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Masters Thesis
Decentralization of Electricity Production in Distribution Network

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1. Renewable energy sources - general overview
2. Renewable energy sources - focus on hydro and biomass application
3. Integration RES to distribution network (guidelines, standards)
4. A case study for connestion of the photovoltaic power plant to distribution network

Bibliography/Sources:

[1] World Energy Outlook 2016
[2] Distribution network code
[3] eVlivy application manual

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Prague, February 20, 2017

Declaration

I declare that I have worked on my diploma thesis titled Decentralisation of Electricity Production in Distributed Network by myself and I have used only the sources mentioned at the end of the thesis. This thesis is the presentation of my original research work. As the author of the Masters thesis, I declare that the thesis does not break copyrights of any other person.

In Prague on 24/05/2017 ______________________________

Acknowledgement

Greatest thanks go to Almighty Allah for giving me the knowledge, understanding and strength to complete this thesis. I would like to thank my families, friends for their support and encouragement to the success of this thesis. Humble thanks go to Ing. Frantisek Vybiralik CSc who happened to be my supervisor for his advice, suggestion and support to make this thesis a success. Also to doc. Ing. Jan Kyncl for his devoted help, time, advice and guidelines during my studies. The last humble thanks go to Ing Famous O. Igbinovia for his guidelines and support to make this thesis a success.

Decentralizace výroby elektřiny v distribučních sítích

ABSTRAKCE

Produkce energie z vodních zdrojů je pravděpodobně jednou z nejstarších technik výroby elektřiny vůbec. Z obnovitelných zdrojů jsou tyto zdroje navíc v Evropě největší. V elektrických distribučních sítích je většina decentralizované výroby elektřiny vyráběna ve vodních elektrárnách.

Tato diplomová práce představuje komplexní simulační analýzu rozvoden NYMBURK a BROD a jejich 22 kV rozvodů ve Středočeském kraji. Simulační schémata byla ověřena pomocí softwaru eVlivy prostřednictvím modelování rozvoden NYMBURK a BROD. Analýza zatížení byla zaměřena na charakterizaci dynamické odezvy a řízení stálosti napětí, ztráty výkonu a řízení jalového výkonu na silnoproudé vedení 22 kV s integrací HPP. Bylo zjištěno, že integrace HPP s komponentou s jalovým výkonem, pracující na činiteli výkonu mezi 0,97 a 0,98, pomůže minimalizovat ztráty vedení, stabilizovat napětí a regulovat reaktivní výkon 22 kV elektrického vedení, připojené k vodním elektrárnám NYMBURK a BROD.

Klíčová slova: Vodní Elektrárna, Ztráty Energie, Aktivní Energie, Reaktivní energie, Decentralizace Výroby Elektřiny, Obnovitelná Energie, Výroba Elektřiny, Distribuční Síť, Rozvodna BROD, Rozvodna NYMBURK

Decentralization of Electricity Production in Distribution Network

ABSTRACT

Hydropower production is perhaps one of the oldest power production techniques and the largest renewable energy sources in Europe. In electricity distribution networks, most of the decentralized electricity production is Hydropower production.

This master's thesis presents a comprehensive simulation analysis of the NYMBURK and BROD Substations and their distribution lines 22 kV in the Central Bohemia Region.

Verification of the simulation schemes using eVlivy software through modelling of the NYMBURK and BROD Substation was used. The loads analysis aimed to characterize the dynamic response and to control voltage stabilities, power losses and reactive power control on the 22 kV power line with the integration of HPP. It has been discovered that, the integration of HPP with a reactive power component working on power factor values between 0.97 and 0.98 helped to minimise the line losses, stabilise the voltage and control the reactive power of the 22 kV power line connected to the NYMBURK and BROD hydropower stations.

Keywords: Hydropower Plant, Power Losses, Active power, Reactive Power, Electricity Generation Decentralisation, Renewable energy, Electricity Production, Distribution Network, Substation BROD, Substation NYMBURK

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List of Abbreviation

AC	Alternating Current
AVR	Automatic Voltage Regulator
CCS	Carbon Capture and Storage
DC	Direct Current
DE	Decentralise Electricity
DG	Distributed Generation
DSO	Distribution System Operators
GDP	Gross Domestic Product
HPP	Hydropower Plant
LV	Low Voltage
MV	Medium Voltage
MVE	Medium Voltage Electricity
OV	Overhead
PCC	Point of Common Coupling
PV	Photovoltaic
RES	Renewable Energy Sources
RPC	Reactive Power Compensator
STATCOM	Static Synchronous Compensator
SVC	Static Voltage Compensator
TSO	Transmission System Operator

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1 Introduction

Decentralized electricity generation (DG) is an electric power source connected directly to the distribution network or on the customer side of the meter. It is also known as distributed electricity generation. The size of the power plant may be varied from Micro-DG, that is below 5 kW, small DG that is between 5 kW to 5 MW, medium DG between 5 - 50 MW, and large DG between 50 -300 MW. Decentralized power is produced close to where it will be used, rather than at a large power plant elsewhere and power is transmitted through the national grid. This type of local generation reduces transmission losses and lowers carbon emissions. Security of supply is increased nationally as customers do not have to share supply source or rely on relatively few, large and remote power stations. Electric power was originally produced at remote hydroelectric dams or by burning coal in city centres, delivering electric power to nearby buildings and recycling the waste heat to make steam to heat the same buildings. But rural houses had no access to electric power. Over time, conventional power plants grew in size, facing pressure to locate far from densely populated areas due to pollution from these plants.

Transmission wires carried the electricity many miles to users with a 10% to 15% loss, a difficult but tolerable situation. Since it is not practical to transmit waste heat over long distances, the heat was vented. There was no good technology available for clean, local generation, so the wasted heat was a trade-off for cleaner air in the cities. Eventually, a huge grid was developed and the power industry built all-new generation in remote areas, far from users.

All plants were specially designed and built on the site, creating economies of scale. It cost less per unit of generation to build large plants than to build smaller plants. Everyone in the electric power industry and government came to assume that remote, central generation was optimal, that it would deliver power at the lowest cost as compared to other alternatives. Long term decentralized electric power can offer more competitive prices than traditional power. Although initial installation costs might be high, a special decentralized energy tariff creates the more stable pricing. Decentralized power is the cost-effective way to achieving low carbon targets. This approach to low carbon power provision gives stakeholders the opportunity to promote a locally provided, sustainable, competitive and smarter electric power choice [1] – [3].

1.1 Balancing Electricity Production and Consumption

Production and consumption of electricity must always be balanced, while dynamics of the system handle small deviations. The consumption of electricity has the tendency to fluctuate continuously owing to end user’s behaviour, and generators need to be controlled to follow the consumer load profile. As renewable production often depends on weather conditions, its generation output will vary independently from the demand for electricity. For the proper planning and operation of an electric power system it is essential to match production and consumption load on different time scales. Investment planning deals with decisions on a horizon of several years. The choices to be made are whether or not to invest in conventional, nuclear or renewable power technology and where to locate them. It is determined which generators will be utilized to supply electricity consumers in the unit commitment process.

This optimization process takes into account the availability of generating units due to maintenance, and estimations of the load and generation by renewable sources. After it has been decided which generators will be online to provide the electric power requested, in the economic dispatch process it is determined how much each generator will generate. A better prediction of renewable power generation is taken into account as well as the latest information on the load consumption. Excellent predictions will be very important as the share of renewable production in the grid increases to perform economic dispatch in an optimal way. Any mismatch between electricity production and load consumption after economic dispatch will be settled by controls that operate in real-time. These mismatches can come from different origins, these are:

- Forecasting errors for production and load consumption.
- Control policy and inaccuracies of production with respect to load consumption.
- And events, such as failures of production, consumed loads or part of the network.

As more and more renewable production is introduced into the power system, the likeliness of causing imbalances is expected to increase. Highly accurate predictions of both consumed load and produced electric power by shortening the prediction time, as well as decreasing the time scales in trading, are expected to reduce this effect. This thesis work focuses on balancing electricity production and load consumed using renewable power sources. This research focuses on the ancillary service meant to support the basic power delivery functions of production, and supply/consumption [4] – [5].

2 Objectives and Methodology

2.1 Objectives

This thesis research analyses the balancing of electricity production and consumption using renewable energy in a decentralized electricity production grid system. This research aims to explain the need for using this method of attendance in balancing electricity production and consumption. It examines the advantages and disadvantages of such system, as well as obstacles that limit their further deployment. Real-power balancing, that is frequency stability and Voltage support, that is voltage stability implementations are examined and compared to emphasize the cases where decentralized renewable technologies are considered as an alternative to grid balancing.
The specific objectives of this thesis are:

- To illustrate the use of renewable power technologies for balancing production and consumption in a decentralized electricity grid network, based on the analysis of both frequency and voltage stability situations.
- To analyse the processes that take place in connection to the implementation of renewable energy technologies, within the context of voltage stability situations in a decentralized grid network.
- To analyse the limitations associated with these voltage stability situations.
- To discuss the key points for the promotion of further use of this technology.
- To define the factors that make renewables power technologies an alternative to balancing electricity production and consumption in a decentralized grid network.
- Along with the resources at hand and other studies, the formulation of the hypotheses in this study is formulated. The formulated hypotheses are:
- Renewable energy technologies are utilized when it is economically or technologically unfeasible to balance production and consumption in a decentralized grid network.
- Electricity production and consumption balancing potential using renewable power sources determine the method of attendance in a decentralized electric power system.

2.2 Methodology

A research is a detailed study of a subject, especially in order to discover new information or reach a new understanding. A problem usually leads to the need to conduct research. This thesis is developed in form of case studies between two distributions Substations NYMBURK and BROD, which provides the descriptive analysis of the research objectives. A case study approach to these research objectives helps to build knowledge by exploring the peculiarity and the uniqueness of renewables power technologies as an alternative to balancing electricity production and consumption in a decentralized grid network. This thesis is developed for laying the groundwork necessary for an extensive literature review, and then using renewable power technology sources in balancing electricity production and consumption in a decentralized grid network within the context of frequency and voltage stability situation.

The created hypotheses were thereafter evaluated to be valid or not valid. The same implications led to conclusions and contributed to clarifying the situation of the implementation of renewable energy technologies, within the context of frequency and voltage stability situations in a decentralized grid network. Following the conclusions, suggestions to support further use of such technologies were made and the directions for future research were mentioned, reaching the starting point of the research process.

2.3 Scope

This research is specific to the use of renewable power technologies for balancing production and consumption in a decentralized electricity grid network, based on the analysis of both Real power balancing (frequency stability) and Voltage support (voltage stability). The scope of this study lies within the assessment of using renewable technologies to balance electricity production and consumption and also sheds light on the impacts it can create on decentralized grid network.

3 Electricity Power Systems

This chapter reviews the status of modern power systems and discusses the possibility for modernizing the grid, thereby creating the modern electricity grid network. The focus is on the technologies of the devices involved.

3.1 Current Research

For some time now, restructuring of the electric-power industry has been taking place, largely due to the introduction of renewable power production technologies. Renewable energy technologies are well suited for the need of decentralized power supply and can be used to achieve voltage stability, reactive power production and to minimize power losses modern power networks. The development of renewable energy is becoming a significant part of the generation capacity in the electric-power industry. Hence, power system analysis should treat these energy sources not only as an energy source, but also as a power source. The effects of the growing renewable power and penetration on the stability and reliability of power systems is of great interest. Wherever, hydro, biomass, wind, solar and other renewable power will be installed on a large scale, studies are carried out to prevent severe consequences for the power system.

Previous research has focused on the effects of adding compensating units such as Static Synchronous Compensator (STATCOM) and Static Voltage Compensator (SVC) to improve the voltage stability at the Point of Common Coupling (PCC) of wind farms and Photovoltaic (PV) sources. A renewable energy system connected to the grid can be utilized as a reactive power compensator (RPC). Its main characteristics are its ability to compensate reactive currents drawn by grid or inductive loads while simultaneously injecting into the grid network the maximum power available from the renewable source. The reactive power compensator feature of renewable systems can also be used to improve the utilization factor of the system. The impact of grid connected renewable power plants on power losses have also been done, analysis shows that placing renewable power plants in the centre of gravity of consumption reduces power losses [6] – [11].

The integration of renewable energy sources into existing power systems is one of the main challenges due to the main concerns about power system stability as well as reliability. In power systems, the issue of voltage stability is one of the main indicators of system stability. Generally speaking, voltage stability issues occur more frequently in heavily loaded systems. It is of interest to note that change in voltage is directly proportional to the change in load. Therefore, voltage stability is sometimes termed as load stability. Voltage variation is a major issue associated with renewable energy. This can be a limiting factor on the amount of allowed renewable energy to be installed.

Renewable generating systems, for instance wind turbines, small hydro power plant equipped with induction generators consumes reactive power. At no load, the reactive power consumption is around 35–40% of the rated active power, and increases to about 60% at the rated power. Reactive power is one of the major causes of voltage instability in grid networks. It also contributes to power losses. Renewable systems like the utility-scale PV plants are designed to produce active power only. Reactive power is avoided due to losses in the inverter, lines and transformers. During three-phase short circuit situation, the consequent voltage drop is that high. However, plants such as PV has to remain joined to the grid and in order to inject a certain amount of short-circuit current. Hence, a centralized static VAR compensation scheme has to be installed to provide the needed VAR since PV schemes produces active power only [9], [12] - [16].

3.1.1 **Modern Electricity Power System**

3.1.1.1 Current Power System

Electricity power transmission and distribution is the vital link between generating stations and consumers, and this is in urgent need of expansion and upgrading in many part of the globe. Growing loads and aging equipment are stressing the electric power system and increasing the risk of widespread blackouts. Modern society these days depends on reliable and economic delivery of electricity. Recent concerns about electricity transmission and distribution systems have stemmed from inadequate investment to meet growing demand, the limited ability of these systems to accommodate renewable-energy sources that generate electricity intermittently, and vulnerability to major blackouts involving cascading failures. However, effective and significant utilization of intermittent renewable power generation located away from main load centres cannot be accomplished without significant additions to the transmission power system.

Additionally, distribution power systems often are incompatible with demand-side options that might otherwise be economical. Modernization of electric power systems could alleviate all of these concerns [17]. The power transmission and distribution system has been called the wonder machine and part of the world’s greatest engineering achievement of the 20th century. Massive power plants deliver electricity from large power plants to virtually every building and facility in every nation on the globe. Modern electric-power systems increase the efficiency of electrical power productions, transportation and distribution, it equally lower carbon footprint for a greener environment. It includes green generation of electricity by means of Solar Systems, Wind Power Technology, Geothermal Technology, Biomass and Hydro Power [17], [18].

The modern electricity power systems have three separate components, these are: production, transmission and distribution. Electricity power is produced at the power generating stations by synchronous alternators that are usually driven either by steam or hydro turbines. Most of the electricity power production takes place at generating stations that may contain more than one such alternator-turbine combination. Depending upon the type of fuel utilized, the electric-power producing stations are categorized as thermal, hydro, nuclear, biomass, wind, solar, Tides, and Geothermal heat. Many of this electricity producing stations are remotely located. Thus, the electric-power produced at any such station has to be transported over a long distance to load centres that are usually cities or towns. This is called the power transmission. Electricity power transmission towers and lines are very common sights in distance places from residential homes.

3.1.1.2 Future Power System

Modern day electric-power systems are complicated networks with hundreds of electricity generating stations and load centres being interconnected through power transmission lines. Electricity is produced at a frequency of 50 Hz. In an

interconnected AC power system, the rated generation frequency of all units must be the same. The determination and regulation of fault levels, active power, reactive power, voltage and frequency are very essential in a modern electricity grid system. Power quality problems are equally addressed by modern mitigation methods [18]. The components of a modern electricity grid are presented in
Figure 1

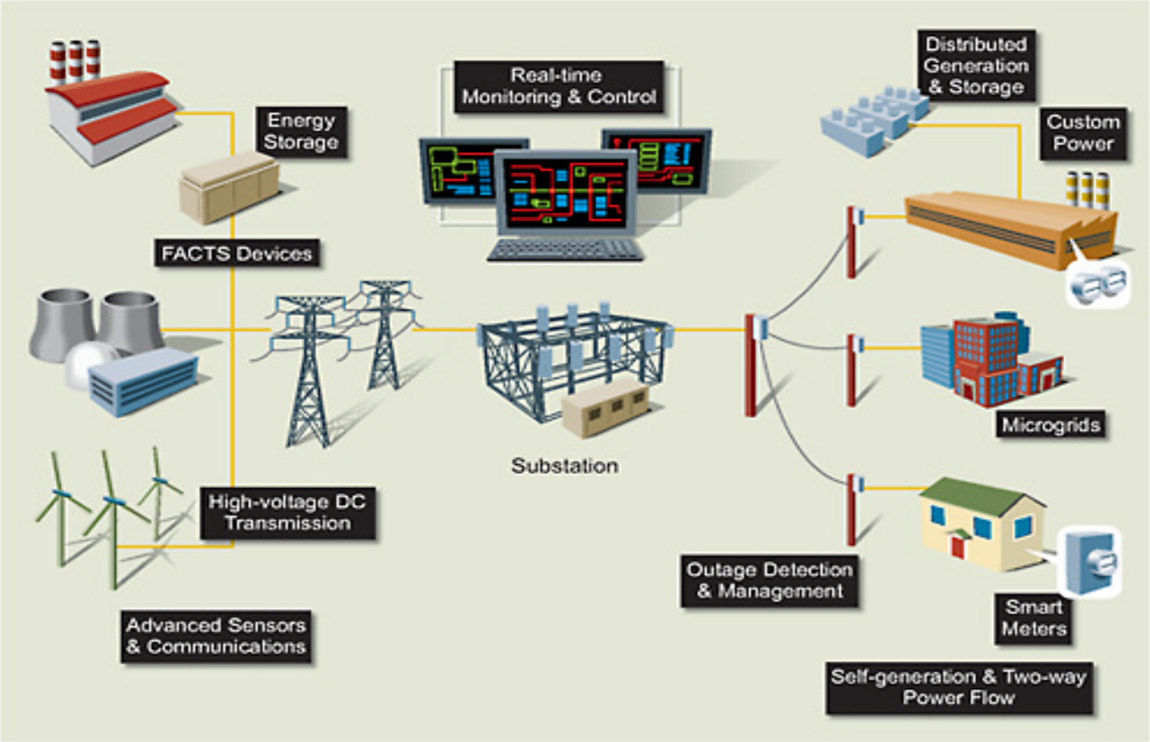


Figure 1: Components of Modern electric power system [17]

Smart Grid: Our current electricity conceived more than 100 years ago was designed simple when electricity was designed when electricity needs/demands was simple. Power generation was localised and build around communities. Most homes has only small energy demands such as a few bulbs and radios. The grid was designed locally to deliver electricity to the consumer and billed once a month. This limited one way inter reaction makes it difficult for the grid to respond to the ever changing and rising energy changes demands in the 21st century.

The smart grid introduces a two-way dialogue where electricity and information can be exchanged between utility and its customers and also senses along the transmission lines. Its diverging network of communication controls computers, automations, new technology and tools working together to make the grid more efficient, more reliable, secure and greener. These technologies work together with the electric grid in order to respond digitally to the quickly changing electric demands. The smart grid enables most technology to be integrated such as solar, wind production and plug in to the electric vehicles charging. The smart grid is designed to replace the aging infrastructure of today's grid, which helps utilities to communicate with the suppliers for easy management of electricity needs. [54]

Micro Grid: Micro grid is simply the local energy grid with control capability, which provides backup to the grid in emergency situation and more economical to use. It can be disconnected from the traditional or local grid and operates independently and its more environmental friendly in some cases.

The power supply from micro grid to an area has been a major challenge due to their distance from the power generation plants. Economically, it's highly expensive to build and maintain a long distance transmission lines. Rural areas with marginal or no access to primary grid power can get power supply from setups like micro grids or independent power grids. Traditionally micro grid uses diesel generators and diesel backup system to generate electricity but with the improvement of newer technology, micro grids start with integration of renewable energy such as wind and solar energy. Micro grids are small and easily affected by fluctuation in supply and demands to maintain grid stability and power quality. Micro must grid continually monitor demands and accordingly regulate generation since unstable grid can lead to blackout or brown out even worse damage assets on the grid.

To maintain the stability of the grid, 10% of the total generated electricity is reserved for managing fluctuations. This reserved capacity is used to ramp power up and down for controlling electricity demand whiles the other 90% is dedicated to the base loads. Ramping can be provided by diesel generator, however it isn't the most efficient use of generators since the operational cost is high, increases transportation costs, create wear and tear on equipment, and increase maintenance cost, which leads to higher carbon emissions. Micro grids are influenced by the intermittent nature of wind and sunshine when variation of cloudy days or less wind may cause significant minute-to-minute fluctuation. In generation output response, diesel generator will need to even ramp harder and more frequently to smooth variations, further increasing cost associated with ramping.

In order to eliminate these cost associated with ramping, battery-based quick response energy storage system can be utilised for diesel generators micro grids. These systems can store energy when the demand is lower than the supply and deliver real time and reactive power to the micro grid when demand is higher than supply. The energy storage system will not only reduce cost associated with ramping diesel generators, but will also reduce carbon emissions. Smart grid is the future supply of electricity needs since it provides more electricity to meet the rising demands, increase energy efficiency, reliability and power supplies. Moreover it integrates low carbon sources into power networks [53], [54]

Smart Meter: Smart meter is basically an electronic measuring device that records consumption of electric energy in an intervals of an hour or less and the information is communicated at least daily back to the utility for monitoring and billing. It enables a two-way communication between the meter and the central system. The communication between the meter and the network can be done through a fixed wire connections or wireless. Smart meters provide customers information about their consumptions, which help them to regulate the amount of energy used. They also encourage decentralised system, micro-generation of energy, thus transforming the consumer into energy producer. Moreover, smart meters enable new energy services for improving energy-efficiency.

They produce fewer radio frequencies as compared to microwaves, Wi-Fi and cell phones and transmit less than 2 minute a day on average. The technology has been thoroughly tested for safety, reliability and accuracy [2]

3.2 Electricity Production

3.2.1 Current State

Electricity is generated in power plants that utilize primary energy sources. These primary sources can either be fossil and nuclear fuels such as coal, lignite, natural gas, oil or uranium, biomass or any other type of renewable energy sources. The production plants are owned and exploited by electricity generation companies. If a generation company owns multiple generating units, it can optimize its generation portfolio via unit commitment and economic dispatch processes. The consumption of electrical energy is constantly varying and, since electricity can hardly be stored in large quantities, the generation of electricity must be matched with demand continuously. As many large generators cannot easily be switched on or off, their output needs to be scheduled in advance. This is done in the processes of unit commitment and economic dispatch. If industrial production requires electricity on a windless winter morning, solar energy systems and wind turbines reach their limits. Then, power plants, which can convert fossil fuels into electricity no matter what the time, provide the electricity quantities required. Power plant technologies are under development for coal and gas, which can generate electricity more efficient and with lower emissions than previously. A realistic comparison of the efficiencies of modern power plant processes helps in decisions on the role of coal and gas in the future energy mix [19].

Burning coal, natural gas and mineral oil generates 60% of electricity worldwide. Fossil power plant technology will remain extremely important for the power supply in the decades to come. Decreasing the carbon dioxide emissions to the atmosphere as a result of this process is the aim of climate protection and is intended to restrict global warming.

3.2.2 Future State

For more efficient power plants and separation of most of the CO_2 using Carbon Capture and Storage (CCS) technology, a variety of development options for power plant processes are available. This process ensures that less than 100 g/kWh of CO_2 is released when converting coal into electricity. Thus, the CO_2 emissions are less than one third of those of natural gas-fired combined gas and steam turbine plants without CCS. The EU set a target called vision 2020 in 2014, where 20% of renewables should be used and 20% reduction of CO_2 emission to be reduced by 2020 in all European countries. Due to this, the increase impact on renewables to reduce the CO_2 emission has been tremendously used by Germany, Norway, Denmark and Sweden. When generating electricity cost effectively, efficiency and emissions are key parameters and must be determined objectively to make the right decisions. By comparing different power plant processes under uniform constraints, their efficiencies and potential CO_2 avoidance can be evaluated with greater precision [19], [20].

3.3 Electricity Transmission and Distribution

After electricity is generated, it needs to be transmitted to the consumers. Extensive transmission and distribution networks are in use for this purpose. Grid operators own and operate parts of the network. In well-functioning electricity markets, grid operators, being natural monopolists, have sufficient incentives to make investments in the part of the electricity grid they own and operate. Within a control area, one Transmission System Operator (TSO) and one or more Distribution System Operators (DSO) will exist. The grids that are operated by the TSO and DSOs are the transmission grid and distribution grids respectively. In Czech Republic and most European countries, the transmission system voltage level is 400/22 kV and the distribution voltage level is 110 kV for high voltage, 22 and 35 kV for medium voltage and 400/230 V for low voltage. Generators and consumers are connected to these grids and act as customers of network services at their point of connection.

An often-overlooked portion of the power and energy industry is the transmission and distribution space, an important cluster of industries that include the production of machinery, electric lines and transformers as well as line management systems such as smart-grid technology that improve efficiency. These are responsible for the actual delivery of the electric-power no matter the generation source, be it solar, gas, oil, wind, hydro, biomass or otherwise to commercial, private and industrial users in a usable format. The transmission and distribution market supplies equipment, services and production systems for energy markets.

The initial stage in the process is converting power from a generation source such as coal, nuclear, wind, hydro, biomass, etc. into a high voltage electrical format that can be transported using the power grid, either overhead or underground. This transformation occurs very close to the source of the power generation. The second stage occurs when this high-voltage power is stepped-down by the use of switching gears and then controlled by using circuit breakers and arresters to protect against surges. This medium voltage electrical power network can then be safely distributed to urban or populated areas. The final stage involves stepping the power down to useable flow voltage for the commercial or residential customer as shown in Figure 2.

While power generation relates to the installed capacity to produce energy from an organic or natural resource, the transmission and distribution space involves the follow up post-power generation production as systems and grids are put in place to transport this power to end users. While the transmission and distribution space does not perfectly follow typical industrial classification systems, its primary industries can be loosely distinguished from power generation [19], [21].

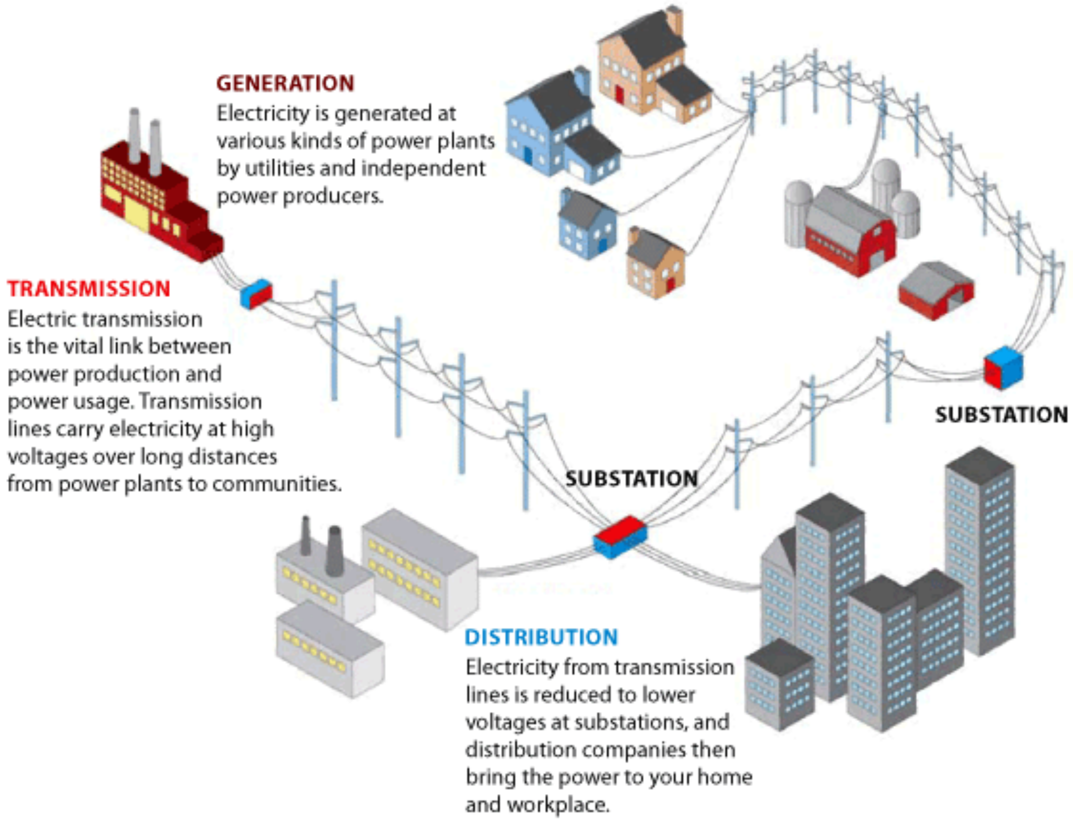


Figure 2: Production, Transmission and Distribution of Electricity [21]

3.4 Electricity Consumption

A nation's electricity consumption has been seen as a useful proxy for measuring economic growth offering a useful alternative to conventional measures such as gross domestic product (GDP) by incorporating the assumption that greater consumption means a better quality of life. However, country-by-country analysis reported in International Journal of Global Energy Issues suggests that this may not necessarily be the case. Despite staggering improvements in energy efficiency of production processes as well as of end-user appliances, growth in emerging economies is as energy-intensive as witnessed among the industrialized nations four decades' past.

The availability of electricity plays a significant role in achieving development outcomes in a few instances, while developmental outcomes such as higher income, themselves drive higher electricity consumption in others. If the production-consumption gap can be narrowed by managing technical and commercial losses in transmission and distribution more effectively, human development outcomes could be improved for nations where a negative impact is seen in their data. The consumption of electricity is a constantly varying process. Nevertheless, there are identifiable daily, weekly, seasonable and yearly patterns. A way to show the annual consumption of electricity is via the load duration curve, which illustrates the number of hours per year, that a certain load in the system (that is consumption) is exceeded [19], [22].

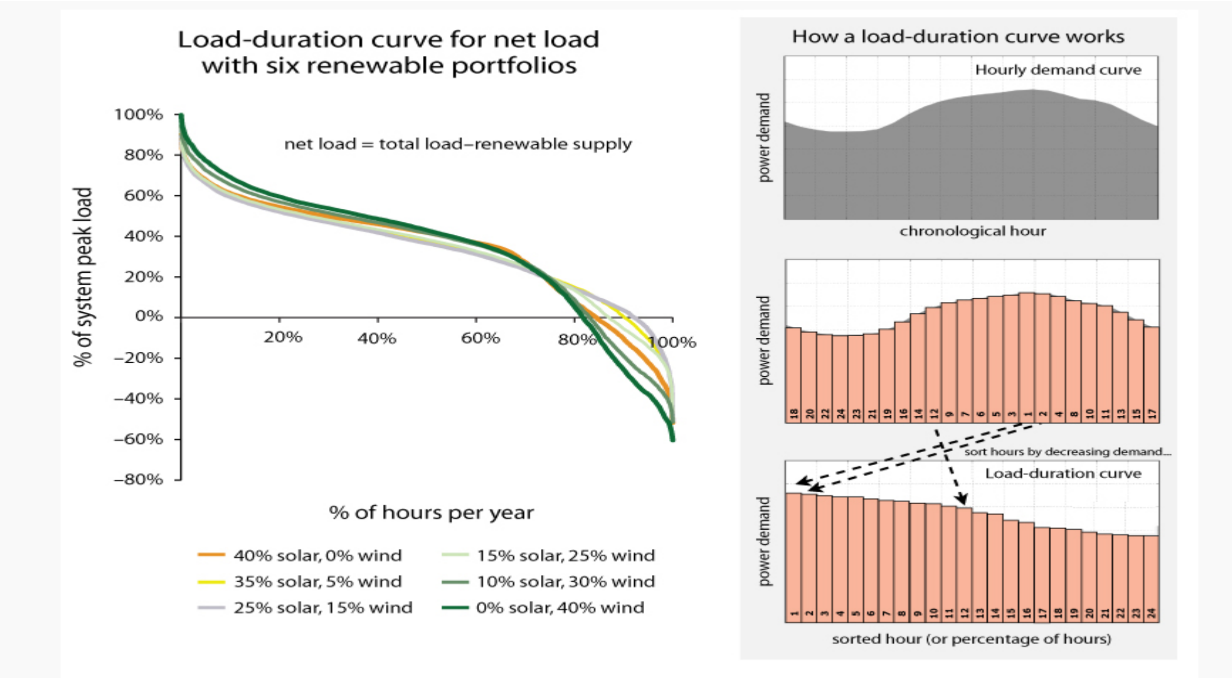


Figure 3: Load Duration curve for six renewable portfolios [51]

3.5 Decentralization of Electricity Production

Decentralized energy, as the name suggests, is produced close to where it will be used, rather than at a large plant elsewhere and sent through the national grid. This local generation reduces transmission losses and lowers carbon emissions. Security of supply is increased nationally as customers don’t have to share a supply or rely on relatively few, large and remote power stations. There can be economic benefits too. Long term-decentralized energy can offer more competitive prices than traditional energy. While initial installation costs may be higher, a special decentralized energy tariff creates more stable pricing. For house builders, developers and PFI consortia, decentralized energy is the cost-effective route to achieving carbon targets. This approach to low carbon energy provision gives the opportunity to promote a locally provided, sustainable, competitive and smarter energy choice. It equally means creating synergy between different energy resources, in another words, generating electricity from many different resources. In such case a domestic power net is required to connect all resources together [23].

Decentralized Energy (DE) is Electricity production at or near the point of use, irrespective of size, technology or fuel used - both off-grid and on-grid. A decentralized energy system is shown in Fig. 2.3. What determines whether electricity generation is DE is not so much how electricity is generated rather where power is generated. DE technologies generate electricity where it is needed. Central generation on the other hand generates electricity in large remote plants and power must then be transported over long distances at high voltage before it can be put to use.

It does not matter what technology one employs, whether it is used in connection with an existing grid or in a remote village, or whether the power comes from a clean renewable source or from burning fossil fuel: if the generator is ‘on-site’ it is DE. This means that, strictly speaking, DE could imply technologies that are not necessarily cleaner for the environment such as diesel generators without heat recovery. More often than not, however, DE is synonymous with cleaner electricity- indeed that is one of DE’s main benefits [24].

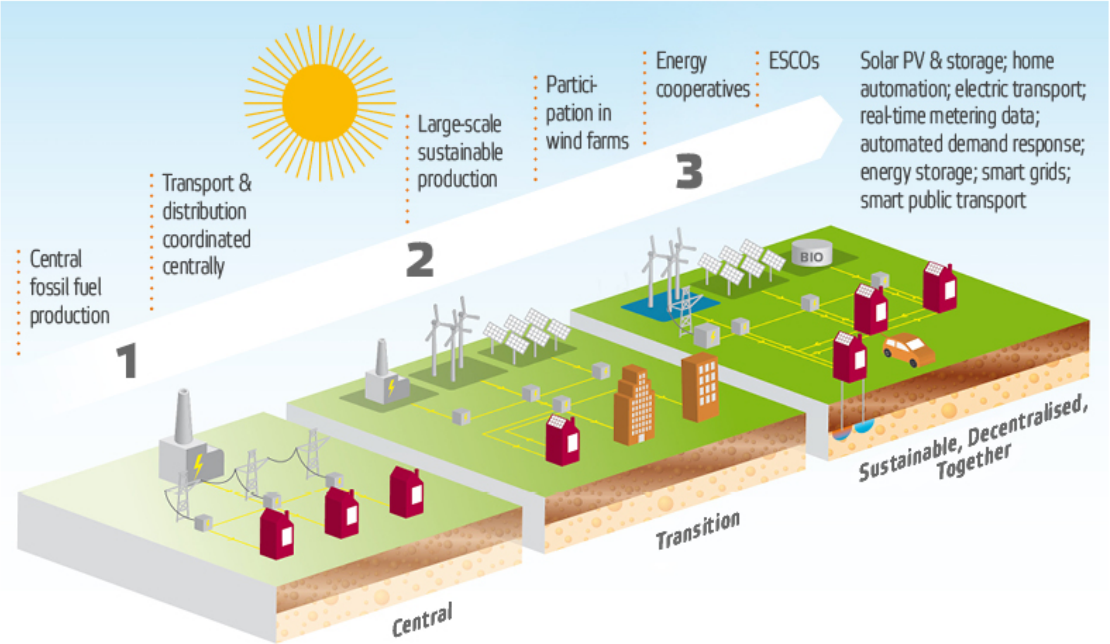


Figure 4: Decentralised Generation of Electric Energy [52]

4 **Renewable Energy**

Renewable energy is energy generated from natural resources such as sunlight, wind, rain, tides and geothermal heat, which are renewable (that is naturally replenished). Renewable energy technologies range from solar power, wind power, hydroelectricity/micro hydro, biomass and biofuels for transportation. Most renewable energy comes either directly or indirectly from the sun. Sunlight, or solar energy, can be used directly for heating and lighting homes and other buildings, for generating electricity, and for hot water heating, solar cooling, and a variety of commercial and industrial uses. The sun's heat also drives the winds, whose energy, is captured with wind turbines. Then, the winds and the sun's heat cause water to evaporate. When this water vapour turns into rain or snow and flows downhill into rivers or streams, its energy can be captured using hydroelectric power.

Along with the rain and snow, sunlight causes plants to grow. The organic matter that makes up those plants is known as biomass. Biomass can be used to produce electricity, transportation fuels, or chemicals. The use of biomass for any of these purposes is called bioenergy. Hydrogen also can be found in many organic compounds, as well as water. It's the most abundant element on the Earth. But it doesn't occur naturally as a gas. It's always combined with other elements, such as with oxygen to make water. Once separated from another element, hydrogen can be burned as a fuel or converted into electricity. Not all renewable energy resources come from the sun.

Geothermal energy taps the Earth's internal heat for a variety of uses, including electric power production, and the heating and cooling of buildings. And the energy of the ocean's tides come from the gravitational pull of the moon and the sun upon the Earth. In fact, ocean energy comes from a number of sources. In addition to tidal energy, there's the energy of the ocean's waves, which are driven by both the tides and the winds. The sun also warms the surface of the ocean more than the ocean depths, creating a temperature difference that can be used as an energy source. All these forms of ocean energy can be used to produce electricity.

Alternative energy is a term used for an energy source that is an alternative to using fossil fuels. Generally, it indicates energies that are non-traditional and have low environmental impact. The term alternative is used to contrast with fossil fuels according to some sources. By most definitions alternative energy does not harm the environment, a distinction that separates it from renewable energy, which may or may not have significant environmental impact [25], [26].

4.1 Hydro Power Plant

On Earth, water is constantly moved around in various states, a process known as the hydrologic cycle. Water evaporates from the oceans, forming into clouds, falling out as rain and snow, gathering into streams and rivers, and flowing back to the sea. All this movement provides an enormous opportunity to harness useful energy. Hydropower provided 16% of the world’s electricity in 2011, second only to fossil fuels. Worldwide capacity in 2011 was 950 Gigawatts (GW). Globally, hydroelectric capacity has more than doubled. Hydropower has grown steadily as a percentage of total electricity generation. It has fallen drastically, largely as a result of the rapid growth in natural gas power plants and other renewable energy technologies such as wind and solar.

Since hydropower depends on rivers and streams for generation, the potential to use hydropower as a source of electricity varies across countries. Many nations generate most of its electricity from hydroelectric dams. The Grand Coulee dam on the Columbia River in Washington is one of the largest dams in the world, with a capacity of more than 6,750 megawatts (MW). In addition to very large hydropower plants scattered around the world, there are equally many smaller hydropower plants. There have been many hydropower plants built across countries around the globe, though the number had fallen. But, a number of these small plants have been restored; as of recent, there is still many hydro plants (not including pumped storage) in operation. These plants account for only a tiny fraction of the dams that block and divert our rivers. [27], [28], [29]. A typical hydro power plant is shown in Figure 5.

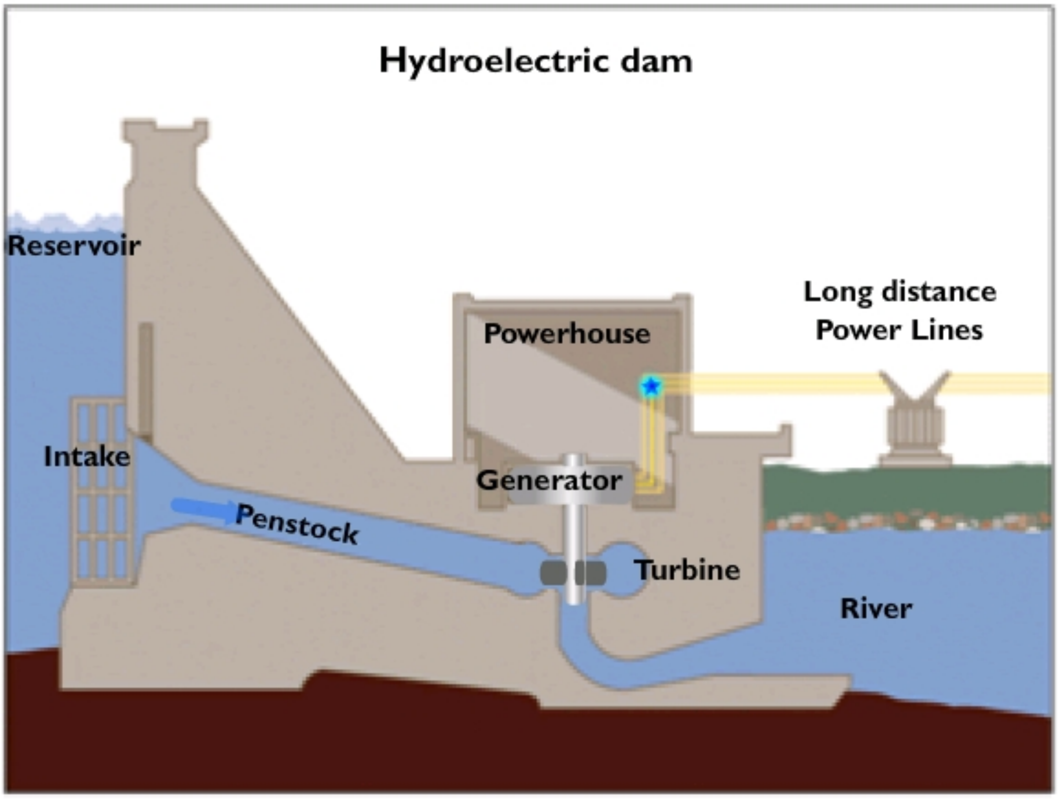


Figure 5: Hydropower Plant [30]

Reservoir

The reservoir works like a battery, it stores water to be released when needed to generate power. The reservoir raises and stores the water level of river to create falling water. The level of the reservoir determines the type of turbine used. The low-pressure head is up to 20 m, the medium pressure head is approximately 20 – 100 m and the high-pressure head is above 100 m.

Penstock

Penstock is basically an intake structure that controls the flow of water to the hydro turbines in the powerhouse. Each penstock has its own head gate, which is at the top, to stop water flow for maintenance or during emergencies. Some of the characteristics of functional penstock include, minimal water leakage, maximum hydraulic performance, structural stability

The scroll case

This is connected at the end of the penstock, which coils around the turbine. It is designed to create a consistent pressure of water entering the turbine around the entire circumference of the distributor blades. [55]

The wicket gate

This is inside the scroll case which control how the water flows into the turbine. The wicket gate is controlled by an external governor system. The governor closes and opens the gate in response to the national grid. When the load on the system is high, the speed of the turbine slows down and therefore the governor system quickly reacts by opening the gates further to speed it back up. The wicket gate is narrow in response to the low load on the system. [55]

Turbine

The turbine is situated beyond the wicket gate. The blades are shaped to extract the most possible spin from the moving water. The runner connects the turbine blades and the shaft connecting to the generator.

Hydro turbine consists of two main types, namely the Impulse and the Reaction turbine**.** Choosing the right turbine for a particular project depends on the height of the standing water, which is also called the ''head'' of the flow. There are other deciding factors to be considered which includes how deep the turbine must be set, the cost and then efficiency of the turbine.

With Impulse turbine, pressure energy turns to kinetic energy. The outflowing water from the turbine is directed as an input to the opposite positioned blades in the runner. In this type of turbine, the runner operates in air, and its turns by one or more jets of water impinging on the blades. The water pressure along the runner path is constant and the relative velocity towards the runner changes only in direction, but the absolute value remains constant. Examples of impulse turbine are Banki (cross-flow), Pelton and Turgo turbine.

Reaction Turbine. The blades of reaction turbines are fully immerse in water and they are fully enclosed in a pressure casing. There is a pressure difference between the input and output of the rotary blades due to the angle at which the blades are angled. These turbines are mostly common on low head applications. Examples of reaction turbines are Francis, Kaplan (propeller) and Archimedes screw turbine [55][57][58].

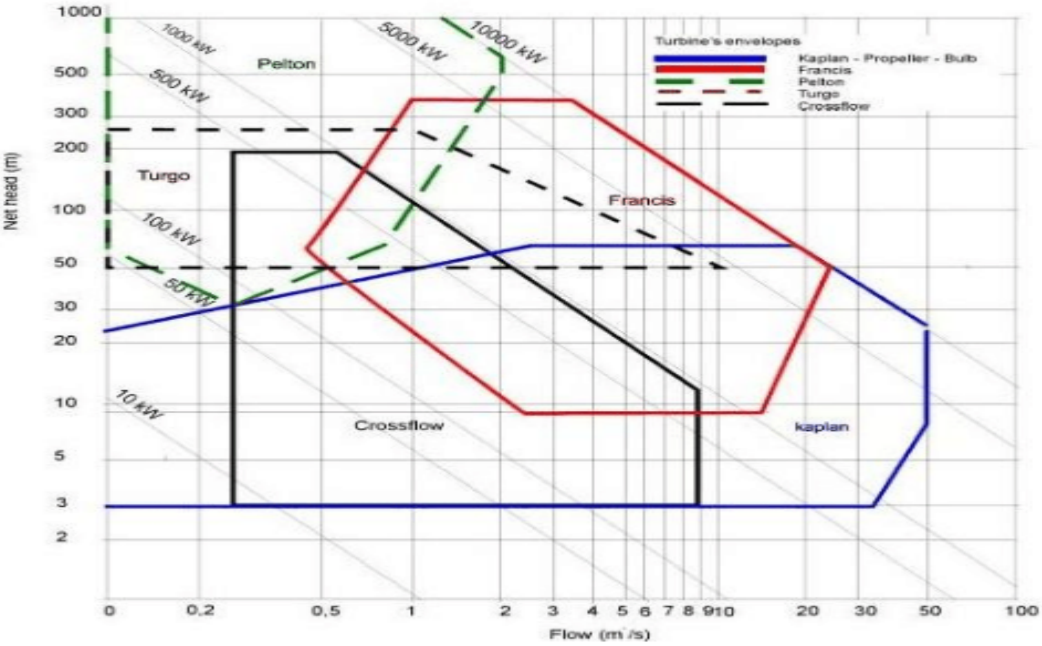


Figure 6: Turbine selection by net head and flow rate [57]

Generator

A generator works on a principle of electromagnetic induction. It converts mechanical energy, which is the rotation of the rotor by the runner into electrical energy. The generator consist of an exciter which gets it's a small DC supply from an external controller called AVR (Automatic Voltage Regulator). Below the exciter, there is a stator and a rotor that is placed between the stator and turned by the runner. The stator is made up of three sets of copper wires called windings. Electricity is produced when coil of the wire on the rotor sweep past the generator's stationary coil stator.

Power House

Once the electricity is produced, it must be transmitted to where ever it is needed, being it our homes, industries, offices, etc. The powerhouse consist of the generators, turbine and control systems.

Calculation of Hydro Power

There are two vitals factors to be considered before embarking on Hydropower project. They are the flow and the head of the stream of the river. The Power output of the generator can be calculated by

$$P = \boldsymbol{\eta} * \boldsymbol{\rho} * \mathbf{Q} * \mathbf{g} * \mathbf{h}$$

Where,

P is power in watts

η is the dimensionless efficiency of the turbine

ρ is the density of water in kilograms per cubic meter

Q is the flow in cubic meters per second

g is the acceleration due to gravity

h is the height difference between inlet and outlet in meters

4.1.1 The Future of Hydropower

Advances in ‘fish-friendly’ turbines and improved data collection techniques to increase the effectiveness of fish passage technologies create exciting new opportunities for the hydropower industry. If constructed and operated in a manner that minimizes environmental and cultural impacts, hydropower projects can provide low-cost, clean sources of electricity to urban and rural areas throughout the world. Harvesting the power from our rivers can be part of a smart and diverse set of solutions for reducing our dependence on fossil fuels, and the impact they have on our climate and public health. The ability to ramp up and down hydropower generation is a valuable source of flexible generation on the electricity grid, which can directly displace coal and natural gas, and help integrate larger amounts of variable renewable energy resources, like wind and solar power.

Since most developed countries have already developed their most accessible areas for large-scale hydropower, growth of these projects will likely be concentrated in nations with growing populations and developing economies. According to the International Hydropower Association, more than 30 GW of new hydropower capacity was commissioned in 2012, with significant investment occurring in South America, Asia, and Africa. Large projects are still under construction in countries, thereby increasing its generation capacity. The potential to develop new large-scale hydropower projects is generally low. However, nations are releasing hydropower mapping that estimates potential of new hydropower development across its rivers and streams that currently do not have hydropower development. There is also additional potential to increase electricity generation at existing hydropower projects by expanding storage, upgrading equipment, and increasing efficiency across the globe [31], [32], [33].

4.2 Types of Hydro Power Plant

Hydropower is basically derived from the force of moving water to turn a turbine. There are four different types of hydropower based on the method of the forced water used to turn the turbine. There are various hydro plants that produce electricity. The large hydro produces electricity greater than 30MW, the small hydro produces 100KW-30MW and the micro hydro less than 100KW. The development of recent technologies has made these types of hydro to overlap. [56][30]

Run-of-river hydropower

In this case, water from the river is diverted using a non-impounded structure called the weir and channel through a penstock to the turbine. Run-of-river is more intermittent as compared to the dam because it relies on the natural flow rates of rivers and natural water variability. It has little or no storage facility and the water flows continuously to supply electricity. With some flexibility of operation for daily fluctuations in demand, water flowing through the turbine is regulated by the facility. [59]

Storage/Conventional Hydropower

In this type of hydro power plant, it uses a dam wall to store water head in the reservoir. Generation of electricity occur when the water is release from the reservoir through the penstock to the turbine.

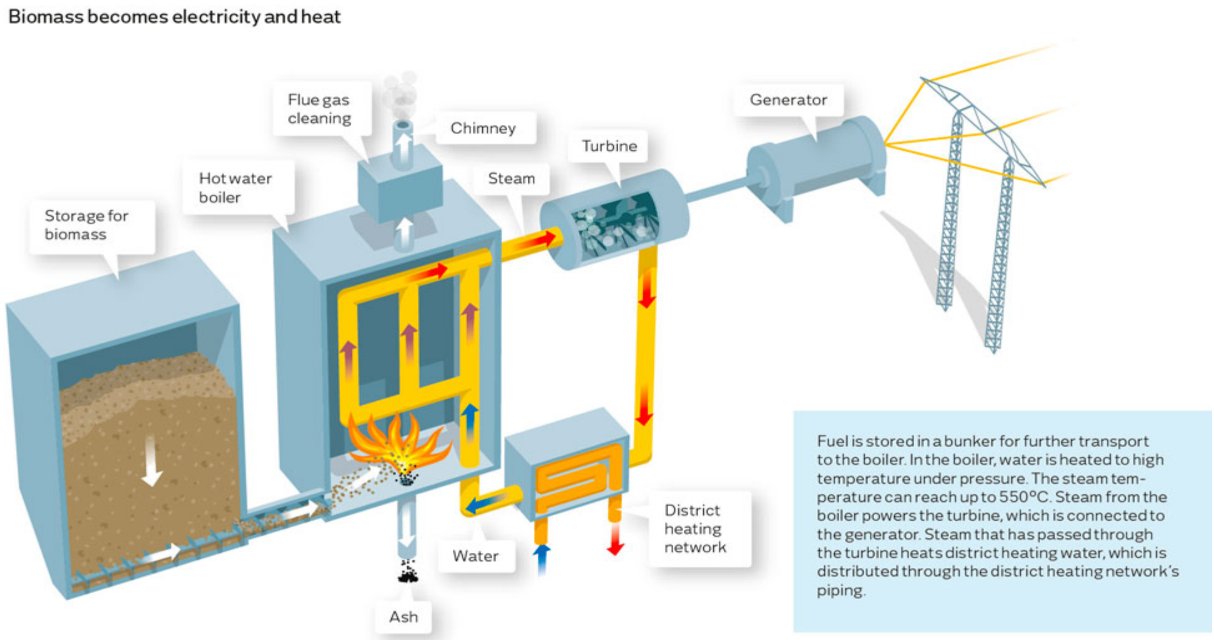
Pumped-storage hydropower
This method is used for load balancing where energy is stored in a form of gravitational potential energy of water. Water is pumped from the lower elevation reservoir to a higher elevation when the electricity demand/prices are lower and then the water from the higher reservoir is used to generate electricity when the demand/electricity price is higher. This method harnesses water that is coupled between a lower and upper reservoir pumps. [59]

Offshore hydropower
With the offshore hydropower, tidal currents or power of waves to produce electricity from seawater. In this type of water accumulation, the water is utilised in a difference between high and low Tide. [30]

4.3 Biomass Power

Biomass power is carbon neutral electricity generated from renewable organic waste that would otherwise be dumped in landfills, openly burned, or left as fodder for forest fires. When burned, the energy in biomass is released as heat. In biomass power plants, wood waste or other waste is burned to produce steam that runs a turbine to make electricity, or that provides heat to industries and homes. Fortunately, new technologies including pollution controls and combustion engineering have advanced to the point that any emissions from burning biomass in industrial facilities are generally less than emissions produced when using fossil fuels like coal, natural gas, and oil.

A biomass-fired power plant produces electricity and heat by burning biomass in a boiler. The most common types of boilers are hot water boilers and steam boilers. Wood chips, residues and other types of biomass are used in the boilers, in the same way as coal, natural gas and oil. Co-firing biomass with coal (replacing a portion of coal with biomass) is an effective method of using biomass for energy purposes and to reduce CO_2 emissions. Coal plants can be made suitable to replace part of the coal by biomass or even to convert fully to biomass – turning a coal plant into a 100% renewable energy plant. In the biomass plant illustrated in Fig 2.5, fuel is stored in a bunker for further transport to the boiler. In the boiler, water is heated to high temperature under pressure. Steam from the boiler powers the turbine, which is connected to the generator. Steam that has passed through the turbine heats district heating water, which is distributed through the district heating networks piping [34], [35].



Fuel is stored in a bunker for further transport to the boiler. In the boiler, water is heated to high temperature under pressure. The steam temperature can reach up to 550°C. Steam from the boiler powers the turbine, which is connected to the generator. Steam that has passed through the turbine heats district heating water, which is distributed through the district heating network's piping.

Figure 7: Biomass for Electricity Generation [35]

Forest products – Woody biomass from multi-functional forests constitutes the majority of today's biomass. Pellets and briquettes are manufactured by compressing by-products from the forestry industry, such as sawdust, bark or small diameter round wood. They are easy to transport, and therefore suitable for export [35].

Waste, by-products and residues – Residues include manure, sewage, sludge and other degradable waste. Liquid biomass waste, such as manure, household waste and sewage plant residues, can be digested to biogas [35].

Energy crops - Energy crops are not used on a large scale for electricity or heat production today. As demand for sustainable biomass increases over time such energy crops may play a more important role in the future. Examples include woody short rotation forestry/crops such as eucalyptus, poplar and willow. But also, herbaceous (grassy) energy crops such as miscanthus can be used. Especially with the use of energy crops it is important to ensure these plantations are established and managed in a sustainable manner [35].

4.3.1 Biomass Feedstock

Biomass energy or bio energy refers to energy produce from organic materials. It can be found in waste as well as living or recently plants. It is the oldest source of renewable energy and made possible by a stored sunlight in a form of chemical energy.

The term feedstock is used to assign to every type of organic material that can be used to produce energy. Depending on the feedstock, they have different energy compositions and they must be converted to usable energy form through one of these processes.

Combustion

This basically means burning of organic materials in the presence of air or oxygen to release heat. It can be used for space heating and also heat steam for electricity generation. The main feed stocks are mainly wood, sawdust and shaving from sawmill, sugarcane, wood waste etc.

Gasification

This is a process of converting solid fuel into the combustible gas mixture through a sequence of thermo-chemical reactions. These processes basically use heat, pressure and partial combustion to create syngas ($CO+H_2+CH_4$), which can be used in place of natural gas. Is one of the technologies used in biomass, which is clean energy, reliable, and flexible, which turns low-value feedstock into high-value products.

Pyrolysis

This process consists of the thermal decomposition of biomass in the absence of oxygen. It is the precursor of the fundamental chemical reaction for both combustion and gasification processes which occur naturally in the first 2 seconds. The product of the biomass pyrolysis includes gasses (methane, hydrogen, carbon monoxide, and carbon dioxide), bio-oil, bio char, liquid and solid char with the proportion of each depending on the parameters of the process. Due to its high efficiency and good environmental characteristics, biomass pyrolysis has been attracting much attention these days.

Anaerobic digestion

It is a natural process and a microbiological breakdown of organic matter by bacteria to methane and solid residue in the absence of oxygen. Both the methane and the solid residue can be burned to produce energy

4.4 Voltage Stability

Voltage collapses usually occur on power system which are heavily loaded or faulted or have shortage of reactive power. Voltage collapse is a system instability involving many power system components. In fact, a voltage collapse may involve an entire power system. Voltage collapse is typically associated with reactive power demand of load not being met due to shortage in reactive power production and transmission. Voltage collapse is a manifestation of voltage instability in the system. Voltage stability refers to the ability of power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating point. The system state enters the voltage instability region when a disturbance or an increase in load demand or alteration in system state results in an uncontrollable and continuous drop in system voltage [36], [37], [38].

A system is said to be in voltage stable state if at a given operating condition, for every bus in the system, the bus voltage magnitude increases as the reactive power injection at the same bus is increased. A system is voltage unstable if for at least one bus in the system, the bus voltage magnitude decreases as the reactive power injection at the same bus is increased. It implies that if, V-Q sensitivity is positive for every bus the system is voltage stable and if V-Q sensitivity is negative for at least one bus, the system is voltage unstable. The term voltage collapse is also often used for voltage instability conditions. It is the process, by which, the sequence of events following voltage instability leads to abnormally low voltages or even a black out in a large part of the system.

The driving force for voltage instability is usually the load and load characteristics, hence, voltage stability are sometimes also called load stability. In response to a disturbance, the power consumed by the loads tends to be restored by load dynamics. This in turns increases the stress on the high voltage network by increasing the reactive power consumption and further reducing the voltage. A major factor contributing to voltage instability is the voltage drop in the line impedances when active and reactive powers flow through it. As a result, the capability of the transmission network for power transfer and voltage support reduces. Voltage stability of a system is endangered when a disturbance increases the reactive power demand beyond the sustainable capacity of the available reactive power resources. The voltage stability has been further classified into four categories: Large disturbance voltage stability, small disturbance voltage stability, short-term voltage satiability and long-term voltage stability [36], [37], [38].

Large Disturbance Voltage Stability

This refers to the ability of the system to maintain steady voltage as a result of large disturbances such as, system faults, loss of generation or circuit contingencies. To determine the form of stability, it requires special examination of the dynamic performance of the system over a period, which is sufficient to capture such devices under load tap changing transformers, generator field, and current limiters. It can also be determine by the system load characteristics and interaction of both continuous and discrete control protection. The system period of the system can be from few minutes to tens of minutes. The system is said to be large disturbance voltage stable if the voltage at all buses settle down at acceptable levels when the subsequent system control actions are taking into consideration. [58] [38]

Small-Disturbance Voltage Stability

This refers to the ability of the system to maintain acceptable level of steady voltages when subjected to small disturbances as a result of a voltage near loads does not change or remain close to the pre-disturbance values. This form of stability is also influenced by the characteristics of loads, continuous controls, and discrete controls at a given instant of time. The small-disturbances stability can be analysed using a small-signal model of the system and its concept is related to the steady state nature. That is, a static analysis can be effectively be used to estimate stability margins. [58]

Short Term Voltage Stability

The study of short-term voltage stability involves dynamics of fast acting load components such as electronically controlled loads, HDVC converters, and induction motors. The study system period of interest of the system can be in the order of several seconds and the analysis requires solution of appropriate system differential equations. [58]

Long Term Voltage Stability

This involves the dynamics of slower acting equipment such as tap changing transformer, thermostatically controlled loads and generator current limiters. The study period of interest requires long-term dynamics system simulation, and may extend to several or many minutes. [58]

Voltage instability is caused by many reasons. Some of the significant reasons are,

- Increase in load or demands
- Generators, synchronous condensers, or SVC reaching reactive power limits,
- Action of changing transformers
- Load recovery dynamics,
- Line tripping or generator outages.

Unstable voltage has significant impact on the reactive power production, consumption and transmission in the system. These can further be prevented by [58] [38]

- Switching of shunt capacitors
- Blocking of tap-changing transformer
- Redispatch of generation
- Load shedding
- Temporary reactive power over loading of generators

4.5 Reactive Power Support

Reactive power can be reduced in practice to improve the system efficiency. These are acceptable at some level, if system is purely resistively or capacitance. It may cause some problem in Electrical system if not controlled. AC systems supply or consume have two kind of power: real power and reactive power. Real power accomplishes useful work while reactive power supports the voltage that must be controlled for system reliability. Reactive power has a profound effect on the security of power systems because it affects voltages throughout the system [39].

Voltage control in an electrical power system is important for proper operation for electrical power equipment to prevent damage such as overheating of generators and motors, to reduce transmission losses and to maintain the ability of the system to withstand and prevent voltage collapse.

In general terms, decreasing reactive power causing voltage to fall while increasing it causing voltage to rise. A voltage collapse occurs when the system try to serve much more load than the voltage can support. When reactive power supply lower voltage, as voltage drops current must increase to maintain power supplied, causing system to consume more reactive power and the voltage drops further. If the current increase too much, transmission lines go off line, overloading other lines and potentially causing cascading failures. If the voltage drops too low, some generators will disconnect automatically to protect themselves.

Voltage collapse occurs when an increase in load or less generation or transmission facilities causes dropping voltage, which causes a further reduction in reactive power from capacitor and line charging, and stills their further voltage reductions. If voltage reduction continues, these will cause additional elements to trip, leading further reduction in voltage and loss of the load. The result in these entire progressive and uncontrollable declines in voltage is that the system unable to provide the reactive power required supplying the reactive power demands [39] – [42].

4.5.1 Importance of Reactive Power Presence in the Grid Network

- Voltage control and reactive-power management are two aspects of a single activity that both supports reliability and facilitates commercial transactions across transmission networks.
- On an alternating-current (AC) power system, voltage is controlled by managing production and absorption of reactive power. There are three reasons why it is necessary to manage reactive power and control voltage.
- First, both customer and power-system equipment are designed to operate within a range of voltages, usually within ±5% of the nominal voltage. At low voltages, many types of equipment perform poorly; light bulbs provide less illumination, induction motors can overheat and be damaged, and some electronic equipment will not operate at. High voltages can damage equipment and shorten their lifetimes.
- Second, reactive power consumes transmission and generation resources. To maximize the amount of real power that can be transferred across a congested transmission interface, reactive-power flows must be minimized. Similarly, reactive-power production can limit a generator's real-power capability.
- Third, moving reactive power on the transmission system incurs real-power losses. Both capacity and energy must be supplied to replace these losses.
- Voltage control is complicated by two additional factors. First, the transmission system itself is a nonlinear consumer of reactive power, depending on system loading. At very light loading the system generates reactive power that must be absorbed, while at heavy loading the system consumes a large amount of reactive power that must be replaced. The system's reactive-power requirements also depend on the generation and transmission configuration. Consequently, system reactive requirements vary in time as load levels and load and generation patterns change. The bulk-power system is composed of many pieces of equipment, any one of which can fail at any time. Therefore, the system is designed to withstand the loss of any single piece of equipment and to continue operating without impacting any customers. That is, the system is designed to withstand a single contingency. Taken together, these two factors result in a dynamic reactive-power requirement. The loss of a generator or a major transmission line can have the compounding effect of reducing the reactive supply and, at the same time, reconfiguring flows such that the system is consuming additional reactive power.
- At least a portion of the reactive supply must be capable of responding quickly to changing reactive-power demands and to maintain acceptable voltages throughout the system. Thus, just as an electrical system requires real-power

reserves to respond to contingencies, so too it must maintain reactive-power reserves.

- Loads can also be both real and reactive. The reactive portion of the load could be served from the transmission system. Reactive loads incur more voltage drop and reactive losses in the transmission system than do similar-size (MVA) real loads.
- Vertically integrated utilities often include charges for provision of reactive power to loads in their rates. With restructuring, the trend is to restrict loads to operation at near zero reactive power demand (at 1.0 power factor). The system operator proposal limits load to power factors between 0.97 lagging (absorbing reactive power) and 0.99 leading. This would help to maintain reliability of the system and avoid the problems of market power in which a company could use its transmission lines to limit competition for generation and increase its prices. [39] – [42].

4.6 Minimizing Power Losses in Electric-Power Network

Developments in small power generation technologies have drawn an attention for the utilities to change in the electric infrastructure for adapting distributed generation (DG) in distribution systems. Employment of DG technologies makes it more likely that electricity supply system will depend on DG systems and will be operated in deregulated environment to achieve a variety of benefits. As DG systems generate power locally to fulfil customer demands, appropriate size and placement of DG can drastically reduce power losses in the system. DG inclusion also defers transmission and distribution upgrades, improves supply quality and reliability and reduces greenhouse effects.

Power losses in distribution systems vary with numerous factors depending on the system configuration, such as level of losses through transmission and distribution lines, Power factor, transformers, capacitors, insulators, etc. Power losses can be divided into two categories: real power loss and reactive power loss. The resistance of lines causes the real power loss, while reactive power loss is produced due to the reactive elements. Normally, the real power loss draws more attention for the utilities, as it reduces the efficiency of transmitting energy to customers. Nevertheless, reactive power loss is obviously not less important. This is due to the fact that reactive power flow in the system needs to be maintained at a certain amount for sufficient voltage level. Consequently, reactive power makes it possible to transfer real power through transmission and distribution lines to customers [43] – [50].

5 Case Study – Overview and Description

In this thesis two distribution network connected to HPP were analysed. The first is the NYMBURK Substation and the second Substation analysed is the BROD distribution network. eVlivy software was used in analysing the case studies.
This case study is to verify the best connecting point to the distribution network between NYMBURK and BROD in Central Bohemia Region.

5.1 Substation NYMBURK

Figure 8 shows the schematic diagram of the NYMBURK Substation, 22 kV distribution power line voltage, and a consumer loads NBK, KOVAN, HAJEK and BYT connected to this power line. Table 1, and Table 2 presents the transformer and generator parameters of NYMBURK Substation and generating station respectively. While, Table 3 shows the parameters of the 22 kV overhead line voltage connected to the Substation

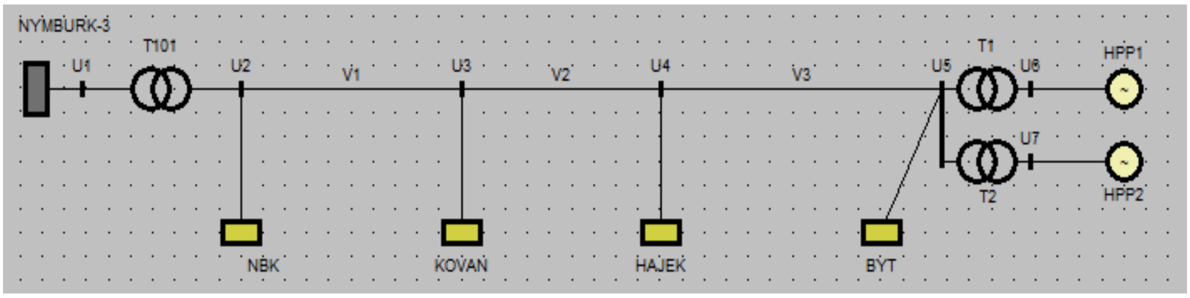


Figure 8: Schematic diagram of 22 kV Overhead line connected to Substation NYMBURK

Table 1: Transformer input parameter for Substation NYMBURK

Transformer	U_1 [kV]	U_2 [kV]	S [MVA]	P [kW]	Uk[%]	Io [%]	Po [kW]
T101	110	23	40	220	11	0,8	50
T1	22	6,3	1,6	14	6	0,8	15
T2	22	6,3	1,6	14	6	0,8	15

Table 2: Generator parameters for NYMBURK and BROD Substation

Generator	Un [kV]	Sn [kVA]	X”d [%]	P [kW]	Frequency	Rated Excitation at rated load	Resistance of the exciting winding
HPP1	6,3	1165	17,7	1000	50	250A/150 V DC	0,474801 W/15st^0 C
HPP2	6,3	1165	17,7	1000	50	250A/150 V DC	0,474801 W/15st^{0}C

Table 3: Input parameters of the Overhead line (OH) Voltage 22 kV for NYMBURK Substation

Power line	Title	Type	Wire Type	R [Ω/km]	X [Ω/km]	B [μS/km]	Line Length [km]	Imax [A]
NYHRA	V1	OH	110AlFe6	0,259	0,368	1,46	1	318
NYHRA	V2	OH	110AlFe6	0,259	0,368	1,46	6,5	318
NYHRA	V3	OH	110AlFe6	0,259	0,368	1,46	3,5	318

Table 4: Load Consumption on overhead line 22kV for NYMBURK substation

Network Node	Voltage [kV]	Power factor [-]	Active Power [kW]	Reactive Power [kVAr]	Apparent power [kVA]	Current I [A]
NBK	22	0,95	11400	3747	12000	289
KOVAN	22	0,95	380	125	400	9
HAJEK	22	0,95	475	156	500	12
BYT	22	0,92	644	274	700	17

5.2 Substation BROD

As shown in the schematic diagram in Figure 9, the Substation BROD has several loads connected to the overhead power line of 22 kV. These loads are named as Z1, Z2, Z3, LYSA and Z5. Distribution load for the other lines is represented by DIST B1 supply from busbar 22 kV Sub BROD (U2). The line parameters for this Substation are listed in Table 4, while the transformer parameters are tabulated in Table 5. Table 6 illustrates the voltage, power factor, active power, reactive power, apparent power and the currents of the loads connected from the main busbar Substation.

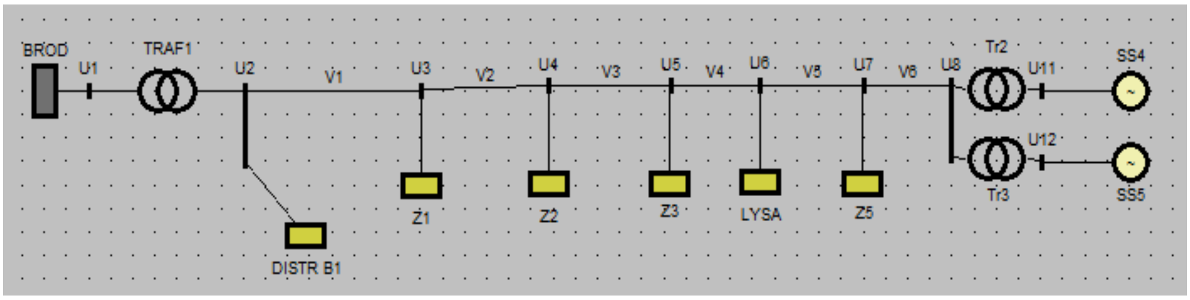


Figure 9: Schematic diagram of 22 kV Overhead line connected to Substation BROD

Table 5: Input Parameters of OH Voltage 22 kV for BROD Substation

Power line	Title	Type	Wire Type	R [Ω/km]	X [Ω/km]	B [μS/km]	Line Length [km]	Imax [A]
BROD	V1	OH	95AlFe6	0,301	0,374	1,448	4	289
BROD	V2	OH	95AlFe6	0,301	0,374	1,448	4	289
BROD	V3	OH	95AlFe6	0,301	0,374	1,448	6	289
BROD	V4	OH	95AlFe6	0,301	0,374	1,448	2	289
BROD	V5	OH	95AlFe6	0,301	0,374	1,448	2	289
BROD	V6	OH	95AlFe6	0,301	0,374	1,448	2	289

Table 6: Input parameter of Hydropower plant transformer

Transformer	U1 [kV]	U2 [kV]	S [MVA]	P [kW]	U [%]	Io [%]	P [kW]
Trafi	110	23	40	212	12	0,8	50
T1	22	6,3	2,5	26	6	0,8	15
T2	22	6,3	2,5	26	6	0,8	15

Table 7: Load Consumption of overhead line 22 kV for Substation BROD

Load	VOLTAGE [kV]	Power factor	Active Power [kW]	Reactive Power [kVAr]	Apparent power [kVA]	Current [A]
DISTR B1	22	0,95	11400	3747	12000	289
Z1	22	0,95	380	125	400	9
Z2	22	0,95	475	156	500	12
Z3	22	0,92	644	274	700	17
LYSA	22	0,92	1840	982	2000	49
Z5	22	0,92	230	98	250	6

5.3 Criteria for connecting NYMBURK and BROD electricity generating plants to the distribution network

The network operator determines the manner of connecting electricity generating plants to the distribution network. In this case study, the network operator is ČEZ Distribution. When connecting hydropower plants to electricity distribution networks, it is very important to evaluate the effects of the backward hydropower production plant to the distribution system of low or high voltage. Which do cover the following feedback effects:

- Change Voltages when operating an electricity generating plant
- Change Stress during switching
- Long-term flicker
- Current harmonics

- Influence to device ripple control (HDO)
- Influence to short-circuit conditions

For hydropower plants, it is usually judged mainly by voltage changes in the operation of the electricity generating plant, issued of harmonic currents and the effect of ripple control devices.

5.3.1 Voltage Changes in the Operation of the NYMBURK and BROD Hydro Power Plants

PPC variations in voltage caused by connecting or disconnecting the electricity generating plant must not exceed limit for the medium voltage (in this case 22 kV). Also, voltage change in the Medium Voltage (MV) distribution network by connecting the hydro electricity generating plant at the connection point (PCC) must not exceed 2%. Variation in Low Voltage (LV) of the distribution system by connecting electricity-generating plant at the connection point (PCC) must not exceed 3%. Voltage changes when switching the hydro electricity generating plant should be about 3%.
PPC variations in voltage caused by connecting or disconnecting hydro electricity generating plant to low voltage (say 0.4 kV) should not exceed 3%. These limits apply only to the case where switching is more frequent as once every 1.5 min., Which is at most for power plants using renewable energy sources (RES), just as this case studies.
Most mass-produced dispersion of resources should have in their technical dossier factor information flicker. The amount of this quality parameter depends on the uniformity of the equipment operation. Generally, machines with great energy of rotating masses have little flicker factor and therefore not a source of flicker, take for instance: turbo generators and hydro generators. Production of electricity from renewable sources is problematic (wind power plants), where it reaches a factor of flicker up to 40 harmonics. The highest values achieved without wind power converters and a small number sheets. Photovoltaic plants are generally deemed to be devices with very low duty flicker. From the perspective of long-term rating of hydropower plants, flicker at each connection point is to be observed considering the following:

- The short circuit of the power networks and the rated apparent power of the connected source that is the hydropower plant.
- Another point to note is the flicker factor declared by the equipment manufacturer.

For these case studies, the main concern is the issue of voltage stability and power losses reduction.

5.3.2 Verification of the NYMBURK and BROD Hydro Power Electricity Network Simulation Capability

The NYMBURK and BROD Hydro electricity plants capabilities of sustaining the 22 kV Medium Voltage Electricity (MVE) power line has been well verified and validated. This must be verified to ensure that the response predictions from the hydropower plants capability are accurate. In all, two verification studies were perfumed to test the accuracy of the grid network. First is the Impedance of the clustered system before and after the MVE was connected to both Hydro-power Stations. The last of verification exercise is the compared results of Short-circuit current before and after MVE is connected to the Hydro-power plants. The results of all the verification exercises were favourable. This gave confidence to pursue more thorough investigations into the dynamic behaviour of the hydropower distribution connected network, by probing the voltage stability and power losses.

5.3.3 Short Circuit Current of Hydropower Stations

The operation of the HPP has influenced the short circuit power of the two Substations as shown in Tables 7 and Table 8. It is expected that, the short circuit current for the HPP should not exceed 1.5 of the nominal current of the power stations.

In the same vein, eVlivy software was used to test the verification of the Short circuit current before and after connecting Substation NYMBURK to the 22 kV MV distribution power line. Table 7 depicts the entire short circuit power table of NYMBURK Hydro-power Station. This same principle applies to the short circuit current of the BROD power station as seen in Table 8. It has been noticed that, the short circuit current and power close to the HPP is much lesser than the short circuit current and power far from the HPP.

Table 8: Short Circuit power table for Substation NYMBURK Hydropower station

Network Node	R 22 kV	R 22 kV	HPP	HPP
	Short Circuit Power [MVA]	Short Circuit Power [kA]	Short Circuit Power [MVA]	Short Circuit Power [kA]
P = 0 MWp	302,9	7,949	85,9	2,255
P =1000 MWp	311,1	8,164	77	2,021

Table 9: Short Circuit power table of Substation BROD Hydropower station

Network Node	R22kV	R22kV	HPP	HPP
	Short Circuit Power [MVA]	Short Circuit Power [kA]	Short Circuit Power [MVA]	Short Circuit Power [kA]
P = 0 MWp	285.14	7,483	44.39	1,165
P = 1000 MWp	293,3	7,698	53,84	1,412

6 Results and Discussions

The voltage profile and power losses analyses for both power stations were carried out using the simulation software documented in Chapter 5. The parameters of the components of the hydro power stations, the parameters for Substation NYMBURK and BROD, reference hydropower site overhead line parameters, the load conditions are all described in Chapter 5. The results of these analyses are presented in this Chapter 6. Focus is on results that are characteristic of the overall system responses.

6.1 Analysis of NYMBURK Distribution Network Results

Table 10: Current and Power at beginning and end of line section

	Node	I [A]	S [kVA]
NYMBURK-3	U1	58,242	11753
T101	U1	58,241	11753
	U2	278,545	11601
V1	U2	12,004	500
	U3	12,009	500
KOVAN	U3	9,603	400
V2	U3	20,81	867
	U4	20,808	869
HAJEK	U4	11,973	500
V3	U4	32,419	1354
	U5	32,41	1357
T1	U5	24,354	1020
	U6	85,047	1031
T2	U5	24,342	1019
	U7	89,254	1031
HPP1	U6	85,047	1031
HPP2	U7	89,254	1031
NBK	U2	288,126	12000
BYT	U5	16,721	700

Table 11 Difference in voltage of the loads connected to 22 kV NYMBURK Substation

Node	Node Name	Voltage U [kV]	Voltage difference α [%]
0	U1	116,515	+5,9
1	U2	24,046	+9,3
2	U3	24,049	+9,31
3	U4	24,111	+9,6
4	U5	24,17	+9.9

Table 9 illustrates the current and power at every node of the NYMBURK distribution network. While the voltage difference on the 22 kV power line shows that the voltage difference increases in value from Node 0 through to Node 4. (That is from +5.9% on Node 0 - +9.9% on Node 4). Power is the product of voltage and current. To transmit the same power to a consumer load, you can increase the voltage and decrease the current. Power is the product of voltage and current. To transmit the same power to a consumer load, the option can be to increase the voltage and decrease the current. Impact of Voltage and Power factor change on the distributed network of NYMBURK power station is shown in Figure 10, and the parameters of the voltage profile at every node are vividly outlined in table 3.9. It can be seen in Figure 10 that as the voltage increases, there is a corresponding increase in the power factor values measured.

Table 12: Voltage profile at every node for Substation NYMBURK

Power Factor	U1 [kV]	U2 [kV]	U3 [kV]	U4 [kV]	U5 [kV]	Difference [kV]
0,95	116,52	24,05	24,06	24,13	24,20	0,39
0,96	116,51	24,05	24,05	24,12	24,18	0,38
0,97	116,51	24,04	24,04	24,11	24,17	0,36
0,98	116,51	24,04	24,04	24,09	24,14	0,34
0,99	116,50	24,03	24,03	24,07	24,12	0,31
1	116,49	24,01	24,00	24,02	24,05	0,24
PASSIVE	116,43	23,994	23,969	23,847	23,80	0

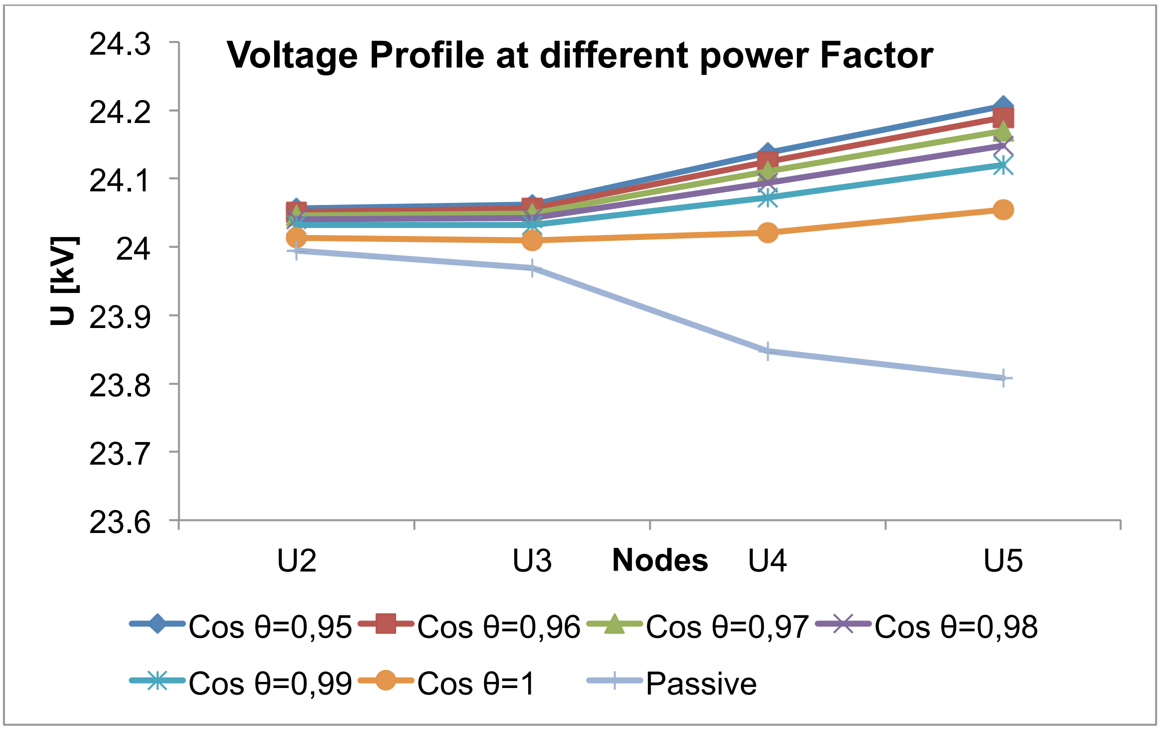


Figure 10: Voltage profile at different power factor for Substation NYMBURK

The measured voltage profile at every node of the NYMBURK Hydro-power Station is tabulated in Table 12, and the voltage profile at different power factor is presented in Figure 10. It vividly shows that the power factor tends to be unity, when the supply voltage was about 24 kV. But the power factor reduces, as the voltage profile of the NYMBURK Hydropower Station tends to increase. Poor Power factor or power factor less than unity causes distribution of electric-power at a constant voltage requiring more current. To distribute high current, higher conductor size power lines are needed. This increases the cost of distribution lines.

Table 13: Parameters of the line Voltage difference at every node of NYMBURK Hydropower Station

Nodes	0,95		0,96		0,97		0,98		0,99		1	
	HPP 1	HPP 2	HPP 1	HPP 2	HPP 1	HPP 2	HPP 1	HPP 2	HPP 1	HPP 2	HPP 1	HPP 2
U1	-0,04	-0,04	-0,04	-0,04	-0,04	-0,04	-0,03	-0,03	-0,03	-0,03	-0,03	-0,03
U2	-0,14	-0,14	-0,13	-0,13	-0,12	-0,12	-0,10	-0,10	-0,09	-0,09	-0,05	-0,05
U3	-0,21	-0,21	-0,20	-0,20	-0,18	-0,18	-0,16	-0,16	-0,14	-0,14	-0,09	-0,09
U4	-0,66	-0,66	-0,63	-0,63	-0,59	-0,59	-0,56	-0,56	-0,51	-0,51	-0,39	-0,39
U5	-0,90	-0,90	-0,86	-0,86	-0,82	-0,82	-0,77	-0,77	-0,71	-0,71	-0,56	-0,56

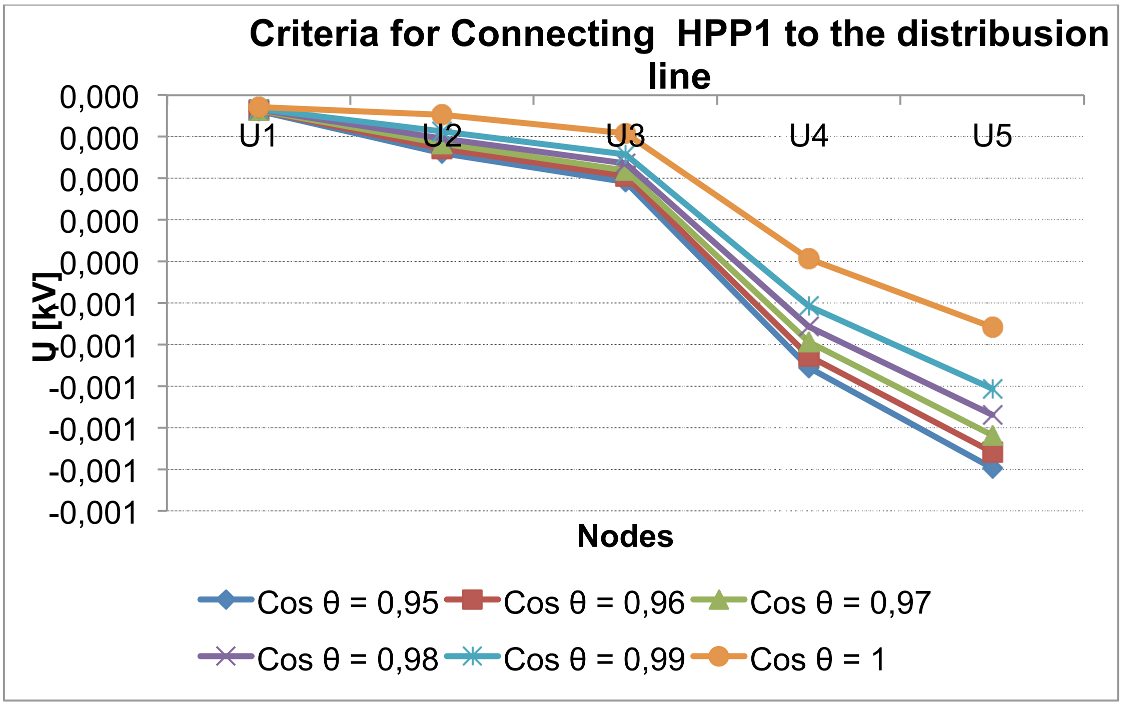


Figure 11: HPP1 Criteria before connecting to Distribution Network of Substation NYMBURK

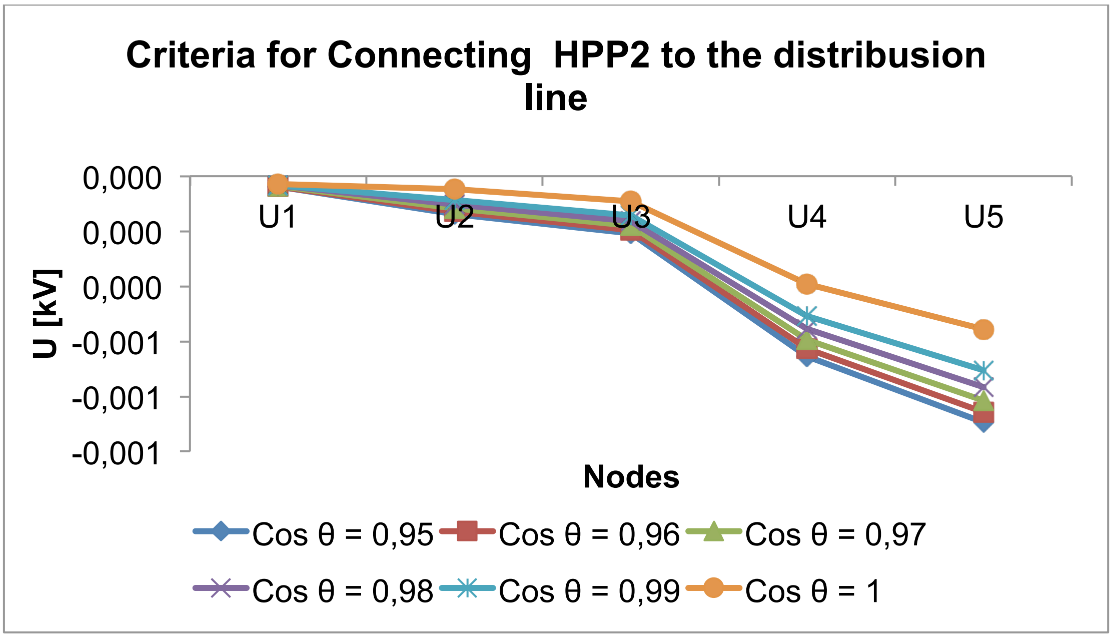


Figure 12: HPP2 Criteria before connecting to Distribution Network of Substation NYMBURK

From Table 13, Figure 11 and Table 12, the difference in voltage before and after connection of both HPP1 and HPP2 with nominal capacity to the 22 kV distribution power line is 0,90%. This value has not exceeded the 2% CEZ Distribution supplier standard for connection to the MV distribution power line. Based on the parameters in Table 13, Figure 11 and Figure 12, the NYMBURK distribution can be connected to the Substation with a power factor ranging from 0.95-1.

Table 14: Parameters of losses at every line section for Sub NYMBURK

Power Factor	V1	V2	V3	Total losses
0,95	0,107	2,264	1,697	3961
0,96	0,106	2,207	2,904	5111
0,97	0,112	2,187	2,857	5044
0,98	0,126	2,217	1,619	3836
0,99	0,155	2,316	2,831	5147
1	0,276	2,902	3,017	5919
PASSIVE	1,158	4,249	0,782	5,407

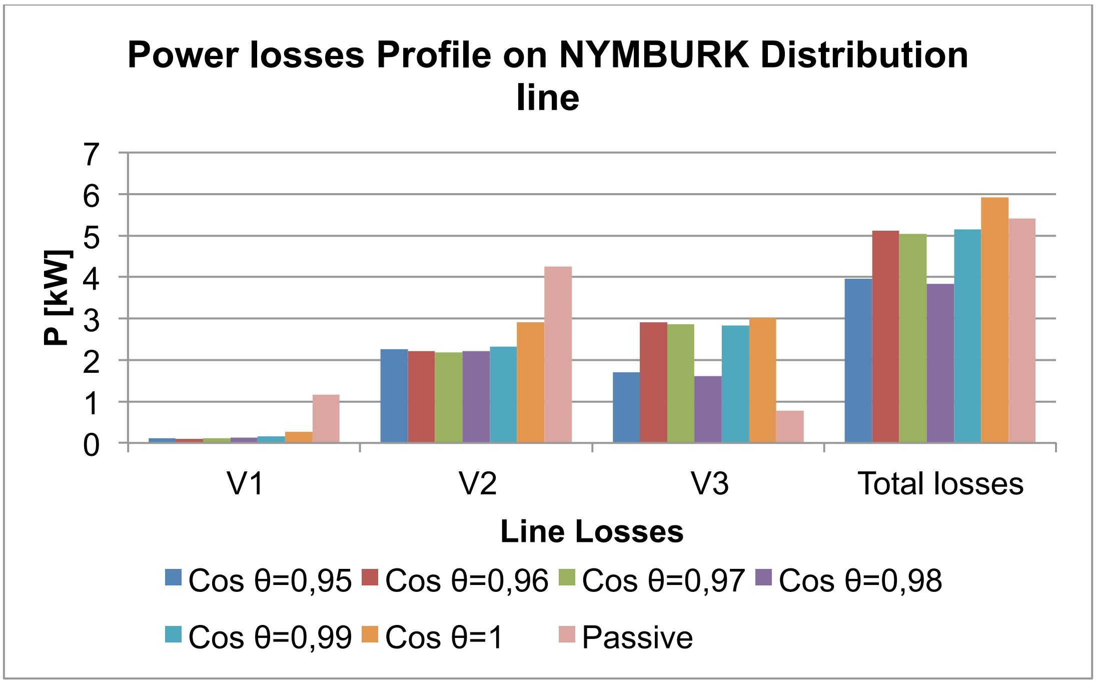


Figure 13: Line Losses on the Distribution Network for Substation NYMBURK

The effect of Power Losses on each distribution power line is shown in Table 14 and Figure. 13. From Figure 13, there is a minimal power loses on distribution power line V1, but increases on line V2 as regards to all the increase in power factor. The variation of power factor has tremendous effect on the line losses. Before connecting the Hydro Power Plant (HPP), the power losses in line V2 increases to a very high level and then decreases on line V3. The electricity distribution losses are the difference between the electricity measured as entering the system and that leaving it.

6.2 Analysis of BROD Hydropower Station Results

Table 15: Current and Power at every line section for Sub BROD

	Node	I [A]	S [kVA]
BROD	U1	70,072	14171
TRAF1	U1	70,072	14171
	U2	333,457	13862
V1	U2	45,259	1881
	U3	45,301	1872
Z1	U3	9,679	400
V2	U3	35,962	1486
	U4	36,008	1481
Z2	U4	12,157	500
V3	U4	24,654	1014
	U5	24,737	1012
Z3	U5	17,108	700
V4	U5	10,651	436
	U6	10,69	437
LYSA	U6	48,913	2000
V5	U6	43,786	1790
	U7	43,778	1794
Z5	U7	6,1	250
V6	U7	49,769	2040
	U8	49,76	2045
DISTR B1	U2	288,647	11999
Tr2	U8	24,884	1023
	U11	86,898	1031
Tr3	U8	24,875	1022
	U12	91,209	1031
HPP1	U11	86,898	1031
HPP2	U12	91,208	1031

Table 16: Voltage difference in network on the 22 kV Sub BROD distribution power line

Node	Name	Voltage [kV]	VOLTAGE DIFFERENCE Un [%]
0	U1	116,753	+6,13
1	U2	23,987	+9,03
2	U3	23,831	+8.32
3	U4	23,702	+7.74
4	U5	23,559	+7,09
5	U6	23,536	+7,98
6	U7	23,586	+7.21
7	U8	23,644	+7,47

Table 17: Voltage profile at every node on the 22 kV for Substation BROD distribution Line

Power Factor	U1 [kV]	U2 [kV]	U3 [kV]	U4 [kV]	U5 [kV]	U6 [kV]	U7 [kV]	U8 [kV]	Difference [kV]
0,95	116,8	24,0	23,9	23,9	23,8	23,7	23,72	23,8	0,79
0,96	116,8	24,0	23,9	23,8	23,7	23,6	23,7	23,8	0,76
0,97	116,8	24,0	23,9	23,8	23,6	23,6	23,7	23,7	0,73
0,98	116,8	24,0	23,9	23,7	23,6	23,6	23,6	23,7	0,69
0,99	116,8	23,9	23,8	23,7	23,6	23,5	23,6	23,6	0,64
1	116,7	23,9	23,8	23,6	23,4	23,4	23,5	23,5	0,5
PASSIVE	116,7	23,9	23,6	23,4	23,0	23,0	23	23	0

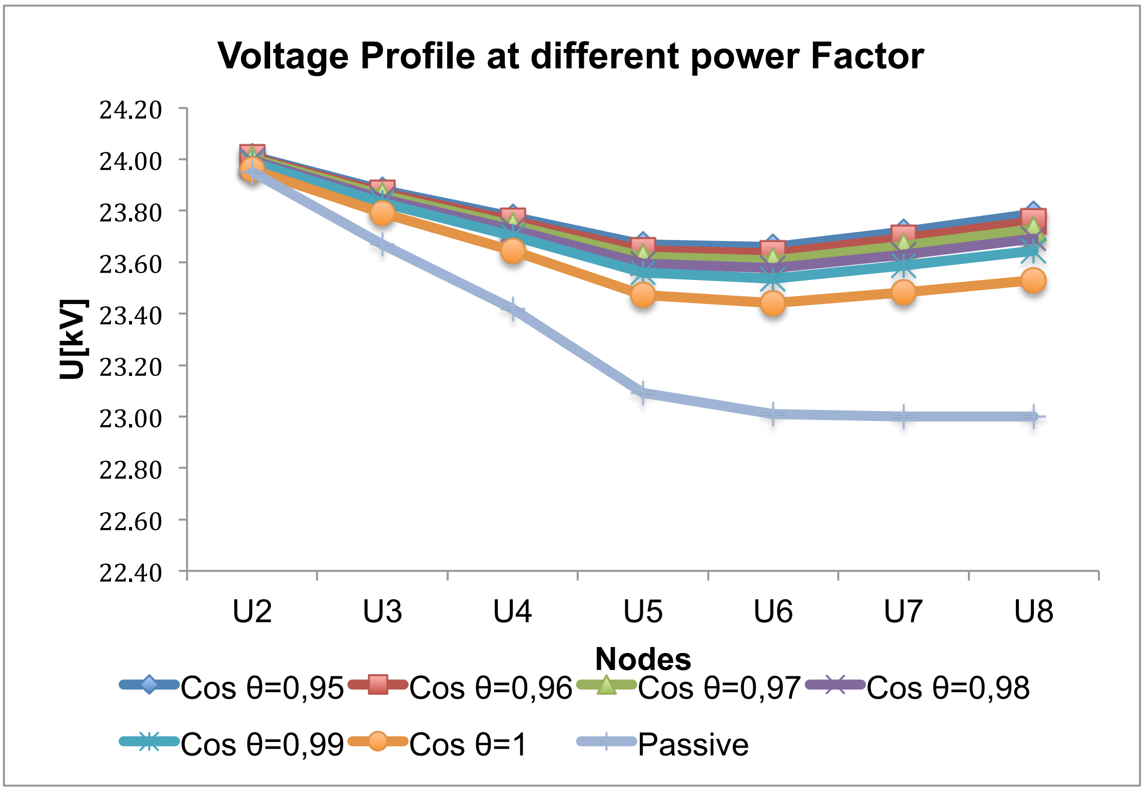


Figure 14: Voltage Profile of Substation BROD 22 kV power line at different power factor

Table 15 presents the current and power between every line section. That is the initial and final current measured at every node of each distribution line. Table 16 shows the Voltage difference on the 22 kV Sub BROD distribution power line, and Table 17 depicts the voltage profile at every node on the 22 kV BROD distribution power line. Figure 14 further describes the voltage profile of the Sub BROD 22 kV power line at different power factor values. But the power factor reduces, as the voltage profile of the Sub BROD tends to increase. Which correspond to the trend at the NYMBURK Hydro-power Station. Poor Power factor or power factor less than unity causes distribution of electric-power at a constant voltage requiring more current. To distribute high current, higher conductor size power lines are needed.

This increases the cost of distribution lines. The large current at low lagging power factor brings about greater voltage drops in alternators, transformers and power lines. This result in decreased voltage at the driving end enables the use of extra equipment to counter act the voltage drop such as voltage stabilizers. These increase the cost of power distribution schemes. The low power factor reduces the handling capacity of the distribution network. The reactive component in the current prevents the full use of machinery in electric-power schemes.

Table 18: Losses on the Sub BROD power line network with different power factor

Power Factor	V1 [kW]	V2 [kW]	V3 [kW]	V4 [kW]	V5 [kW]	V6 [kW]	Total Losses [kW]
0,95	6,792	4,149	2,674	0,088	3,589	4,626	21,830
0,96	7,069	4,386	2,952	0,137	3,522	4,547	22,476
0,97	7,405	4,677	3,304	0,206	3,462	4,473	23,321
0,98	7,835	5,053	3,769	0,303	3,409	4,403	24,469
0,99	8,444	5,594	4,451	0,457	3,369	4,342	26,200
1	10,159	7,143	6,464	0,95	3,398	4,32	27,164
Passive	33,173	26,8	29,583	5,749	0,071	0	68,505

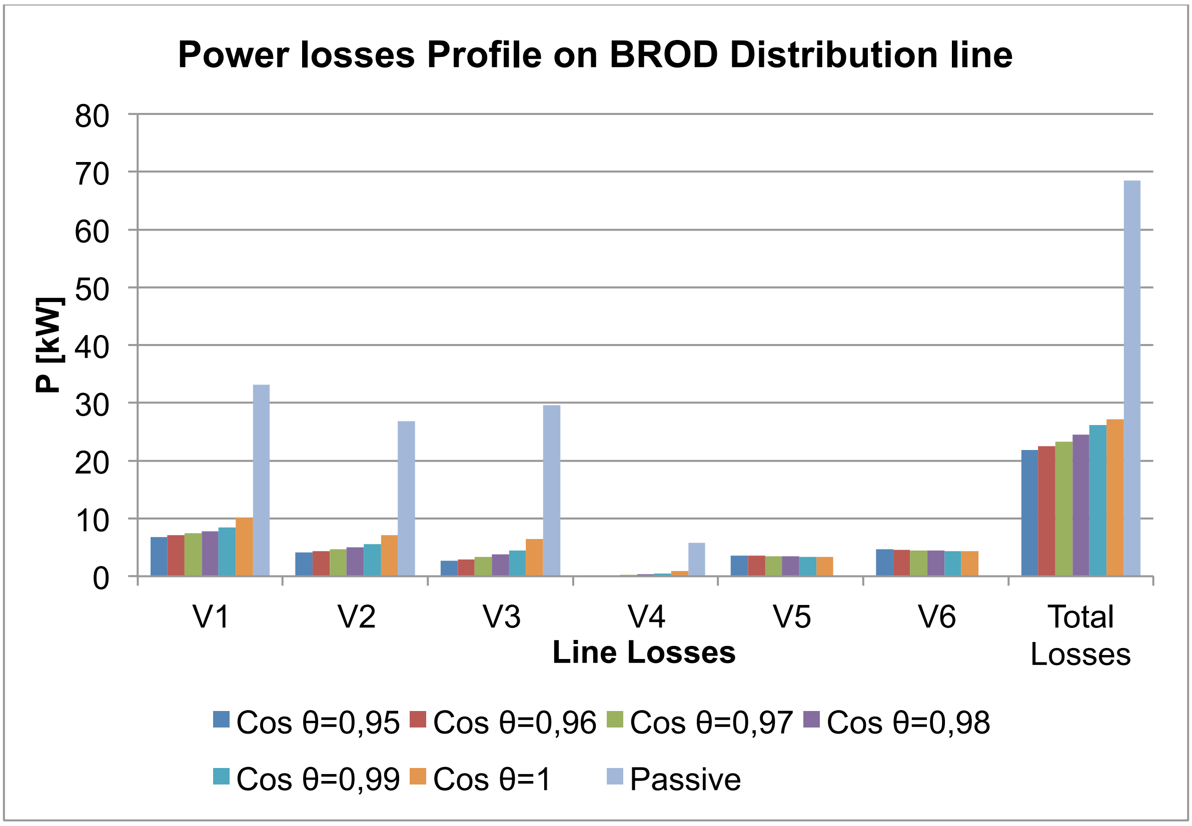


Figure 15: Power Losses profile on the Substation BROD power line Network

From Table 18 and Figure 15, the losses on the BROD power line Network increases as the power factor increases. The highest losses occur in line V1 where as the lowest losses in line V4. The variation of power factor has tremendous effect on the line losses. As shown from Figure 15, the losses increase to a very high level when the HPP is disconnected. Which means that, the HPP can be used to control the power factor and therefore reduce the current as well as the losses on the 22 kV BROD distribution power line. This scenario is quite same as that of the NYMBURK Substation.

Table 19: Conditions for connecting HPP1 and HPP2 to the Sub BROD distribution network

Nodes	0,95		0,96		0,97		0,98		0,99		1	
	HPP 1	HPP 2	HPP 1	HPP 2	HPP 1	HPP 2	HPP 1	HPP 2	HPP 1	HPP 2	HPP 1	HPP 2
U1	-0,04	-0,04	-0,04	-0,04	-0,04	-0,04	-0,01	-0,01	-0,01	-0,01	-0,01	-0,01
U2	-0,15	-0,15	-0,14	-0,14	-0,13	-0,13	-0,10	-0,10	-0,08	-0,08	-0,04	-0,04
U3	-0,22	-0,22	-0,21	-0,21	-0,20	-0,19	-0,39	-0,39	-0,36	-0,36	-0,27	-0,27
U4	-0,69	-0,69	-0,66	-0,66	-0,63	-0,62	-0,68	-0,69	-0,63	-0,63	-0,50	-0,50
U5	-0,94	-0,94	-0,90	-0,90	-0,86	-0,85	-1,12	-1,12	-1,04	-1,04	-0,84	-0,84
U6	-1,08	-1,08	-1,04	-1,03	-0,99	-0,98	-1,26	-1,26	-1,17	-1,17	-0,96	-0,96
U7	-1,22	-1,22	-1,17	-1,17	-1,11	-1,11	-1,40	-1,40	-1,30	-1,30	-1,07	-1,07
U8	-1,36	-1,35	-1,30	-1,30	-1,24	-1,24	-1,54	-1,54	-1,43	-1,43	-1,18	-1,18

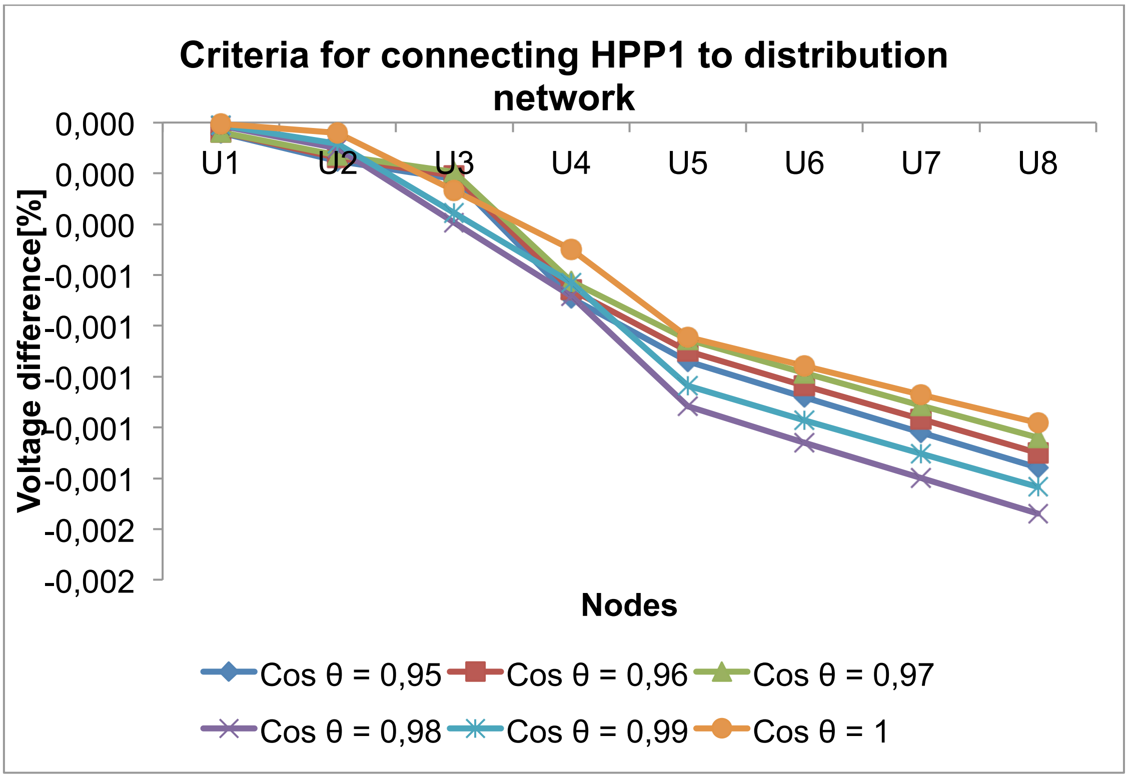


Figure 16: Connection of HPP1 to the Substation BROD distribution Network

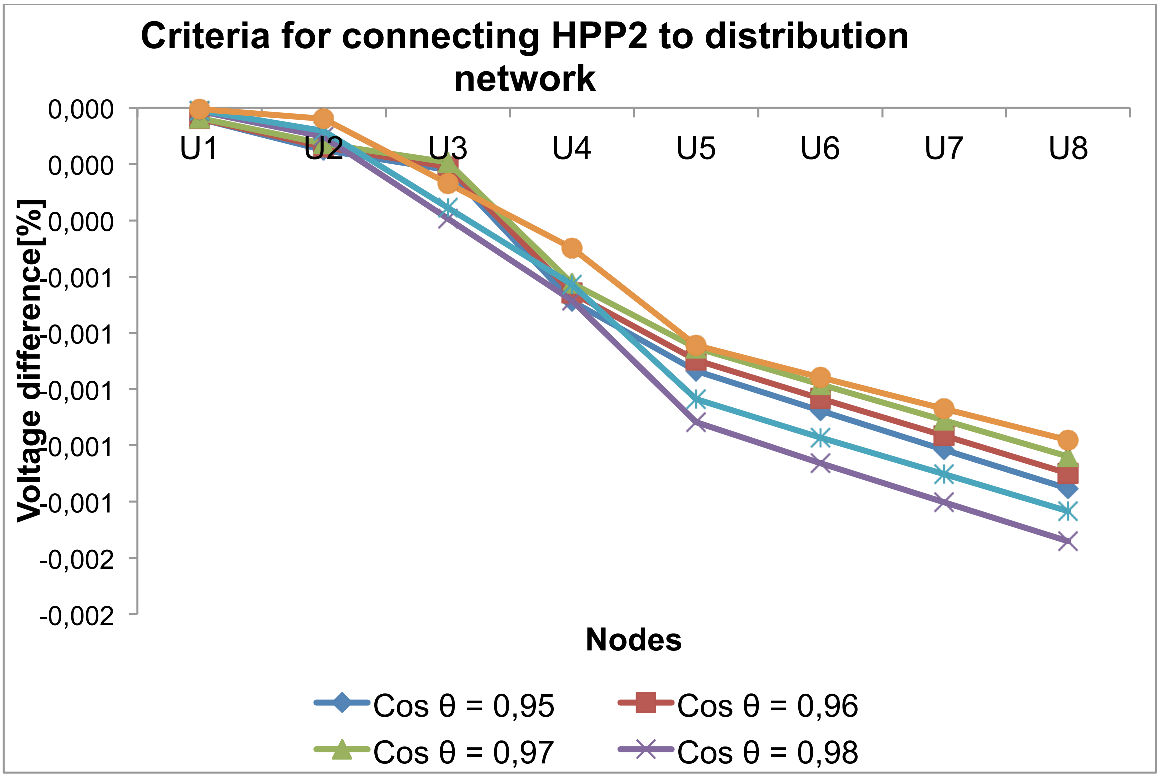


Figure 17: Connection of HPP2 to the Substation BROD distribution Network

From Table 19, Figures 16 and 17. The maximum difference in voltage before and after connecting both HPP1 and HPP2 to the BROD distribution network with capacity of 6.3kV each to the 22 kV distribution line is 1,54 %. This value has not exceeded the 2% Czech standard for connecting loads to the MV distribution network. Hence, the BROD distribution electricity network can be connected to the generation station with a power factor ranging from 0,95-1.

7 Conclusion

The integration of HPP in both Sub BROD and NYMBURK distribution line has obviously affect the overall power system, both in voltage profile, network losses and reactive power control. This study assessed the dynamic of network losses before and after integration of HPP into the BROD and NYMBURK distribution line and then determines the most optimum location, size of distributed generations and reactive power to reduce network losses and improve voltage profile of the system

From the calculation and analysis using eVlivy software, the influence of HPP in Sub BROD is a bit lower than the influence from Sub NYMBURK. Both Sub BROD and NYMBURK fit the Czech criteria of 2% nominal voltage standard for connection of MV into the distribution line with a power factor range from 0,95 to 1. The distribution company in this case has choice to choose which substation to connect to the distribution line without any limit.

The voltage profile of the system after integration of HPP with a total capacity of 2 MW has generally not much significant changes as shown in Figure 10 and Figure 17. However, there are several buses located close to the HPP for both Sub NYMBURK and BROD, which have some voltage improvement.

Nevertheless, before the integration of HPP into the distribution network, there is slight increase in losses at V2 for Sub NYMBURK and very high losses in V1 for Sub BROD as shown in Figure 13 and Figure 15 respectively. The main causes of the increment are due to the location of BROD Substation, which is located further from the Substation as compared to the NYMBURK Substation. After the integration of HPP with a reactive power component, the active power losses on the distribution network reduce tremendously for both Substations. The line losses, which are far from the HPP were high and it reduces as it approaches the HPP but increased again due to the high load demand in LSYA for BROD distribution line.

It has been observed that, with the integration of HPP and a reactive power component working of power factor value between 0.97 and 0.98 has helped to minimise the line losses, stabilise the voltage and control the reactive power. The integration of HPP has made possible reduction in voltage difference and power losses, which is better for Distribution Company since it reduces the cost of distribution line. The overhead line for NYMBURK has a higher cross section as compared to the BROD. It's recommended for line from BROD Substation, that higher cross-section of overhead line should be used in future.

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