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Development of learning modules for wind and hydropower

Master´s Thesis in the Master Degree Programme, Electric Power Engineering

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ABSTRACT

In this report the master thesis project “Development of education modules for wind and hydropower” is described, requested from the company IETV Elektroteknik AB. IETV offers control equipment for hydropower plants. The origin of this project is inquiries from customers who want to get knowledge and a deeper understanding regarding operation and troubleshooting of the plant. Due to this an education package has been developed. The educations are divided into four different parts; A, B.1, B.2 and C. Part A is an education for land owners and decision makers, concerning the basics of wind and hydropower. Included are basic technique, environmental aspects and economics. Part B.1 teaches how to operate IETVs system in an appropriate way. This includes programming, purpose and function of all the components in a control system delivered by IETV. Part B.2 describes possible faults that can appear in the system, including troubleshooting. Both B.1 and B.2 contains theory and practical examples. Part C is a deeper technical education containing the units and its drives in a hydropower plant. The education was evaluated during a final presentation for employees at IETV, who approved to the material and found it useful. The future work for this education includes an information update as the different techniques develop.

Keywords: ***Education modules, Hydropower, Wind power, Control system***

Table of Contents

1 INTRODUCTION

This report describes the master thesis project “Development of education modules for wind and hydropower”. In the introduction, the background of the project is described as well as the purpose, method, goals and delimitations.

1.1 Background

IETV Elektroteknik AB, further on referred to as IETV, is a company providing automation service for hydropower plants such as consulting services, rotating converters, surveillance, maintenance and limited education within these areas. IETV customers are usually owners of smaller hydropower plants, either as private owners or power companies. IETV has received several inquiries for more advanced education services in basic wind and hydropower technology as well as an education within IETVs system. The education package includes four different levels, A, B.1, B.2 and C.

The interest in environmental friendly energy sources has increased during the last years. Decision making parties in the world, among these, the Swedish government, has decided that the total emissions should be reduced. The future lack of oil and uranium is also a concern that increases the interest in energy produced by renewable fuels. Actions for increasing the amount of renewable energy are therefore made. Thus, the interest to learn more about environmental friendly energy production with as large profit as possible is increasing. For private investors, this increasing interest gives good business opportunities due to the increased demand of renewable energy. Part A origins from inquiries for an informative education regarding wind and hydropower technology and above all the economical aspects for understanding the possibilities, problems and limitations for possible investments. These are some of the most appropriate renewable energy sources for Swedish conditions, suitable for private companies, landholders and decisions makers.

Customers have also specifically asked for an education where the manuals on IETVs systems are explained in a clear way together with practical examples to clarify further. In addition they desired to troubleshoot the system for faults without assistance. These inquires started the development of part B. Part B is divided into two parts, B.1 and B.2, and is meant to make the customers more independent and to decrease the maintenance costs for IETV. One part of IETVs services is to perform maintenance on their delivered equipment in control systems for hydropower plants during the warranty period. After this, the customers pay for these services. After this education, customers can perform basic maintenance and efficient operation on their own. This will be achieved with theoretical information during the first half of the education and practical exercises in a hydropower plant during the second half. The yield for the customers is reduced service costs after the warranty period. Level B.1 is the basic course for operating the plant and B.2 is an intermediate course where troubleshooting is introduced.

Level C is constructed for the operating personal to get a deeper knowledge about the technology behind the system. This includes technical details about different types of generators, turbines and actions in the system.

1.2 Purpose

The purpose of this project is to create an education package corresponding to IETVs requests. See **Appendix A** for a brief project description. The overall purpose from IETV was to make a sustainable education package with high standard. The education should be adjusted for a company of IETVs size and for their customers. Thus, the first part of the project was to develop the content of the project and to make a complete outline. The educations aim to advocate IETV and to get a high reputation due to a high quality, with relevant and important content. The educations are presented in PowerPoint for convenience which enables easy modification for the lecture and comprehensiveness for the customers. The educations gives IETVs services more substance and the possibility to provide even better service to their customers by offering fully developed education modules together with their products.

After education A, customers should decide whether or not it is suitable for an investment in wind and/or hydropower technology. The participants should associate wind and hydropower with IETV as a natural source for expertise and services which gives IETV more customers and also enables for IETV to extend their services in the future to also include wind power. Level A is an education with the purpose of being appropriate for mainly private companies, landholders and decisions makers.

IETVs customers have asked for an education regarding operation of a hydropower plant to be more independent. By hiring IETV for educational purpose, the customers will be more independent when being able to perform maintenance on their own. IETV will reduce the service cost during the warranty period and the customer's costs afterwards. The customers will be more educated within their system for more efficient and reliable operation. Level B educates the customers in IETVs control systems to get a deeper understanding in operation, different devices, how they function and possible faults. Since level B involves both theoretical and practical education the education includes a PowerPoint presentation presenting the theory that practically later is used during a demonstration in a hydropower plant. The purpose of part C is to enable the participants to fully understand the system and for instance understand why a fault appears and thus how to solve it.

1.3 Goal

The education should be of a quality representative for IETV. The goal is to give the customers, after participating in the course, the inquired knowledge. A well performed education contains both good presentation material and a well educated lecturer. The documents for the lecturer, delivered to IETV will ensure that the lecturer is well educated.

The education material is extensive and enables the lecturer to adjust the content for a specific customer regarding inquires and previous knowledge.

For level A the participants should after a complete education have a good overview of the aspects for wind and hydropower considering economic, technical and environmental aspects. They should also know whether any of these could be a possible investment for them, considering their resources. For such an investment IETV will be the obvious partner for control equipment and surveillance of the plant.

The goal for level B.1 is for the operating personal to feel confident enough about IETVs system to perform easier maintenance on their own control equipment, operation during normal conditions and to set parameters for different control devices. This requires knowledge about the different parts as well as the interaction of the system. For level B.2 the customer should be able to perform troubleshooting on their own. Some previous knowledge in the system is presupposed, thus the fundamental in hydropower technology is excluded. The practical exercise is a guideline with suitable topics and examples appropriate for a well educated lecturer within IETVs systems.

After a completed course of level C the employees are more profound understanding the technique and operation behind their power plant. The result is also a better ability of the staff to operate the plant during setting of parameters.

1.4 Delimitation

IETV has requested a specific time frame for each education. In part A, some of the technical aspects are excluded since the goal is to make a brief introduction of the technology to appeal costumers not to familiar with wind and hydropower plants. Consistently throughout part B and C the education is limited to IETVs system and the parts outside the system are omitted. Regarding this report; the education has a total range of 25 hours excluding lunches, thus the material is extensive and cannot be presented in its whole.

During the development of the education material, IETV have shared proprietary information, hence, many of the sources and material cannot be revealed. Neither can all information about IETVs system, nor the full content of the educations be presented in its full extent. In some parts the information can appear to be insufficient due to confidentiality and for further information, IETV can be contacted. For part B.2, almost all information is confidential.

The lecturer for the practical exercises is a technical expert of control systems in hydro power plants, thus IETV only require guidelines of these.

1.5 Method of Master thesis work

There will be four sub deliveries to IETV with the different educations. However, the gathering of information for all projects will start at week one. For an interesting and educative theoretical presentation, books and articles regarding presentation techniques will be used.

Since part A is theoretical a documentary research is essential for this task. The basic information about wind and hydropower will be found in technical reports and books. These will be found through Chalmers library, catalogs and databases, or at the Internet. The information about costs and profits can be found in literature as well as calculations based on different hydropower plants. Relevant documents from IETV will provide information for the project. This education concerns information that constantly needs to be updated due to developments, thus if possible, reliable internet sources will be used to enable a simple update in the future.

Part B contains a theoretical part and a practical demonstration with exercises. Field studies at hydropower plants are therefore essential. The visits will be combined with a presentation of the plant provided by a technical expert from IETV. Included is a considerable part of the information needed both for the practical and theoretical part of the education. The field studies will provide pictures for the theoretical education and give possibility for preparation, planning and design of the practical exercises. The instructional manuals and circuit diagram from IETVs systems will be used as references for describing the system. For knowledge about different faults, fieldtrips and interviews with IETVs personnel will be used.

The method for part C will be similar to the one in level A with a documentary research on technical reports, books and databases found at libraries and the Internet. Included are also material and documents provided by IETV.

2 IMPLEMENTATION

The project was developed from a project description delivered by IETVs, see **Appendix A**. These descriptions were further developed into an appropriate education with clearance from IETV. All the necessary changes and adjustments have been approved during meetings. Even though the main headlines of the educations are set by IETV, it has been further developed and increased in extent throughout the project.

For start, research for presentation technique was made. For an interesting education the lecturer needs to be well educated, thus an extensive text document is included with the different education. The text gives more information about the subject and how to find a flow in the education. The education is broad and presumably the lecturer wants to adjust the education to a suitable level for the participant's knowledge. Thus there are more slides than needed, considering that it is easier to remove a slide than to construct a new one.

To make the participants more observant and to keep an active discussion, questions will be allowed all throughout the ongoing education. However, there will be more time for questions reserved in the end of each part. Following each presentation is an agenda that gives an approximate time consumption to enable for the lecturer to extend or shorten the time used for questions to fit the education into the given time frame.

For part A, internet has been used as a primary source, considering wind and hydropower are developing rapidly. This is to enable for IETV to update the information in a convenient way, and all the sources are given in the education material. The customers are then ensured to receive a relevant and updated education, since the wind and hydropower business and technique develops rapidly. The content includes the basic technology, environmental- and economy aspects. Whether a plant will be profitability or not is an important part and gives the participants a chance to calculate whether their plant will be profitable. This includes calculations on repayment time and annual income to find the total profit. Considering both wind and hydropower are renewable energy sources the environmental aspects are of the essence. For a more inspiring presentation several pictures was included in the PowerPoint.

The main content included in education B.1, B.2 was given by IETV, based on the goals for each education and the specific customer. Gathering of information for part B.1 and B.2 mainly consist of internal reports and interviews provided by IETV. A field trip to Rydboholms hydropower plant took place during the early stage of this project and resulted in pictures and information from IETVs service personnel Kenneth Benjaminson at the plant. This included start and stop of the plant as well as troubleshooting. Later on, more interviews with Kenneth took place for further information. To ensure well educated participants, the mornings will be spent on theoretical knowledge and the afternoon follows up with practical examples from the theoretical education.

B.1 gives an overview over IETVs control equipment and different parts controlled by IETVs control system for a hydropower plant. This is of great importance considering that the participants want to be more independent and be able to perform easier operation. The education follows the hydropower plants structure, starting with the turbine that transforms the kinetic energy of the water to mechanical energy, further converted by the generator to electricity. Thus the turbine and generator function are explained. Following is the control equipment, including the control cabinet, magnetizing equipment and the function of these. The communication system further explains how the control equipment communicates and which components that communicates external and internal. Education B.1 is finished with maneuvering of the plant to give the participants the wanted independency. Here, start, the different stops and functions are explained. For customers that want to know more, the supplementary course B.2 is used. For troubleshooting Kenneth Benjaminson was used as a main source considering his experience and knowledge in the subject. In addition, internal material from IETV and data sheets for different components was used.

For part C, information was gathered in scientific articles and books. Here the purpose is a deeper knowledge and therefore many calculation examples are included. The outline was the different parts of the hydropower plant and some parts are therefore the same as from part B.1, but includes more extensive information. This part includes deeper theory for employees with good knowledge from the previous levels. The education deals with different types of generators, turbines and system protection. Theory concerning operation of the plant is also included together with practical examples.

The project has been developed over four month. The contact with IETV has been continuous, including meetings, interviews, telephone interviews, study visit and emails. All contact has been carefully prepared with issues that have occurred during the project. This has been important since IETVs employees has been the main source of information. The amount of time required for contact has been approximately one full day a week. The project was finished with a presentation of the project for the project leader Malin Frimar, one person from construction side and a technical expert. After this their opinions were gathered and evaluated. All text was also reviewed and approved by IETVs employees, Malin Frimar, Kenneth Benjaminson, Mikael Hag and the CEO of IETV, Magnus Carlsson.

In this report economical calculations are presented and the currency used is SEK, Swedish currency. The calculations are performed in the SI system.

3 RESULT

Following is the result from this project which is the content and layout of the educations. As mentioned in **Chapter 1.5** the complete education cannot be presented considering the extensive material and demands from IETV to keep the education exclusive for paying customers. Neither can much of IETVs technology be revealed.

According to the results of presentation technique the education material contains slides with as small amount of text as possible. This is to ensure that the participants pay attention and finds the lecturer interesting since his information is more detailed than the slides. [19] The outline, layout and content for each part are presented in this chapter. The education delivered to IETV is presented in Swedish to agree with inquires from the customers. Swedish words are translated in pictures if the information is relevant for this report. Many pictures are subjected for illustrating a typical outline, not for its contents, and are therefore not translated. For the visual appearance of the PowerPoint the content is inessential considering the object is meant to illustrate a possible appearance on a slide, not the technical content presented in the text.

The delivery to IETV contains PowerPoint education material containing 452 PowerPoint slides, extensive text document of 165 pages, for the lecturer. For part B.1 and B.2, a guideline for practical demonstration is also included. In addition part B.2 is delivered with further more information for the participants containing extensive information in troubleshooting. The teaching material included with each education consists of the PowerPoint slides with belonging text; the amount of text can vary. **Figure 3.1** shows three pages of this text document as the typical appearance. The text itself is irrelevant; here the layout is the object. This document also includes the appropriate time consumption for each part and necessary preparations for the lecturer.

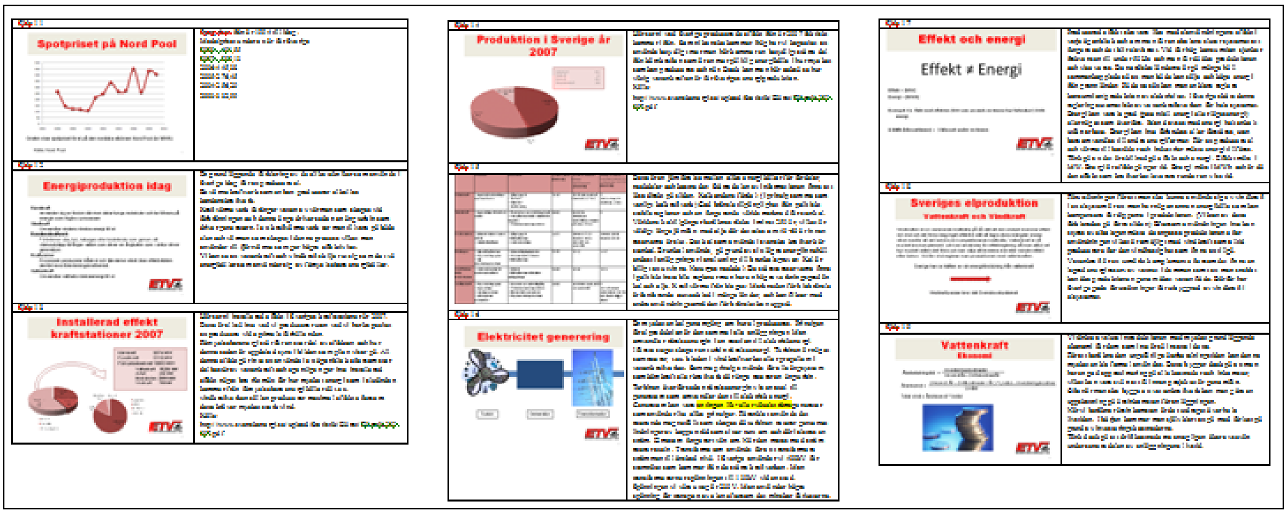


Figure 3.1: An example of the text material attached for the lecturer.

3.1 Layout of part A

The layout is designed with pictures, colors and a small amount of text to make the slides entertaining and easy to understand. In **Figure 3.1.1** the general appearance for part A is showed. The result is a brief and entertaining education.

Figure 3.1.1: Four examples of PowerPoint slides from education A.

Table 3.1.1 shows an outline of the education together with estimation for the time consumption of each part.

09.00 - 09.10	Introduction
09.10 - 09.30	Environmental aspects • Environmental goals • Energy usage • Generation of electricity • Economical calculations
09.30 -10.20	Hydro power • History • Technology • Advantages/ Disadvantages • Economical aspects Questions
10.20 -10.30	Break
10.30 -11.20	Wind power • History • Technology • Advantages/ Disadvantages • Economical aspects Questions
11.20 -11.50	Closure and discussion
11.50 - 12.00	Evaluation and examination

Table 3.1.1: The outline of education A.

Since the participants aim to learn the economics about renewable energy and are assumed to have only basic knowledge about the subject, the education starts with a basic introduction. Then wind and hydropower are dealt with and the participants get to know the most important aspects of these. Finally, to make the participants confident investors in wind and hydropower, a large part of the time is reserved for discussion and questions.

3.2 Content of education A

In this chapter, the main information found in education A is presented in text form. This is to get an overview of the content in the education. Some parts are excluded due to the extensive education material. The total range of part A includes 69 PowerPoint slides and a text document for the lecturer of 28 pages including 6860 words.

3.2.1 Social aspects of wind and hydropower

The environment has been a well debated topic for a long time with issues like acid rain, air pollutions and the greenhouse effect, due to emissions, mainly consisting of carbon dioxide and methane. Today the world energy sector is emitting 25 % of all greenhouse gases. In Sweden this number is 13 % due to the large amount of hydropower in the power system. Even though this number is low in comparison, it can be reduced to lower values. This can be achieved by increased usage of renewable energy sources.

There are many reasons for decreasing the usage of non renewable energy sources. As already mentioned, to protect the environment, but there is also economical-, political and social aspects. Today's society is depending on excessive usage of energy. Oil, coal and uranium are today's main sources, for power production, these are finite within a limited time frame; therefore other options must be available. The political instability in many of the oil producing countries is also a reason for trying to decrease the oil dependency. The economical aspect includes increased cost for releasing emissions and costs for increased seawater level.

Political actions will be taken by the government to reduce emissions and to encourage renewable energy production. Regulations for protection of the environment are discussed on several different political levels and these regulations as well as economical subventions are made to encourage development. The Swedish government is planning an investment of 3 billion SEK for the climate- and energy area, as well as subventions for the development of renewable energy sources. The European Union, EU has goals to decrease the emissions of carbon dioxide with 20 % from 1990's values and to produce 20 % of EU's energy from renewable energy sources in year 2020. The Kyoto protocol decided in 2003 a long-term goal to reduce emissions with 70 % of 2003 years level. [10] EU is regulating the emissions by using certificates of emissions. This regulation result in emission limits, and hence a power plant can only emit the amount of certificates that they possess. EU can limit the amount of certificates and thereby the emissions and also increase the costs for emissions. This gives carbon dioxide neutral energy sources an advantage.

The Swedish government is handing out “green electricity certificates” for production of carbon dioxide neutral energy; the sources included are solar power, wind power, wave power, bio fuels, peat for combined power and heating plant, and hydropower with some restrictions. The certificates are only given to small-scale plants, new plants, potentiation, nonprofit plants and for resumption of old plants. The power companies in Sweden have to invest a certain percentage of their electricity distribution in these green electricity certificates. This percentage increases when the government wants a larger part of the power production to be from renewable energy sources. This all indicates why there are good economical possibilities in these types of energy sources. [17]

The incomes for alternative energy sources are the green certificates and the delivered power to the grid. The average price for one green certificate 2008 was 282 SEK/MWh [14], average price for selling electricity on Nord Pool, the Nordic power trading network, 491 SEK/MWh [20]. This results in total income for year 2008 of 773 SEK/MWh.

3.2.2 Hydropower

Today almost 50 % of the electric power production in Sweden is produced with hydropower. The development started over 100 years ago and has been an important part of the Swedish industrialization progress. In Sweden all potential for larger plants are used or protected due to environmental reasons, thus future investments includes small scale hydropower plants and potentiation of older ones. In Europe though, 25 % of the rivers are unexposed and can be further developed.

3.2.2.1 Technology

When using hydropower the potential energy of the flowing water is transformed to kinetic energy, further converted to mechanical energy through the turbine. The generator utilizes the mechanical energy produced by the turbine to produce electrical energy. To protect the turbine a lattice is used to collect unwanted and harmful waste. The electricity produced by the generator is transformed to the right voltage level for the electric grid with a transformer. The water is stored in a water magazine which also functions as energy storage. Produced power has to be equal to consumed power in each moment to prevent frequency disturbances that can affect the whole grid. The water reservoir gives advantages towards other energy sources since the water flow is proportional to power production. Thus by changing the inlet gate, different amount of water can enter the plant. The large amount of hydropower in Sweden preferably is used to adjust changes in demand and supply in the electric gird [15].

The plant can be built in a large range of sizes and can be adjusted to different environments with different height of water head and water flow. When planning the construction of a hydropower plant, several aspects have to be considered. The amount of flowing water, the head of water and the possibilities for a water magazine affects the amount of produced power. From this information a suitable turbine and generator can be chosen [16].

A control system is essential for a hydropower plant. For example, water levels at a magazine need to be controlled and the equipment needs to be protected from faults such as lightning and overheating. This is important for improved lifetime and less maintenance. The control system is also important for maximum efficiency, which in a hydropower plant is high, often larger than 80 %. [23]

3.2.2.2 Environmental aspects

Even though hydropower is considered an environmental friendly energy source, there are several environmental impacts that need to be considered. The main impact from hydropower plant origins from the water magazine. The magazine drastically changes the ecosystem of the river from flowing to still water and thereby increases the amount of water in the system, and increases the duration of stay for different animals. Few animals and plants can adapt to the new ecosystem. There is also an increased transportation of organic material from the edge of the water together with changes in temperature and turbidity. The plant is also an obstacle for fishes that travels upriver but this can be solved with fish ladders on the sides of the plant. The water magazine risk to be frozen solid compared to a river with constant moving water and deep holes are made where the fish can stay during winter and the water magazine is never completely emptied. The animals attaching their eggs on the water line are affected since the water level in the magazine varies and the eggs may die due to lack of water. [1]

The digestion of organic material produces carbon dioxide and methane, which are both greenhouse gases. A measure for reducing the environmental impacts is to remove all trees and organic material around the magazine before filling up the water magazine. Old hydropower plants use oil to lubricate the turbine. However, this could be solved easy by changing to newer self lubricating turbines [24].

3.2.2.3 Economy

There is a large investment cost for building a hydropower plant, but the long lifetime and the free fuel still makes hydropower a competitive renewable energy source. The investments costs for the plant depend on the following factors, presented as a percentage of the total cost:

- Turbine, 15 %
- Water magazine, power station and water magazine gate, 60 %,
- Generator, 4 %,
- Converter, power lines, 14 %
- Constructing costs, 7 %. [2]

The costs will increase considerably if the water magazine cannot be placed naturally in the river and the river has to be redirected to another path [1].

The running costs are based on, maintenance and service, 30 SEK/MWh. There are also insurances and taxes for the plant. Energy tax and real estate tax, which is 2.2 % in year 2009 to 2012 this will be lowered to 1.7 %. [5] The cost for service and maintenance on the plant increases with the age of the plant.

The cost for the control system is based on the used components, for example, what kind of turbine, generator and how many water magazines that are used, but mainly on the size of the plant. A 300 kW system costs approximately 300,000 SEK and a 700 kW system 750,000 SEK. After installation there are costs for the maintenance and the surveillance system. If the customer wants to use surveillance on the plant through ADSL this increases the costs with 500,000 SEK and 1000 SEK per month. [23]

The incomes consist of the electricity certificates and the produced power [13]. The produced energy is depending on the turbine, the amount of water and the head of water.

3.2.3 Wind power

The usage and development of wind power in Sweden started in the 1970th when the oil crises increased the interest and development of wind power all over the world.

3.2.3.1 Technology

The main components in a wind power plant are the tower, the rotor blades and the powerhouse consisting mainly of the generator. The components in the powerhouse vary and there are different options for specific conditions, examples are; gear box, brake and emergency brake. The tower is designed to decrease vibrations and to reach undisturbed wind at higher heights. The rotor blade is constructed to use maximum amount of the wind. The efficiency of the plant is depending on the area covered by the rotating blade, the air density and most important is the wind speed. The turbine should have low losses to maximize the efficiency.

Wind power as the only power producing technology in the power grid is not an option since, as mentioned before the production must be equal to the demand at each moment. Wind power plants always produce maximum power possible and can therefore not handle higher demands. In Sweden, hydropower is used to meet changes in demand. Other energy sources could be used, for example coal condenses plants.

There are limits for wind power plants and to withdraw maximum power is not always possible. The wind-power curve can be seen in **Figure 3.2.1** and shows how low and high winds that the plant can handle. As shown in this specific case winds less than 1.5 m/s cannot deliver any power and the maximum output power is 1.4 kW.

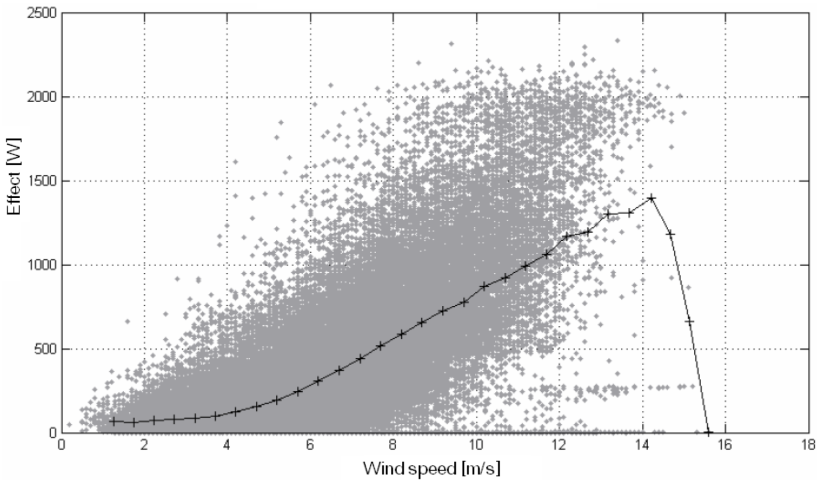


Figure 3.2.1: A wind-power curve

If the wind is too strong, there can be large stress on the blades. However, a mechanical brake is not preferable considering the large generation of heat produced by the brake. Instead other systems are used, either the blades are ductile and operates with stall-regulation, or pitch control is used where the angle of the blades can be adjusted to let more wind pass.

3.2.3.2 Environmental aspects

The production, installation and recycling of the wind power plant gives emissions. The main consideration concerns changes in landscape that may bother people. There are also problems with shades and noise from the plant but this is regulated and investigated before construction. [8]

The effect on wildlife is not yet fully investigated. The birds are affected and have to change their natural route by flying around the plant. Some raptors avoid building their nests close to windmills. However, the birds often avoid collision with the plants. Fish are affected during construction of the plant when cables are put in the seabed and foundations are made. However, fish likes the artificial reefs created by the foundation of the plant. [22]

3.2.3.3 Economy

The profit from wind power highly depends on political regulations. The fuel is free but the investment costs are high. Just like for hydropower the advantages are the free fuel which gives low running costs.

Before building a wind power plant a pre-study is of major importance, to assure that the investment can be profitable. Estimations of investment costs, annual production, annual profit and running costs have to be made. In this the average wind speed over the year is important. Measurements made by Sweden's meteorological and hydrological institute, SMHI can be bought for the area or measurements for the specific positions could be performed by using a wind measurement device. The seller of a plant should provide the customer with a wind-power curve and with this information, an approximation of the annual production can be made. The size of the plant should be based on the economical conditions since the larger the plant, the higher the investment costs is, but a higher production gives a larger profit. The cost for the plant is also based on access to the place, for instance if there are roads or these have to be build, how far away the connection to the grid can be made or if new power lines have to be built.

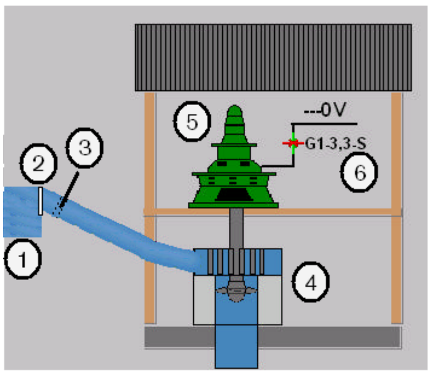
For a typical wind power plant approximately 82 % of the total investments costs consist of the plant itself, foundation 6 %, connection to the grid 3 %, electrical installations 3 %, soil 2.6 % and road together with other expenses 1 %. [4] The running cost of the owner of the wind power plant includes insurance, real estate tax, energy tax, service and maintenance. The energy tax is only for plants over 59 kW. There might also be amortization on loans.

For an 11 kW Hannevind wind power plant the total investment is 250,000 SEK. For larger installations above 1 MW the approximation can be made by using 12 MSEK/MW for one turbine, fundament and internal electric connection, 2 MSEK per windmill for extra height of the tower, 1.2 MSEK/km for building a road, 170,000 to 240,000 SEK/MW and km for connection to the nearest grid. If the plant is located where the average temperature is below minus eighteen degrees Celsius, at least one month of the year, an additional cost for adjustments has to be added. This is 5 % of the costs of the turbine, fundament and internal electrical connection. [3]

The investment cost is high for building wind power plants and alternatives by sharing the costs are available for investors with less capital. For example by founding a company or an economical association. An economical association has to be at least five members and the advantage is the reduced personal responsibility for economical losses. [7] Another option for landholders, are to lease the land for wind power plants. [26]

3.3 Layout of part B.1

In part B.1 the different part of a typical system controlled by IETVs and its different parts are explained. To justify the arrangement of the education, see **Table 3.3.1**, **Figure 3.3.2** was used. **Figure 3.3.1** gives a typical hydropower plant, following parts are included.



1. Water magazine
2. Inlet lattice
3. Inlet gate
4. Turbine
5. Generator
6. Transformer

Figure 3.3.1: The basic principle of a hydro power plant. [28]

The water is stored in a magazine. Through an inlet gate and an inlet lattice, the water flows to the turbine. The turbine runs the generator and the electricity is delivered to the electric grid through a transformer.

To simplify the instruction manuals delivered with IETVs systems, many pictures are used to compare the manuals and reality. Examples of layout are illustrated in **Figure 3.3.2**.

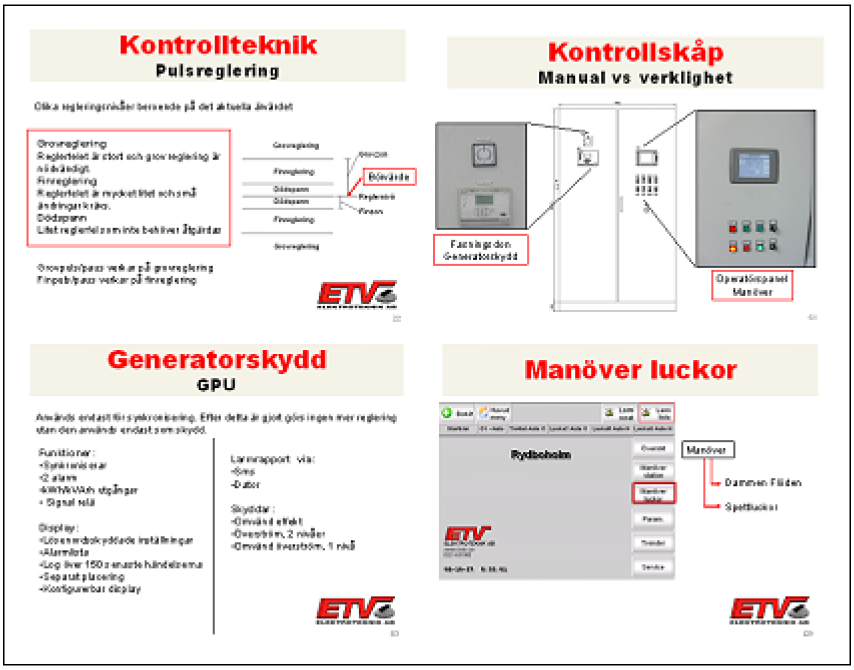


Figure 3.3.2: Four examples of PowerPoint slides from education material for B.1.

Following in **Table 3.3.1** is the outline and an approximation of time consumption

08.00 - 08.10	Introduction
Theoretical education	
08.10 - 10.00	General hydropower Generator and turbine Control system Control cabinet Magnetization cabinet
10.00 - 10.15	Break
10.15 - 12.45	Equipment outside the cabinets Communication Control Maintenance
11.45 - 12.00	Questions
12.00 - 13.00	Lunch

Practical exercise	
13.00 - 15.00	Demonstration • The hydro power plant • IETVs equipment Practical examples • Maneuver
15.00 - 15.15	Break

15.15 - 16.30	Practical examples • Reset parameters • Maintenance
16.30 - 17.00	Closure. Examination and evaluation

Table 3.3.1: The outline of education B.1.

3.4 Content of education B.1

In this chapter, the main information found in education B.1 is presented in text. This is to give an overview of the content in the education. Since the education material is extensive and some parts are even confidential some content is excluded. The total range of part B.1 includes 150 PowerPoint slides and a text document for the lecturer of 57 pages and 8330 words.

3.4.1 Turbines

There are three main types of turbines possible for usage in hydropower plants; Kaplan, Francis and Pelton. It is possible to use several turbines in one plant, for example three Kaplan or one Kaplan and one Pelton. The choice of turbine depends on the head and water flow at each specific case, see **Table 3.4.1**. Larger turbines often have efficiency over 90 %.

Turbine	**Rated head of water [m]**	**Rated water flow [m^3/s]**
Kaplan	Low: 2-70	High: 1-200
Francis	Medium: 10-300	Medium: 0.3-100
Pelton	High: 80-1600	Low: 0.1-20

Table 3.4.1: The most commonly used turbines. [32]

Kaplan turbine shown in **Figure 3.4.1** is used for low heads of water, and is therefore the most common turbine for small hydropower plants. Advantages are the high efficiency for low heads of water; a drawback is the high construction cost. This type of turbine is an underwater turbine and operates completely covered by water.

Figure 3.4.1: Kaplan turbine [12]

In **Figure 3.4.2** the important parts for a Kaplan turbine are shown; including guide vanes, runner and the outlet draft tube. The water first passes through the adjustable guide vanes and into the adjustable runners. Afterwards it is sucked out in the draft tube used to decelerate the water and recover kinetic energy.

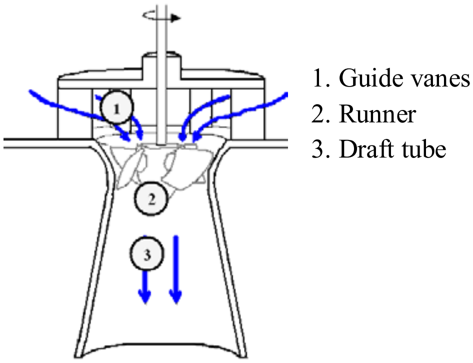


Figure 3.4.2: Shows the guide vanes, runners and the draft tube of a Kaplan turbine.

The draft tube is constructed with an increasing area of the pipe, to decrease the pressure after the turbine. This results in a pulling force on the inflowing water. This avoids the out flowing water from the turbine to affect the inflowing water to the turbine which results in speed incensement. When the turbine is rotating the water can pass through without releasing all its kinetic energy. This kinetic energy is lost without the guide vanes, which rotate the inlet water in an opposite rotation to the runner, to secure maximum used water energy. The guide vane is flexible and adjusts the amount of water flowing thorough the turbine. Every position of the guide vane corresponds to an optimal angle of the runners, found through a combination curve. By constructing a combination curve for each turbine and water speed for different angles of the guide vane it is possible to regulate the guide vanes for maximum efficiency. In old systems only one combination curve was used but today the system is operating with different curves for different inlets. [24] The guide vane angle is on X-axes and runner angle on the Y-axes. Regression analysis is used to connect the different point in the curve. **Figure 3.4.3** illustrates an example for a combination curve made for a Kaplan turbine. [11] A combination curve is only used for Kaplan turbine.

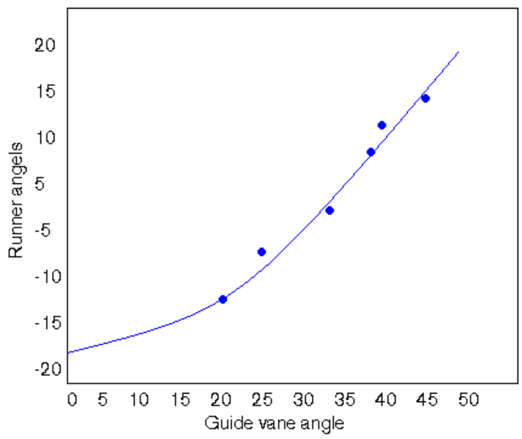


Figure 3.4.3 Combination curve that describes the optimal angle of the runners in relation to the angle of the guide vain for different water flows.

The Francis turbine, **Figure 3.4.4,** is similar to Kaplan turbine but suitable for average high heads of water. The water enters the non-adjustable runner in radial direction and passes out axially. It is with the adjustable guide vanes that the water flow is controlled while the angle of the runner is fixed. Francis turbine is characterized by reliable operation, simple construction and high efficiency.

Figure 3.4.4 A Francis turbine [12]

The Pelton turbine, **Figure 3.4.5** is used for high heads of water for an impulse turbine, which indicates a placement above the water surface and operation in air. There are no adjustable guide vanes and therefore no need for a control system. Pelton turbine has the advantages of compact construction, stable running and easy operation.

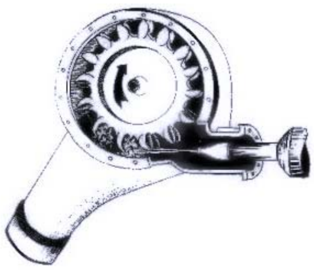


Figure 3.4.5: A Pelton wheel turbine [12]

3.4.2 Generators

There are two types of generators used in hydropower plants, synchronous and asynchronous. Depending on the specific condition of a plant the choice of type and number of generators can vary. Sometimes both types are used in the same plant. The synchronous generator, se **Figure 3.4.6**, is the most common one for applications in larger hydropower plants. It is cheaper than the asynchronous and has a simple construction and therefore requires less service. A drawback is the requirement of a gear box for smaller plants and the more expensive power electronics. Larger plants uses slow moving synchronous generators that enables operation without a gearbox.

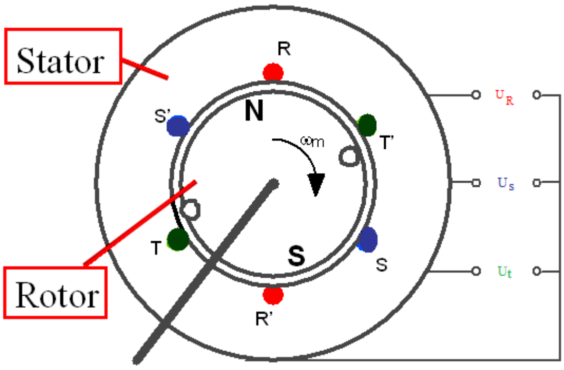


Figure 3.4.6: The synchronous generator

The synchronous generator works at a constant speed independent of the load. A magnetizing process is needed to compensate for reactive power consumption in the generator. The magnetizing equipment is delivered by IETV as a separate magnetizing cabinet, one for each synchronous generator. A 400 V AC in the cabinet is transformed into 115 V AC and led through thyristors producing a direct current in to the rotor windings. This magnetizing current is measured with a shunt device and shown in an analog display on the front door to the cabinet. The field current varies with the produced power; higher production gives higher magnetizing current. Since the magnetizing current controls the reactive power and therefore also the voltage, it is essential with high functionality. If the magnetizing equipment fails with the excitation, the generator consumes reactive power from the grid and there will be a voltage drop. If this continues the voltage will drop to lower levels than the transformer can handle and the current will increase and cause a serious fault. When the generator has reached the synchronous speed a grid connection enables power delivery.

For the synchronous generator the grid connection is needed in order for functionality. Requirements for synchronization includes that the grid and generator have equal frequency, 50 Hz, the same amplitude, the same phase sequence and the same phase angle. If these requirements are not fulfilled during the connection, the generator and the turbine could be damaged. In IETVs system and in all modern plants the synchronization is either done with the generator protection unit or with a separate synchronization device [16]. During the start the magnetization is turned on to function as a field exciter, however, during start, the magnetization process is delayed to avoid energy losses. [28]

The asynchronous generator is used for smaller hydropower plants and is suitable for low power applications. The most common usage is as an electric motor. When using an asynchronous generator the speed is slightly above the synchronous speed but it delivers power at lower speeds than the synchronous generator. The speed is though depending on the load. However, it is self-magnetizing and does not require a gear box or brake. The major drawback is the consumption of reactive power. [23] When starting the asynchronous generator the Generator Protection Unit contains a soft start devise. This ensures a start where the currents are limited and a voltage drop is avoided. [28]

3.4.3 Overview of the plant

The main circuit diagram for the entire plant can be seen in **Figure 3.4.7**. Features included are transformers, voltage and current control, disconnection switch, earth and short-circuit of cables, over voltage protection and prevention of reactive power overload as well as the main switch unit. This is used to control the incoming voltage cables to the plant from the grid. [28]

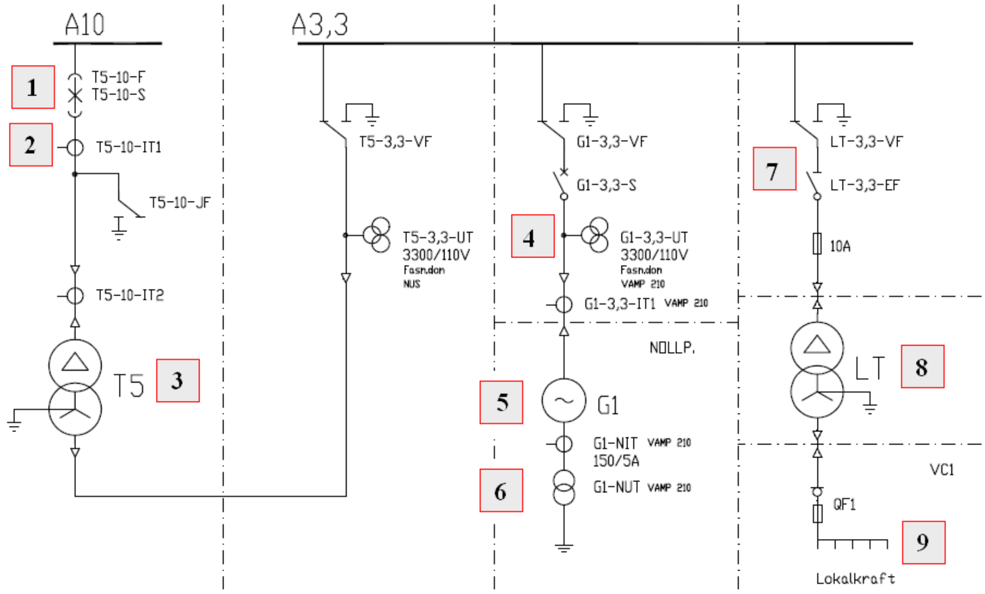


Figure 3.4.7: The main circuit diagran for the high voltage components in the system. [28]

1: Breaker, connecting to the electric grid
2: Current measurements with a curren transformer
3: Transformer
4: Voltage measurements with a voltage transformer
5: Generator
6: Generator protection unit
7: Breaker
8: Transformer for local power
9: Local power supply

3.4.4 The control cabinet

Almost all the control equipment from IETV is placed in the control cabinet. Included is the software for the controlling process, protection devices, communication devices etc. In this control cabinet the customer can use IETVs equipment for running and controlling the hydro power plant. When building a control system and a control cabinet there are standards that preferably are used to simplify troubleshooting and maintenance for other service personal. IETV uses the standard SS-EN 60204-1 as a base during construction of the cabinet and SS-EN 61346-1 a base for drawing the components. These are Swedish types of standards.

3.4.4.1 PLC

PLC stands for programmable logic controller and is the main part of the control system. This is where the software programming of the control system is performed; parameters are adjusted, for example maximum allowed temperature in a winding before an alarm. IETV uses the program GX Developer for programming of the PLC and this is a program bought from the company Beijer Electronics. The PLC consists of many preset functions such as a PID regulator that will be explained later on in **Chapter 3.8.6.2**. Via a computer the functions of the PLC can be viewed and programmed. The functions are illustrated with block diagrams. The blocks can handle different functions of the PLC, for example a block can compare two values. This enables the user the possibility to create new blocks for special requirements.

The PLC consists of a number of input and output sockets. With a GX Developer the PLC can set and compare the signals and also store information. These are the parameters that are used for controlling the system.

Controlling a system includes both surveillance and regulation. During surveillance the PLC compare input values with parameters set by the owner and trigger an alarm if the input exceed or fall below the given parameter. These parameters are given by sensors placed on varies locations in the plant, for example in windings and in the water magazine. The sensors send signals to the PLC for determination whether these values are within reasonable limits, otherwise an alarm will be trigged. However, regulation is when a system is regulated to act in a certain way. The regulating system also controls the output to determine whether the input needs to be adjusted to get the right output by using feedback. A surveillance system is only monitors a value without any control. [9]

Two types of regulation in used in the PLC; pulse- or PID regulation. The regulation is used to set new values in the PLC that is maneuvered through a touch screen. This regulates parameters such as water level in the magazine, temperatures etc to a preset value. For pulse regulation the control system from IETV uses different intervals for the regulation. The level of regulation needed is based on how much the present value differs from the reference value, see **Figure 3.4.8**. If the difference is large the system will use rough regulation. If the difference is within an acceptable level but still not close enough, small regulation is used. In case the difference is in an acceptable level no regulation is needed and the system is in the no regulation interval. These levels are divided into zones defined as rough zone, fine zone and no regulation zone. The wanted value is defined as the regulation level. The levels of acceptance are individual for each specific case and can be changed after the installation by the customer. PID regulation will be explained later on in **Chapter 3.8.6.2.**

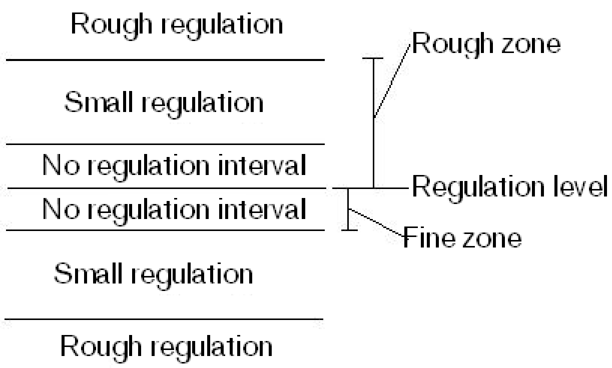


Figure 3.4.8: The regulation intervals for pulse regulation used by IETV.

3.4.4.2 Generator protection devices

The generator needs to be protected for several different types of faults such as fault current, over- and undervoltages, frequency variation and unbalance in the phases. The generator is suited for rated values and even though some small variations are accepted, long term violations of these can cause damage on the generator. Protection devices ensure that the generator runs at too high or low values at a minimum period of time, when the abnormal values occurs the generator is turned off. [18] The less abnormal conditions the longer lifetime, less maintenance are needed and higher efficiency is obtained. The generator can also be disconnected from the grid to prevent damages affecting this. [24]

IETV uses three different types of generator protection devises. GPU- generator protection unit, GPC- generator protection controller and a generator protection relay, VAMP 210 of the brand VAMP, model 210. For synchronous generators a GPU is used and for asynchronous generators a GPC. These also handle the synchronization to the grid when starting the plant. A VAMP 210 is always used with a synchronization device named CSQ3 to enable synchronization. The generator protection device has a display and can indicate by signal lamps what has happened, a list with occurred alarms and events can also be provided. [28]

3.4.4.3 Lightning protection devices

Lightning protection is performed both in the cabinet and on the equipment outside. By using galvanic separated devices the cabinet is protected against lightning, most important is to protect the PLC. The voltage supply, 230 V to 24 V used in the cabinet is galvanic separated from the other voltage supply device and a fault in one of these do not affect the other one. Outside lightning protection is used to protect cables and antennas by ordinary lightning protection equipment based on the rolling sphere theory. Still, a common problem is that sensors are broken by a lightning stroke in the area and the protection system is not totally secured from faults. [24]

3.4.5 Communication systems

The control system needs to communicate both internal and external. Internal communication includes devices such as contact between PLC and GPU. External communication handles contact between for example the water magazine gate and PLC. There are several different options for the communication, either through a cable or through air via radio communication, satellite etc. A lot of factors are affecting which kind of communication system that could be used. In some cases there are already functional cables in the ground that could be used. If the control cabinet and the magazine are separated by a mountain a cable is unsuitable and analog radio communication is preferable. The communication system has to be reliable since the control of the plant is depending on its functionality. [28]

3.4.5.1 Internal communication system

The internal communication is used for communication between different control cabinets, PLCs, screens, sensors and generator protection units, using different methods for different applications. There are three different internal communication systems that IETV uses, profibus, Ethernet and analog communication. Profibus is an open field buss that makes it possible to transfer information fast and is used to connect automation equipment such as the PLC. Ethernet uses optical fiber, coaxial cable or double copper cable. Profibus and analog communication can be transmitted via radio communication where it is not appropriate or possible to use a cable. [28]

3.4.5.2 External communication system

The external communication system is used for control and running of the system from a computer remote from the plant. This is also used for receiving information about faults in the plant. This is sent to a cell phone or a computer. The different communication systems are sent through air or wires and some of the options are ADSL, GPRS, 3G, satellite, telephone modem or radio. [24]

3.4.6 Power supply in case of power outage

Shutting down the plant can cause damage if performed improperly, and therefore the control system is equipped with an emergency power supply. In a hydropower plant, batteries are used and these are often on 110 V. There is a second emergency power supply, using a diesel generator setup, in case the power outage is long lasting. This is to prevent flooding in magazines; the water gates always need to be functioning. [28]

3.4.7 Operation of IETVs systems

In the front of the control cabinet, touch screen or buttons could be used for operation of the plant. Following is the possible ways for operation of IETVs systems in a hydropower plant.

3.4.7.1 Effect regulation and water level regulation

The plant can be controlled with water level regulation or effect regulation. Water level regulates with the water gates to keep a certain water level. The amount of energy produced is depending on the water level in the magazine. The produced power in the plant then varies constantly. Effect regulation regulates with the generator to keep a certain output power. Effect regulation can only be used during short periods of time since the water level requirements for the magazine cannot be violated. [23]

3.4.7.2 Modes

The system can be operated in different modes depending on purpose. Normally the plant runs at normal mode using automatic control. If the parameters shall be changed on the touch screen placed on the control cabinet, the manual mode is used. When performing services, the system should be put in service mode. Then the protective devices are disconnected and therefore, the personnel need to be cautious.

3.4.7.3 Stop

There are three different ways to stop the plant. These are normal stop, fast stop and unloaded stop. A stop can be performed manually or automatically if a fault appears. Fast stop is only used when serious faults occur, often electrical ones. The generator breaker is instantly switched off and the inlet fast deceleration valve is used. This means that the generator can career and be damaged. There is a fast stop button on the front of the control cabinet in case of an emergency.

A normal stop is used when the plant is stopped manually under normal conditions or as an automatic stop for less serious faults when a fast stop is avoidable. The generator breaker is on for as long as the power is larger than the predefined value. The inlet is reduced with a valve.

Unloaded stop are used for all mechanical faults and has functions like a normal stop. The breaker is switched on when the power is down to zero and the only difference is that the fast deceleration valve is tripped. The unloaded stop is almost as fast as the fast stop but the generator do not career since the generator breaker is not switched off until the effect is at zero. [28]

3.4.7.4 Display function

In order to control the plant customers can use the touch screen monitor on the front of the control cabinet. In this monitor it is possible to see and modify parameters related to the plant. The different monitoring applications are for the generator, (produced power, temperatures in the windings and so on) and then the actual values are shown. [28] It is possible to see old operation conditions like changes in temperature, water levels and produced power. These values are saved for a couple of weeks. By using external communication one can use a larger server and save data for several years. [28] Setting of parameters includes water levels, positions of the gates, position of the runner, temperatures and alarm levels. The different chosen parameters decide the allowed intervals and whether a fault shall cause only an alarm or if a fault shall stop the plant. For example if a value is preset to 10, the fault may occur when the signal is 10±1, and the breaker is activated at 10±2 to generate a stop. **Figure 3.4.9** shows the design of the monitor. Here it is possible to navigate between overview, maneuver of the plant, maneuver of gates, parameters, trends and service by pushing the buttons. [28]

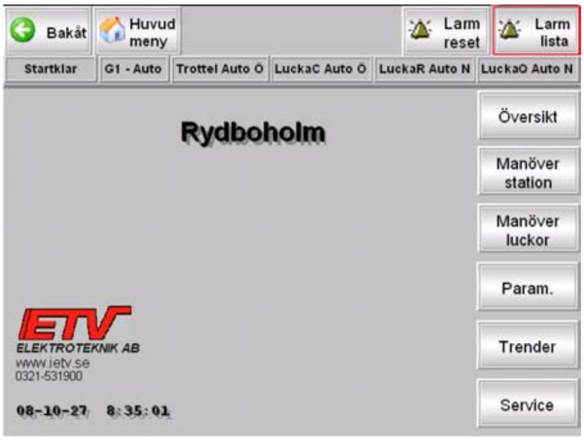


Figure 3.4.9: The touch screen monitor. [28]

3.4.8 Guidelines for practical exercises

Following is a brief description of the practical exercises that will take place in a hydropower plant during the afternoon. This is in order for the participants to know how to run the plant. The practical exercise will proceed during 4 hours.

The practical exercise is a repetition of what was said during the theoretical education, consisting of three parts, a demonstration of the plant, practical examples and finally a small examination. This ensures that the participants can, from looking at a circuit diagram tell were the parts are in reality. The main circuit diagram is shown in **Figure 3.4.7**, however, in excess of this one, further material are confidential. The participants should throughout the demonstration and with examples try different exercises themselves. This is important since they should feel secure enough to do this on their own after the course. All plants are different in several aspects, for example rated power, type of turbine and generator, and required safety level. Therefore the control equipment and its drives are different as well. The practical examples and the time spent on each part have to be adjusted depending on the plant where the education takes place. The lecturer is assumed to have a good knowledge in IETVs systems and should therefore be able to do these adjustments.

First a demonstration of the plant is held including a short overview of the plant. The different parts, magazine, tube, turbine, transformer, control cabinets and so on are showed. Further on an explanation for connections are made and the ratings of this generator is described. Special features for the plants should be explained and explained. After this a more specific demonstration of IETVs system is done including the control- and magnetizing cabinets as well as the different sensors. Following is an overview of the cabinets describing purpose and function of the parts in the cabinet. An overview of the sensors shows which sensors that are used, what they are measuring and whether they are digital and analog. The part concerning the screen is mostly a repetition of the theoretical education. Here the participants should try to find different functions. The list of different alarms is also shown. This is approximated to 40 minutes. The participants must after the course is finished be able to run the plant on their own and therefore, about 25 minutes will be used for the different procedures of operation. The lecturer will show how to put the system in service mode and let the participants try. Also make sure that they fully understand the difference between service mode and automatic mode.

For start and stop of the plant, the lecturer will explain the theory behind a start concerning the magnetizing- and the synchronization process and also explain what kinds of systems that are used for doing this in this particular system. After explaining the different types of stop and when they are used a guideline is explained for when to use which stop. This is finished off with doing a normal stop and let the participants try. No other stops are made since these are only for emergencies and could damage the generator.

To run the plant from a computer, one has to be able to connect to the touch screen. 15 minutes will be spent for showing how to connect to the screen and let the participants try. This could be done in different ways for different plants. Also show which functions that one could use when being connected this way and how it can be useful. One of the most important maneuvering parts is to be able to set appropriate parameters. The lecturer will explain how it is done and let the participants set different parameters and also explain how the different parameters affect the plant.

Next part of the practical exercise is to learn more about the basic maintenance on the system and this will last for an hour. The maintenance should be performed approximately one or two times a year. This is included in a service provided by IETV that the customers can buy, but after this, they should be able to do it on their own instead. Therefore different participants should try the different parts while the lecturer gives instructions on how it should be done. Following are some basic examples:

- Change battery in the PLC
- Capacity control of the batteries
- Testing of relays
- Inspection of the magazine/s, the gates and the tube.

Finally, there is an examination for about 20 minutes. Each participant gets one task and performs it while the others are watching. This is to make sure that they feel secure enough about the system to do it on their own. Examples of different tasks that could be handed out are:

- Explain and show the different parts of the plant.
- Explain and show the different parts of the control system
- Show and explain the functions on the screen
- Put the plant in service mode
- Stop the plant
- Start the plant
- Connect to the screen via a computer
- Set parameters
- Change battery in the PLC
- Make a capacity control of the batteries
- Make a testing of relays

If the lecturer now realizes that there are some part that all participants have problems with conducting or understanding, there are some time left in the end for repeating these and for the participants to ask their final questions.

3.5 Layout of part B.2

In this part the education B.2 is described. The design of this education is informative, but many views from IETVs program are used to simplify. This can be seen in **Figure 3.5.1**.

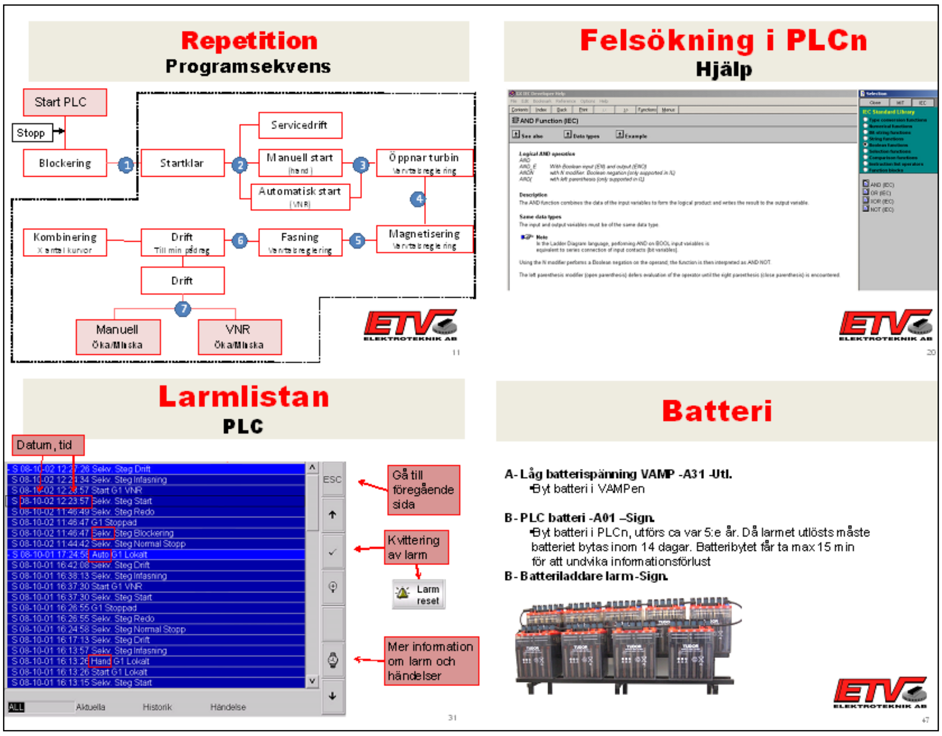


Figure 3.5.1: Four examples of PowerPoint slides from education B.2.

To make the troubleshooting easy to understand, a typical design of the slides has been developed using SmartArt in Microsoft PowerPoint. This can be seen in **Figure 3.5.2**. This structure enables an easy search and solution path for different faults.

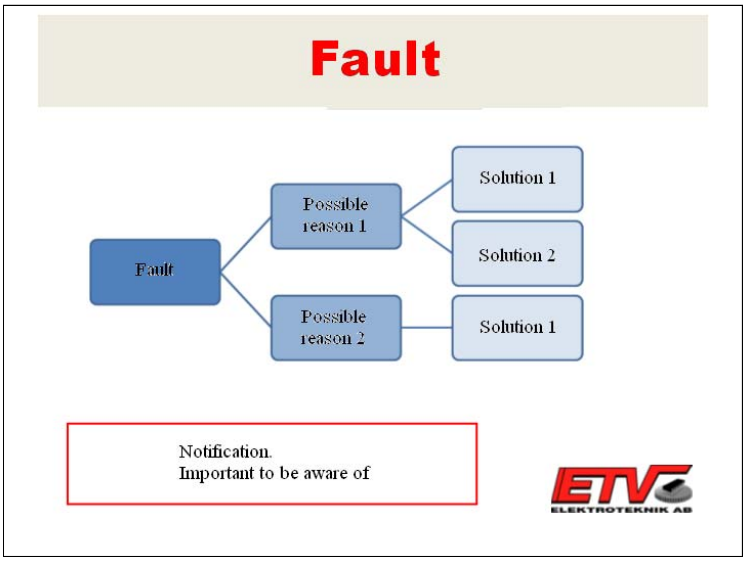


Figure 3.5.2: This Figure shows the typical design of a slide concerning fault search.

Following is the outline for education B.2 together with estimation for the time consumption of each part that enables the lecturer to adjust the education, see **Table 3.5.1**. To simplify the education, the faults and troubleshooting are separated into two parts. The approach for troubleshooting different faults is in many cases similar and thus these are presented first. After this the different faults are presented referring back to previous parts about troubleshooting. This proceeding enables the participants to see the faults and understand the different ways for troubleshooting and included are warnings and notifications for special cases. As mentioned before different plants uses different faults decided by the owner, thus all faults are not relevant for a specific plant.

Theoretical education	
08.00 - 08.15	Introduction
08.15 - 10.00	Repetition of B1 PLC Notification directory Troubleshooting
10.00 - 10.15	Break
10.15 - 12.00	Alarms • Batteries • Voltage and currents • Magnetization • Frequency • Earth faults • Head • Temperature • Oil o Hydraulic o Start and stop Closure
11.45-12.00	Questions

12.00 - 13.00	Lunch

Practical exercise	
13.00 - 15.00	Practical exercises, part one Demonstration • The hydro power plant • IETVs equipment Practical examples • PLC • Trends
15.00 - 15.15	Break
15.15 - 16.30	Practical exercises, part two Troubleshooting • Sensors • Grid • Magnetization cabinet • Earth protection • Lubrication
16.30 - 17.00	Closure. Questions, examination and evaluation

Table 3.5.1: Outline of education B.2.

3.6 Content of education B.2

In this chapter, some of the information found in B.2 is presented in text form. This is to give an overview of the content of the education. Since most of the material is confidential, only a limited amount of the information, restricted by IETV, is presented below. The total range of part B.2 includes 104 PowerPoint slides and a text document for the lecturer of 40 pages including 8430 words.

In this education troubleshooting the system is explained. To understand faults and to troubleshoot is a complex task which requires a deep knowledge and experience of the system.

From two real life notification directories written by IETVs control equipment at hydropower plants the following text includes common faults that were found. There are several types of faults that can occur and the solutions can vary with types and occasions. For example, in modern plants problems with the analog circuits gives a specific alarm but this is not the case for older plants. The faults will be explained in the following text, the theory behind, what can cause these kinds of faults and troubleshooting for a solution. Some of the problems are rather complex and there is no straight forward way to find the reason. The fault may also be very unusual and these faults have been excluded in this report as well in the education and the customers are recommended to contact IETV for further consultancy. Rotating machines are often measured with rpm, which are rotations per minute to indicate the speed. The faults can be either electrical, rpm-dependent mechanical, rpm-independent mechanical or other faults outside of IETVs equipment such as fans and ventilation in the building. The notification directory provides information on priority of the alarm and what kind of stop that occurred.

3.6.1 Classification of faults

There are three different classifications for faults, priority A, B and C. A has the highest priority and is defined by IETV together with customers, B and C is defined entirely by customers. This gives the customers possibility to adjust alarm levels and change them later on. However, the notification directory, which kind of fault that can disengage an alarm is decided by IETV. In the notification directory the priority of the alarm is listed. Priority A indicates that there is a serious fault and the most common solution is a stop of the plant, either through a fast stop or an unloaded stop. Priority A is further divided into A1, A2 and A3. Priority B and C are less serious faults. The customers can decide over these faults and for smaller plants the owner can decide to exclude C.

3.6.2 Common reasons for faults

The most common fault is due to lightning, even though there are several protective devices used for protection. This often causes an error in the sensors used for measuring temperature, angles, water level and so on. Sometimes the sensors are misplaced and this could be due to human mistakes or an unpredicted event. It is important to control the sensors so they have not been moved or been covered by dirt.

3.6.3 Troubleshooting

In the control system old data can be found, for example produced power, water levels, temperatures and so on. The values are stored for a long time and can be shown in a trend view at the operator display. The trend view includes an event list including faults and changes in the plant. The latest trends are the first source for guidance when troubleshooting the system. After a fault has occurred and an alarm has been trigged, the trend function in the PLC is preferably used as a start for troubleshooting. By adjustments on for example inlet, it is possible to see how the equipment reacts and find possible sources of the error.

3.6.4 List of faults

The notification directory shows which type of stop that the alarm has caused and the faults in- and out port. The name of the fault explains the problem and in which component the fault has occurred.

Table 3.5.2 shows the head of a notification directory for one fault. First is MIT that indicates at which memory bit the fault is stored. The identifier is used for programming in the PLC and the alarm text is shown in the operator display. The display text always starts with an A, B or C which indicates priority of the alarm. Following is the component that has a fault and A01 represent the component label that can be used for identifying the component in the circuit diagram and in the cabinet. The last part in the display is either Utl. that indicates a stop has occurred or Sign. indicating that there only been an alarm and no stop. I/O indicates where the in and out gate of the component is placed. Following A-alarm, B-alarm and C-alarm is clarification to simplifying determination of alarm priority. If start block is marked a block preventing a start is activated and the plant cannot be started automatically, thus a manual start is needed. Alarm call indicates that the alarm occurred.

MIT	Identifier	Alarm text	I/O	A-alarm	B-alarm	C-alarm	Quick stop	Normal stop	Unloaded stop	Start block	Alarm call	Explanation
M1100	ml_Lag_Batterispanning_PLC	B- PLC batteri - A01 - Sign.	M8005		X					X	X	

Table 3.5.2: Header of a notification directory

3.6.5 Faults

To easily see the structure among fault these have been divided into groups appropriate for this education. The dividing is in regard to where the fault appears or what causes the fault. Unfortunately IETV expertise in troubleshooting is confidential and cannot be presented in this report, contact IETV for further information within the subject. In the teaching material the following fault and troubleshooting were included.

- Batteries in PLC and the generator protection device are finite and need to be changed on regular basis
- Under-, over- and unstable voltages are all serious faults that can appear in the system
- Over- and unstable currents
- Over- under- and unstable frequency caused by the grid or generator
- Magnetizing problems resulted from loss of excitation
- Too low and high temperature
- Earth protection
- Start and stop of the plant
- Too high or too low water level
- Problems with the hydraulic unit
- Switches
- Other faults such as faults concerning fans or other less critical faults

3.6.6 Material for the participants

With this education, additional material is attached concerning the possible faults and troubleshooting for these. This text document includes table of contents, where it is easy to find a fault and then use the material for description and a convenient guide line when troubleshooting. The entire material contains eight pages but is confidential material since this is one of IETVs unique area of expertise.

3.6.7 Guidelines for practical exercises

Following is a brief description of the practical exercises that will take place in a hydropower plant during the afternoon. This is in order for the participants to know how to search for faults.

During the practical demonstration troubleshooting for a fault is demonstrated and the participants will have the opportunity to perform it themselves. Throughout the education the different faults should be discussed. For instance, oil levels are an important source of error concerning temperature faults. The demonstration starts with an overview of the plant where all the essential parts are shown and described. IETVs control system was explained in detail in part B.1 but a short repetition will be held including the cabinets, the sensors and the touch screen.

In the control cabinet the PLC is demonstrated; how to use the program for troubleshooting and connection. How the feature trend is used and controlled is also shown. The most common fault source is the sensors and 30 minutes of the demonstration will focus on this. The participants will know how to measure on different type of sensors. How to use measuring devices for testing signals, how to use a voltmeter and an ampere meter for detecting signal errors. Finally an ohmmeter will be used for demonstrating how to troubleshoot temperature sensors. The grid is another fault source. Although this one is uncontrollable, it is still important to be certain whether this is the source of the fault. Voltage, current and frequency measurements will be performed and explained. Following is the magnetizing cabinet with the important feature of magnetization. In the magnetizing cabinet input and output current will be measured and then compared to the correct values. These are within an interval and therefore, it can only seen whether the current is in reasonable intervals. The demonstration continues around the plant. A short-circuit test involves measuring the current in all three phases in the windings. This is done by doing a short circuit test which was described earlier. Other ground faults are measure from neutral of the generator to ground and measure the voltage drop over a resistance.

Last is a focus on problems concerning lubrication. The participant will learn how to check the oil level sensors, the oil pump and the oil pipes and make sure of their functionality.

The demonstration will be summed up with an examination and discussion to make sure the participants know how to troubleshoot a hydropower plant and can perform all the different tasks on their own.

3.7 Layout of part C

In this part, education C is described. This consists of similar parts as the previous educations, however, more details and technique is included. The headlines are arranged as follows, and are similar to part B.1 to simplify the interaction between the different parts. After requests from IETV, no time frame is included in the agenda.

The outline of the education:

- Efficiency
- Turbines
  - Types
  - Combination
- Shaft and gear
- Generators
  - Asynchronous generator
  - Synchronous generator
- Transformers
- Sensors
- Control theory
- Safety
- Closure
- Questions and discussion

Figure 3.7.1 shows the design of some slides. There are a large amount of calculations, tables and figures that can be seen on these which is used consistently throughout the education. Considering the high technical depth, several pictures are used to simplify the understanding of formulas and descriptions.

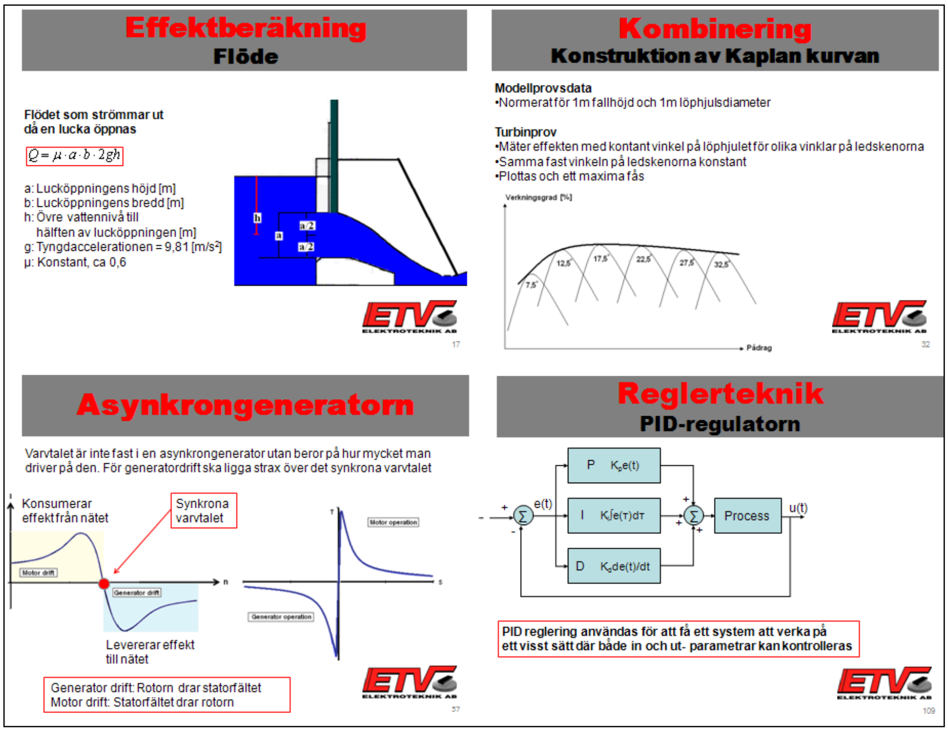


Figure 3.7.1: Four examples of PowerPoint slides from education material for part C.

3.8 Content of education C

The main content from education C is presented below. Several parts are excluded due to the large size of the education and problems with confidentiality. The total range of part C includes 129 PowerPoint slides and a text document for the lecturer of 40 pages consisting of 9630 words.

3.8.1 Output power

When talking about electrical devices, rated values are used. Rated values gives the normal and optimal operating conditions. The rated power is the delivered power for rated current. The unit for power is referred to as watt, W, see **formula 3.8.1.** For power calculations, other units for power can appear. Power is the derivative of energy over time and is often expressed as joules per second. Power is thereby defined as the energy amount in Joule converted to Watt during one second.

$$W = \frac{dE}{ds} = \frac{J}{s} = \frac{N \cdot m}{s} = \frac{kg \cdot m^2}{s}$$ **[3.8.1]**

W: Watt
E: Energy
J: Joule
N: Newton

To calculate a correct output power from a hydropower plant is essential for many reasons. Partly for knowing the expected economical profit, but mainly when designing the control system. Then the rated power is essential when setting the limits for stop of the machine and when setting alarm levels in the control system. Incorrect calculations are a common reason for problems with the control system. [6]

3.8.1.1 Head of water

The power delivered by a hydropower plant depends on several different factors. The most important ones are the water flow and the head of water. There are three different concepts regarding heads of water.

- Gross head: The higher water level to the lower water level which usually is called head.
- Net head: The gross head minus the energy losses.
- Useful head: Net head.

The net head is usually used for calculations in the hydropower plants. The energy loss that reduces the net head comes from the inlet, channel and tube.

3.8.1.2 Losses

Friction losses origins from water passing the rugged surface of the pipe line, the line from the magazine to the generator. Hence, the selection of material for pipeline is essential for friction losses. The smallest losses are from pipes constructed by PCV. Steel has higher friction losses and the highest loss origins from concrete. The friction losses, H_f are shown in **formula 3.8.2.** [6]

$$H_f = f \cdot \frac{L}{D} \cdot \frac{U^2}{2g} \qquad \textbf{[3.8.2]}$$

f: Reynolds number, corresponding to the quota between the inertia forces and the friction forces.
L: Length of the pipe
D: Diameter of the pipe
U: Average speed of the fluid
g: Gravity constant

To minimize the friction losses a large pipe should be used and the average speed of the fluid should be as low as possible.

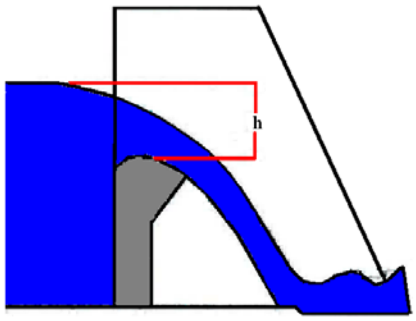
Additional losses in a hydro power plant are the stream losses in a point originated from narrowing pipe, widening of pipe or direction changes of the pipe. **Formula 3.8.3** illustrates these. [21]

$$h_t = k \cdot \frac{U^2}{2g} \qquad \textbf{[3.8.3]}$$

h: Additional losses
k: Resistance coefficient
U: Average speed of the fluid
g: Gravity constant

3.8.1.3 Water flow

When calculating the water flow, the construction of the water magazine needs to be taken into account. There are two different cases, either it can be constructed using obstacles for the water, placed in the outlet of the water magazine, see **Figure 3.8.1,** or using gates, see **Figure 3.8.2**. The obstacle, often constructed by timber, can be adjusted depending on the wanted output flow from the water magazine.



3.8.1: Water head for an obstacle construction

The flow from this kind of construction is described with **formula 3.8.4.** [2]

$$Q = \frac{2}{3} \cdot \mu \cdot b \cdot h^{3/2} \cdot \sqrt{\frac{2}{3}}$$ **[3.8.4]**

μ : A constant of 0.6 for this type water magazine.

b: Width of the opening

h: The distance between the head water head to the obstacle.

Usually a water magazine uses gates for adjusting the water flow. An example of this is shown in **Figure 3.8.2** and the calculation needed for this case is shown in **Formula 3.8.5.** [2]

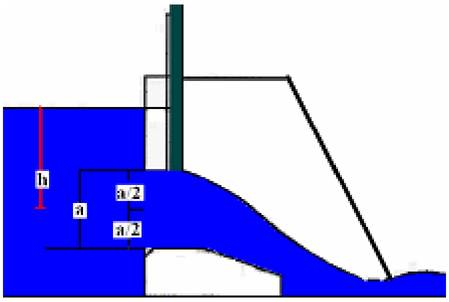


Figure 3.8.2: Water head for a gate construction

[3.8.5]

$$Q = \mu \cdot a \cdot b \cdot 2gh$$

μ : Corresponding to a constant of 0.6

b: Gate opening

g: Gravity constant

a: Gate height

h: Distance from the upper part of the head to the middle of the gate

3.8.1.4 Power calculations

Once the flow and useful head is calculated, the power delivered from a hydropower plant can be calculated. To find the actual output, the efficiency of the plant needs to be considered. Notice that this is the power produced in the hydro power plant and there are of course additional electrical loses when delivering the electricity out on the electrical grid. These are however not included in these calculations. The efficiency then depends on losses in the turbine, generator and the transmission. Efficiency for the turbine is around 0.85, generator 0.95 and the transmission 0.97. This gives an approximate total efficiency of 76 %. The total output power can be calculated with **formula 3.8.6.** [21]

$$P_{th} = H \cdot Q \cdot g \cdot r \cdot n_{tot} \qquad \textbf{[3.8.6]}$$

H: Net head
Q: Water flow
r: Density of water
n_{tot}: Total efficiency

To increase the power output, the efficiency of the plant can be improved, as well as the head of water. The head can be increased by increasing the amount of water in the magazine, but only to a preset level. There are rules set by the government to improve the security for hydropower plants, restricting the allowed water levels in the magazine. RIDAS is a guide line for water magazine security distributed by Svensk Energi. [31] [2]

The efficiency of the turbine depends on whether it is a Pelton, Kaplan or a Francis. This is shown in **Figure 3.8.3**.

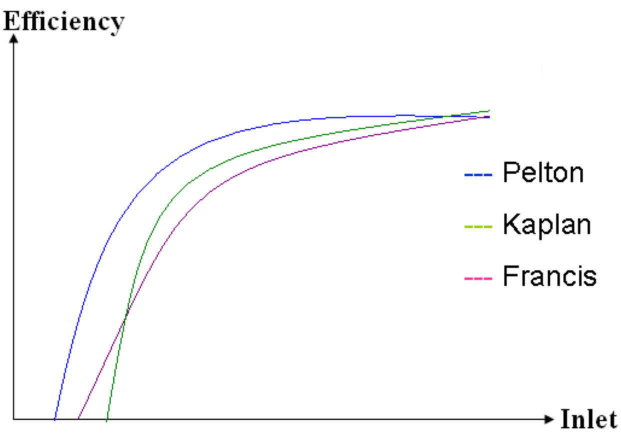


Figure 3.8.3: Efficiency of turbine

3.8.2 Construction of a combination curve

For a Kaplan turbine a combination curve is used to adjust the guide vanes and the runners to find an optimal operation point in order to withdraw maximum efficiency for different inlets. The curve can be bought together with the turbine or constructed by measurements. For construction of a Kaplan curve by measurements, the output power is measured for a constant angle of the runner with different angles on the guide vanes. In the next step the angle of the guide vanes are held constant and the angle of the runner is changed. This test will result in a graph displaying the maximum efficiency for different inlets. By using these maximum the combination curve is achieved. **Figure 3.4.3** shows a typical combination curve.

Today the regulator uses several preset combination curves for different water flows, but IETV is developing a new system with a dynamic combination curve that is constantly updated for the current water flow. This will increase the efficiency even more. However, this is not completely developed yet.

3.8.3 Shaft and gear

The shaft between the turbine and the generator has to be connected. To run a hydropower plant in direct operation is the cheapest solution and an asynchronous generator could be connected without any regulation between. However, since a synchronous generator has to run on its synchronous speed, some sort of adjustment has to be made. A gear could be used for this but usually a transmission belt is used for this purpose.

3.8.4 Generator

The two types of generators for alternating voltage used in hydro power plants: Synchronous and asynchronous generator was described previously in **Chapter 3.4.2**. In this part these are further explained.

3.8.4.1 Induced current

A generator uses the interaction between current and a magnetic field, described by Faradays induction law. This is illustrated in **Figure 3.8.4.** The metal winding in the changed field induces a voltage that induces a current in the winding. Faradays law states that the induced voltage in a coil is proportional to the magnetic flow regarding time.

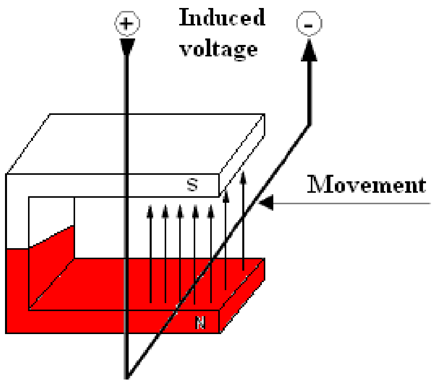


Figure 3.8.4: Faradays induction law

Lentz law states that the induced current will act to counteract the change in magnetic flow. This describes in what direction the current will flow.

3.8.4.2 Pole pair number

A generator has a number of poles divided equally into north and south poles. Usually it is therefore described as the pole pair number, since there is always a corresponding south pole to a north pole, and vice versa. The pole pair number is determining at what speed the generator is rotating. This can be seen in **formula 3.8.7**. The frequency is set by the frequency on the electric grid, which in Sweden is 50 Hz.

$$n_s = \frac{f \cdot 60}{P} \qquad \textbf{[3.8.7]}$$

n: Speed of the generator
P: Number of pole pairs

3.8.4.3 Synchronous generator

To produce a rotation in the generator, magnets and currents are used. Faradays induction law has been explained and it is therefore easy to imagine operation. The main parts of the synchronous generator are rotor, stator and windings. The rotor consists of poles and with a current these are magnetized into north and south poles. These are then pulling the stator's magnetic field when the generator rotates. The speed of the synchronous generator is synchronous which means that the magnetic field and the rotor are rotating with the same speed. Because of this, a gearbox is required since the turbine does not rotate at the synchronous speed constantly.

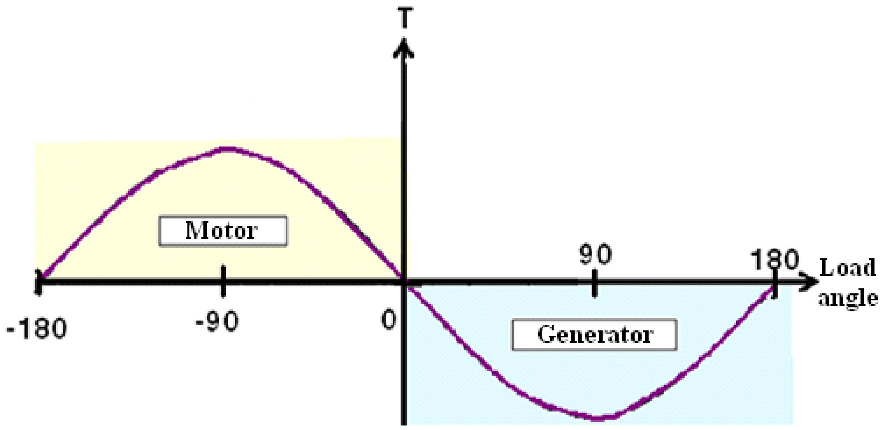


Figure 3.8.5: Synchronous generator

If a synchronous generator is operating as a generator, then the rotor is pulling the stator field, for motor operation the stator field is pulling the rotor. The speed of the rotor and the stator field are the same and the sequence of these fields determines whether it is motor or generator mode. This is described as the load angle and it is the angle between the stator field and the rotor. This is shown in **Figure 3.8.5**. [29]

3.8.4.3.1 Magnetization

A synchronous generator consumes reactive power. Therefore, when using a synchronous generator, the production of reactive power needs to be compensated with usage of a reactive producing device. This device creates reactive power from a rotating magnetic field created by the magnetizing process and thus, reactive power is created. This compensate for the consumption of reactive power in the generator. However, the synchronous generator can be either a hysteresis generator or a commutated generator. The hysteresis generator type has magnets in the rotor and therefore do not need any separate magnetization equipment. This is only for the commutated generator. The advantage of the magnetization process is that the outgoing voltage can be controlled.

The external magnetizing process is inducing a direct current to the rotor windings. The amount of reactive power has to be adjusted to the amount of produced energy in the generator, accomplished by adjustments of size for the direct current. Therefore the control systems secure the induced current to the rotor windings to be correct in relation to the produced power. This is done with a PI regulator [25]; see **Chapter 3.8.6.2** for more information. The direct current is produced with a half controlled AC/DC rectifier, and by using this one the current is controlled by two thyristors. [28]

3.8.4.4 Asynchronous generator

An asynchronous generator is very much like a synchronous generator. It consists of a rotor, a stator and windings. The stator is the fixed outer part and it is made from an iron core. Between the rotor and the stator there is an air gap that should be as small as possible, since the magnetic flux needs to be able to pass easily. The rotor is made of an iron core as well. The asynchronous generator has a rotor cage consisting of conductors and a short-circuit ring instead of poles which is the case for the synchronous generator. The rotor is pulled around with induction from the stators magnetic field. In an asynchronous generator the speed is asynchronous which means that the stator magnetic field is rotating, slightly lagging the rotor. [30]

The rotation speed determines whether the asynchronous generator is operating as a motor or a generator. This is shown in **Figure 3.8.6**. For a generator, the speed should be slightly higher than the synchronous speed and for a motor, slightly lower. The difference in speed is described as the slip, see **Formula 3.8.8**. The slip therefore describes the difference in speed between the magnetic flow and the rotor. [29]

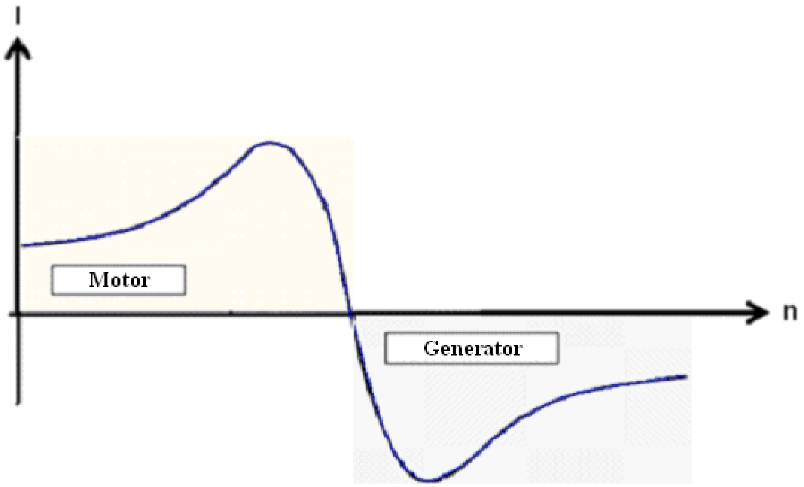


Figure 3.8.6: Asynchronous generator

$$s = \frac{n_1 - n_2}{n_1} \quad [3.8.8]$$

n_1: Synchronous speed
n_2: Mechanical speed

3.8.4.5 Difference between synchronous and asynchronous generator

The difference between the two types of generators is the design of the rotor. In a synchronous generator the rotor consists of poles and these pulls the magnetic field of the stator, while in an asynchronous generator the rotor is consisting of a rotor cage and a short-circuit ring instead of poles.

The choice between the generators is made depending on the size of the plant. In smaller plants, asynchronous generator are preferably used since they are cheaper, simple to connect to the grid, does not require as much control equipment, does not require a gearbox and can deliver electricity at lower speeds. In larger plants a synchronous generator is used.

3.8.5 Sensors

A sensor detects and gives information and is an essential part of the control system. There are several different types of sensors on the market today and the techniques are varying depending on what should be measured. The sensor consists of three main components, the detector, the sensor element and inner signal processing. The detector is directly affected by the measured parameter further transformed into a physical quantity possible to transform into an electrical signal. The inner signal processing affects the signal in order to make the output signal useful. Here the signal can be changed from analogue to digital or vice versa.

What type of sensor element that is used in the sensors defines the sensors into three different types; resistive, capacitive or inductive. These are divided into types based on what physical law that is used. Resistive sensors are mainly used to measure temperatures, angles and lengths. Capacitive and inductive sensors can both measure lengths, differentials etc. A sensor always uses a physical connection between the input and output signal. For instance, if a temperature should be measured, the connection between a metals resistance and temperature is used. Depending on the resistance of the metal the temperature can be found in a temperature- resistance for each type of sensor. [27]

3.8.6 Control technology

It is important to distinguish between the concepts of surveillance and regulation. In a control system in a hydropower plant both is used. If surveillance is used the sensor is contacted to a breaker and an alarm. In a control system, pulse regulation or a regulator can be used. [23]

3.8.6.1 Pulse regulation

Pulse regulation is an old and less advanced way of controlling a process than PID regulation. As the name implies it uses pulses for regulating for either increasing or decreasing a value. For instance, if the water flowing into the turbine needs to be regulated there needs to be either an increase or decrease of the gate opening. The size of the pulse is depending on the regulation fault. This can be seen in **Figure 3.4.8** and was explained in **Chapter 3.4.3.1**.

3.8.6.2 PID regulation

In more modern systems a PID regulator is used. PID stands for the different parameters in the regulator.

- P, denoted as Kp - proportional influence, used to control the speed of the regulator.
- I, denoted as Ki/s - integral influence, used to improve the compensation for low frequent interference.
- D, denoted as Kds - derivative influence, used for the system's speed to be increased without the system becoming unstable. [9]

IETV usually uses the P and I part of the PID regulator when programming the PLC. The programming and parameter setting of the regulator is performed with the program GX Developer. These can be designed in different ways depending on the requirements from the system. Previous experience from designing these for applications in hydro power plants makes it easy for IETVs staff to set these in a correct way.

3.8.6.3 Stability

If the speed of the regulation is too high, the system will be unstable and if the regulation is to slow the demands of the system may not be reached. The stability can therefore be a problem in a regulation system and this origin from errors in the dimensioning of the parameters Kp, Ki and Kd. However, in a hydropower plant the regulation processes are slow and the parameters controlled naturally changes slowly, i.e. water level in the water magazine and opening of the water gates. Therefore, stability in the regulation systems is not a problem, thus the D part in the PID regulator is not used. [23]

3.9 Evaluation

During the final part of this project a summation of the education packages was presented to three, for this matter, relevant employees at IETV. The audience consisted of one person from construction, one technical expert and the project leader, Malin Frimar. The presentation was a combination of B.1, B.2 and C abridged into three hours. This evaluation contributed to the correct opinion of whether the goal of the project was fulfilled. Malin Frimar was satisfied regarding the requirements given from the start of the project. The participants were overall satisfied and certain that the presentation was adequate, considering information, layout and extent. They agreed, all parts needed were included and they found a clear distinguish between the different education levels, which was a main concern for them. They mentioned for example advantages like the possibility to change timeframe and to remove slides if necessary, as well as the detailed education material for the lecturer. The practical exercises was agreed to give useful real life examples for maneuvering the plant, for examples start, stop, perform maintenance and searching for faults.

Even though the education in its whole has never been presented the education material has been carefully reviewed by several of IETVs employees, Malin Frimar, Kenneth Benjaminson, Mikael Hag and the CEO of IETV, Magnus Carlsson. They all approved to the content and found the educations representable for IETV.

4 CONCLUSIONS

The project proceeded without any major difficulties and the project was fulfilled as the goal was reached. However, no exact conclusion regarding the result of the quality for customers can be made, since no actual education yet has been performed. However the approval from IETV gives an indication of a well accomplished project. The evaluation was satisfying and the overall project is considered to be successful. Since the aim was to deliver useful educations for IETV, the project resulted as desired. The evaluation proved the educations to be helpful for the customers to better understand the system.

When developing a teaching material, the customer's previous knowledge in the subject needs to be considered and the educations in this project needs to be adjustable for a wide range of customers. The challenge could be solved by producing a longer education material than necessary after the conclusion that to remove a slide is easier than to construct a new one.

Conclusions regarding the lecturer and the teaching material involve the importance of an extensive amount of text exclusive for the lecturer. This thought arose during the start up when the amount of text on the slides was to be minimized. However, a well prepared lecturer needs more extensive information for a comprehensive education.

4.1 Future work

Since this education is made with a wide application range, for different types of customers, the lecturer may have to adjust the slides to suit the audience based on their previous knowledge and what kind of system that their power plant uses. Some of the information need to be updated regularly to be relevant, for instance new technologies in wind power can emerge and the economical conditions changes. Also IETV could change their technology and therefore need to update the education.

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APPENDIX A

Project description – education project within energy production

Purpose:
Create a sustainable education package for IETVs customers that has sufficiently high quality and doable for a company of IETVs size. For example: one person should be able to give the education for five to eight persons.

Content:
The following parts should be included:
A) Renewable energy production for decision makers: (3h)
An overview in wind and hydropower production helpful for decision makers within municipalities, private companies, land owners etc. Basic technique, economy, environmental impacts, questions and discussion. For approximately 10-15 persons.
B) Operating personal hydropower. Part 1: Operation, control (8h)
Educate o*perating personal* in IETV:s control equipment. Management: run, set parameters, start, stop, maintenance. See manuals and circuit diagrams.
For example: Generator protection unit, touch screen, PLC, direct current system, external communication.
Practical examples.
C) Operating personal hydropower. Part 2: Service and fault search control (8h)
Further educate operating personal in troubleshooting IETVs control system.
Practical examples.
D) Intensifying in *hydropower control theory*
Educate persons that have previous knowledge in hydropower, for example operating executives or operating personal.