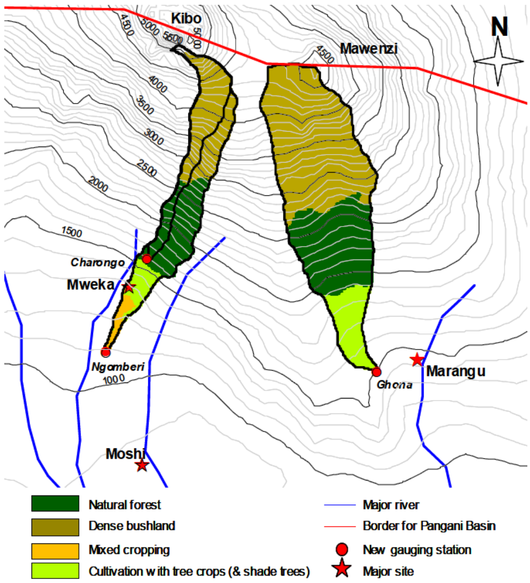

Figure 3.6: Two of the catchment areas of the hydrological study made by Røhr. (Røhr, 2003)

Three gauging stations have been established, and measurements of stream gauging and perspiration has been gathered over the course of several years. This resulted in three hydrological models of each catchment area. River Una and Marangu are not included in these models, however an hydrological profile can be estimated from the nearby and similar data of the river Ghona, seen in the map in Figure 6. Assuming that the run-off in catchment areas of Ghona and Una are proportionally the same, a duration curve for Una can be made from the area ratio.

3.3 Design of Scheme

3.3.1 Intake

Main purpose of the intake is to gather a required volume flow of water to the turbine. Several factors must be considered for the design, and it must be adapted for hydrology and requirements for minimum environmental flow.

Intake design therefore sets the basis for turbine operation, and a poorly designed intake could result in high head losses and poor system efficiency. Location of the intake is decided by the topography. A small dam is often constructed to reduce the water velocity, calm sedimentation and secure a certain volume flow through the intake. River based intakes often consists of dam and intake in the same construction (Fladen et al., 2010)

In order to avoid debris, rocks and leaves from entering the channel and turbine, a trash rack is installed at the intake. Trash racks should be optimized to cause as little head loss as possible. Regular trash racks are often installed in an angle on the ends of the dam, to create as favourable flow conditions as possible.

An alternative to the ordinary trash racks is the self-cleaning Coanda intake. This intake makes use of the Coanda effect of water deflecting from its regular path, to follow a concave surface. Use of Coanda screens is environmentally friendly and nearly maintenance free, as debris and rocks are swept over the screens, while clean water deflects through the screens and into a pipe inlet below. The screens has a bar clearance from 3 mm to 0.6 mm and will remove 70-80 % of sedimentation down to this size according to supplier Brødrene Dahl (Dahl, 2010b)

Figure 3.7: Coanda intake, 400 L/s. (Dahl, 2010b)

Screen design is custom-made to each site according to $Q_{overflow}$. This decides Q_{inlet} and Q_{bypass}. At small $Q_{overflow}$ there will be no water to continue down the river. As water flows over the crest of the weir, it meets an acceleration plate to provide a smooth flow to the bars. The acceleration plate has an ogee shape fit to the free water surface.

Water is gathered in a culvert underneath the Coanda screens.

3.3.2 Supply Pipe

The supply pipe transporting flow from intake to reservoir, can be made either by open channel or as a pipe arrangement. Supply pipes are in this case the most convenient option, as the water is already cleaned through the Coanda screens.

Available pipe materials ranges from steel, ductile cast iron, PE and glass fiber, each suitable for different site conditions and budgets. PE-pipes are commonly used low head small-scale sites, in addition to PP and PVC pipes that are commonly used for supply pipes (Dahl, 2010a). When installed in steep terrain, these pipes should be fixed with anchors or buried to prevent unwanted movement in the pipes. Most pipes are delivered in length of 6 m to 18 m and connected by flanges or socket sleeves (Skår, 2014).

Friction in pipes increases with decreasing diameter, while the price increases with diameter. Choice of pipe diameter is therefore usually based on an optimization between cost of lost production through head loss and pipe costs. Optimizations often demand specially designed pipes, and most low-cost systems are therefore based on choosing affordable standard pipe sizes.

Design of a pipe system is based on calculations of head losses in the system. The major losses occur from wall friction and viscous effects while minor losses from bends and obstructions in the pipe. Head loss is defined from the Darcy-Weibach Formula 1 (White, 2007, p. 350).

$$h_f = f \cdot \frac{L}{D} \cdot \frac{C^2}{2 \cdot g} \qquad [m] \tag{3.1}$$

f	Darcy friction factor	[-]
L	Length of pipe	[m]
D	Diameter of pipe	[m]
C	Velocity of water	$[m/s]$
λ	Friction coefficient	[-]
g	gravitational force	$[9,81 m/s^2]$

The friction coefficient is found from the Moody diagram as a function of the Reynolds number and $\frac{\varepsilon}{D}$. More on this is found in Appendix .13.

Minor losses of a system include losses from valves, contractions and bends, and is defined as following

$$h_f = \zeta \cdot \frac{v^2}{2g}$$

Friction coefficient, ζ is often provided, dependent on shape and size.

In order to determine the functioning head loss in pipes, one must also include the material effects from welding connections. This is often forgotten when designing the pipes, according to head loss. Necessary data is usually given through the supplier (Skår, 2014).

3.3.3 Valves

Valves are a necessary part, even for small-scale hydropower systems. Main functions include closing down the waterway, stop of turbine operation and drainage for pipe maintenance and inspection. Longer pipe systems require one valve in each end in order to secure maintenance and ensure safe stops. The penstock should also have two valves, one located after the reservoir in order to empty the penstock, and one in front of the turbine, as a system shut down valve. Gate valves and butterfly valves are the most common for low head sites, and could be operated both automatic or manually. Gate valves are the most economical choice of the two.

An air valve should be located after the intake valve in order to exhaust air from the waterway pipe. This is important both during operation and while filling and draining the pipes.

3.3.4 Forebay Tank, Spillway and Penstock

The reservoir or forebay pool is located just before the penstock, to provide a stable and constant flow to the penstock and turbine. It will also prevent fluctuations and lower the risk of air entering the penstock. Reservoir size depends on the desired level of backup storage, as a rule of thumb it is recommended to be 60 - 100 times the volume flow (Ardser and Karcheter, 2009).

The reservoir receives water from the waterway and feed this to the penstock while excess water is led back to the river through a spillway channel. A float controlled valve or alarm should be installed to shut down operation if the water level were to sink to a critical level. This is to prevent air in the penstock. Spillway channel must be dimensioned to lead out water in the same rate as the intake. In accordance to risk of land slides and erosion, this should be lead back to the river in a pipe or channel.

The penstock must have a suitable design according to the pressure and inclination. Build-up of pressure through the penstock requires safe foundation blocks or buried pipes. Bends along the inclination should be kept at minimum to reduce the head loss. The bend at turbine level should be connected to a pipe to calm the flow before it enters the turbine.

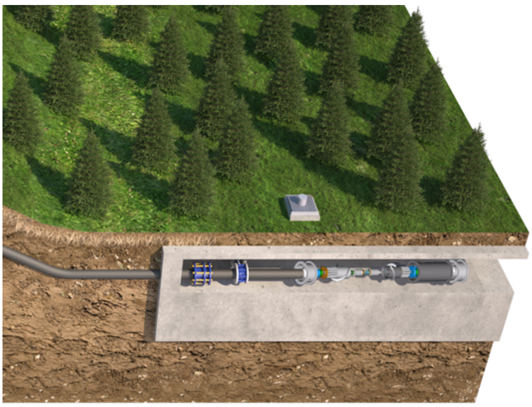

Figure 3.8: Turbine located underground. (Skår, 2014)

3.3.5 Turbine Installation

Although the contra-rotating turbine is a robust turbine, it must be protected against flooding, damages and exterior impact. Aggregates with separate generator and turbine are vital to keep in safe distance to water, with regard to the generator. Normal power house can be a simple building, with the turbine installed away from risks of overflow. However the contra-rotating turbine is designed with the possibility of in-water installation. It has been estimated that installation of a draft tube should improve the efficiency with $7 - 8$ % (Nielsen et al., 2006). The turbine must therefore be submerged to gain maximum effect.

A proper foundation is important and the turbine should be fastened while still being allowed some movement, in order to reduce shear strain. It has been considered to place the turbine in a bunker underground, as seen in Figure 8. Such a solution would still provide an easy access, while at the same time minimizing the environmental impact. This is however highly dependent on appropriate soil mechanics.

3.3.6 Control Building

Electrical equipment should be located in a small building in safe distance from the river and at an easy accessible location. There are two cabinets: the multi-instrument with frequency control and soft-start system, as seen in Figure 9. These control and operate the turbine.

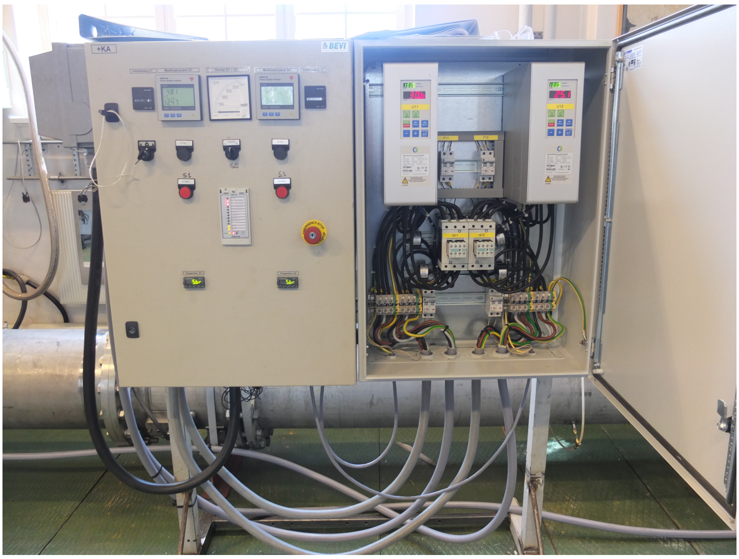

Figure 3.9: Cabinets for frequency controller and soft-start system. (Gjevik, 2014)

3.4 Electrical System and Dump Load

The two independent generators are asynchronous, and will therefore produce electricity through a rotational speed that is higher than the nominal speed of the generator. A counter-torque is developed in the generator to oppose the runaway speed. Asynchronous generators are dependent on an exciter field during start-up, and this will be given through a battery bank. If the turbines were to rotate at a speed lower than the nominal speed, it would function as a motor, drawing power from the grid instead.

Power is produced in each of the two generators individually. According to previous testing, stage I will produce most up until a certain equilibrium, from where stage II will produce most. Output power from the generators will be delivered out on a stand-alone hotel grid, to ensure electricity during national grid blackouts. Such a stand-alone grid requires a continuous balance between load demand and power production. Frequency control is therefore necessary, as the grid frequency should be kept to 50 Hz, both on stand-alone and national grid.

An increasingly used solution for load governing is the dump load system. Governing of the turbine will be done through an electronic load controller (ELC) for asynchronous generators and dump load heat resistors. The ELC will keep the generator torque constant by connecting and disconnecting dump loads, with the change in consumption loads.

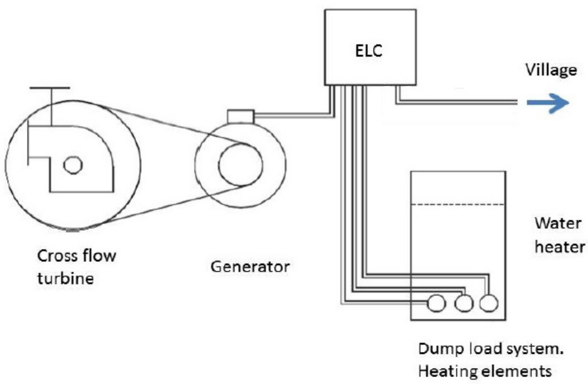

Figure 3.10: Set-up of dump load system. (Hveem, 2013)

This method utilizes all excess power and burns it off in heat resistors. These can be installed in a water tank, to provide hot water for household supply. Heating resistors are appropriate for this use, as they tolerate highly fluctuating loads. Hveem (2013) installed and tested such a system at the Waterpower laboratory in 2013. He also investigated the use of larger energy system where solar energy, known as photovoltaic (PV) energy or wind energy is included. Such hybrid energy systems will increase flexibility and reliability. Especially PV energy offers increased flexibility as it can be stored in battery packs and used to supply a changing demand (Hveem, 2013).

3.5 Maintenance

The importance of maintenance in such projects is often neglected. This has been one of the bigger challenges with projects within technical developing aid, causing unnecessary break downs. The culture of maintenance need is different, and it is rumoured that there are in fact no word for 'maintenance' in Kiswahili, the official language of Tanzania. One does not fix something before it is broken. It is therefore important to implement a good and basic maintenance system, that will ensure an up-to-date scheme.

Such a system can be developed by following maintenance theory plans, though this must be adapted to the location and cultural differences for those who will perform the daily maintenance. Some of the biggest challenges are lack of motivation among the operators and high turn-over rates which will prevent sufficient experience. One of the most important motivational factors is to create a common ground and ownership to the system.

Further, maintenance management must be developed. This will consist of an assessment of all parts in the system with connected risks and severity of potential outcome. From this overview a maintenance plan can be developed and critical parts are hereby check more frequently and an evaluation of the condition can be kept updated.

A good system for reporting errors during inspections, is vital in order to learn from experiences and errors. Simple and informative reports should be made on faults or suspicious behaviour. Valves and bends in pipes are especially exposed and should be periodically inspected. A detailed maintenance plan should be developed according to recommendation from the suppliers including systems for reporting small errors and component history. This is especially important with change of staff, and to adapt and improve the system by experience (Development, 1998).

3.6 Turbine Testing in the Waterpower Laboratory

In order to find the best operational point of the turbine after the improvements of BEVI, the turbine was tested at the Waterpower Laboratory. Set up of the lab is shown in 11 and by pumping water from the basement, the turbine's behaviour over different characteristics can be monitored.

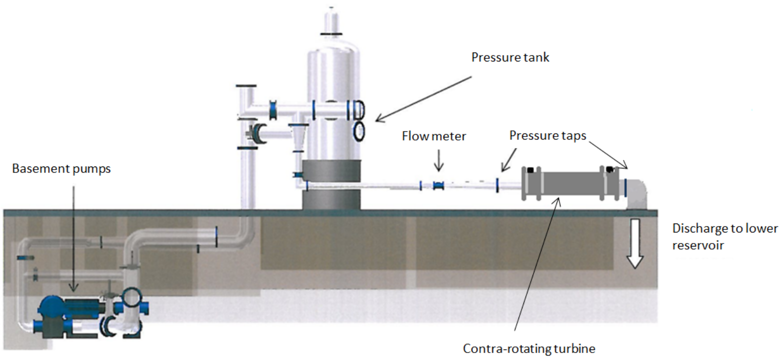

Figure 3.11: Set up in lab. Adapted from: Hveem (2013)

Goals of the testing are an efficiency and head-discharge curve. These can be used to evaluate the turbine characteristics against the site and BEVI's improvements. The basic principle of efficiency measurement is to find the relationship between available energy, according to the actual power production of the turbine.

$$\eta_{turb} = \frac{P_{out}}{P_{in}}$$

Available effect to the turbine is easily found by water density ρ, gravity g, volume flow Q and available head, H.

$$P_{in} = \rho \cdot g \cdot Q \cdot H$$

Produced effect is normally found by measuring the torque and rotational speed, however this is an inconvenient option for this turbine. This effect can instead be found from the generator input, by determining voltage U, current I and phase displacement $cos(\phi)$. By dividing this on the generator efficiency η_{gen}, the produced turbine effect can be found.

$$P_{out} = \frac{U \cdot I \cdot \cos(\varphi)}{\eta_{gen}}$$

However both the generator efficiency η_{gen} and the phase displacement $cos(\phi)$ are varying with load, making these calculations without value. An active effect output can instead be read directly from the displays on the frequency controller. P_{out} would then be defined as active effect divided on generator efficiency.

As this turbine consists of two independent generators the results can either be found both for each stage or combined. In this case it is primarily of interest to find the total efficiency curve for the turbine, though noticing differences between the two stages. As illustrated in Figure 11 the volume flow is measured by a flow meter in front of the turbine. Pressure taps installed at the inlet and outlet of the turbine, gives the differential pressure over the turbine. Other necessary values are given by the soft-starter and the frequency controller.

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Chapter 4

Site Conditions and Prototype Characteristics

Fieldwork was performed in the period February 13th to 1st of March 2014 in Arusha and at Marangu Hotel, Tanzania. This was an important groundwork for the further design planning and understanding of the local conditions. The first week was spent visiting Arusha Technical College and performing fieldwork at Marangu Hotel together with supervisor Torbjørn K. Nielsen and professor Daniel Ngoma from ATC. The final week was spent collecting information from Marangu Hotel and Professor Ngoma at ATC. Following is a list of the main interests from the feasibility study:

- Gross head of penstock
- Length of channel, from intake to reservoir
- Head difference of channel, from intake to reservoir
- Site conditions at intake, reservoir area and powerhouse location.
- Electrical situation at Marangu Hotel
- Cooperation between GreenEnergy, ATC and Marangu Hotel.

Figure 4.1: Air photo of the hotel area, seen from north. (Brice-Bennett, 2014)

Some necessary equipment was brought from the Waterpower Laboratory and most activities were thoroughly planned in advance. Main work is described in the following section, while a more detailed description of the field work can be found in Appendix .3 and .13.

4.1 Site Description

As seen in figure 13, the intake is located about 1 km north of the hotel area. Today's channel runs through several different properties on its way, though Marangu hotel has full right of the water use (Brice-Bennett, 2014). The channel enters the hotel area on the northwestern side, and follows a small private road inside the area. The hotel's swimming pool located on the south-west part of the property, was used as reservoir of the previous power site in 1910. This new site is planned at the same location, though with the forebay tank located at a lower level from the pool depending on the turbine performance.

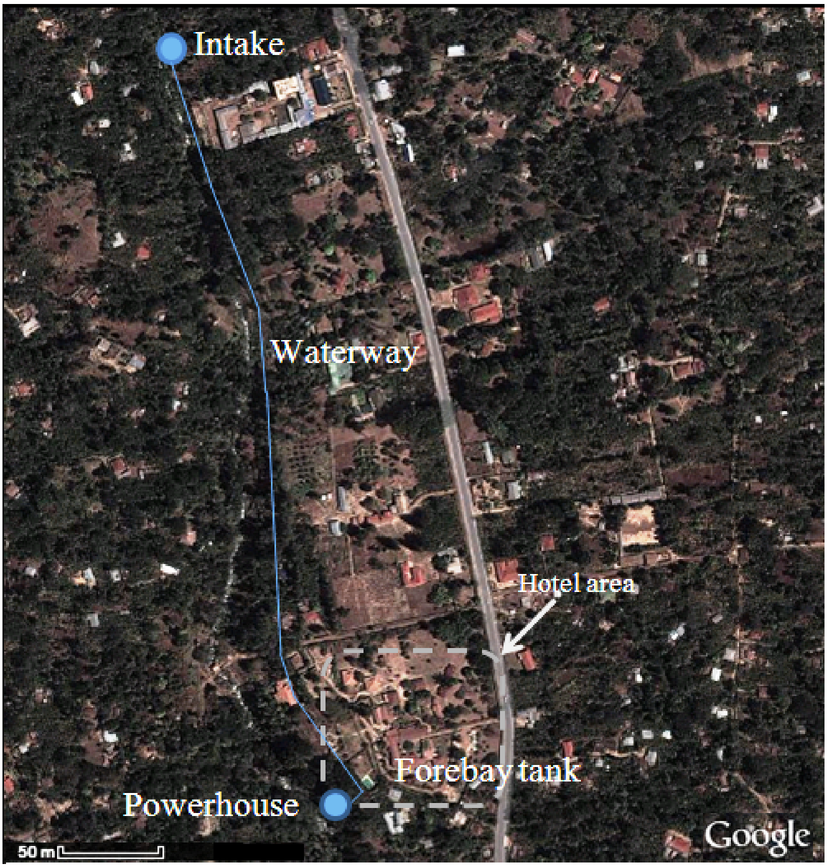

Figure 4.2: Waterway from intake to powerhouse.

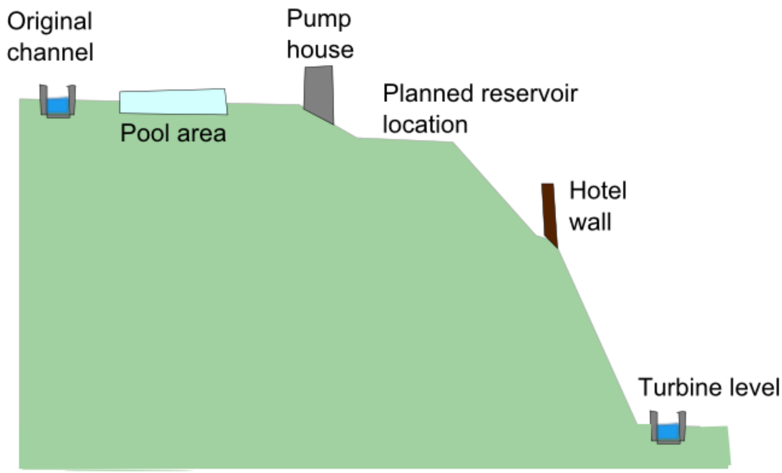

Figure 4.3: Overview of the site.

An old channel and gate valve are visible down at the river bed. These descend from the old hydro site and are suggested as a fitting basis for the planned turbine location.

4.1.1 Intake

The current intake is a simple side intake with no trash rack. A small dam has been made using rocks and bags of sand, diverting water to the channel from half of the river width. An estimated 12 L/s is provided from this intake while the installed turbine will require 200 L/s. The intake must be accordingly enlarged to secure the minimum flow of the turbine. Una had a quite low discharge at the time of fieldwork, as this was just prior to the rainy season. Flow is by visual determination estimated to be merely 200 L/s to 300 L/s. There had been some more rain than usual during the last months, however the river was said to be at low level, by the hotel owner (Brice-Bennett, 2014).

Figure 4.4: Intake and small dam from upstream.

4.1.2 Channel from Intake to Reservoir

The channel running through the hotel area, has its intake approximately $900\,\mathrm{m}$ upstream from the hotel, in the river Una. Water flows in the open air channel with a moderate inclination slope of 4-5 degrees and some jumps of $0.1\,\mathrm{m}$. The average width is of $0.4\,\mathrm{m}$ and material of the channel changes from earth to concrete to rocks. At some locations there are no movement in the water and this might cause some challenge for design of the supply pipe. Running through gardens, schools and public paths, the pipes should be dug down in order to keep it secured and prevent vandalism.

Using a GPS, the channel was walked and mapped. A decent length was given from the GPS tracking, although the head difference was only approximated. This is due to the uncertainty of elevation measurements with GPS and the elevation measures that were found along the route gave an illogical range of results. Elevation along the exsiting channel, from intake to forebay site is therefore estimated to be about $6\,\mathrm{m}$ to $7\,\mathrm{m}$ over the course of $900\,\mathrm{m}$ channel. More details on the channel is found in Appendix .13. Head from intake down to the estimated forebay location is $7\,\mathrm{m}$.

Figure 4.5: Walking along and tracking the channel.

4.1.3 Head of Penstock, from Feservoir to Powerhouse

Measured available head of a hydro scheme is one of the most specific site characteristics. The current channel continues out of the hotel area, while the planned penstock and forebay location will be located down towards the pool area and Una as seen in Figure 14. The hotel wall traverses along the hill, and the path down to the riverbed is therefore from outside the hotel wall. There is a door in the hotel wall making it accessible from the hotel, though keys could not be found at the time.

Overgrown with bushes, the hill is light soil and larger rocks requiring clearing and preparations of the ground. Inclination is estimated to be approximately 43 degrees. The hill from the hotel down to Una therefore turned out somewhat steeper and more impassable than anticipated, demanding adjustments of planned methods for measuring the head of the penstock. Two different methods were mainly used to measure the head from the reservoir area to the river bed below.

Manometer

During the field work planning, it was decided that the head could be measured through the water pressure over a head difference. A clear garden hose, pressure cell and electrical manometer was brought and installed at the site. The terrain complicated the measurements and as the tube was finally filled with water the electronic manometer failed to show rational data, as seen in Appendix .13.

Figure 4.6: Filling the hose with water just below the hotel wall.

Laser with Distance and Angle Measurement

A distance measuring laser was also brought to the field. With the laser positioned at the forebay location, the distance down to the riverbed visible below could be measured. By also noting the angle of the laser distance measurer, the head could easily be found as seen in Appendix .13. The laser distance measurement gave a head of 34 m from the planned reservoir location down to turbine level.

4.1.4 Turbine Level

An old channel and gate valve are visible down at the turbine level, transversely to the penstock. While the river is diverted 4 m out from the channel by a small, grass island, some water runs straight through the island, in the channel. The 0.5 m wide channel is considered as a possible foundation for the turbine. This could be of proper protection to the robust turbine and offer an easy solution of draft tube.

Figure 4.7: Channel and gate valve at turbine level.

4.2 Hydrology

It was first considered to bring a flow measurer to find the exact channel flow, however this was not carried out, since volume flow measurement performed only once towards the end of the dry season, has little credibility. In addition, the intake arrangement will be upgraded to the new scheme, and would therefore give a different basis for the actual volume flow. Field estimations gave approximated channel flow of 12 L/s and a river flow of about 300 L/s. These are based on rough calculations and will naturally include an uncertainty. Hydrology will therefore be based on the data from the Ghona catchment area gathered in the PhD-thesis by Røhr (2003).

Daily discharge at Ghona can be seen as highly varying from year to year, as seen in Figure 19. The curve shows a varying discharge from year to year. It can be noted that 1999 was a relatively wet year, while 2000 turned out a very dry year, with no visible peak discharge. Measurements were unfortunately, abruptly stopped in the spring of 2001, due to vandalism and theft of the data logger.

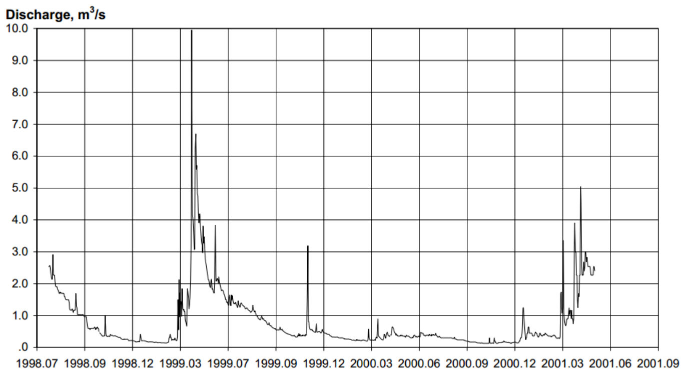

Figure 4.8: Observed daily discharge at in Ghona river. (Røhr, 2003)

The Ghona catchment area has a contributing area of 47.7 km^2, disregarding surface run-off in the areas above 2800 masl, which can be considered non-significant (Røhr, 2003). Older maps from the area, provided by Killingtveit (2014), show an estimated catchment area for Una of 14 km^2. The factor of 3,4 can therefore be utilized for the approach of a discharge curve for Una. With new values on the vertical axis, the new discharge curve can be seen in Figure 20. This estimation gives a mean daily discharge of approximately 200 L/s.

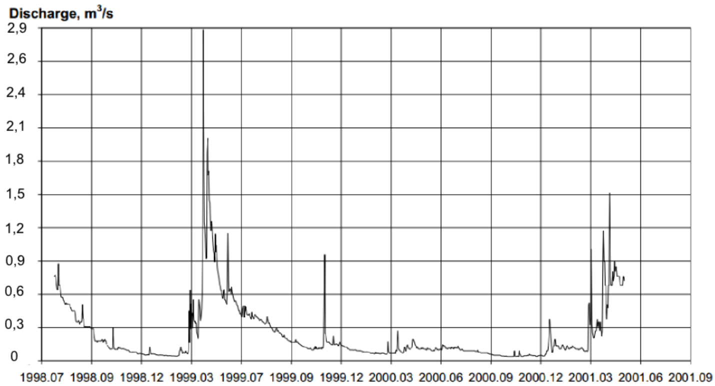

Figure 4.9: Estimated daily discharge in Una river. Adapted from Røhr (2003)

For hydropower planning, the available flow in a river is more visually illustrated in a flow duration curve. This curve will provide a graphical view of the probability of a certain minimum discharge, and is commonly used in feasibility studies. The flow duration curves has been produced by the Ghona discharge data, collected from Røhr (2003). The discharge data has been modified by the catchment factor, as a correspondence of the two areas is still assumed.

Data from the wet year of 1999 and the dry year of 2000 was available, and has been included in each of the flow duration curves. This provides a broader basis for evaluation.

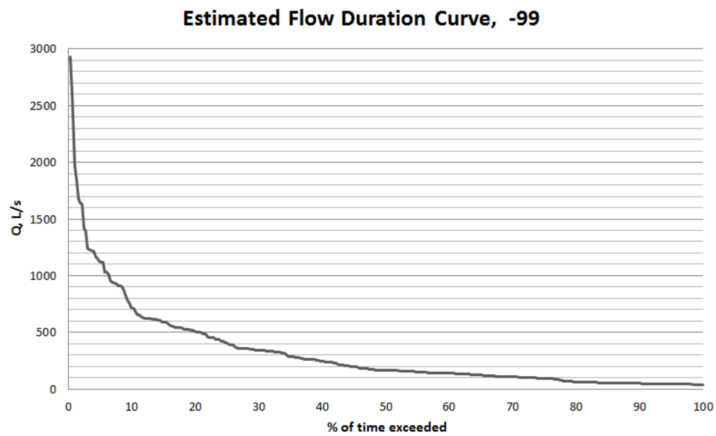

Figure 4.10: Duration curve -99, Una. Estimated with discharge data from Røhr (2003)

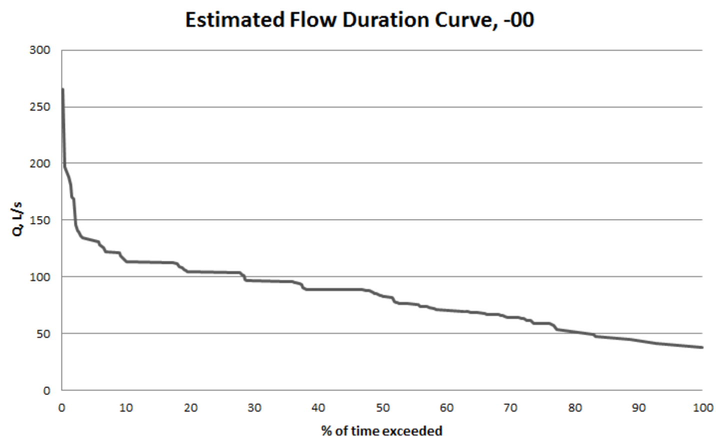

Figure 4.11: Duration curve -00, Una. Estimated with discharge data from Røhr (2003)

From a wet year, such as 1999, Una has a have a flow equal to or exceeding, the turbine design flow of 240 L/s, 42% of the time. However during a dry year, such as 2000, Una only provides a flow equal to, or exceeding 240 L/s, 2% of the time. This will be reviewed further in Chapter 0.22.

Based on conversations with hydrologist Killingtveit (2014), there should be no need to consider environmental changes in discharge in this short period of time. However, there might have been an increase in the use river water for irrigation. Killingtveit also estimated the possible, sustainable flow for hydropower use in Una, of 20 L/s to 50 L/s.

4.3 Electrical Situation at Marangu Hotel

Marangu Hotel has a pre-paid arrangement with the electric supply company TANESCO. As the electricity grid is highly unreliable, the hotel also has three diesel generators, frequently used as back-up power. There are two single-phase and one three-phase generator, used according to the required power consumption. According to the owner Seamus, these would easily have a consumption of 5 L of diesel per hour (Brice-Bennett, 2014).

Hotel electricity is distributed from a control panel by the office building. Here a changeover switch decides between the different input power source and receiving circuit branch. Changeover switches are also located by the generators, in order to decide the input coming up to the main control panel.

Figure 4.12: One of the three diesel generators.

Figure 4.13: Main changeover switch.

The input from TANESCO, or one of the generators divides into five different branches supplying the hotel area with electricity. A map over the branches can be found in Appendix .13. These are connected and disconnected depended on a schedule and available power. A possible coupling with hydro electricity will most likely only be connected to the most vital power requiring branches.

A solution with a dump load system could be well fitted to Marangu Hotel. The system could be incorporated by connecting the heating elements to a water tank for laundry use. Thereby, the surplus power would not go to waste, but could be used for heating of water. The turbine would then be controlled by an ELC adapted for asynchronous generator.

BEVI had however installed a multi-instrument with a frequency controller, in addition to the soft-start system. This would give no use of a dump load system, since load and frequency changes would be directly controlled by the multi-instrument.

4.4 Turbine testing in the Waterpower laboratory

Testing of the turbine prototype was performed through the facilities at the Waterpower laboratory at NTNU, in May 2014. This was done to investigate how the operational characteristics of the prototype had been changed after the upgrades at BEVI. As illustrated in Figure 11 the turbine was installed in the small turbine rig, and operated with a head ranging from 0 m to 25 m.

Rotational speed of the pump in the basement is the only controllable parameter during testing. It provides both operational head and volume flow for the turbine and is adjusted through a LabView program. Generators are controlled from the front panels on the frequency controller and the soft-starter. A thorough manual for turbine test operation is found in Appendix 0.28.

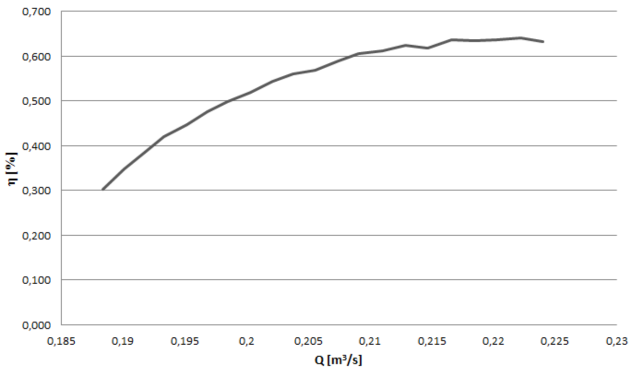

Figure 4.14: Efficiency curve.

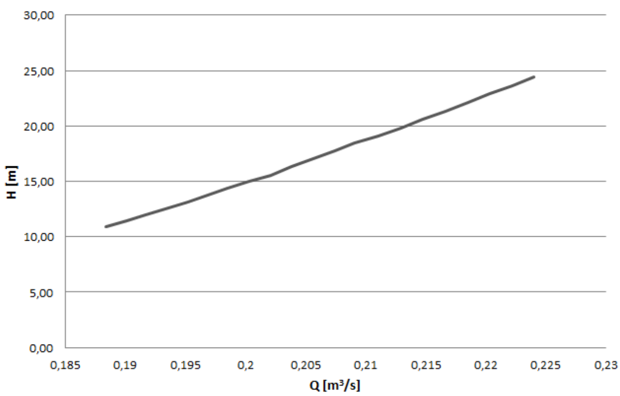

Figure 4.15: Head-discharge curve.

The turbine was quite loud during operation, which might indicating a drag and inaccurate shaft positioning. Power generation was available from a head of approximately 10.8 m, with quite low efficiency and power output, as expected.

Prototype performance

Prototype testing showed an efficiency of $63 - 64\%$ with a head of 22 meter and flow of $0.22\,\text{m}^3$/s. Figure 25 shows that the turbine can maintain a efficiency over $52\ \%$ if the volume flow is kept above $0.22\,\text{m}^3$/s.

Operated with a head of 18 m to 25 m the generators repeatedly fell off production. BEVI informed that this was due to a motor protecting switch located in each generator set to 25 A. This information was not given until the end of the tests, however BEVI reassured that this is passable as long as the temperature was kept below $80^{\circ C}$ (Andersson, 2014). All tests had been run with an average 39 A without recording temperatures. Hopefully this has not damaged the generators and temperature measures should be attached before further testing.

By restarting the generators, they regained production and the head could again be increased before one fell off again. Operating with head over25 m, the turbine shifts into an unknown error, causing loud noise and increased vibration. Operational head was lowered during this behaviour, to avoid permanent damages.

Sources of errors

One is the uncertainty in calibration of flow meter, which was last performed by student Øystein Hveem in June 2013 (Hveem, 2013). This was considered acceptable, partly as new calibration would delay the testing further.

The turbine require an exact installation of the shaft inside the pipe. The shaft is held by three asymmetric bars that must be precisely attached in order to prevent touching. This has not been double checked after receiving the turbine from BEVI before installation. Touching internally in the turbine could cause a loss of efficiency.

Chapter 5

Results

Technical and social conditions have made a foundation for the scheme design, presented in this chapter. Ranging fields of studies are combined to provide a suitable and sustainable layout. The result is shown in the overall presentation of a layout, presented below.

Design of the micro-hydropower plant has been developed in cooperation with members from GreenEnergy, and Ngoma from ATC. Components has been chosen together with Skår, from the supplier Brødrene Dahl (Skår, 2014). Components are a part of their assortment through sub-suppliers. A list of chosen components is presented in Appendix .13. For the following scheme design, Una is assumed to provide a sufficiently available discharge. Uncertainty of the hydrology will be further discussed in Chapter 0.22.

5.1 Design Overview

As lab tests in chapter 0.15 showed a suitable turbine head of 23 meter, it is preferred to install the forebay tank directly above the hotel wall. This gives a turbine head of 23 m, and 10 m extra head for the supply pipe. Head for the supply pipe will therefore be 24 m, consisting of 7 m channel head and 17 m from the current channel down to the chosen forebay tank.

Design is illustrated in Figure 27. It can be noted that the penstock inclination in the 3D CAD drawings is too steep. Correct inclination should be approximately 43 degrees.

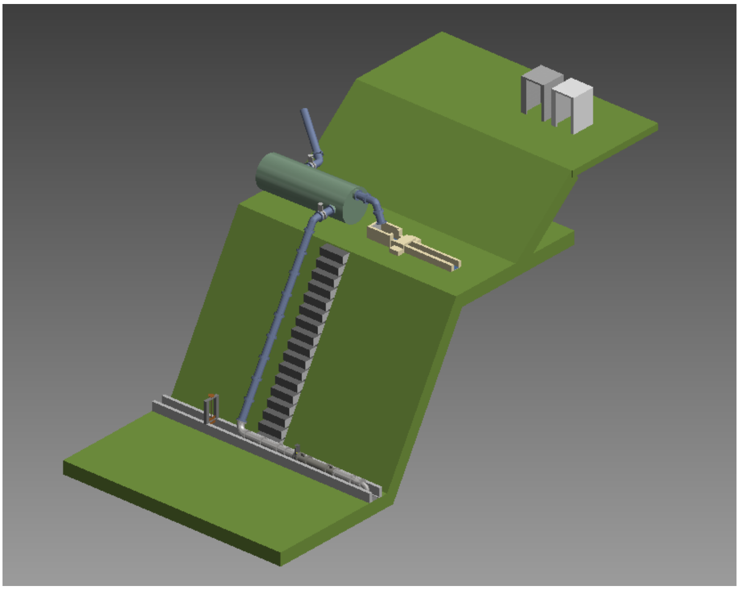

Figure 5.1: 3D CAD drawing, overview of scheme design.

This would provide a power output of

$$P = \rho \cdot g \cdot Q \cdot H \cdot \eta_{turb}$$

$$P = 1000\frac{kg}{m^3} \cdot 9,81\frac{m^2}{s} \cdot 230\frac{m^3}{s} \cdot 23m \cdot 0.86$$

$$P = 32,7\ kW$$

General overview of the scheme starts with a Coanda intake located across the river bed, which will secure a volume flow of around 250 L/s. Following from the intake, a knife valve and air valve will be connected to the piping. The waterway piping will bring the water approximately 900 m down to the forebay tank with a total head of minimum 7 m. This head will be dependent of where the forebay tank is located, ranging from 7 m to 15 m. With a capacity of 18 000 L the forebay tank can maintain a stable supply to the penstock and turbine. From the penstock, the water runs through the turbine and out through a draft tube. Control panels will be located near the pool pump.

5.1.1 Intake

Design of the intake is based on a desired inflow of 250 L/s. UK subcontractor Dulas Ltd produces Aquashear Coanda screens appropriate for this scheme design. With a relatively high intake requirement compared to river discharge, the intake should be build across most of the river width. A spillway channel should be added to ensure a maintained river flow, downstream the intake. Since the Coanda intake requires a head loss of about 1 m, the river must be dammed up with a crest of 1.5 m. The Coanda screen will be mounted as seen in Figure 28.

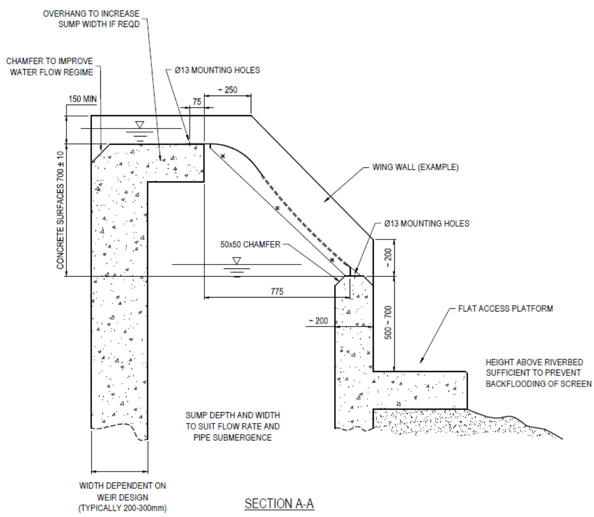

Figure 5.2: Coanda intake. (Skår, 2014)

From the culvert under the Coanda screens, the flow will be led through a cone reducing the diameter from 680 mm to 500 mm. To keep a secure and stable waterway, a knife valve is located after the cone. The valve is again connected to a T-piece, known as a branching element.

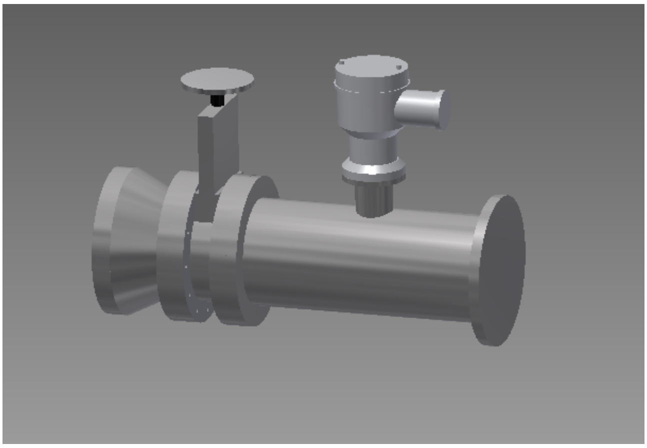

Figure 5.3: 3D CAD drawing of component assembly, after Coanda intake.

5.1.2 Air valve

With supply pipes reaching up to 900 m long, there is need for a low and high pressure air relief valve in the system. The valve will be connected to a T-piece branching element coming from the knife valve. Located perpendicular to the pipes, the air valve will relief air stuck in the pipe, and avoid negative pressure when water is drained.

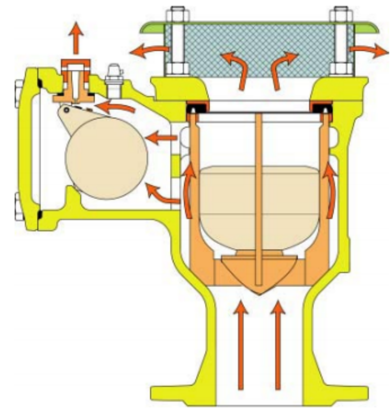

Figure 5.4: Air valve, after intake. (Skår, 2014)

5.1.3 Supply pipe

The supply pipe, leading the water from intake to the forebay tank, will consist of buried PP or PVC pipes in a range of sizes. These different sizes are chosen to simplify and decrease the transportation costs, as the pipes can be transported inside each other. It is therefore natural to choose pipe diameters in a range from 400, 450 and 500 mm. With a total length of 950 m, and 6 m per pipe, the pipe costs will be a substantial part of the expenses. Total head from intake to forebay tank makes out an approximated 17 m, and calculations from Appendix .13 gives a total head loss of 2.54 m. The supply pipes will be kept in a trench covered with about 300 mm soil. The trench should be dug along the current channel.

5.1.4 Forebay tank

As the Coanda intake provides already cleaned water, the reservoir should be a closed tank. A glass fibre tank will be used as a cost-effective solution for the forebay pool. The tank will be transported inside a shipping container and dimensioned accordingly. With diameter of 2 m and a length of 5.8 m, the tank will provide a storage capacity of more than 18 000 L.

Three flange connections, seen in Figure 31 will be welded to the tank. Two of them will have a diameter of 400 mm matched with the supply pipe and the penstock. The last flange will ha a diameter of 450 mm and will be a connection to the spillway channel. Exact flange position will be calculated at a later stage in the process.

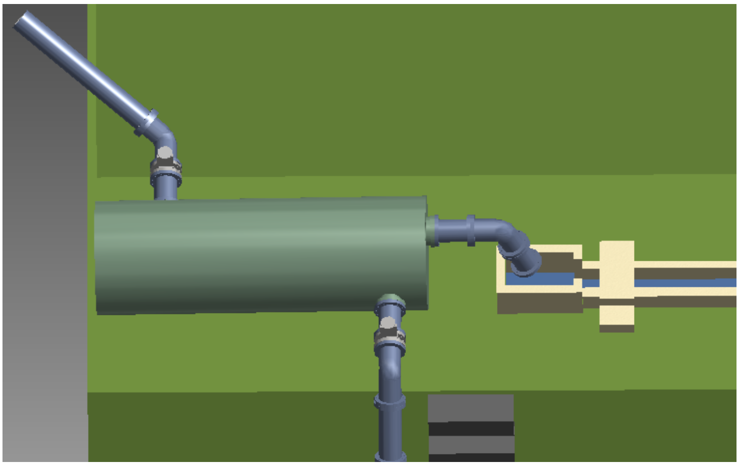

Figure 5.5: 3D CAD drawing of forebay tank and its flange connections.

5.1.5 Penstock

PE-pipes are suitable for penstock installation due to its durability of pressure build-up (Fladen et al., 2010). These are flexible and have a high tensile strength appropriate for the penstock.

From the forebay tank, there will be a short PE-pipe connection, before the manual gate valve. This valve is installed in order to empty the penstock for inspections and maintenance. A bend is included at the top to bring the penstock pipes down the hillside, with about 43 degree inclination. Down at turbine level a new bend directs the volume flow horizontally into the turbine, located in the existing channel. The PE-penstock pipes with 6 m length will be anchored to the hillside using concrete armoured anchors.

Total pipe length of the penstock is approximately 37 m, and will cause a head loss of 0.383 m calculated in Appendix .13. With a gross head of 23 m, the net head of the system will be of 22.617 m.

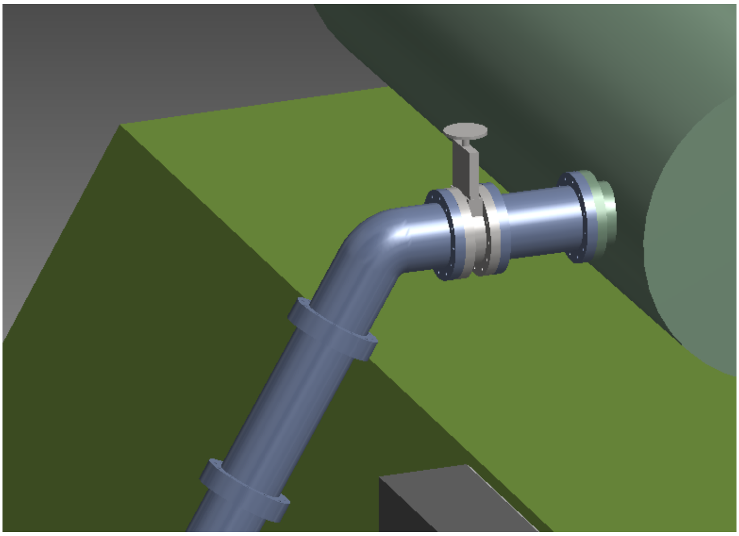

Figure 5.6: 3D CAD drawing of penstock connection from forebay tank.

5.1.6 Spillway

Spillway of the system is included from the end of the 2 m diameter tank. From here a flange will connect the tank to a bend and guide the water into a small channel pool and further along the spillway channel, as seen in Figure 31. Steps over the channel are included for a safe route to the penstock and turbine. The spillway channel has a width of 0.4 m and will carry the water about 500 m down to river Una with a small inclination. This water will be available for irrigation and of free use for the local.

Inlet volume flow of the intake is dimensioned to 250 L/s, and the spillway must therefore be able to conduct this amount of water away from the system. This is vital in case of operational problems, where penstock is closed while intake still provides flow to the forebay tank.

A floating valve will be included, in order to close down operation if the water level in the tank were to decrease below a minimum level. An alarm will go off symbolizing the need to close the turbine valve and stop operation.

5.1.7 Turbine Installation

From the penstock bend there is a flanged pipe of 1 m, which is located in front of the turbine. This pipe will have a collar welded on the middle and a socket for the manometer will also be included. The Zeta gate valve is located between the collar pipe and the turbine, the same principle as at intake and by the reservoir tank. Foundation will be based on the existing channel, with a draft tube submerged in the channel.

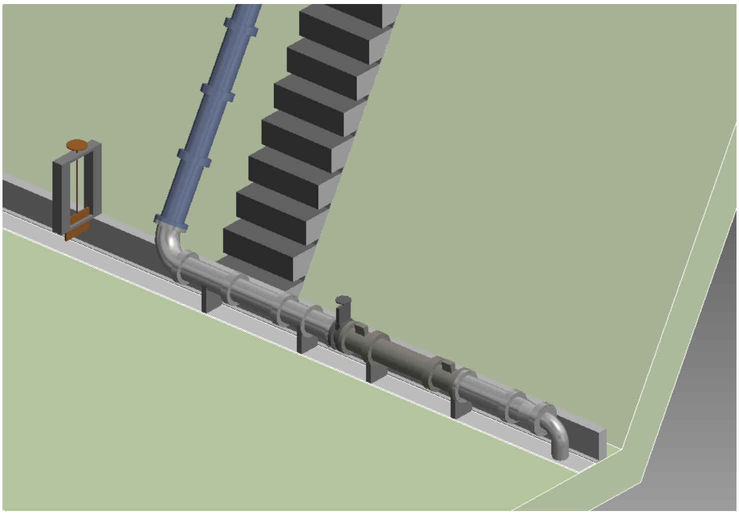

Figure 5.7: 3D CAD drawing of turbine installation in existing channel.

The turbine is designed to withstand most external effects, however the wires from the generators should be kept safe. It could be considered to build a small, protective building covering the turbine during rainy season and floods. This will also provide extra security for the turbine.

5.1.8 Electrical Arrangements

The turbine will provide electricity through an isolated grid connected to some of the most vital branches at Marangu Hotel. Main power demand of the hotel is 34.1 kW as seen in Appendix .13, and the noted sources are were the independent grid will be localized.

The asynchronous generators will be connected to external capacitor batteries that will excite required leading voltage, to induce a magnetic field for operational start-up. An installed frequency converter will convert the produced frequency to the desired frequency on the stand-alone grid. The conversion is done via current rectifier and current inverter, which will provide the desired 3 phase voltage and frequency. The capacitor batteries will functions as dump-loads for the operation, as all unused load is stored here. When the batteries are full, they must be changed, or turbine operation must be shut down. Control of this will require a PLC-system (Andersson, 2014). Single line diagram covering the generators and soft-starters is included in Appendix .13.

5.2 Further Procedure for Realization

During the start-up phase of this project it is vital to clarify the roles of the different parties. An agreement must be made between GreenEnergy, Arusha Technical College and Marangu Hotel in order to define ownership and responsibilities. The turbine is considered to be donated to Arusha Technical College, to whom Marangu Hotel would pay a rental price. In a project with four different parties these definitions are very important in order to avoid disagreements and misunderstandings along the way.

Pangani Basin Water Board manages the water resources of the area and will give the final approval for utilization of water for power production. During the field work, it was decided that professor Ngoma would be in charge of the further process of the application.

5.3 Local Precautions

Due to local conditions and experience from other similar projects, some precautions should be made in this project development.

Parts have been known to be stolen from site and sold at lucrative buyer's markets, as experienced by Røhr (2003), who's measuring equipment was stolen, Chapter 0.13. Preventive measures would include the location of supply pipes underground in trenches.

As the intake scheme and supply pipes are outside the hotel premises, these would require extra safety measures. The inlet valve should be secured, to avoid unauthorized operational stops.

The turbine is located on the river bed, just outside the hotel area. Some level of security is required for the turbine and wiring, in order to prevent damages and theft. The turbine should be properly secured to the channel. Wiring from the generator should be covered and protected, from the boxes on top of the turbine up to the control building.

All participants of this project should also be kept aware of the extensiveness of corruption in Tanzania. A clear and direct attitude against corruption must be maintained in the project. A survey by the Global Corruption Barometer in 2006 report that 33 % of African respondents had paid a bribe during contact with utilities (U4, 2007).

5.4 Construction Phase

The construction phase of this project will require thorough plans of the process. Detailed preparations can ensure that most of the necessary work can be done with manual labour, not requiring professionals for other than supervision. Guidelines and manuals should be developed and updated during the preparations and installation process. This is also an suitable opportunity for practical training of operators and maintenance technicians.

Marangu Hotel are able to contribute with necessary manual workers, from their staff. Such work might include digging of pipe trench and building concrete intake construction, installation of penstock and anchors (Brice-Bennett, 2014). This will require detailed plans of pipe path and the elevation. As the supply pipes will be placed underground, it is vital that the work is done with high precision. This is to avoid damages and leakages on the pipe, as it is difficult to detect and locate possible errors and damages.

The hill of the penstock and river bed area is overgrown and impassable and must therefore be cleared on an early stage of the process. Steps are planned along the penstock path down to the turbine level to ensure an easy access. This is valuable both during operation and building, and should be completed on an early stage. At turbine level, a foundation for the turbine must be made in the channel. Correct fastening points must be included to get a proper installation, without loss of efficiency.

Access down to the turbine level might be a challenge for installation of turbine and penstock. A possible solution is installation of a winch or crane truck from the forebay tank location, to reach down to the turbine level. This would reduce environmental impact during installation, as turbine, equipment and penstock can be transported down instead of clearing a road path down to the river bed.

The construction phase is estimated to last about six months, depending on the preparations. A thorough work plan must be made out in advance and a project manager should be involved in order to keep superior responsibility for the process and progress. Skilled personnel from both BEVI and Brødrene Dahl should be present and in charge for the technical completion and the requirements for a certain precision. Manual work with electrical and mechanical components should only be performed by skilled personnel.

5.5 Operation

Operation of the turbine should the kept as dummy-proof as possible. The routines for start-up and shut down are fairly simple, after the upgrades at BEVI, including the soft-starter.

Start-up procedures for the turbine are as following:

1. Open manual valve down by the turbine
2. Wait for water to spin the runners.
3. Press the buttons for soft start-up.
4. The generators will start and when the angle and momentum is correct, the turbine connects to the grid.

Shut down procedures are quite similar and the manual gate should be partly closed, to throat the flow, before shutting off the soft-starter (Andersson, 2014).

The turbine and electrical system is connected to an isolated hotel grid. Current electrical set-up for Marangu hotel consists of a main switch that decides input electricity from either the grid or one of the three diesel generators. Here an individual switch will be introduced that offers electricity from the turbine. The hydroelectric switch will be connected to an isolated grid that only will cover the most vital branches of the hotel, including main building, kitchen and offices.

5.6 Maintenance

Although this scheme is nearly maintenance-free, there are some required maintenance instructions. It is also important that proper inspection routines are developed from the start, to ensure that events of errors or damages will be discovered and fixed.

Day to day operation should be handled by operators at Marangu Hotel, while ATC could step in as professional resource, and do repairs and more advanced maintenance work.

Specialized maintenance routines must be developed for the Marangu scheme. A possible error-reporting system that could work at Marangu, is notes that will be filled out for each situation. An alternative could be to create a system that could receive text messages. In this way the operators could easily send a regular text message, where the situation is described. All reports must be gathered in a database, either digital or physical from where the maintenance plan will be updated to ensure a continuity and optimal premises for operation.

As this is a turbine prototype, there is a minimum amount of existing maintenance plans. Main maintenance priority will be on the Coanda intake, which should be cleaned for algae monthly, as well as regular inspections to ensure a proper operation. Turbine installation, and bearings should also be checked regularly. This is especially important considering the operational difficulties experienced at the last test in laboratory.

5.7 Economy

Micro-hydropower projects are known to have somewhat high initial costs, however the operational costs are almost none-existent. This is especially visible compared to diesel generators, which will not have as high initial costs, but instead offer the permanent expense of diesel fuel.

This specific project is based on contribution from the different collaborators. Basis of the whole project is the donation of the prototype turbine to ATC. This prototype has been produced and improved with funding through a development program of NVE.

Further on, most of the expenses are spliced by the different partners. Marangu hotel has agreed to cover most manual work with their hotel staff, as they have a large working capacity with a low employment rate in the nearby community. Components for the civil work will be provided by Brødrene Dahl. They too have an interest in guaranteeing the versatility of their product range by rural installations and a minimum demand of maintenance.

An overview of the different components and expenses is found in Appendix .13. Final expenses that are still to be covered, are also presented. These final expenses, such as transportation and installation costs will be covered by donations. Companies from Norwegian industry will be encouraged to buy shares in the project of 10 000 NOK a piece. A total of 100 shares will be available, in order to cover the last expenses. Sale marketing of these shares was started by GreenEnergy at a conference this spring, but due to a lack of specific plans and a finished feasibility study, this was postponed.

All electrical equipment is likely to be covered by the electric company BEVI and they will also be responsible for installation of this equipment.

A detailed budget can be found in Appendix .13 with cost estimation from GreenEnergy, Brødrene Dahl, and Ngoma from ATC.

All components for the civil arrangements, including intake structure, supply pipes, forebay tank and penstock, is estimated to 380 000 NOK. Most expensive components include supply pipes and the Coanda intake. The prototype has a value of roughly 1 500 000 NOK, however the economical resources put into the development has been substantially higher. An estimated, potential sale price of the turbine would end at $400 - 500\,000$ NOK, in order to compete with similar turbines on the marked.

Costs for the civil work has been estimated from Ngoma. These prices include labour for the workers and materials.

- Mass concrete = USD 180 per m^3
- Reinforcement = USD 1.8 per kg
- Form work = USD 6 per m^2
- Excavation = USD 90 per m^3
- Backfill = USD 36 per m^3

Based on these prices, the channel costs will be quite high, covering a distance of nearly 1 km. According to the potential agreement, Marangu Hotel will cover these costs.

Of the costs that are still not covered by any partner, the transportation will be a large contributor. All civil work prices from Brødrene Dahl is included transportation to the nearest harbour. According to Ngoma, the nearest harbour is Mombasa, Kenya, at a 564 km distance. Estimated costs from Ngoma insinuated a price of 132000 NOK per container. Customs might be a challenge. Cost for transport of the turbine in a container from Norway to Mombasa is estimated to 24 000 NOK.

Summed up, this scheme would have an estimated, actual value of 1.9 mill NOK. Remaining expenses after each partner's contribution, would include transportation, training, professional installation and grid connection. This is budgeted to 840 000 NOK, and needs funding by industry and interested parties.

Income of this scheme, would constitute of the savings in diesel expenses. With an estimated use of 25 L diesel per day and 7 open hotel seasons, the saved cost could amount to 40 000 NOK.

Chapter 6

Discussion

6.1 Chosen Layout

The chosen scheme has been designed with regards to low-maintenance requirements and affordability. Design has been based on the performed field work, and achieved turbine characteristics from testing in the Laboratory.

The final layout is largely based on components from the product range of supplier *Brødrene Dahl*. A more sustainable solution might instead be to choose local suppliers which would make spare parts and maintenance easily accessible. This would also support local industry and the chosen product range could be a good basis for future exploitation of micro-hydropower in the area.

However, the chosen products are simple and affordable parts and matches the turbine prototype as a low-maintenance, easily operated scheme design. Prices are kept low on most components, except from the Coanda intake and the pipes, that usually contribute to a large part of the budget, especially on such long supply pipes.

6.1.1 Intake

One of the main contributors to the low maintenance demand of this scheme, is the Coanda intake. It could therefore be a fitting technology for smaller projects in rural areas, if not for the high costs. Brødrene Dahl are, through this project hoping to show that the intake system is adaptable for most site conditions and creating a larger marked for the concept. This might lower future price of the intake, making it an affordable solution.

As hydrology showed to be an uncertainty in the planning, an alternative could be to create a real dam at the intake. By damming up an basis of water, the turbine operation could be ensured with a backup supply of water. However, this would result in a drainage of the downstream river. Causing unknown environmental effects and displeasure among the downstream communities, this is not a favourable option.

6.1.2 Supply Pipe

Supply pipes are intentionally buried down next to the channel, in order to keep the visible traces to a minimum. This is also a preventing solution in order to avoid vandalism and theft of the pipe parts. The length of the channel causes unfavourable risk, and the pipes will contribute to a great share of the system costs. A gentle inclination down to forebay tank should be ensured to maintain a smooth flow.

Head loss of this supply pipe is calculated to 2.5 m, giving a gross head 21.5 m, as explained in Chapter 0.16.3. The material connection effects, as explained in Chapter 0.8.2, has not been included in this head loss. If this shows to have a great effect, the gross head of the supply pipes might create difficulties for a functional operation. This is, however not assumed to amount to a influencing effect.

The forebay tank was first assumed to be located approximately 10 m above the chosen location. This would have resulted in a gross head of mere 11.5 m, resulting in a somewhat higher vulnerability of water supply to the forebay tank.

6.1.3 Forebay tank

The location of the turbine and forebay tank was chosen based on the measured turbine characteristics. As prototype tests showed an appropriate operational head of 23 m, a suitable fit for the forebay tank was placed by the hotel wall. This location is an appropriate and secure solution for the system. Installation of stairs going from the pool area down to the tank, through the door in the wall, and down to the turbine would make the scheme easy accessible, for operation and maintenance.

An alternative could be to keep the forebay tank at the planned reservoir location, and bring the turbine installation 10 m up the hill. This would create some extra challenges and a concrete foundation would have to be built, in order to provide a secure turbine installation. As the turbine would be located somewhat closer to the hotel wall, security of the turbine could be improved, not only considering vandalism but also the rainy season with its unknown effects of flooding. This solution would cause higher construction challenges and costs in order to maintain a level of security. It is also highly dependent of soil conditions and is not favourable for this scheme.

6.1.4 Turbine Installation

Required extent of turbine foundation and shelter is still somewhat unclear. Generally, the turbine is made to sustain installation in water, if wires are properly secured. Challenge therefore reveals itself during the rainy season and to what extent the river water level will increase, and wear the installation. The hotel owners specified that the river was largely affected by seasons, and would easily tear off crossing pipes, located above the usual river height.

The turbine must have an ensured positioning of the shafts to avoid touching as this will drastically lower the efficiency. In order to avoid shear stresses to the turbine and shaft, the turbine must be allowed some movement, while being properly fixed to the foundation.

6.1.5 Electrical Arrangements

With the provided frequency controller and capacitor batteries, a specific dump-load system was not required. The provided system will however, function similarly, where all excess load will be stored in batteries, instead of being burned up in heating elements. The solution will provide a flexible system and with several battery packages included, Marangu Hotel could have full batteries as back-up for later use. Such a solution can open up for connection with PV energy for an increasingly flexible system.

6.2 Hydrology

Hydrological basis has only been estimated through this study, since such work require years of measurements and observations of the specific river and catchment area. This will therefore be a substantial uncertainty throughout this thesis. One of the big challenges with this project is therefore whether there is enough water to safely operate the contra-rotating pipe turbine. During the fieldwork, it was estimated that the river had a discharge of approximately 300 L/s. This was a one-time estimation, prior to the rainy season, and should not be used directly as further assessment.

As no hydrological data was available for the specific area of Una, the assessment has been done based on a neighbouring river and catchment area. The assumption that Ghona river will have relatively equal hydrological characteristics as Una river, is highly discussable. Location of the two areas is separated only by 2 km, estimated from maps (Røhr, 2003).

Røhr (2003) summarizes the area as "*High annual precipitation with complex distribution patterns occurs on these slopes.*". Accordingly, the catchment areas could have decisive local diversity. With this regard, the estimations should be assessed as indicative values. The two years providing adapted data for discaharge in the river Una are differ substantially, with one relatively wet year, in 1999 and a dry year in 2000. It is assumed that these will provide a sufficient hydrological foundation combined.

During a dry year, such as the one in 2000, there would not be a sufficient river discharge for operation of the turbine. Time interval between each dry year, has not been found. A wetter year, could theoretically be run with sufficient flow, 42 % of the time.

This availability is still highly dependent on the time of year, according to the rainy seasons. There is an increased discharge during months March to May, as well as a visible peak in October and November. Correspondingly with the main rainy season, the hotel is closed for three months from April. This implies that the power level is at a minimum during these periods, making it needless to generate power during the period with the most available discharge.

Foundation of this estimations of catchment areas is based on a area calculation from two old maps overlooking the area. An insecurity therefore follows the statement of a 14 km^2 catchment area, as seen in Appendix .13.

Based on the uncertainties following the assumption of hydrological basis, and the low expected discharge rates, there is a decreasing probability of further development of the scheme with the contra-rotating turbine. A solution could be to only operate the turbine during shorter periods, as sufficient flow is available. Further progress of this project should involve a more thorough hydrological basis for Una, for support or dismissal of these estimations.

The electrical control system of the turbines that offers an flexibility with the battery pack is a great advantage for the fluctuating discharge. With this system, the turbine could be operated at sufficient discharge and save all excess power in different battery pack. This could utilize the rainy season to a larger extent, even though the hotel is closed for guest. While still not an optimal solution, this opens for a potential implementation.

6.3 Suitability of Turbine

Turbine testing of the prototype at the Waterpower Laboratory, showed results that were somewhat lower than anticipated. The decreased output power and difficulties during operation at same head and flow as the last turbine test, might indicate that the turbine characteristics has not been improved after the last upgrades at BEVI.

One explanation might be the mechanical installation of the turbine, which can have large consequences if the shaft is not properly located. Previous testing showed this to be a substantial source of error and a lot of time went to mount the shaft properly. This was not done during these lab tests, as the turbine was delivered fully assembled and and therefore not closer investigated before installation in the laboratory.

On the other hand a potential cause of the poor result is the fact that as the upgrades of the generator included recoiling and recasting of both sets, they can not actually be compared to old results. The turbine now has new characteristics and as the turbine efficiency was found from the generator data, it would highly inflict the result. If the efficiency were to be found from shaft torque and rotational speed, as it theoretically should, the results might be quite different.

During calculations of the turbine efficiency, a constant generator efficiency was used. However this value would vary with the load and a generator efficiency curve should be obtained. Unfortunately, this curve was not easily available from BEVI and could not be assessed within this project.

Result of turbine's best efficiency point showed a total production of 27 kW at $63-64\%$ efficiency. Lundekvam (2006) predicted an increased efficiency of $8-10\%$ only due to installation of a draft tube in the further testing, and this has not shown any difference, since last testing with a received efficiency of 60 %.

Lab tests also revealed that the operational range of the turbine was largely decayed as the turbine showed an increasing vibration and destructive noise level. At operation with head above 25 m, load ticking noises indicating touching occurred as well as generators falling off the grid. As mentioned in Chapter 0.15 there had been installed 35 A circuit breakers on each generator which caused the fall off.

It seems that the performance of the prototype has decreased drastically. Based on the gained results operation should be adjusted to a lower power output in order to avoid dangerous heating of the generator. Turbine operation is likely to be improved by a thorough installation of the hubs, which might increase the expected power output.

6.4 Economic Review

The economical aspects reviewed in Chapter 0.22 indicates that the future of this project is highly dependent on the agreement between the different collaborators. If one of the four main collaborators were to withdraw from the project and loose motivation, the project would have large difficulties in the further process.

The project is also highly dependent on external funding of the remaining 840 000 NOK required for completion and start-up. A thorough job is required for the industry and companies to see the motivation for why they should contribute and engage in this company. Current plan is to further extend this project as competence building for ATC and Marangu village. Contributing partners would be invited for a stay at Marangu Hotel, including a detailed tour of the scheme and other plants in the nearby area. A plaque presenting all partners would be installed at site. Consequently there is quite a way until this project is financially secured for realization.

6.5 Social Consequences of this Project

Although it may be assumed, this is not a development aid project. Marangu Hotel is one of the biggest and most successful businesses in the Marangu area, fully capable of covering the expenses of its power supply. However, the hotel is a large employer for people in the nearby area and installation of hydropower might result in a community development.

Building of this plant would demand manpower, which Marangu Hotel can provide from their working staff. The goal would then be to engage, so that some of the workers could be motivated to get to know the turbine during installation. Later these workers could get key roles, in order to operate and maintain the turbine.

One of the installation challenges, is the channel which today brings water through several properties. A sudden disappearance of this accessible water is likely to cause some displeasure, even though all rights of the water are legally property of Marangu Hotel. Initial plan was to keep water in the channel while digging down the supply pipe.

It is important that the community is included in this project and avoid negative reactions from the community. This could show to be a challenge as the hotel is already fully supplied with electricity. Despite the legal water rights, many might find it greedy and unfair that the hotel will build and take water from the river that to some extent is a part of their everyday life. Such reactions might cause vandalism, damages and theft of parts of the scheme.

Installation of a power site at Marangu Hotel will hopefully create an increasing interest of hydropower on a small-scale level. The cooperation with ATC and Professor Ngoma has already created a small spin-off effect, as a Norwegian volunteer women, Tone Ellefsrud has started a cooperation with ATC. This is a great opportunity where her students can get information about ATC, and the career opportunities available there.

Positive effects from cooperation with ATC would be to help create a more practical study. An increasing experience from hydropower development in the Moshi area could create more projects. Local professionals and students from ATC can be included as a part of feasibility, developing and building phase of projects, together with the local communities. Such an experience on development project might be of great interest to many of the NGOs that are establishing projects in the nearby areas. Such projects often has funding and a goal, but might lack procedures on how to adjust the work to the local conditions. ATC could then offer their expertise for creation of technical, sustainable projects.

6.6 Environmental Consequences

Small-scale hydropower has the advantage of minimum environmental effects compared to larger schemes. Potential consequences must nevertheless be clarified and minimized. Main effects of this site would be from the intake structures built across the river. Severity of this is again dependent on the hydrology and river discharge. However a environmental flow bypass should be included in order to maintain the river environment downstream the intake. Other environmental consequences can be erosion of river bank during rainy season when the river flow increases drastically. Concrete dams can be tore down and water can make its way on the outer sides of the dam, creating erosional damages to the hillside.

Implementation of this scheme will substantially reduce the emissions from the diesel generators. With a consumption of 5 L/hour the reduction of use would be substantial, considering the frequently grid blackouts.

Chapter 7

Conclusion and Further Work

The aim of this project has been to assess the site conditions at Marangu Hotel, Tanzania. This is done based on the potential installation of the contra-rotating pipe turbine, donated by GreenEnergy. Turbine characteristics was tested at the Waterpower Laboratory and field work was performed in Tanzania, to ensure a proper groundwork for the study.

Concept behind this scheme design is a minimum demand for installation, operation and maintenance. Several different technical fields of study are included in the feasibility study in addition to the socio-economic and cultural aspects required to create a sustainable project.

Turbine tests proved poorer results than expected, after the upgrades of the generator. Operation was showed largely dependent on a volume flow above the design flow of 200 L/s, of where it reached a maximum efficiency of 63%. Poor characteristics are assumed to be due to inaccurate installation of the hubs or possibly deterioration of the generators during upgrades.

The hydrological basis turned out to be one of the main uncertainties of this study. Poor hydrological data of the area, resulted in estimations of river discharge and flow duration curves from discharge data of a nearby river. The flow duration curves adapted to the river Una, covered years 1999 and 2000, respectively a wet, and a dry year. Results of expected discharge showed quite large variations. A sufficient river discharge, is assumed available 42 % of the time, during a wet year. With a lower availability during dryer years, this is not sufficient for a reliable full-time turbine operation. An alternative could be to operate the turbine part-time, controlled by need and available river flow. With battery packs and frequency control, this could be a part of a flexible energy system, where the turbine is operated when sufficient discharge is available. It is still unclear how much of the time, the turbine would be operable. An implementation based on the hydrological results shown in this thesis, is not an evident recommendation.

Further work will be based on a decision made by the initiators in GreenEnergy and the other collaborators, on whether they will continue feasibility work of the site. The poor expected discharges, although based on uncertainties, imply future challenges in the further development. Further assessments of the project should include thorough hydrological discharge measurement in Una. If installation at Marangu Hotel is not favourable, other potential locations should be considered.

Future plans of GreenEnergy and their contra-rotating turbine includes production of a new and improved prototype. The company has found a site location in Norway, with dispensation for concession requirement, for a potential installation. The site at Marangu itself has proved highly suitable for a micro-hydropower scheme, with convenient location, easy water access and sufficient security. Installation of a less flow-requiring turbine such as the cross-flow turbine could be a feasible option. In order to meet the power need of Marangu Hotel, such a scheme should be designed with a power production of 30 kW to 40 kW.

The dump-load system has not been reviewed thoroughly in this thesis, as it could not directly be implemented in the Marangu scheme. Further research on this area is strongly encouraged. This has definite interest for further development and improvement of micro-hydropower schemes.

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Appendix A

Guide for testing of contra-rotating pipe turbine

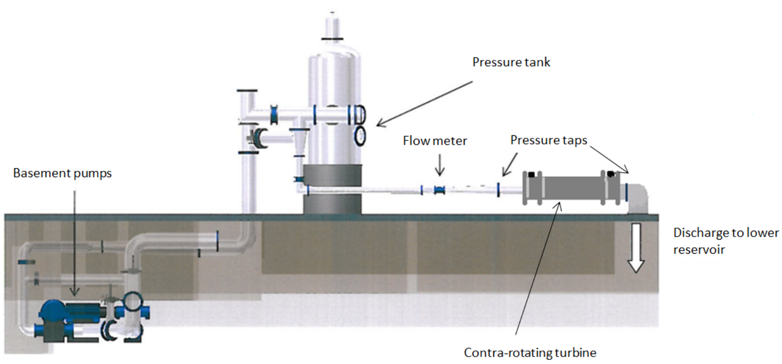


Figure A.1: Set-up in lab

A.1 Preparations

1. Calibration of pressure transducers and flow measurer if necessary.
2. Ensure the loop from pump to turbine is open, and that all other valves are closed. The loop to the small turbine rig is called 'studentsløyfe'.
3. Ensure that the pressure tank has water filled over the 'studentsløyfe' outlet.
4. Make sure that the draft tube is submerged and that both pressure tubes are filled with water.
5. Turn on the safety switch on the left side of panel 1 to let electricity to the panels.
6. Make sure all switches inside the lockers are turned up. NB: The switches are noted with the color red when on!
7. Set up a work station by the multi-instrument and soft-starter, with one computer showing differential pressure and one having a remote controlled access to the lab and pump settings, 38.
8. Turn on the pump's frequency controller located in the basement. The switch is turned to 1 and then moved further past the 1 and held for a few seconds. Let the switch back to 1, as it starts up.

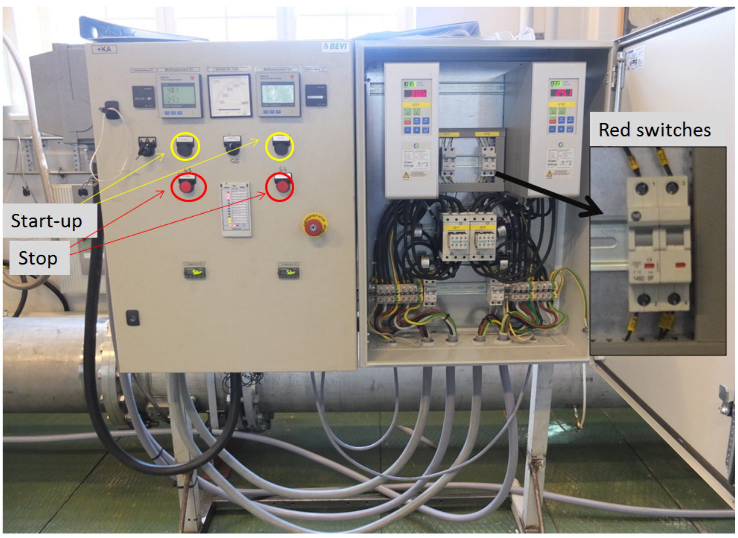


Figure A.2: Frequency controller and soft-starter

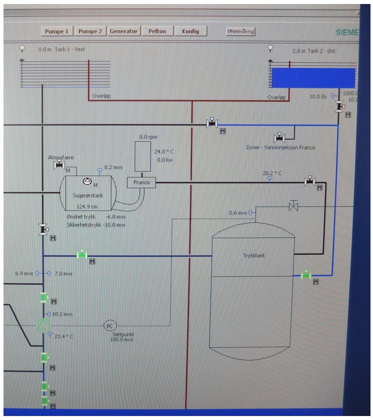


Figure A.3: Display of open loop from pump to turbine, ref 2.)

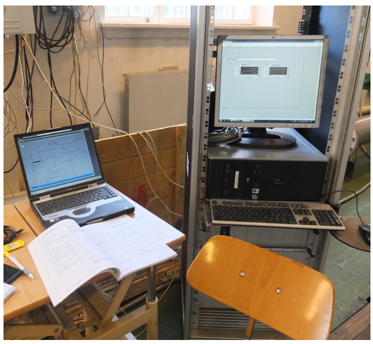


Figure A.4: Work station set-up

Operation

1. Turn on the basement pump 1 from the Labview program. This can be remote controlled from a laptop by the testing area. The pump starts at 100 rpm and increase the speed by adding +100 rpm. This turbine can start with a head of approximately 10 meter and pump speed of 470 rpm.

2. As the pump is running, fully open the valve in front of the turbine, located in front of the bend.
3. Wait some seconds for the water to stabilize and drain air bubbles before starting the generators. Push the button G1 and G2 to initiate the soft-starters. The sound of a switch clicking in indicates the start up of each generator.

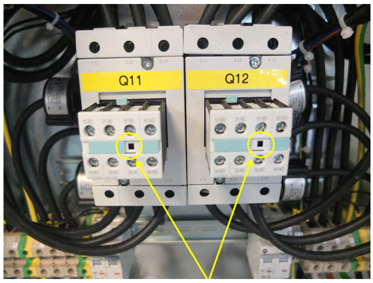


Figure A.5: Switches, indicating if the generator is connected to the grid, ref 3.)

Recording results

1. Operational data is found on the frequency controller's panels. Use the one showing: Σ of kW, PF, VAr and Hz. This is the last panel.
2. The kW value from each generator is the output power, that can be used to find turbine efficiency by dividing the output power on the generator efficiency. Equations are found in chapter 0.11.
3. Increase the pump speed by 10 rpm at a time and note the results of;
   - Δp
   - Q
   - kW

   Following data can be useful to note in order to check results:
   - PF
   - VAr
   - Hz
   - The two ampere values from the soft-starter, panel 100.

4. Should the turbines fall out, due to a too low/high pressure or high Ampere i.e. these buttons will jump back out and the panel will shut down. The turbine will make a lot of noise. Restarting is simply done by appropriately adjusting the operation and a push on the start button for the stopped turbine.

A.2 Shut down

1. Adjust the pump down to the minimum setting, approximately 10 meter and 470 rpm
2. Disconnect the two generators.
3. Adjust the pump down to 300-200 rpm
4. Close the manual valve by the bend
5. Take the pump down to 100 rpm and turn it off
6. Turn off the main switch on the multi-instrument
7. Turn off the frequency controller for pump
8. Clean up

A.3 Note

BEVI has installed 35 Ampere on each generator, which is causing the fall off. Pay attention to internal temperature in the generators as this Ampere-values are reached. Temperature probes must be installed properly before further testing.

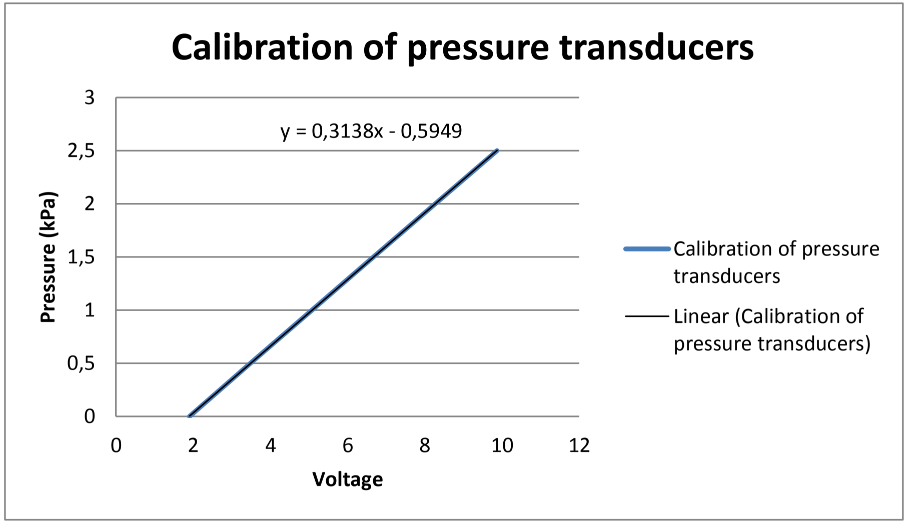
Appendix B

Pressure calibration

Calibration of pressure transducer

Rig:	Contra-rotating pipe turbine test rig
Operator:	Kristin Gjevik
Date:	13.05.2014

Pressure [Bar]	Voltage	Pressure [kPa]
0	1,904	0
0,503	3,494	51,0
1	5,079	101,3
1,501	6,677	152,1
2,001	8,273	202,7
2,5	9,869	253,3



Appendix C

Field report

A two week field trip to Tanzania was performed from February 13th to March 1st in order to gather necessary data for the design. Supervisor Torbjørn Nielsen joined the work for the first of the two weeks. The trip would include a visit to Arusha Technical College and Marangu Hotel, where the hydro power project is located.

C.1 Preparations

The preparations for the field work started in January, while the dates of the trip were not yet decided. The main purpose of the field work would be to measure an estimated height and head of the system. Also, the head difference and flow rate of the intake channel to the reservoir would be of interest. As several experienced hydrologist could tell me, it could be hard to confirm an elevation head using GPS in these areas as it is difficult to connect the GPS to enough satellites. It was therefore chosen to bring a manometer and a garden hose so that the height difference could be measured using a pressure cell to find the pressure at the bottom of the hose. After many discussions it was chosen not to bring a flow meter as the flow of the channel would not be directly used in the system, as well as the measured results would not be representative for the whole year and all the different seasons.

Equipment and instrumentation brought from NTNU included hose, pressure cell, connections for the hose, a distance measuring laser, GPS and measuring tape.

C.2 Program for fieldwork

Day	Activity	Read more
1 - 2	Arrival day and visit at ATC	.6
3 - 4	Weekend. Sightseeing and safari in Arusha National Park	
5	Arrival at Marangu Hotel. Inspection of intake	.7
6	Meeting with the owners. Visit from Prof Ngoma from ATC. Field work on channel/intake/riverbed	.8 and .9
7	Measure height with manometer. Meeting with Tone. Head measurement with laser.	.10
8	Tour of electrical system with owner Seamus. Visit from Daniel. Prof. Nielsen went back to Norway	.11
9	Documentation of field work. Sorting of photos	
10	Documentation of field work. Lunch with Tone	
11	Walk to intake for last measurements and pictures. Social day with guests and owners of Marangu Hotel	
12	Last data and pictures of riverbed. Visited the local school with Tone	**??**
13	Travelled back to Arusha	
14	Working day at ATC	.12
15	Working day at ATC	
16	Working day at ATC and departure back home	

Following is more detailed description of some of the activities and fieldwork in Marangu. Calculations, measurements and assumptions are found in Appendix

C.3 Visit at ATC

Friday morning we met up with Prof. Daniel Ngoma from ATC who took us to the college. The visit started with a meeting with the principal, Dr. Richard Masika and the board of ATC, where we talked about ATC, its history and train rides. Afterwards Daniel gave us a tour of the different facilities of the college and classrooms teaching everything from jewellery to carpentry and mechanics. The facilities were impressively clean and well maintained even with German lathe and milling machines from the 1930's still running as never before. To provide enough income the college also functioned as a producer of different patented cooking ovens, cross-flow turbines as well as metal gates and fences.

After the tour we had a talk on future plans both with the field work and general co-operation. Torbjørn is very eager to include ATC in an EnPe-project were ATC would collaborate with the University of Dar es Salaam and NTNU. Dr. Masika was also very interested in this. In addition, ATC has just gotten funding from NORAD of 27 million NOK. There is an old hydro power plant near Kilimanjaro International Airport, called Kikuletwa built by Germans in the 1930's which supplied Moshi and Arusha with electricity until 1989. Since then, the power plant has decayed, and the plant has now been given to ATC with no charge from TANESCO, the Tanzanian electrical power company. ATC will now renovate the machine hall as the civil works is in a somewhat good condition. They will also create a training centre for mechanics and operators for hydropower. A third goal that might be put into action on a later basis is the creation of a new power plant downstream of the existing power plant. The project is in a planning and development phase with is set to be from 2014-2018.

C.4 Marangu Hotel

Marangu Hotel is a beautiful and very calm place, run by three siblings from Ireland, who grew up here. After arriving the hotel midday Monday, Torbjørn showed me the walk up to the river intake of the channel, also known as the furrow. It was a very nice walk in the green and beautiful scenery of Marangu. The intake now had some water, and we could clearly see that there was built a small dam guiding some of the water into the channel.

By the hotel's pool area there is a lower level with a view over the river. This is the penstock and powerhouse location, and where we needed to estimate the head. At a quick glance we realised that the rope would not be sufficient, as the steep hill was overgrown and blocked by the hotel wall at a third of the total height. The new plan for measuring the height would now be by distance laser and two different GPS to control the result.

We tested the laser for a while but found it very difficult to measure over 20 m, without getting the error message 255. It was also very hard to recognize the laser dot on far distance, especially on the green background. After some tries it was decided that we would try again at dusk, hoping the dark would make it easier to spot. This was a success at we measured a distance of 51 meters at an angle of 53 degrees.

C.5 Meeting with hotel owners

We had an meeting with Seamus and his nephew from the hotel after Daniel from ATC arrived Marangu Hotel on Tuesday. Torbjørn presented our plans for the hydropower project, and updated them on the financial plan. Luckily Marangu Hotel were willing to provide workers for the civil work and also cover the concrete parts of the intake solution and the reservoir. We had prepared a few questions. The main building of the hotel is in constant need of power, due to offices, freezers, shops etc. This building should therefore be first priority to get power supply. They showed us the licence for the water rights from 1969, that confirmed that they are allowed to use up to $2m^3/s$ of water from the river for so-called hotel use.

It was decided that Daniel and ATC would be in charge of the contact and approval from Pangani Water Authorities. Seamus estimated the channel to be 700-800 meters, and told that the rain season in March and April, could cause extreme conditions in the river, tearing off crossing pipes etc. Marangu Hotel are willing to provide maintenance for most mechanical and civil work of the system, though they have no qualifications to perform electrical maintenance. It is therefore a question whether ATC can supply this. Also, this collaboration should be confirmed in a written agreement or gathered in an organization as the question of ownership arises. We are interested in having ATC as a part of this project and therefore Torbjørn suggested that perhaps ATC should be the official owners of the turbine, and that Marangu Hotel should pay ATC in rent. This is still not decided and will be followed up by Johnny and Bjarte when they travel to Marangu to continue the project in March.

C.6 Fieldwork: Site inspection

Dao from the hotel offered great help and with his machete and local knowledge he led us along the whole channel, even through private gardens and schools. With the GPS we could track the length of the channel to be about 800 meters. We also tried to measure the height at different points, but this showed to have a large uncertainty showing a mix of heights on the elevated path. From the walk and the inclination of the channel of around 4-5 degrees, it is assumed that the channel has an elevation of maximum 10 meters.

Arriving at the intake in the river, we took pictures and some measurements of the river bank. There was a visible concrete dam in the river, but this had no function. At the channel intake two thirds of the river was dammed with rocks and a couple of sand bags to lead water into the channel. Still, there was not a lot of water in the channel, though the river maintained an okay flow.

Doa also brought us to the riverbed below the pool, where the turbine would be located. By the riverbank there was a 50 cm channel carrying water from the river with a big old gate valve. Seamus had told us that the hotel used to have hydropower electricity in the 1930's with a turbine situated down there. The hotel wall had an old door in it which did no longer have a key but could be a good choice for easy accessible penstock location. The height of the hill was still hard to confirm and the GPS were still showing varying results.

C.7 Field work: Head measurement with manometer and laser

Torbjørn and I decided to try and measure the head up to the wall using the manometer as we had brought the hose and equipment all the way from Norway and had no lack of time. Though, when trying to connect the pieces, of course we had one combination missing. Luckily, the guys at the mechanical corner of the hotel, ran to a local workshop and managed to weld the two pieces together. Dao joined us to the river again, and the work with the 50 meter hose started.

The hose was dragged up to the wall and we started to fill the hose with water. Two bottles were used to fill the tube with water, running up the hill to the wall to try to avoid air bubbles in the hose. This took hours with Torbjørn, Dao and myself running up and down the steep hill in the warm Tanzanian sun. After some measuring problems, we cut the hose into the correct length of about 30 meters in order to see air bubbles more easily. When trying to measure with the electrical manometer, it gave a first result of 180 bar, before jumping over to only showing an error message. Torbjørn who was standing at the wall with the end of the hose, came down and tried to fix the hose. We also brought the hose down to what was definitely not more than 5 meters to ensure we were not over 2 bar pressure difference, the maximum of the pressure cell. This was still not working properly. Although we got numerical results, these were decreasing as Torbjørn brought the hose to a higher head.

With one last try, refilling the hose, restarting the manometer and taking out all the visible air bubbles, we got some results, though these were not trustworthy. We therefore ended the manometer project, regretted that we had trusted the electronics and not brought the mechanical barometer, provided by Bjarte. We decided to instead do a second try on the laser at dusk to confirm yesterday's result.

At around 7 pm the laser was tested again, this time to a different rock we had chosen from the river bed, earlier that day. The result now was 48 metres at 43 degrees, confirming a head of around 33 meters. This head is pushing what is accepted for the turbine, as the generator might burn out from over speeding.

C.8 Tour of electrical systems

Thursday morning Torbjørn and I met with Seamus and had a tour of the electrical systems of the hotel. We saw the three diesel aggregates, one large being 3-phase and two smaller 1-phase generators. All generators used approximately 5 litres of diesel per hour.

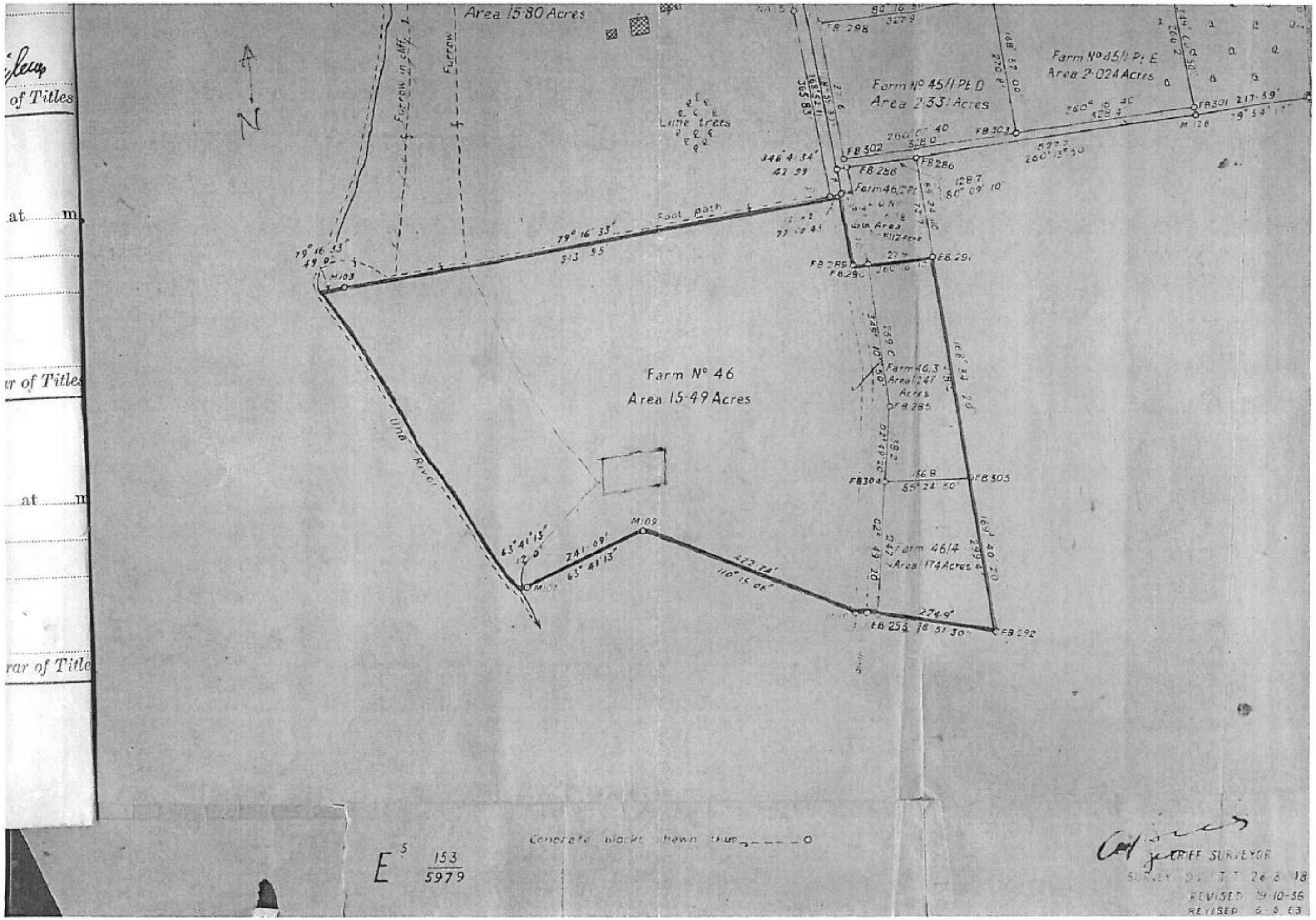
Electricity was covered through a pre-paid system with TANESCO, after many arguments and faults in the past. Electricity came into the grid with three-phase and 400 V and was taken from there on 16 mm cables, which is very small. Most in the hotel is single-phase, except from a spin dryer, irrigation pump and cooker requiring three-phase. There is a distribution board in all of the buildings. The generators are located in two houses with changeover switches. These chooses first between the single phase generators, and the between the single or three phase. The same goes for the main distribution board in the main building, choosing between no power, electricity from the grid or diesel generator electricity. The different hotel cabins usually have no power during the day and hot water is provided by solar power on the roof of the cabins.

C.9 Final days at ATC

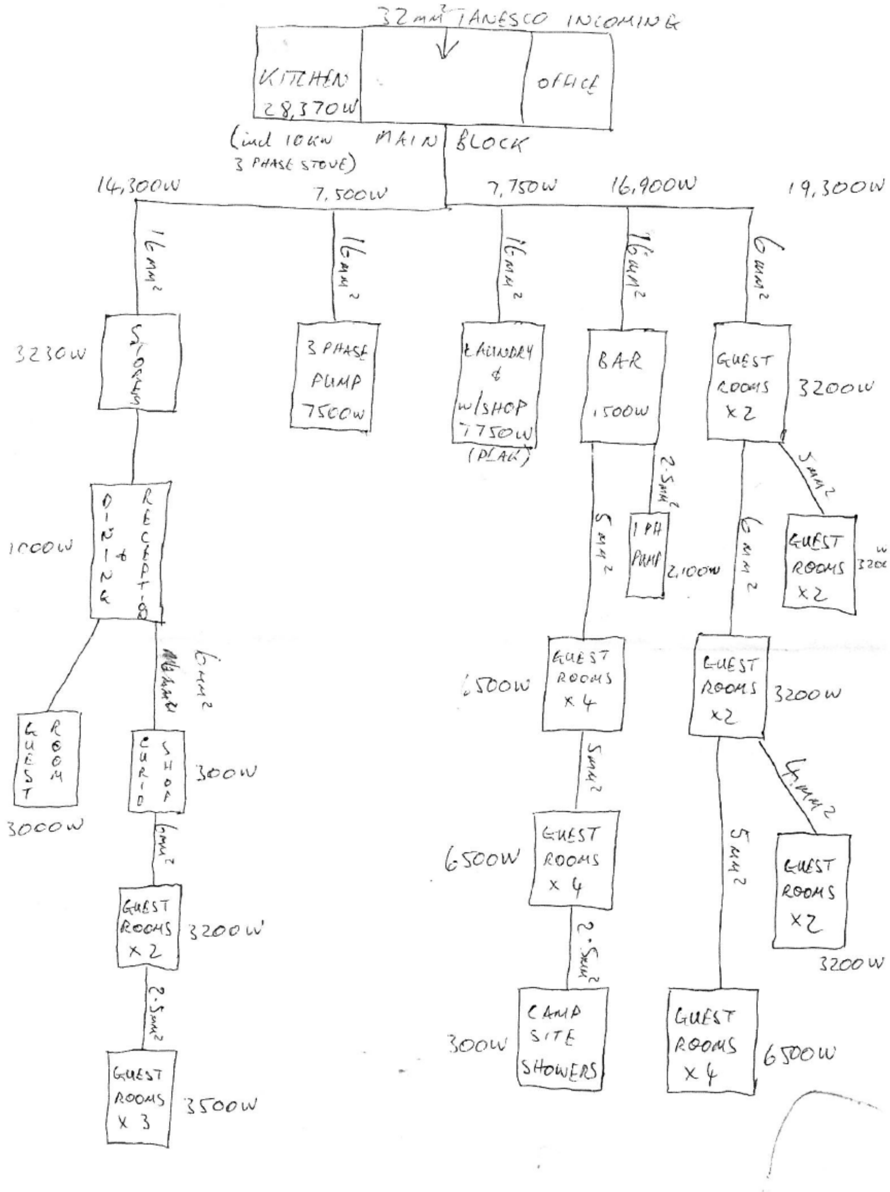
Back in Arusha I got to spend three days at ATC with Ngoma. We sat at his office working and discussing different part of the project most of the days in between his classes and college tours.

Ngoma tried to arrange for a car and driver for us to visit their power plant Kikuletwa on my last day of the field work. The plant is situated right by the airport but unfortunately this was not possible.

C.10 Additional data



of Titles
at m
r of Titles
at m
rar of Title
N
Furrow in cliff
Furrow
Area 15·80 Acres
Lime trees
Foot path
79° 16' 33"
913 95
79° 16' 33"
49 0
M103
Farm N° 45/1 Pt D
Area 2·331 Acres
Farm N° 45/1 Pt E
Area 2·024 Acres
FB 298
FB 302
FB 303
FB 301
217·59'
FB 286
FB 288
FB 289
FB 290
FB 291
346 4 34'
42 99
Farm 46/2 Pt
128 7
80° 09' 10
Farm N° 46
Area 15·49 Acres
Farm 46/3
Area 1·247
Acres
FB 285
FB 304
FB 305
56 8
55° 24' 50"
Farm 46/4
Area 1·74 Acres
Una River
63° 41' 15"
12 0
241·09'
63° 41' 13"
M109
110° 15'
FB 292
274·9'
78° 51' 30"
FB 293
Concrete blocks shewn thus — — — — o
E[5] 153/5979
CHIEF SURVEYOR
REVISED 19-10-56
REVISED 6-5-63



32MM² TANESCO INCOMING
KITCHEN 28,370W
OFFICE
(incl 10KW 3 PHASE STOVE)
MAIN BLOCK
14,300W
7,500W
7,750W
16,900W
19,300W
16MM²
6MM²
STORES
3230W
3 PHASE PUMP 7500W
LAUNDRY & W/SHOP 7750W (PEAK)
BAR 1500W
GUEST ROOMS x2
3200W
2.5MM²
1 PH PUMP
2,100W
5MM²
DINING + RECEPTION
1000W
GUEST ROOM
3000W
CURIO SHOP
300W
GUEST ROOMS x4
6500W
GUEST ROOMS x2
3200W
4MM²
CAMP SITE SHOWERS
300W
GUEST ROOMS x3
3500W
GUEST ROOMS x4
6500W

1	3 Phase Irrigation Pump	C50	C50	3 phase Cooker	19
2		C50	C50		20
3		C50	C50		21
4	Laundry / Workshop	C50	C50	Top office	22
5	Bar / Rooms 29-36 / Tennis / Water Pump	C50	C50	Kitchen deep freezes	23
6	Rooms 15, 16 - 37, 38	C50	C50	Room 1, 11, 12 - 18, 19, 20 / Dining / Toilets / Reception / Curio shop	24
7	Cooker control unit	C50	C50	Single socket - kitchen	25
8	Cooker control unit	C50	C50		26
9		C50	C50		27
10		C50	C50		28
11		C50	C50		29
12		C50	C50		30
13		C50	C16	Spin Drier	31
14		C50	C16		32
15		C50	C16		33
16	Sub-distribution board	C50	C50	Sub-distribution board	34
17	Sub-distribution board	C50	C50	Sub-distribution board	35
18	Sub-distribution board	C50	C50	Sub-distribution board	36

Appendix D

Field data

Consisting of:

1. Channel description
2. Laser measurement
3. Manometer testing
4. Estimated catchment area, Una

Channel overview

Powerhouse

GPS:
E0335874
N9635729

Reservoir

GPS:
E0335897

Intake

GPS:
E0335698

Length	What	Details
150 m	Pool, garden, campsite, house	Grass and earth channel, dammed water by a pumphouse
15 m	Garden of house, ends with a wall	Step of 10-15 cm, with a partly clogged trash rack
102 m	Long stretch on other side of wall, through a garden which ends with a fence	Step of 10 cm under the wall
32 m	Jungle forest on the other side of fence. Stops at new fence.	Step of 10 cm and a partly clogged trash rack
150 m	Through the garden of a school. Stops at new fence	Step of 10 cm and a partly clogged trash rack
80 m	Jungle forest. Stops at fence.	Concrete channel
400 m	Last stretch up to the intake along the	Concrete channel
929 m	**TOTAL**	

Turbine head

Measured using a distance laser

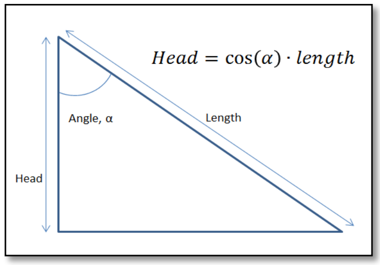
Distance was measured to two different rocks on the other side of the river. Both were visible with at clear sight from the reservoir area. The rocks were located at the same height as the likely turbine location and measurment was taken from top of the fence, approx 1 meter over the ground.

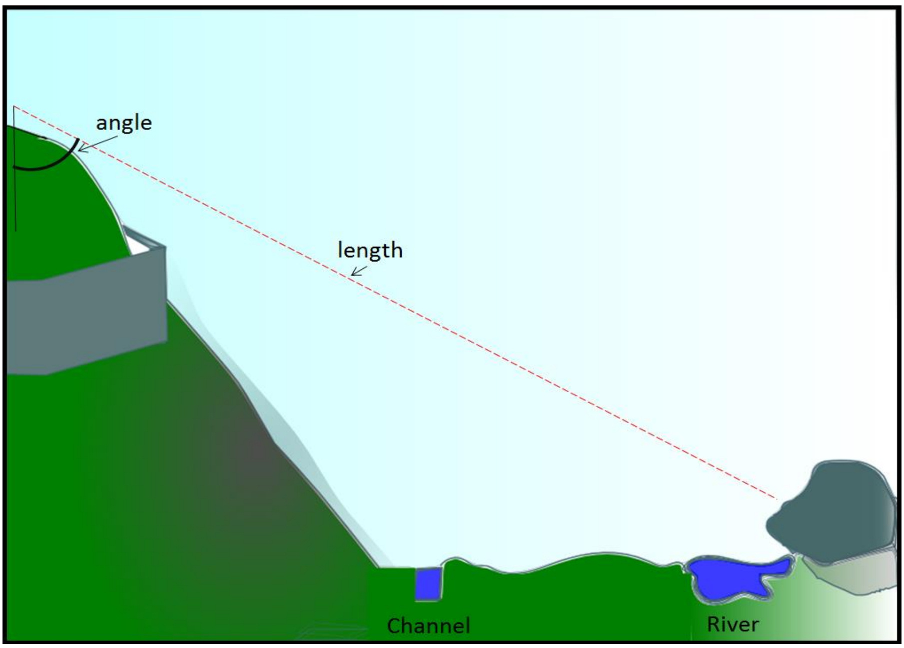
First try:

Angle	43 degrees
Length	50,3 m
HEAD:	34,30 m

Second try

Angle	43 degrees
Length	48,15 m
HEAD:	32,84 m





Manometer head measurements

Not applicable due to errors

101,3 kPa equals 1 bar
1 bar equals 10 meter head

Test 1	
1,80 bar	18,0 m
2,00 bar	20,0 m
1,77 bar	17,7 m
1,76 bar	17,6 m
1,67 bar	16,7 m
1,43 bar	14,3 m
1,37 bar	13,7 m
1,31 bar	13,1 m

These values were measured at a height of approximately 15 meter. We were not able to get a stable measurement as the pressure dropped while the hose was kept at constant head. This is a indication of an unknown error somewhere in the system.

Electrical manometer was restarted and the hose was

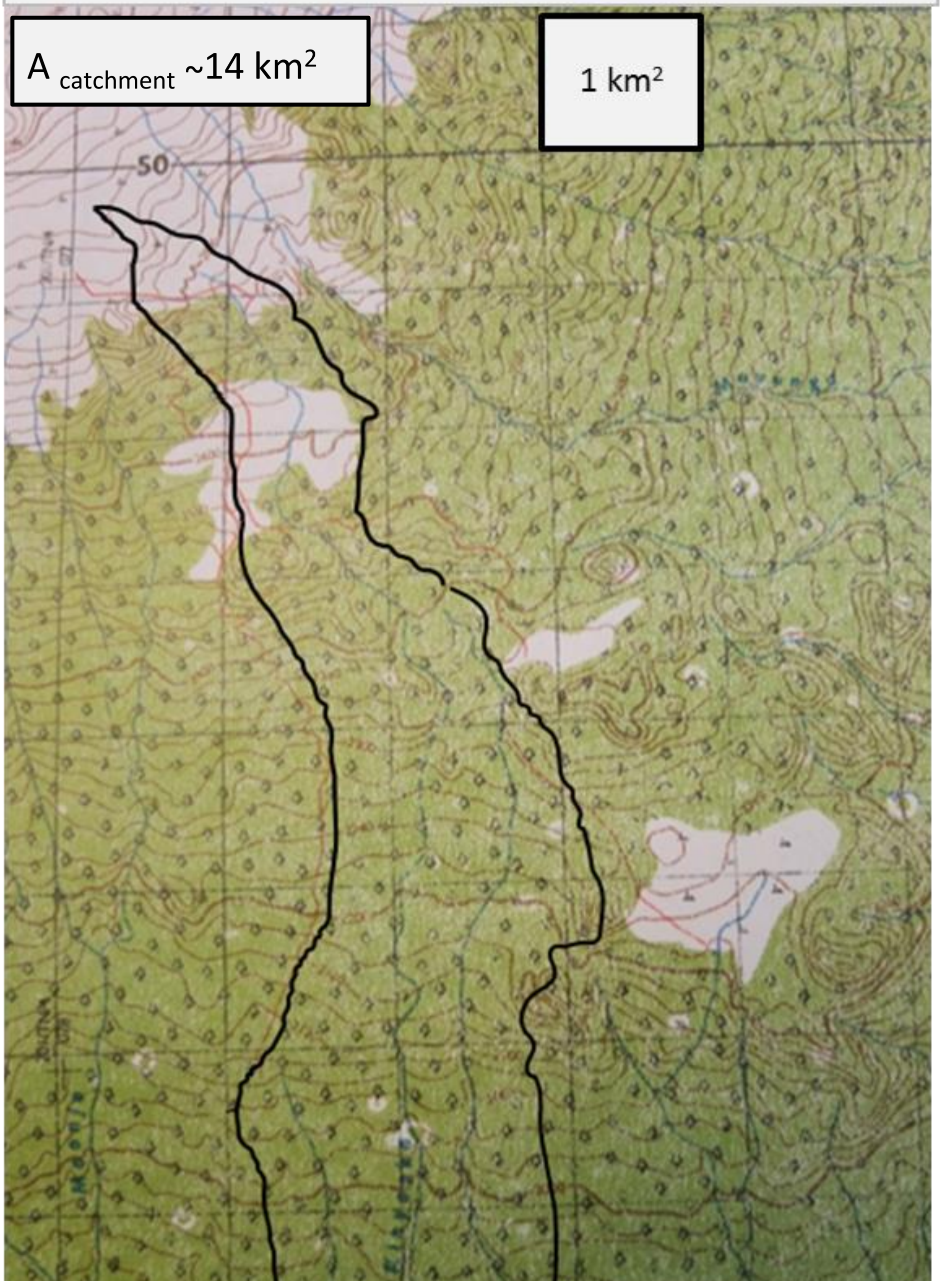
Test 2	
1,33 bar	13,3 m
1,33 bar	13,3 m
1,38 bar	13,8 m
1,37 bar	13,7 m
1,38 bar	13,8 m
1,37 bar	13,7 m
1,36 bar	13,6 m
1,35 m	13,5 m
1,22 bar	12,2 m
1,21 bar	12,1 m
1,21 bar	12,1 m

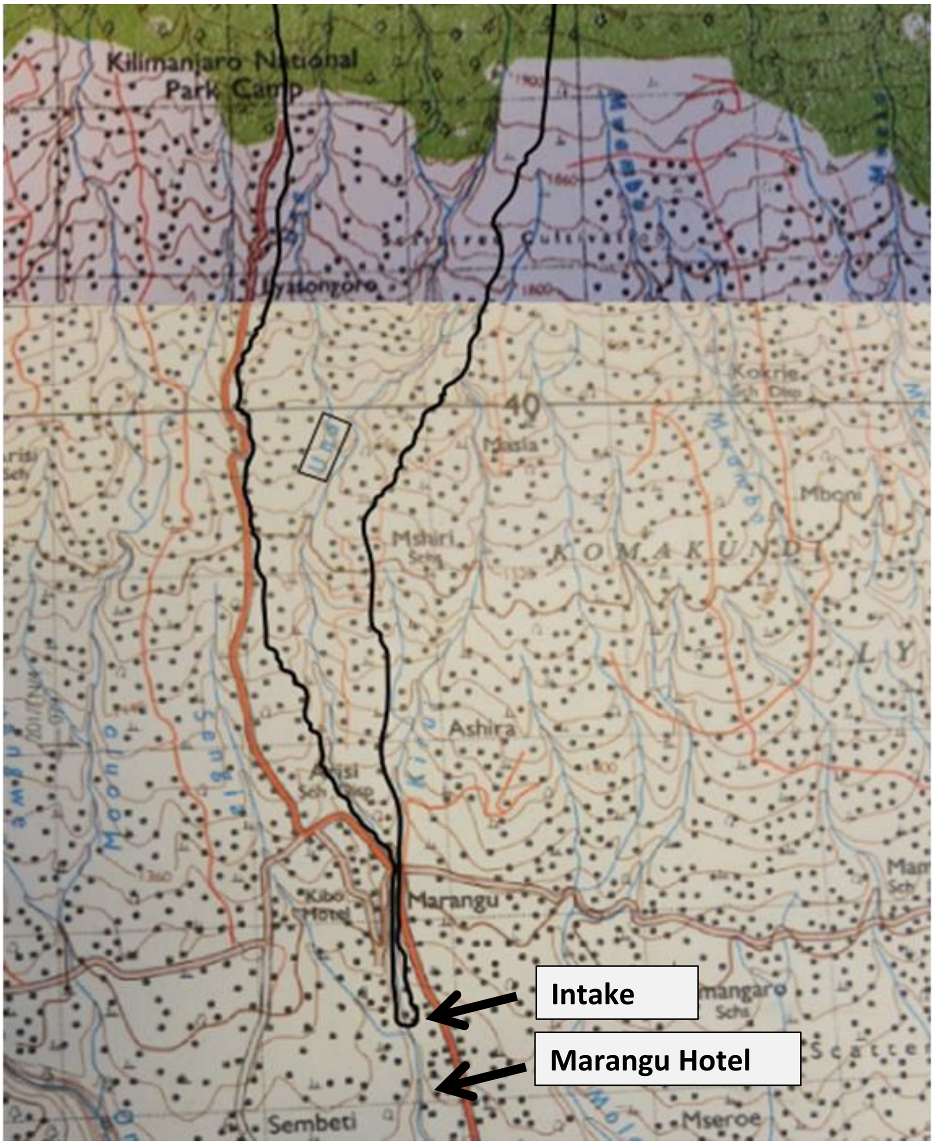
Next results were somewhat realistic, confiming a height of 13 meters up to my position. However as I walked upwards with the hose, the values droppen. Shortly after the manometer went into error again. Now the manometer was only beeping and not showing any results.

The measurements were therefore stopped after 5 hours of work.

Next time a manual manometer should be brought as

Catchment area, Una river




Kilimanjaro National Park Camp
Lyasongoro
Masia
Mshiri
KOMAKUNDI
Kokrie
Mboni
Ashira
Marangu
Kibo Hotel
Sembeti
Mseroe
Intake
Marangu Hotel

Appendix E

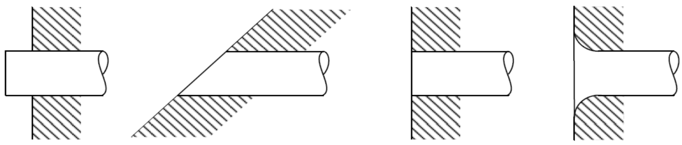
Head loss and pipe calculations

HEAD LOSS - coefficients

from Idelchik, Handbook of hydraulic Resistance, 3rd edition

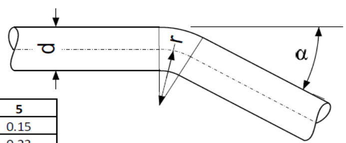
$$h_f = \zeta \cdot \frac{v^2}{2g}$$

Loss, intake



$\zeta = 0.5$ up to 1.0 | $\zeta = 0.8$ | $\zeta = 0.5$ | $\zeta =$0.4 down to 0.03

Loss, bends



r/d	1	2	3	5
ζ (α=20°)	0.36	0.25	0.20	0.15
ζ (α=45°)	0.45	0.38	0.30	0.23
ζ (α=90°)	0.60	0.50	0.40	0.30

Loss, valves

Values of ζ

Position of the gate valve	h/D_0										
	0.10	0.15	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.0
	With a recess for the valve disk (graph a)										
In the system (the gate valve is followed by a straight tube), Curve 1	200	77.0	33.0	11.0	4.70	2.35	1.23	0.67	0.31	0.11	0.05

SUPPLY PIPE

PP or PVC-pipe

Constants		
ny=	0,000001	m^2/s
g=	9,81	

Data		
D1=	0,5	m
D2=	0,45	m
D3=	0,4	m
Q=	0,2	m^3/s
e =	0,0015	mm
L=	317	m

$$A = \frac{\pi \cdot D^2}{4}$$

A1=	0,196	m^2
A2=	0,159	m^2
A3=	0,126	m^2

$$Q = V \cdot A$$

V1=	1,019	m/s
V2=	1,258	m/s
V3=	1,592	m/s

Friction loss			1	2	3
Reynolds number	$Re = \frac{v \cdot D}{\upsilon}$	Re=	509295,82	565884,24	0,064894982
Relative roughness		e/D (mm)	0,0030000 mm	0,0000033 mm	3,750E-03 mm
Read from the Moody diagram		f=	0,0131	0,0128	0,0126
	$h_f = f \cdot \frac{L}{D} \cdot \frac{c^2}{2g}$	hf =	0,4387376	0,7259906 m	1,288 m

Loss in intake				
Loss coefficient		ζ=	0,5	[-]
	$h_f = \zeta \cdot \frac{v^2}{2g}$	hf=	0,026	m

Loss in bends				
Loss coefficient		ζ=	0,8	[-]
	$h_f = \zeta \cdot \frac{v^2}{2g}$	hf=	0,042	

Loss in valves	fully open			
		ζ=	0,05	[-]
Inlet		hf=	0,003	m
	$h_f = \zeta \cdot \frac{v^2}{2g}$			
Exit		ζ=	0,11	[-]
		hf=	0,014	m

TOTAL HEAD LOSS	hf=	2,535	m

PENSTOCK

PE-pipe

Constants		
ny=	0,000001	m^2/s
g=	9,81	

Data		
Di =	0,4	m
Q=	0,2	m^3/s
e =	0,003	mm
L=	37	m

$$A = \frac{\pi \cdot D^2}{4}$$
$$Q = V \cdot A$$

A=	0,126	m^2
V=	1,592	m/s

Friction loss

Reynolds number	$Re = \frac{v \cdot D}{v}$	Re=	636619,7724	
Relative roughness		e/D (mm)	0,0000075	mm
Read from the Moody diagram		f =	0,0126	
	$h_f = f \cdot \frac{L}{D} \cdot \frac{c^2}{2g}$	hf =	0,150	m

Loss in intake

Loss coefficient	$h_f = \zeta \cdot \frac{v^2}{2g}$	ζ=	0,8	[-]
		hf=	0,103	m

Loss in bends

Forebay tank	$h_f = \zeta \cdot \frac{v^2}{2g}$	ζ=	0,45	[-]
		hf=	0,058	
Turbine		ζ=	0,45	[-]
		hf=	0,058	
		hf_tot=	0,116	

Loss in valves *fully open*

		ζ=	0,05	[-]
Forebay tank	$h_f = \zeta \cdot \frac{v^2}{2g}$	hf=	0,006	m
Turbine		ζ=	0,05	[-]
		hf=	0,006	m
		hf_tot=	0,013	

TOTAL HEAD LOSS	hf=	0,383	m

Appendix F

Components and economical review

List of components in the Marangu Scheme

Components provided by Brødrene Dahl								
	Name	What	Known dimensions					Estimated costs*
Intake:	Aquasheer Coanda screens		250 l/s	1	pc	50 000	NOK/pc	50 000
	Cone	Cone from Coanda to T-piece	680 - 500 mm, h=300	1	pc	7 500	NOK/pc	7 500
	T-piece	Connection to Air valve	DN1=500mm, DN2=100 mm	1	pc	6 325	NOK/pc	6 325
	Air valve	Double office air valve	type: 9000, PFA:16, DN=100 mm	1	pc	4 600	NOK/pc	4 600
	Zag Zeta Knife Valve	Gate valve, handwheel	DN=500mm	1	pc	15 870	NOK/pc	15 870
Waterway	Pipe	PVC/PP	400 mm, 6 m long	53	pcs	616	NOK/m	32 648
	Pipe	PVC/PP	450 mm, 6 m long	53	pcs	665	NOK/m	35 245
	Pipe	PVC/PP	500 mm, 6 m long	53	pcs	715	NOK/m	37 895
	Muffe/socket sleeve		400/450/500 mm	159	pcs	included in pipe		-
	Cone	Between different pipe sizes	Dn500-450-400 mm	3	pcs	3 800	NOK/pc	11 400
Forebay	Zag Zeta Knife Valve	Handwheel	DN=400mm	1	pc	13 800	NOK/pc	13 800
	Loose flange on tank	Inlet and outlet of tank	DN=400mm	2	pcs	6 000	NOK/pc	12 000
	Loose flange on tank	Outlet, spillway	DN= 450 mm	1	pc	6 000	NOK/pc	6 000
	Forebay tank	Oil tank, dim. To fit container	d=2m, L=5,8 m	1	pc	35 000	NOK/pc	35 000
Penstock	Zag Zeta Knife Valve	Gate valve, handwheel	DN=400mm	1	pc	13 800	NOK/pc	13 800
	Pipe	PE-pipe	DN=400mm	32	m	528	NOK/m	16 896
	Anchors	Concrete anchors to penstock	holding 400 mm pipe	3	pc	5 000	NOK/pc	15 000
	Muffe/socket sleeve		400 mm	2	pcs	2 100	NOK/pc	4 200
	Pipe bend	43 degree bend	DN=400 mm	2	pcs	5 600	NOK/pc	11 200
Turbine	Flange pipe	Pipe, with manometer socket	DN=400mm, PN=10, L=1000 mm	1	pc	9 600	NOK/pc	9 600
	Zag Zeta Knife Valve	Handwheel, operational stop	DN=400mm	1	pc	13 800	NOK/pc	13 800
	Anchors	Concrete anchors to turbine	holding 400 mm pipe	5	pc	5 000	NOK/pc	25 000
TOT	*included transportation							377 779 NOK

Components provided by GreenEnergy

	Name	What	Known dimensions					Estimated costs	
Turbine	Contra-roating cross flow prototype with draft tube		40kW					450 000	
	Soft-starter and multi-instrument							7 500	
TOT								457 500	NOK

Work provided by Marangu Hotel

	Name	What	Known dimensions					Estimated costs	
Manual work	Trench for supply pipe	Excavation and backfill	L=950 m, B=0,4 m, H=0,7 m	266	m^3	539	NOK/m^3	143 241	
	Concrete dam and Coanda installation		B= 0,3m, H=1,5m, L=2,5 m	1,1	m^3	1 077	NOK/m^3	1 212	
	Steps along penstock	Concrete and formwork	L=35m, B=1m, D=0,4 m	14	m^3	1 077	NOK/m^4	15 078	
	Spillway channel	Open channel concrete channel	B= 0,4 m, H=0,6 m L=10000 mm	17	m		per piece	20 000	
TOT								179 531	NOK

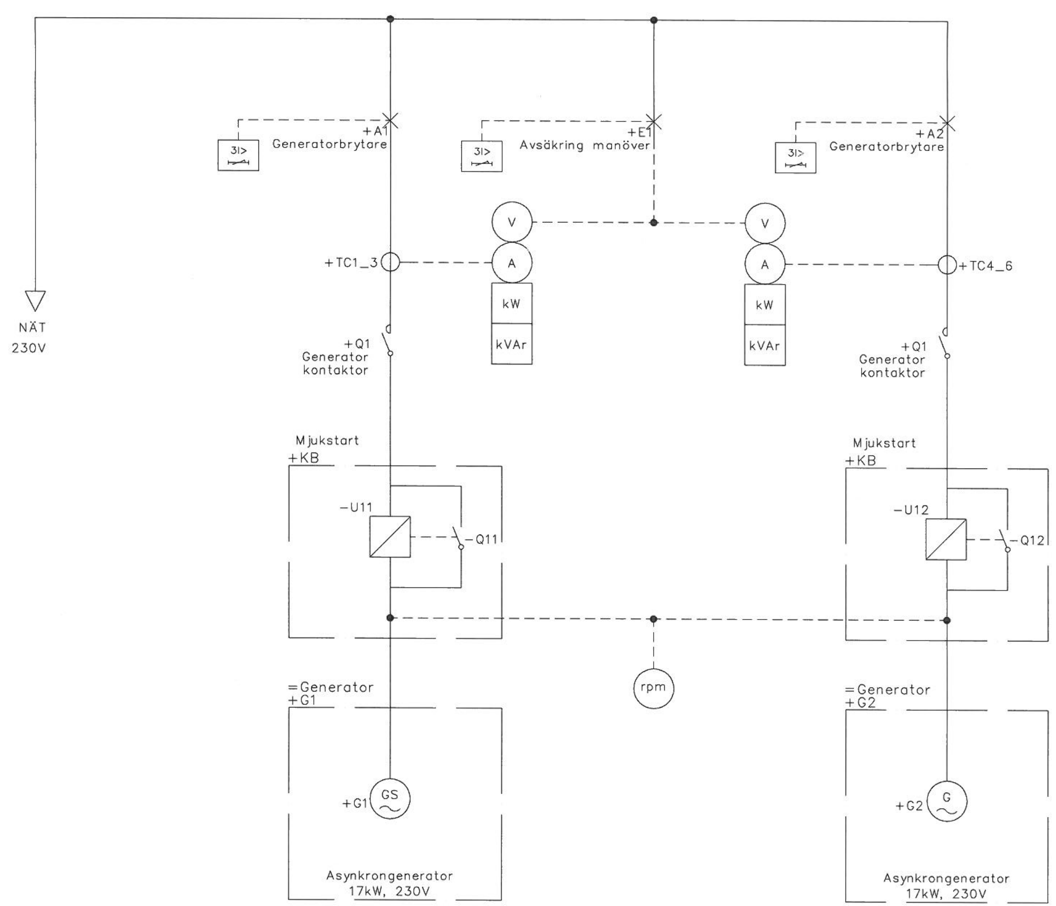
Real expences: Manual, concrete work and transportation

	Name	What	Known dimensions					Estimated costs	
Building	Supervision civil, BD	Travel expences						20 000	
	Supervision el, BEVI	Travel expences						20 000	
	Winch or crane truck	Hire						20 000	
	Turbine housing	Concrete building						50 000	
	Training							10 000	
	Grid expences							35 000	
Transportation	Turbine and el.syst	Norway - Marangu	20 ft container	1		23 600	NOK/pc	23 600	
	From shipping port	Port(Mombasa,KEN) - Marangu	how many? 22289,6 each	5		131 509	NOK/pc	657 543	
TOT								836 143	NOK

TOT COSTS	1 850 953	NOK

Appendix G

Single line diagram



Rev In	Revision	Godk	År Vecka	=Styrskåp +KA Översikt enlinjeschema Copyright BEVI Sweden

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Blomstermåla
+46 499-27100
Sweden

Konstruktion kontrollerad av	Overview Diagram
Ritning kontrollerad av GF	Dränkbara gen. Sinvent AS
Ritad av MW	Avdelning kraft · År Vecka 05-40

1268-5

Rev In	Blad
Rev In	Blad 1
	Nästa blad 2

Appendix H

Risk assessment, field work

FELTKORT FOR LEDER AV FELTARBEID

Navn: Kristin Gjevik Mob. nr.: +47 988 09 726

Bostedsadresse: Gaubekveita 10, 7010 Trondheim Forsikringsselskap: Gjensidige

Aktuelt sambandsutstyr på feltarbeidet: Mobiltelefoner
Hvilket utstyr er tatt med på feltarbeidet, hvilke frekvenser tenkes evt. brukt på sambandsutstyret, o.l.

Nærmeste pårørende (navn, adresse og telefonnummer):

Marit Gjevik, Fossumhavene 35, 1359 Eiksmarka, 48284497 / 67141719

OPPLYSNINGER OM FELTARBEIDET*
Feltarbeidets navn/type, innhold/aktiviteter:

Oppmåling og befaring av lokasjon for potensielt mikro vannkraftverk ved Kilimanjaro, Tanzania.

Feltområde/arbeidssted: Arusha og Marangu i Tanzania, se reiseplan for mer detaljer.
Det er spesielt viktig å beskrive dette nøye dersom feltområdet/arbeidsstedet er vanskelig tilgjengelig.

Antall deltakere (inkl. leder): 2

Varighet Fra: 13.02.14 Til: 01.03.14

Når har evt. deltakerne fritid under feltarbeidet? Helger; 15.-16.01, 22.-23.01

Reiserute: Trondheim - Amsterdam - Kilimanjaro Int, t/r
Inkluder flightnummer, flyavganger og avtalte bedriftsbesøk, etc. dersom dette er aktuelt.

Overnattingssteder: Se reiseplan
Navn, adresse, telefonnummer til hotell/pensjonat o.l. Opplys hvis det overnattes i telt/campingvogn o.l. på feltområdet.

Transportmidler: Fly, buss, bil
Reg.nr. ved bruk av egen eller statens bil.

Medbrakt sikkerhetsutstyr: Førstehjelpsutstyr

KONTAKTPERSONER*
Kontaktperson ved egen enhet: Anita Yttersian Tlf: 73 59 27 00

Annen kontaktperson: Wenche Johansen Tlf: 73 59 38 57
***** Fylles ut ved feltarbeid uten spesielle risikomomenter (se Feltarbeid – for deg som leder). Ved mer omfattende feltarbeid utarbeides egen reiseplan.**

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

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.

Sted/dato: Trondheim / 11.02.14 **Signatur:** Kristin Gjevik
Utfylt feltkort oppbevares ved egen enhet.

Enhet: EPT v/IVT **Dato: 11.02.2014**
Linjeleder: Olav Bolland
Deltakere ved risikovurderingen (m/ funksjon): Kristin Gjevik (Fagansvarlig)

ID nr	**Aktivitet fra kartleggings-skjemaet**	**Mulig uønsket hendelse/ belastning**	**Vurdering av sannsyn-lighet** (1-5)	**Vurdering av konsekvens:** Menneske (A-E)	Ytre miljø (A-E)	Øk/ materiell (A-E)	Om-dømme (A-E)	**Risiko-verdi**	**Kommentarer/status Forslag til tiltak**
1	Transport til/fra flyplass i Norge	Kollisjon, utforkjøring	1	D	A	A	A	1D 1A 1A 1A	Bruke sikkerhetsbelte og holde fartsgrensen
2	Flytransport til/fra Tanzania	Kollisjon, havari	1	E	B	B	A	1E 1B 1B 1A	Flytjeneste kjøpes kun av anerkjente operatører
3	Buss- og biltransport innad i Tanzania	Kollisjon, utforkjøring	2	D	A	A	A	2D 2A 2A 2A	Bruke sikkerhetsbelte og holde fartsgrensen. Benytter lokale sjåfører
4	Besøk av vannkraftverk	Klemfare, støy sprut	1	C	A	C	B	1C 1A 1C 1B	Bedriftens samt våre egne HMS regler gjelder. Det vil bli brukt briller og hjelm inne i kraftstasjonen. Omvisning vil skje med guide.
5	Besøk i nasjonalpark	Påkjørsel, dyreangrep	2	D	A	A	A	2D 2A 2A 2A	Aktsomhet skal utvises i tillegg til å følge guidens retningslinjer

6	Måling av høyde i bratt terreng	Fall, beinbrudd	2	D	A	A	A	2D 1A 1A 1A	Bruke gode sko og sikre seg om man jobber i høyden
7	Brudd på vannslange ved høydemåling.	Vannsøl, oversvømmelse	1	A	B	B	A	2A 2B 2C 2D	Sikre at det ikke er skarpe objekter i veien.

Sannsynlighet
1. Svært liten
2. Liten
3. Middels
4. Stor
5. Svært stor

Konsekvens
A. Svært liten
B. Liten
C. Moderat
D. Alvorlig
E. Svært alvorlig

Risikoverdi (beregnes hver for seg):
Menneske = Sannsynlighet x Konsekvens Menneske
Ytre miljø = Sannsynlighet x Konsekvens Ytre miljø
Økonomi/materiell = Sannsynlighet x Konsekvens Øk/matriell
Omdømme = Sannsynlighet x Konsekvens Omdømme

Sannsynlighet vurderes etter følgende kriterier:

Svært liten 1	Liten 2	Middels 3	Stor 4	Svært stor 5
1 gang pr 50 år eller sjeldnere	1 gang pr 10 år eller sjeldnere	1 gang pr år eller sjeldnere	1 gang pr måned eller sjeldnere	Skjer ukentlig

Konsekvens vurderes etter følgende kriterier:

Gradering	Menneske	Ytre miljø Vann, jord og luft	Øk/materiell	Omdømme
E **Svært Alvorlig**	Død	Svært langvarig og ikke reversibel skade	Drifts- eller aktivitetsstans >1 år.	Troverdighet og respekt betydelig og varig svekket
D **Alvorlig**	Alvorlig personskade. Mulig uførhet.	Langvarig skade. Lang restitusjonstid	Driftsstans > ½ år Aktivitetsstans i opp til 1 år	Troverdighet og respekt betydelig svekket
C **Moderat**	Alvorlig personskade.	Mindre skade og lang restitusjonstid	Drifts- eller aktivitetsstans < 1 mnd	Troverdighet og respekt svekket

B **Liten**	Skade som krever medisinsk behandling	Mindre skade og kort restitusjonstid	Drifts- eller aktivitetsstans < 1uke	Negativ påvirkning på troverdighet og respekt
A **Svært liten**	Skade som krever førstehjelp	Ubetydelig skade og kort restitusjonstid	Drifts- eller aktivitetsstans < 1dag	Liten påvirkning på troverdighet og respekt

Risikoverdi = Sannsynlighet x Konsekvens
Beregn risikoverdi for Menneske. Enheten vurderer selv om de i tillegg vil beregne risikoverdi for Ytre miljø, Økonomi/materiell og Omdømme. I så fall beregnes disse hver for seg.

Til kolonnen ”Kommentarer/status, forslag til forebyggende og korrigerende tiltak”:
Tiltak kan påvirke både sannsynlighet og konsekvens. Prioriter tiltak som kan forhindre at hendelsen inntreffer, dvs. sannsynlighetsreduserende tiltak foran skjerpet beredskap, dvs. konsekvensreduserende tiltak.

Aktiviteter

Hvilke aktiviteter skal foregå i feltarbeidets ulike faser? *Eksempler: kartlegging, måling, innsamling, preparering av materiale, etc.*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Kartlegging, oppmåling, befaring osv
Hvordan utføres arbeidet? *Eksempler: boring, sprenging, måling, dykking, fiske, observasjon, etc.*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Måling og observasjon.
Er det krav om godkjenning/tillatelse til planlagt aktivitet? *Må det skrives avtaler/kontrakter med grunneiere, myndigheter, organisasjoner eller andre?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Avklart med grunneier.
Kan bruk av aktuelt utstyr på feltarbeidet medføre fare for skade på menneske eller ytre miljø? *Er utstyret forskriftmessig vedlikeholdt? Er det nødvendig å ha med reservedeler?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Se risikovurdering. Nødvendige forhåndsregler er tatt.
Er det nødvendig med sikkerhetsutstyr/personlig verneutstyr? *Hva slags utstyr?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Gode sko og hodelykt.
Medfører feltarbeidet smittefare? *Er det nødvendig med vaksiner?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Vaksiner og malariatabletter tas som henvist fra vaksinasjonskontor.
Er det nødvendig å ha med førstehjelpsutstyr? Hva slags førstehjelpsutstyr?	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Normalt førstehjelpsskrin er medbragt.
Har alle deltakere fått all nødvendig informasjon og opplæring?	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Ja

Feltarbeidsområdet

Hvilken type terreng/omgivelser er det i feltarbeidsområdet? *Høyfjell, utmark, skog, dyrket mark, vann/sjø, is, bre, grotter, eller annet?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Dyrket mark, like ved Kilimanjaro
Foregår feltarbeidet nær bebyggelse og infrastruktur? Kan dette medføre problemer?	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Foregår rett ved hotellet, og dette er klarert med eierne.
Hvordan er klima og værforhold? *Hvilken årstid er det?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Regntid, fare for kraftige regnbyger
Kan det oppstå språkproblemer på feltarbeidet? *Er tolketjenenester tilgjengelig?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Engelsk er godt utbredt, og vi skal samarbeide med lokale.
Hvilke betalingsmåter er aktuelle? *Hvilken valuta benyttes? Er det nødvendig å ta hensyn til spesielle bestemmelser for skatt, toll eller valuta?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Hovedsakelig kontant i Tanziania shilling og noe dollar
Gjelder spesielle regler, eller er det restriksjoner på innføring, bruk, oppbevaring eller utføring av utstyr, kjemikalier, sprengstoff, radioaktivt materiale eller annet?	☐ **Må vurderes**	☑ **Ikke aktuelt**	Kommentar: Ingen påvirkning
Hvilke muligheter er det for kommunikasjon i feltarbeidsområdet? *Kan telefon/mobiltelefon benyttes internt i landet og til Norge/andre land?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Telefon- og mobilforbindelser på hotellområdet.
Hvor kan man få bistand? *Norske utenriksstasjoner, ambassader, konsulater, helsevesen, eller andre steder?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Se kommunikasjonsplan
Kan kulturelle forhold påvirke eller bli påvirket av feltarbeidet? *Nasjonale helligdager, ferieperioder, fastetider eller annet?*	☐ **Må vurderes**	☑ **Ikke aktuelt**	Kommentar: Ingen påvirkning
Hvilken type mat er det tilgang på? *Er det nødvendig å ta spesielle forhåndsregler i forhold til allergier, religion, eller annet?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Ingen problemer med å få tak i mat.

Hvilke muligheter er det for personlig hygiene?	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Gode muligheter på hotellene
Hvordan håndteres/avhendes avfall fra feltarbeidet? *Må spesielle forhåndsregler tas for farlig avfall?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Utstyr som blir tatt med ned og ikke skal tilbake blir håndtert med Marangu Hotell

Transport

Hvilken type transport skal benyttes? *Bil, buss, båt, kano, snøscooter, fly, helikopter eller annet?*	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Fly, buss, bil
Hvordan er trafikkforhold, transportmuligheter og/eller kvalitet på transportmidler?	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Varierende, kjører ikke selv, men sitter kun på med lokale.
Gjelder spesielle regler eller restriksjoner for bruk av transportmidler/kjøretøy i feltarbeidsområdet?	☐ **Må vurderes**	☑ **Ikke aktuelt**	Kommentar: Nei
Er nødvendig sikkerhetsutstyr tilgjengelig? o *Skip/fartøy/fly/helikopter med skipsfører/pilot: Skipsfører/pilot er ansvarlig for nødvendig sikkerhetsutstyr. Anvisninger fra skipsfører/pilot skal følges. Leder av feltarbeid plikter å gjøre seg kjent med hvilke sikkerhetsregler som gjelder om bord og videreformidle dette til alle deltakere.* o *Båt, rigg, kano eller lignende: Redningsvest, flytevest, overlevelsesdrakt eller lignende.* o *Småbåt: Dregg, årer. Hjelpemotor skal følge med hvis forholdene tilsier det. Dødmannsknapp skal tilkobles såfremt slik knapp er montert.*	☐ **Må vurderes**	☑ **Ikke aktuelt**	Kommentar: Ikke aktuelt

Andre forhold som kan påvirke eller bli påvirket av feltarbeidet

Anleggsarbeid.	☐ **Må vurderes**	☑ **Ikke aktuelt**	Kommentar:
Dyr på beite, annen landbruksaktivitet.	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Tilpasses underveis
Fauna, verneområder, rovdyr, etc.	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Tilpasses underveis og nødvendige tiltak gjøres.
Pågående jakt. *Informasjon fås fra lokalt politi eller lokal viltnemd.*	☐ **Må vurderes**	☑ **Ikke aktuelt**	Kommentar:
Prostitusjon, rusmiddelbruk, kriminalitet.	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Normale forhåndsregler tas.
Politisk styringssystem og stabilitet, fare for politisk uro, krig, terrorhandlinger eller annet.	☑ **Må vurderes**	☐ **Ikke aktuelt**	Kommentar: Normale forhåndsregler tas.