Czech Technical University in Prague

Faculty of Electrical Engineering

Department of Electrical Power Engineering

Bachelor Thesis

Study of distribution Network Voltage for the DER operation

Author: Aldair da Costa Baptista

Supervisor: Ing František Vybíralík, CSc.

BACHELOR‘S THESIS ASSIGNMENT

I. Personal and study details

Student's name: **Baptista Aldair Da Costa** Personal ID number: **453308**

Faculty / Institute: **Faculty of Electrical Engineering**

Department / Institute: **Department of Electrical Power Engineering**

Study program: **Electrical Engineering and Computer Science**

II. Bachelor’s thesis details

Bachelor’s thesis title in English:

Study of Distribution Network Voltage Profile for the DER operation

Bachelor’s thesis title in Czech:

Napěťový profil distribuční sítě s obnovitelnými zdroji energie

Guidelines:

1. General review on renewable energy sources
2. Characterize basic RES type (principles, advantages, disadvantages ?)
3. Rules and standards for connection of RES to distribution network
4. A case study for selected type of RES (photovoltaic) in variants

Bibliography / sources:

[1] Distribution network codes
[2] eVlivy application manual
[3] SCHLABBACH, J, D BLUME a T STEPHANBLOME. Voltage quality in electrical power systems. London: Institution of Electrical Engineers, c2001, x, 241 p. IEE power and energy series, 36. ISBN 978-085-2969-755.

Name and workplace of bachelor’s thesis supervisor:

Ing. František Vybíralík, CSc., Department of Electrical Power Engineering, FEE

Name and workplace of second bachelor’s thesis supervisor or consultant:

Date of bachelor’s thesis assignment: **19.02.2018** Deadline for bachelor thesis submission: **25.05.2018**

Assignment valid until: **30.09.2019**

Ing. František Vybíralík, CSc. Supervisor’s signature	Head of department’s signature	prof. Ing. Pavel Ripka, CSc. Dean’s signature

III. Assignment receipt

The student acknowledges that the bachelor’s thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the bachelor’s thesis, the author must state the names of consultants and include a list of references.

.

Date of assignment receipt	Student’s signature

Declaration

I hereby declare that I am the sole author of the thesis entitled “Study of distribution Network Voltage for the DER operation“ and all of the duly references and quotations have been marked in the respective list of references.

In Prague on 21 May 2018 Signature

Acknowledgements

First and foremost, I would like to thank God almighty for his grace and countless love.

I wish to express my sincere appreciation and gratitude to the supervisor of my thesis, Vybíralík František, CSc. for the necessary guidance and assistant in producing this work.

To all relatives, friends and faculty colleagues, and all the other people whose names I did not mention but contributed directly or indirectly to this work I would like to express my gratitude.

Abstract

The current demand for new alternatives to fossil fuels leads us to explore new types of technologies that are based on renewable sources. Renewable resources have a huge index of availability and present an almost infinite cycle of regeneration; this makes them ideal for energy generation.

The appearance of technologies based on renewable resources comes along with a new set of unanswered questions like how effective these renewables technologies are. What are their prospects? Which effects they have on the environment? Can they be integrated with our current distribution network?

This bachelor thesis proposes to answer all of the above questions and focus on a particular scenario where a Hydropower plant was integrated to the distribution network.

Key words: Renewable Energy, Hydropower, Integration to the distribution network, Rules, and Guidelines.

Abstrakt

Současná poptávka po nových alternativách k fosilních palivům nás vede k hledání nových typů technologií založených na obnovitelných zdrojích. Obnovitelné zdroje mají obrovský ukazatel dostupnosti a představují téměř nekonečný cyklus regenerace, což je činí ideální pro výrobu energie.

Technologie založené na obnovitelných zdrojích přichází spolu s novou sadou nezodpovězených otázek, jako je účinnost těchto obnovitelných technologií? jaké jsou jejich vyhlídky? Jaké mají vliv na životní prostředí? Mohou být integrovány do naší distribuční sítě?

Tato bakalářská práce navrhuje odpovědět na všechny výše uvedené otázky a zaměřit se na konkrétní scénář, kdy byla hydroelektrárna integrována do distribuční sítě.

Klíčová slova: obnovitelná energie, vodní energie, integrace do distribuční sítě, pravidla provozování.

Contents

Figure List

Table List

List of abbreviations

AC	Alternating Current
BP	British Petroleum
CSP	Concentrating Solar Power
ČSVE	Česka společnost pro větrnou energii (Czech Wind Power Company)
DC	Direct Current
DER	Distributed Energy Resources
GWh	Gigawatt Hours
HAWT	Horizontal Axis Wind Turbine
Hz	Hertz
IO	input-output
kV	Kilovolt
kW	Kilowatt
m	metre (meter)
min	minute
MW	Megawatt
NREL	National Renewable Energy Laboratory
NTK	Národní Technická Knihovna (National Library of Technology)
OH	Overhead Line
PV	Photovoltaics
SHC	Solar Heating and Cooling
UK	United Kingdom
UNFCCCU	United Nation Framework Convention on Climate Change
USA	United States of America
V	Volts
WWII	War World Two

1. Introduction

Every system needs to be feed by something, it needs the energy to run, for example, the human body, is feed from proteins and water necessary to perform all of its vital functions, the human body cannot stay alive if it not sustained. The word energy in physics express the capacity to produce work, by its own energy can be displayed in nature in different forms being distinguished by means of production, availability, and other factors. So we do not have a textbook definition of energy by its definition is closely associated with the production of work. In science this word (from the Greek *εν*, "(in)", and *έργον*, "work": rephrasing that it leads to, "in work") it refers to a physical quantity necessary to describe correctly the interconnection between two physical systems.[1]

If we go back to history, to the year of 1773 to be more precise a French chemist named Antoine Laurent Lavoisier did an experiment in which he determines that in a closed system isolated from any transfer, the mass remains constant in time, this principle is known as the principle of conservation of mass. Energy in its essence it is not so different than mass; energy cannot be created or destroyed it can be only transformed, this principle is known as the law of conservation of energy. The key word is Energy and the way we get it is of equal importance. In nature, we have a lot of raw materials and natural resources that we can transform it and obtain energy.

Energy is a big part of our society and it is primordial to our wellbeing, so one of our greatest challenges is to make sure that everyone has access to it and on the same level preserves our environment. Most of the energy produced by our systems have a significant environmental impact since our primary source of energy is fossil fuels (oil, gas, and coal). Fossil fuels have in their composition high levels of carbon dioxide and other greenhouse gases who are ultimately responsible for the global climate change.

It is important for us to establish a difference between the energy obtained in a friendly environmental way, and energy obtained in a noxious environment, so we will be dividing them into to two groups of energy resources, (the non-renewable ones and the renewable ones) with emphasis on the second group.

Non-renewable energy resources are natural resources in general which are encountered in nature in fixed quantities and their usage rate is much quicker than their natural production rate, for example,

---

[1] By Energia, Wikipedia in Portuguese | available at https://pt.wikipedia.org/wiki/Energia

the nuclear energy has in its base a radiative metallic element called uranium, which is extracted from the earth and cannot be reset quickly enough.

However, on the other side of the fence, we have the renewable energy resources, which are encountered in nature in abundant capacities, and they have a quick regeneration capacity and are easy to maintain.

The most common example of this type of resource is water since the surface of our planet is over 71% covered by water.

By converting energy from one form to another one is important to keep in mind the efficiency that these systems have, the efficiency can be understood as the ratio between the obtained output and the required input.

Later on, we will be discussing and comparing different solutions involving the most popular types of energy.

The world in general is taking steps into adopting a more renewable and sustainable way of energy production and a vibrating example of this is the signing and the ratification of the Paris agreement, which bounds the 176 parties of UNFCCC. The objective is to make real efforts to keep reducing the global level rise well below 2 degrees Celsius above pre-industrial levels and come up with initiatives to limit the temperature even further to 1.5 degrees Celsius, aiming to strengthen the capacity of countries to deal with the impact of climate change. [2]

These renewable energy sources have a crucial task to maintain energy demand low and at the same time do no harm to the environment, and every day technology evolves to further push this agenda.

The challenges that we face today is to make sure that we are transitioning into a greener future and at the same time, we are making sure that we are producing enough green energy to maintain our standard of living, and that is what we will be addressing during this bachelor project.

[2] By The Paris Agreement | available at https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

2. Chapter I — Present Day World Energy

Since the beginning of times, the humankind had to rely on the resources that the Mother Nature had at their disposal to be able to survive. We conquer fire, and a few years later we were using the solar power, water, and wind, which were based the first civilizations. Those technologies evolved until we reached the industrial era.

From this point, the fossils took over and substituted wind and waterpower becoming popular on the worlds energy field. Every year we can expect an increase on the actual consumption of energy, and we can affirm that not only looking into our metric counter. Energy consumption by it owns is not only related to electricity we can look at it by other indicators as transportation, heating fuel, and others.

The renewable energy sources supplies mainly in large scale by the radiation emitted by the sun, large hydro, traditional biomass, wind, geothermal, and biofuel. The traditional biomass according to our data was by far the renewable that supplied more, observing a growth in a few regions.

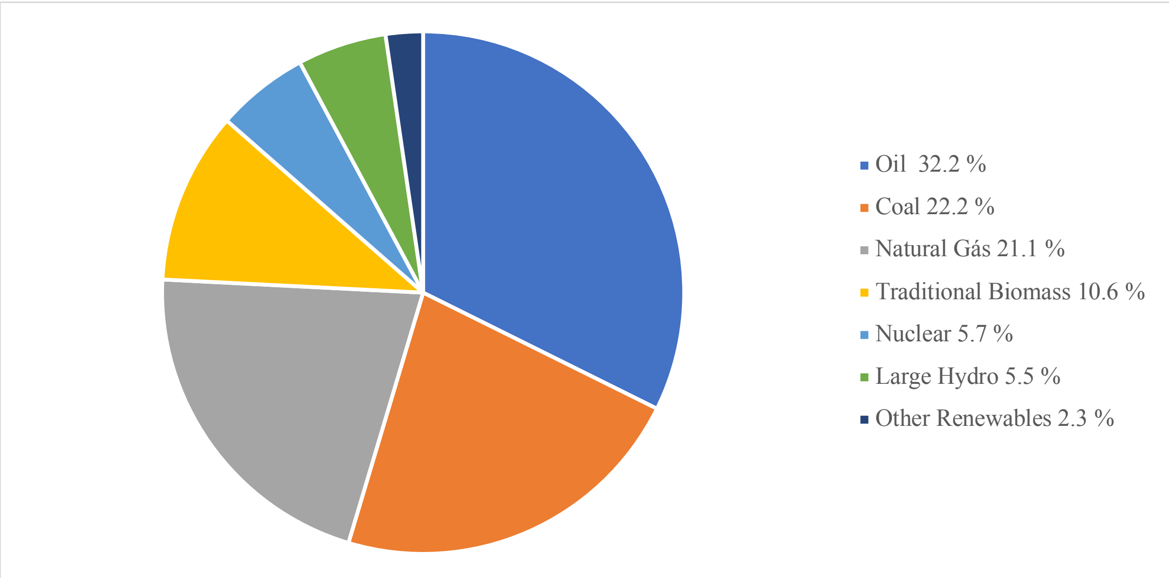

Figure 1 — Percentage contributions of various energy sources to world primary energy consumption | sources: BP, 2003, United Nations, 2000

The renewable energy sources in 2002 were adding 18% of world final consumption, this number can differ between sources due to the lack of the precise number of the contribution of the traditional biomass fuels and the non-standard method of calculating the energy contribution of hydroelectricity and other electricity producing renewable sources.

Let us farther introduce the concepts of electricity generation. Electricity generation comes from the idea of obtaining electric power from sources of primary energy (being renewables and non-renewables). The companies that generate electricity safeguard electricity generation this take place in power plants, this part, and a good example of it here in the Czech Republic would be CEZ Group.

Inside this process, we encounter the decentralization of energy which the name already suggests that is the generation/ storage of energy on site (close to the production facility) in order to avoid transmission losses. Usually, this generation is done by small to medium scale devices connected to the grid known as DER.

After the electricity is generated it must be transmitted, at this part the grids and distribution operators take their part of the transmission and distribution network. The transmission line carry high voltages at long distances and at the distribution line this electricity is lowered in a substation and the distribution companies delivered the electricity to final consumers.

DER can be encounter on the range of 3 kW to 50 MW, the most common DER technologies commercially available and considered emerging technologies are: Microturbines (with a 28% to 33% efficiency), Fuel Cells (with a 45% to 55% high temperature efficiency and 30% to 40% low temperature efficiency), Energy Storage/UPS Systems.

We also have other DER Technologies such: Photovoltaic, Large Wind turbines, Internal Combustion engine. Price wise the internal combustion engine is the cheapest one to maintain, but has setbacks such: environmental emission issues, noise, and the marginal cost of production.

Before getting a DER, is important first to identify the reasons for wanting one, consider other options technology wise, cost/savings analyses, elaborate a plan of development and execute it, consider the risk/benefits. From the technologies described here Photovoltaic and the Large Wind turbines are the DER technologies that are more plentiful renewable.[3]

---

[3] By Distributed Energy Resources (DER) | available at: https://www.wbdg.org/resources/distributed-energy-resources-der

3. Chapter II — A general view on Energy generated by Renewable sources

In this new era, the trend of adopting environmentally friendly solutions capable of substituting the strong presence of fossil energy solutions is growing each day. This popularity translates into an increase of demand of professionals working with these technologies. A major advantage of renewable sources is that they come with life healthy benefits that will lead to a better quality of life.

The most common types of renewable technologies are based on solar thermal energy / solar photovoltaics, bioenergy, wind energy, geothermal energy, and hydroelectricity / tidal power / wave energy.

The geothermal, biomass, and wave energy are considered the most stables among these different types of renewable technologies. The ones depending on gravity (ex: tidal power) are frequently stable. The solar thermal energy / solar photovoltaics, wind energy are variable and not stable.

Being renewable implies that these sources have a much higher life span than conventional fossil sources, globally we can say that price wise the fossil sources are influenced by their availability since they are limited, which is not the same when we use a renewable solution (Fixed costs).

Compare it to our traditional fossil sources we verify that is difficult to generate large capacities, this happens due to the fact that most of the common renewable solutions are facilities of small and medium size.

Another step back of using these sources is that they do not have fixed capacities since they have a huge dependence for example on the weather forecast and climate changes if we are using a solar panel on a rainy day we expect to produce less power than in a bright sunny day.

The future of the renewables passes by increasing their efficiency; decrease their initial investment price, and a few incentives and regulations. The year of 2016 marked one milestone into the race of a much greener Planet Earth.

In 2016, the solar energy was considered to be more competitive than the others were and cheaper than the Wind energy.[4]

---

[4] By Bloomberg New Energy Finance via independent Study ‘Climatescope 2016’ | available at: http://2016.global-climatescope.org/en/summary/

3.1. Solar Energy

The sun since earlier times already had many things to offer; one thing is certain that the sun will keep shining at least until the end of this planet. It is present on the orientation of time, and in trivial day applications like generating fire, cooking and heating as well.

The sun is our main source of light providing energy to earth thanks to this most of our flora and fauna is sustained, the human body benefits from it by producing vitamin D. The Heat and the light from the sun which are available using different technics and every year more developed technologies is considered to be solar energy. Solar energy is a renewable energy prevenient from the sun. This is possible by taking into account the radiation generated from the sun. It is important to have first a clear knowledge of the weather forecast to take a better advantage of these technologies.

We can classify these technologies in the way the solar energy is captured, converted and distributed; to distinguish them we use two separate groups (Active and Passive). The active group deals with devices designed to capture this energy using different constructs; this group includes photovoltaics panels and solar thermal collectors. The passive group relies on different passive techniques described in the bioclimatic architecture.[5]

There are three main ways of taking advantage of this radiation. The first one is the thermal approach of the solar energy, which consists of using his radiation to heat a fluid, depending on his temperature is used to produce hot water or steam water. This process is called SHC.

The second way of the taking advantage of the solar energy is to use Solar Photovoltaics (PV); here the conversion of solar energy to electric energy is direct obeying the photovoltaic effect (an electric current is produced between two different materials in contact when they are stricken by electromagnetic radiation or light). Between the two of them, the Solar photovoltaics is the one that as experience significant advances in his development.

The third main process is known as CSP, which uses mirrors to concentrate the energy from the sun.

Dealing with solar energy as an alternative to other sources of energy we are most likely certain to encounter difficulties. These difficulties includes the fact that it is available only during daylight, price of storage (batteries and accumulators), price of initial capital , but on the other hand it is a

[5]By Energia Solar via Wikipedia en Español https://es.wikipedia.org/wiki/Energ%C3%ADa_solar#cite_note-13

clean solution, with low maintenance costs, sustainable, and offers possibility of being disconnected from the grid.

3.1.1. Solar Thermal Energy

Solar thermal energy uses the heat from the sun to his advantage to deliver to end consumers. Basically, we are capturing the suns energy (trapping the sun heat) and we use the heat redirecting it to our homes via heating systems as hot water, steam water or space heating. They are also well-documented applications of solar thermal energy in industrial capacities.

We can collect thermal energy into different systems, for example for low-temperature solar heating we have a strong dependence on glazing.[6]

I believe that many of us when we were kids we used to transform light into heat, this experiment is very popular and simple to set, for this, we only need a magnifying glass and bright daylight. The experiment consists into burning or heating a surface buy magnetifying the intensity of sunrays.

It is primordial to say that one of the most important properties of the glass is the fact that it is transparent to visible light and infrared radiation waves (short ones; on the case of long infrared radiation waves the glass is opaque).

Other ways of collecting solar energy can be active solar heating, which always involves a discrete solar collector, most of the time these solar collectors are mounted on the roof, mainly to gather solar radiation. These collectors absorb temperatures under 100 degrees Celsius and used for domestic hot water or swimming pool heating.[7]

A simple working flow of a solar energy diagram using low temperature solar heating would be the solar radiation at the beginning following with a solar collector, that use the radiation to control the heating of a fluid, this fluid (water or air) is used at the final stage of this working chart we encounter the thermal energy.

Usually, these systems have a storage facility unit that delivers thermal energy during days in which the sun presence is absence (rainy or cloudy days).

---

[6] By “Renewable energy, POWER FOR A SUSTAINABLE FUTURE”, 2ND EDITION, edited by Godfrey Boyle, Chapter 2: Solar Thermal Energy by Bob Everett. NTK code: b13932a pp. 18

[7] By “Renewable energy, POWER FOR A SUSTAINABLE FUTURE”, 2ND EDITION, edited by Godfrey Boyle, Chapter 2: Solar Thermal Energy by Bob Everett. NTK code: b13932a pp. 19

These last two elements (the solar collectors and the storage unit) are the main elements of a solar thermal installation using active solar heating.

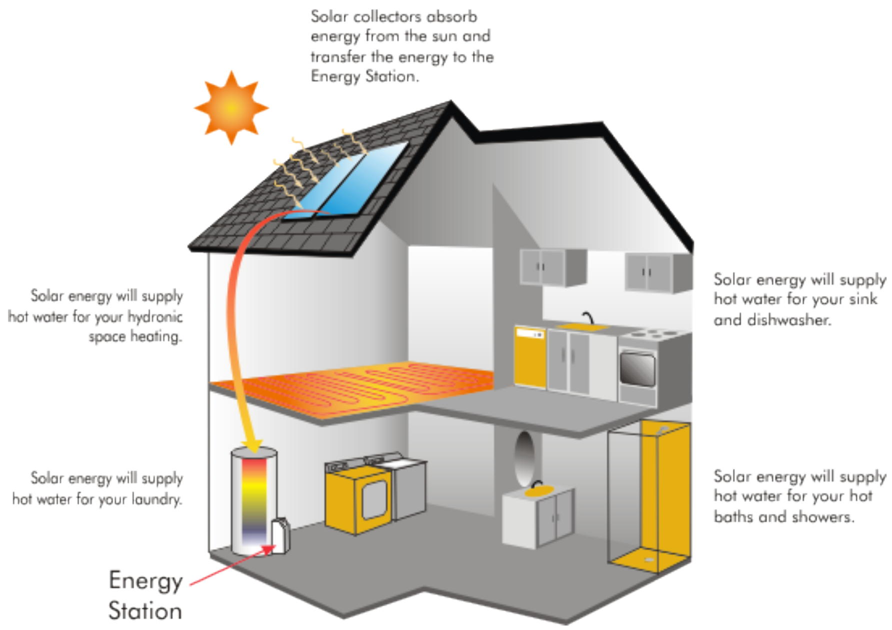

Figure 2 — Typical diagram of a low-temperature solar heating | source: City of calabassa.com

The solar panels present on figure 2 are typically made out of three components (gazing, the absorber plate and insulation), this plate is usually sprayed with black ink to maximize absorption and cover on the back to avoid heat losses.

This schematic does not differ a lot from the active solar energy the only significant difference is on the size of the collectors, and the storage tanks. These collectors also have an abundance of variants and can be narrow to flat plate collectors and unglazed panels.

The difference between them is that the unglazed collectors disregard the heat losses because they are vastly used on environment, which the heating of water and the ambient temperature varies so little.

Next on the list are the Passive Solar heating systems, their main characteristic is that they do not use any sort of delivering devices, usually they take advantage of the natural construct of the buildings. Usually, these buildings are well insulated and designed to avoid overheating during the warm seasons. It is also beneficial to them to avoid being in the middle of taller buildings in order to benefits from the sun. Stepping a few foots out of low-temperature application for solar energy we will encounter the solar thermal engines based on mirrors.

We use mirrors to concentrate the rays of the sun to generate enough boiling water to rotate steam engines, this leads to a driving state of an electric generator. This technology in a few cases can be cheaper than the photovoltaics one. We can encounter three main types of power solar concentrators that are parabolic trough concentrator systems, parabolic dish concentrator, and solar chimneys.

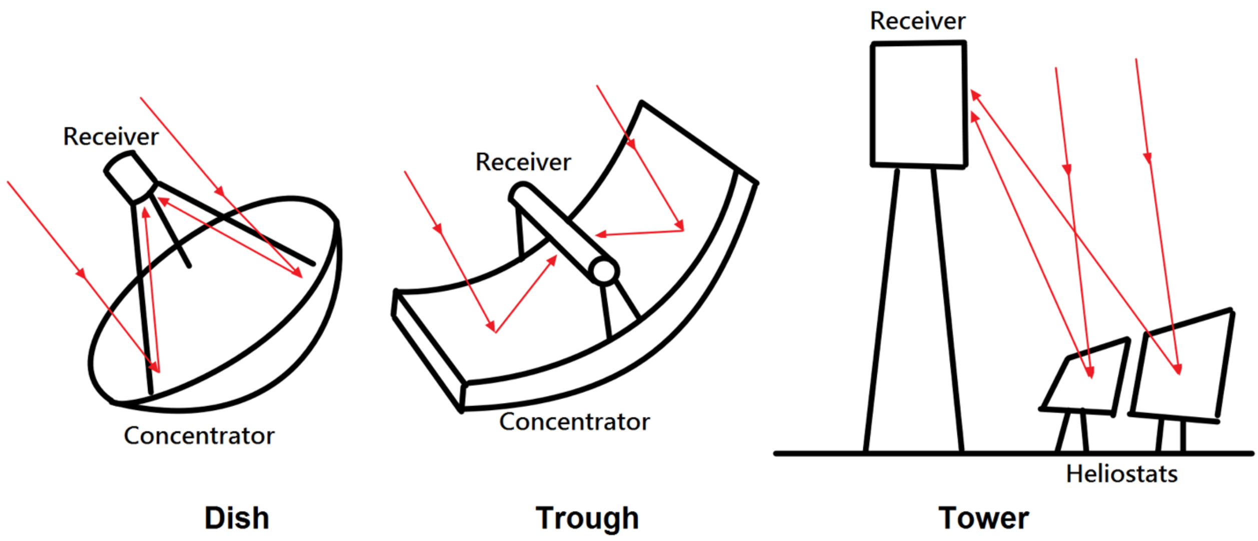

Figure 3 — Different types of concentrators | source: Wikimedia Commons

3.1.2. Solar Photovoltaics

The term "photovoltaic" is formed by matching the Greek word for φως ("light"), and from "volt", (the unit of electromotive force, and the force that causes the motion of electrons). The word itself is associated with the generation of electricity by light (hence the photovoltaic effect). This effect is related to semiconductor materials (silicon in our particular case).

When incident light (light in our case is considered to have energy particles named photons) strikes the cell (which is formed by the P-N junction of silicon) the electrons go to a higher state of energy so they become excited and free to travel from the “P” layer to the “N” layer of the material making them conduct electric current.

To form a photovoltaic module this cell must be in series and usually they have a nominal voltage of 0.5 V, usually, they form modules made by 30, 32, 33 and 36 cells in series suitable to the required application. These modules can be also combine and form arrays.

These cells can be classified according to their production method being reduced to three groups (monocrystalline silicon cells, polycrystalline silicon cells, and amorphous silicon). The monocrystalline silicon cells are the first generation of silicon sells having in their base a single lattice structure. They are manufactured on special ovens and cut into special thin pastilles usually with a thickness in the range of 0.4 mm to 0.5 mm approximately.[8]

The monocrystalline silicon PV modules are highly efficient but are expensive due to higher levels of energy labor wasted during production.

The production process is also very slow however; we can still make less pure silicon crystalline PV modules and cells not compromising a lot of our efficiency. For example, the Polycrystalline silicon cells have a lesser cost of production compared to the monocrystalline one and required less labor in their production.

They are less effective than the monocrystalline one due to the crystal imperfections during manufacturing.

These cells are manufactured by molten small pieces of pure silicon in special molds, so the atoms cannot restructure into a single crystal so it forms a polycrystalline structure with surface separations between the crystals.

The amorphous silicon cells among the others are the ones that presents the smaller production and the smallest efficiency. Their cells show very thinly films.

Figure 4 — Different types of PV Cells and their power output | source: Ledwatcher.com

PV systems can also be used in connection with the grid. The PV system uses the grid as a storage unit. In a very sunny day the PV system sustained the operations reducing the billing of electricity,

[8] By Efeito fotovoltaico | available at: https://paginas.fe.up.pt/~ee97234/efeito_fotovoltaico.htm

and in a very cloudy day or during night the PV solution does not have enough capacity to sustain, the demand, the grid compensates or provide the needy assistance at this domestic setup.

These grid-connected systems have a synchronous inverter that transforms DC power that comes from the PV into AC Power. In order to be accepted by the grid this must be in the correct voltage and frequency. These PV technologies have a huge initial cost but a very low running cost. They have a low environmental impact, no noise emission.

3.2. Bioenergy

Bioenergy is a renewable energy type that is produced using living matter. This living matter is formed by a biological or mechanical process and transformed into organic and industrial matter. This organic and industrial matter can be transformed into biofuel (for example the biodiesel is formed by wood and plant seeds) or can be burned to produce heat and power.

The most noticeable forms of bioenergy are the biofuels and biomass. The biofuel is the one that has a non-fossil source in his manufacturing process they are fuel made out of agriculture products such sugarcane, maize, soy, and others. Biomass we can consider all of the living matter found on earth, plausible with a lot of energy stored in it. In this sense, we can say that biomass is used to produce biofuel. The bioenergy sources can be divided into two main source groups: the energy crops and the wastes. Energy Crops are becoming very popular because are a plausible alternative to fossil fuels since does not depend on the regulation of oil markets, and the fact that they made out of woody or herbaceous plants makes them really cheap to harvest and to maintain.

The main problem with energy crops is the fact that are increasing controls over wood removal due to environmental problems. However, we have the option of using herbaceous Plants (plants with reduced wood, flowery plants), or sugarcane, and maize has an energy crop (in this case consider to be agriculture crop).[9]

Wastes are residual substances that are discarded after they serve their primary use. In the process of generating bioenergy, we have residues such:

- wood residues, (for ex: during the process of acquiring wood we can encounter a lot of leftovers, a common use of this is to use as firewood to generate heat) ,
- temperate crop waste (for ex: residuals from wheat and maize being the two main cereal temperate in the world),

---

[9] By "Renewable energy, POWER FOR A SUSTAINABLE FUTURE", 2ND EDITION, edited by Godfrey Boyle, Chapter 4: Bioenergy by Stephen Larkin, Janet Ramage & Jonathan Scurlock. NTK code: b13932a pp. 114

- Tropical crop waste (is similar to the temperate crop production the difference is that they are being used for fuel as well, ex: the bagasse from the sugar cane.), and
- Animal waste (ex: sewage sludge by anaerobic digestion process).[10]

Bioenergy as itself plays a major roll on reducing the pressure on the fossil-fuel industry, and doing that while emitting close to zero greenhouse gas emissions, improving soil fertility, delivering reliable energy. Bioenergy reliability is larger than wind and solar but on the other hand can lead to deforestation and waste of resources for food production; they also take considerable space of production and overall is a more expensive alternative to fossil fuels.

3.2.1. Biomass

Biomass is popular defined, as "plant matter such trees, grasses, agricultural crops, or other biological material" (NREL 2011). An important property of biomass is its carbon neutrality. Since we already establish the use and importance of biomass, it is necessary to go to their conversion process into energy.

There are four types of conversion processes that are used to transform biomass; these processes are chemical conversion, thermal conversion, thermochemical conversion, and biochemical conversion.

The chemical conversion of biomass consists of using chemical processes to transform biomass into energy. This conversion vastly uses chemical reactions, so we need an ester (a chemical compound derived from acid) to bond with the alcohol, after the reaction, these acids become combustible.

This process is called transesterification and a good example of a product made by this process is the biodiesel.[11]

The thermal conversion includes transforming the biomass for power and for heat, and evolves processes such:

- Combustion — this includes direct burning, so the biomass is burned in a boiler to produce steam, after that the steam is fed to a turbine connected to an electric generator that rotates because of the steam flow and electricity is generated.

[10] By "Renewable energy, POWER FOR A SUSTAINABLE FUTURE", 2ND EDITION, edited by Godfrey Boyle, Chapter 4: Bioenergy by Stephen Larkin, Janet Ramage & Jonathan Scurlock. NTK code: b13932a pp. 115

[11] By Bioenergy Conversion Technologies | under the section Chemical Conversion, available at: http://www.wgbn.wisc.edu/conversion/bioenergy-conversion-technologies

- Pyrolysis and Torrefaction — the pyrolysis will expose a biomass feedstock to high temperatures above 430 degrees Celsius under controlled pressured environment and low oxygen levels (also at this level, the biomass is exposed to combustion). The Torrefaction the same approach as Pyrolysis (applying heat in the absence of oxygen), but the difference is that the applied heat is smaller than in Pyrolysis (typically from 200 to 320 degrees Celsius).[12]

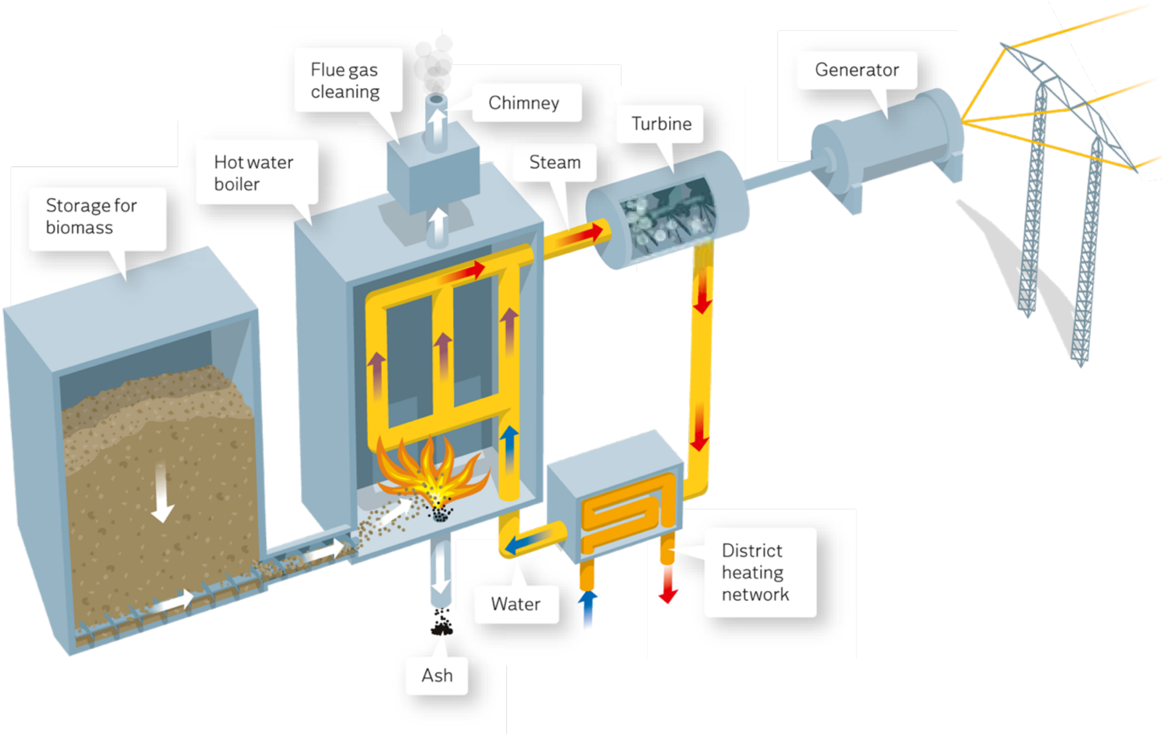

Figure 5 — Biomass Power Plant using combustion | source: Vattenfall

Biomass is solid at its essence, so by converting the biomass into gas we can expand their range of applications, for example, we can use biomass in a gassy state for heating purposes.

This is possible due to the thermochemical convention process to be more precise gasification (in this process we are increasing the temperature of a biomass until it forms a gas). This gas can be then used in gas turbines and steam turbines to produce electricity.

---

[12] By Bioenergy Conversion Technologies | under the section Thermal Conversion available at: http://www.wgbn.wisc.edu/conversion/bioenergy-conversion-technologies

Another popular process to convert biomass to energy is the biochemical conversion. Biochemical conversion includes Fermentation and the anaerobic digestion. Fermentation is deemed a complex process to convert biomass into energy so this leaves us the anaerobic digestion.

The anaerobic digestion is vastly used in the recycling, treating and process of waste. Can be also considered to be a type of fermentation (converting waste in free oxygen environments), we are converting organic material (for ex: wet organic waste like animal feces) into biogas.

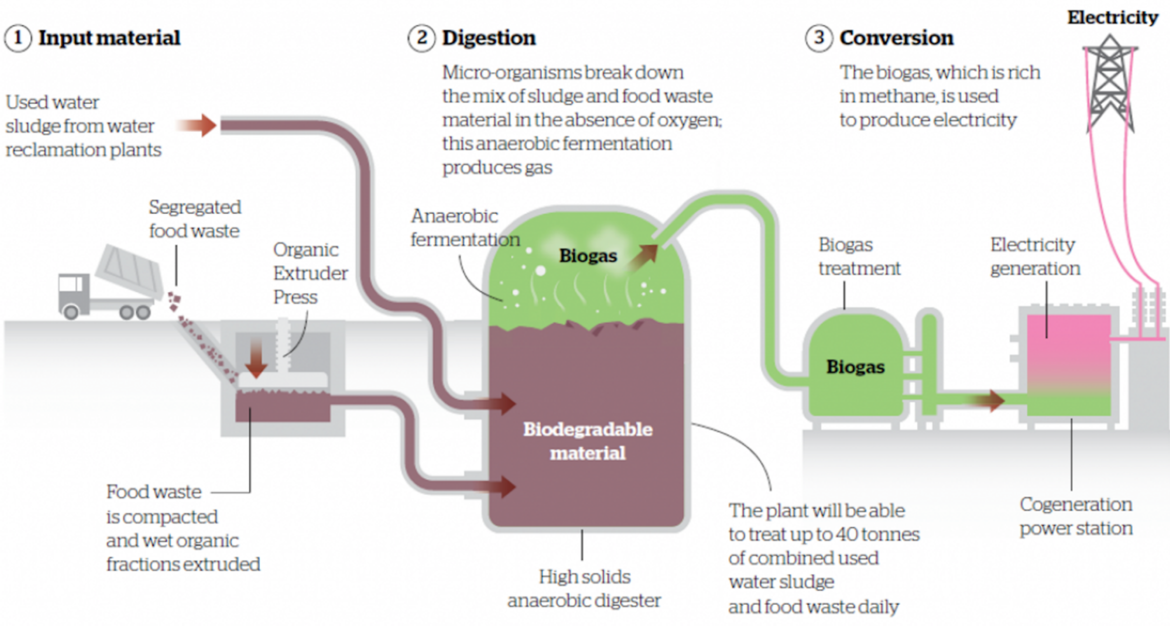

Figure 6 — Anaerobic Digester Working Principle | source: Anaergia

3.3. Wind Energy

The wind is the flow of gases resulting from the variations in atmospheric pressure, most of the wind in earth is air masses, these air masses have kinetic energy, this kinetic energy is then converted to other forms of energy this is called Wind power.

$$\text{Kinetic energy} = \frac{1}{2} \times mV^2 \qquad (1)$$

If we imagine a volume of air passing at velocity V through a ring enclosing an area A each second, we can calculate the kinetic energy in the wind, the following deduction will be:

Mass (m) of air per second = air density × volume of air per second = air density × area × length of cylinder of air flowing per second

= air density × area × velocity

i.e. m = ρ·A·V ⇒ substituting for m in (1).

We have Kinetic energy per second = ρ·A· V^3(joules per second) equal to power (watts) = kinetic energy in the wind per second (joules per second) ideally

$$\mathbf{P = 0.5 \cdot \rho \cdot A \cdot V^3} \text{ [watts].}[13] \quad (2)$$

Wind power converts the airflow kinetic energy through the rotational mechanical movement of a wind turbine into mechanical energy that power an electric generator. It is important to mention that the power contained in the wind is not equal to the power that is extracted by a wind turbine; this difference appears because of losses in every conversion process.

Wind energy is not new to humankind, since a long time we are using wind energy to pump water and grind grain, sailing ships and others. In our days, we expand the applications of wind energy by using wind to generate power that is harness without pollutants.

Globally wind energy it is a solution that is potentially growing fast but, much of the wind power is encounter in zones of difficult access (far by the sea or high altitudes) making it inaccessible.

However the remaining amount that is accessible has been estimated to be 20 times the electricity demand in 2013 (300 million GWh per year).[14] The wind energy can also be considered a type of wind energy due to the solar influence on the wind (the sun heats the earth and the wind is caused by the difference of heat in distinct regions).

Table 1 — Functional wind turbines in Czech Republic in individual years | source: ČSVE

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Power [MW]	116	148	192	215	217	260	269	283	283	283*	308*
Production Capacity[GWh]	125	245	290	336	397	416	479	472.4	573	496.9	591

[13] By "Renewable energy, POWER FOR A SUSTAINABLE FUTURE", 2ND EDITION, edited by Godfrey Boyle, Chapter 7: Wind Energy by Derek Taylor. NTK code: b13932a pp. 248

[14] By "RENEWABLE ENERGY ‚a first course" by Robert Ehrlich, Chapter 7: Wind Power , ISBN 978-1-4398-6115-8, NTK code: b16816 pp. 183

From this table, we can clearly see that increase of capacity production here in the Czech Republic, with a special attention of the two last year's (*) been an estimate of the total installed capacity of the functional Wind Power Plant, is currently in operation 303 MW.

3.3.1. Wind Turbines

Through history, the wind has been used to propel sailing boats, but later on, they were using wind on mills to mill grain, and grind spices, these mills due to their particular function of converting wind energy into rotational energy using adjusting blades were named windmills.

Later on, over the years many other devices were developed to harness wind like wind turbines still in use today.

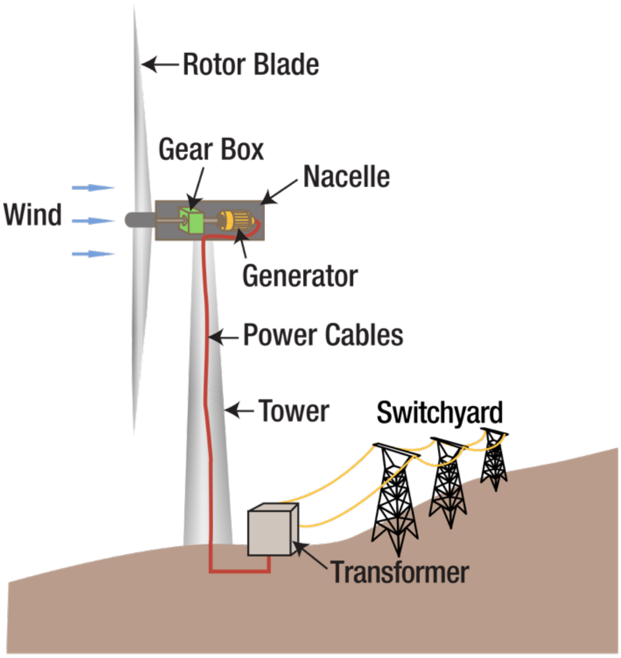

Figure 7 – Common Wind Power Plant | source: Mechanical Booster

A wind turbine is composed of three major components[15]:

---

[15] By Conserve Energy Future | under the section what is Wind Energy ? , available at: https://www.conserve-energy-future.com/wind_into_energy.php

- Rotor — the rotor is the component that has blades attached to a centerpiece and it is responsible for converting the kinetic energy of the wind to rotational energy. The wind makes the blades rotate and create a mechanical rotational movement.

- Nacelle — is a centerline enclosure where the rotor is attached, It is important because it protects components such gearbox (used to increase the speed of the generator), generator (it is an electric generator that in fact converts the rotational energy to electricity), brakes and others.

- Tower and Foundation — the tower is the structure responsible for supporting the rotor and the nacelle and as well for elevating the rotor and the nacelle to better capture the wind. For stability purposes, a foundation is built to ensure that the tower is lying in a consistent ground.

The transformer in *Figure 7* serves the purpose of increasing the voltage to be transmitted over the line. Modern turbines fall into two main categories: horizontal axis and vertical axis configuration. In the beginning, most of the windmills were using the vertical axis configuration.

Horizontal Axis Wind turbines are mainly based on the axial flow type that means that the rotation axis is in line with the wind, having a Yaw drive that makes sure the rotor is facing the wind direction.

Usually having two or three blades and in some cases a large number of blades covering a solid disc. In contrast, the two or three blades horizontal axis wind turbine is considered to have low solidity, having rotors similar to aircraft propellers.

This low solidity wind turbines are the most common type of wind turbine to be manufactured predominantly used to generate electricity.[16]

We also have rotor configuration in which the rotor is facing the wind (upwind configuration) which reduce tower shading; and we have the configuration where the rotor is in the back (downwind configuration), leading to less expensive production costs.

---

[16] By "Renewable energy, POWER FOR A SUSTAINABLE FUTURE", 2ND EDITION, edited by Godfrey Boyle, Chapter 7: Wind Energy by Derek Taylor. NTK code: b13932a pp. 235

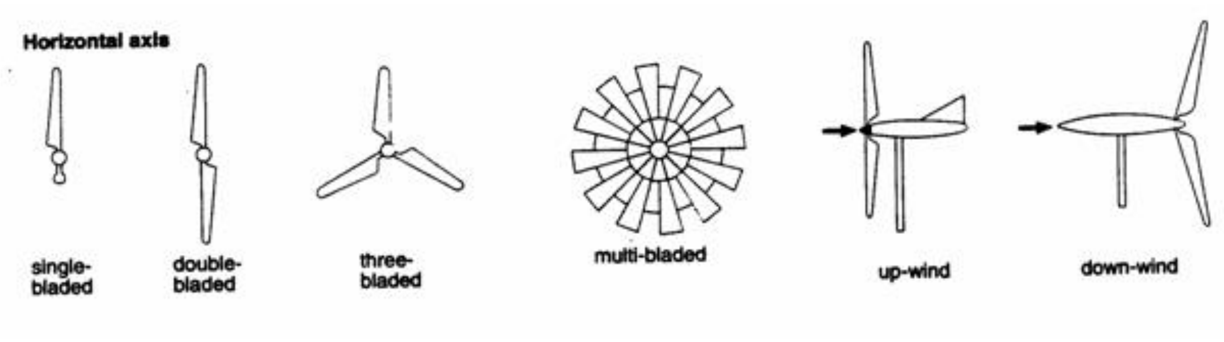

Figure 8 — HAWT types | Source: Energy Systems Research Unit

Vertical Axis Wind turbines are mainly based on the cross flow type, this means that the wind flows across the axis as the rotor blades turn. Due to their vertical axis, they do not need to reposition the rotor when the wind changes direction this is a clear advantage over the HAWTs. Modern VAWTs benefit from the work of a French engineer named Georges Darius and the Finnish engineer Sigurd Johannes Savonius.

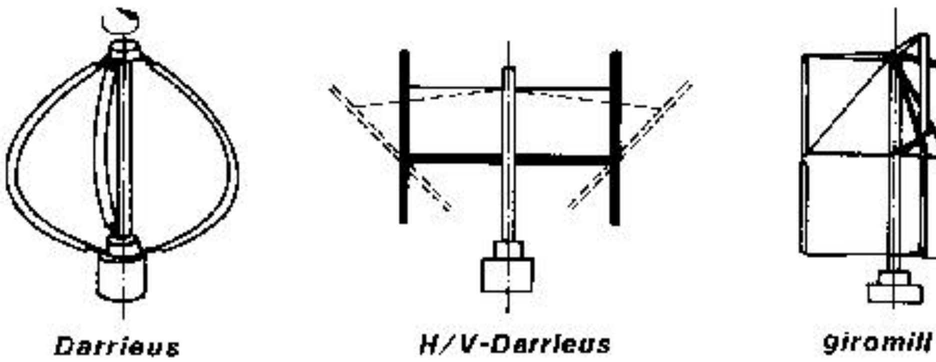

Figure 9— VAWT types | source: Heiner Dörner Windenergie

The power generated from wind turbines is carbon-free, does not require the use of water supplies and doesn't represent a risk of soil contamination or degradation, however, is proving to be very noisy, and represent significant risks of electromagnetic interference, but higher risks like marine species conservation, and birds migratory flux are coming with the development of offshore wind solutions[17].

[17]By "Renewable energy, POWER FOR A SUSTAINABLE FUTURE", 2ND EDITION, edited by Godfrey Boyle, Chapter 7: Wind Energy by Derek Taylor. NTK code: b13932a pp. 270

It is more expensive to harness wind offshore than inland, but the wind blows faster offshore, which means higher Kinect Energy, and consequently, a higher amount of energy can be transformed. The most significative projects on offshore wind energy are coming from Germany, UK, Denmark and Sweden.

3.4. Geothermal Energy

The current demand on a source of energy that pledges to do no harms to the environment has taken us to different paths and the development of inventive technologies, for example, the geothermal energy uses the heat contained within our planet Earth. Their early applications included bathing and heating.

The mantle of the heart has direct contact to the earth's crust heating the rocks underneath, the earth crust gives place to a geothermal reservoir, so is frequent that after rain, these drops enter the earth surface and return in form of hot water.

Basically, this type of energy is based on resources with high heat content like hot water, steam, hot dry rocks and others, which we can find at some places at the surface of the earth, but in general the deeper we go beneath the surface we encounter higher temperature. These resources are then pumped to feed steam turbines connected to a generator helping to produce electricity for our day use applications, this process takes place in a Geothermal Power plant.

The use of Geothermal Energy for electricity purposes is dated in the first decade of the nineteen century in Larderello, Italy was built the first geothermal power plant on the hands of the Italian Scientist Piero Ginori Conti, using steam to generate electricity.

The subsequent years were appearing other power plants, which are the case of the first power plant in the USA, and the second in the world on the year of 1922, with a production capacity of 250 kW[18].

The cost of using geothermal energy reflects on noisy environments during drilling and perforation, the sinking of the earth surface, investment costs and the possibility of having a dry spell.

Other significant disadvantages of adopting these technologies are the necessity of electricity to power heat pumps, projects development time, sustainability and high risk temperature working

[18] By Cleanenergyideas | under the section A history of Geothermal Energy , available at: https://www.clean-energy-ideas.com/geothermal/geothermal-energy/history-of-geothermal-energy

environment, however, if we adopt geothermal energy as an alternative source to fossil fuels we benefit from significative reduced prices of electricity, low maintenance cost, and high efficiency.

Among renewable energy solutions, the geothermal energy is the only one that does not suffer directly or indirectly influence of the sun, thanks to this and other factors many countries are making an effort to increase production of geothermal energy.

Table 2 — Top 10 Countries based on installed power generation | source: ThinkGeoEnergy

Rank	Country	Installed Capacity In [MW]	Rank	Country	Installed Capacity In [MW]
1st	United States	3591	6th	Mexico	951
2nd	Philippines	1868	7th	Italy	944
3rd	Indonesia	1809	8th	Iceland	710
4th	Turkey	1100	9th	Kenya	676
5th	New Zealand	980	10th	Japan	542

A portion of these countries did not reach their geothermal target like is the case of Indonesia (reach 12600 MW by 2025), Italy (reach 6.749 GWh/year generation from 920 MW capacity by 2020), Kenya (1900 MW by 2016 and 5000 MW by 2020) and Philippines (1500 MW added 2010-2030)[19].

Countries like New Zealand, Italy, Iceland, and Japan developed their geothermal potential mainly in steam fields and have huge industrial applications. This is a clear sign that the geothermal industry is growing at a good rate and opening path to the development of new technologies and techniques to further explore geothermal energy.

There exist three basic types of geothermal power plants and they are Binary Cycle Power plants, Dry Steam Power plants, and Flash Steam power plants.

[19] By World Energy Council | Source: REN21(2016), available at: https://www.worldenergy.org/wpcontent/uploads/2017/03/WEResources_Geothermal_2016.pdf

3.4.1. Binary Cycle Power Plant

A known advantage of this power plant compared to the other two types is that doesn't need a slightly higher temperature of hot water because it uses a separate working fluid normally pentane hydrocarbon or isopentane (methyl butane). With the help of a heat exchanger which is fed out hot water, this fluid is vaporized and placed in a turbine that is connected to an electric generator.

The remaining vapor is then converted to a liquid by means of condensation in a closed loop. The remaining hot water returns to the reservoir along with the fluid that is cooled with the help of the injection well[20].

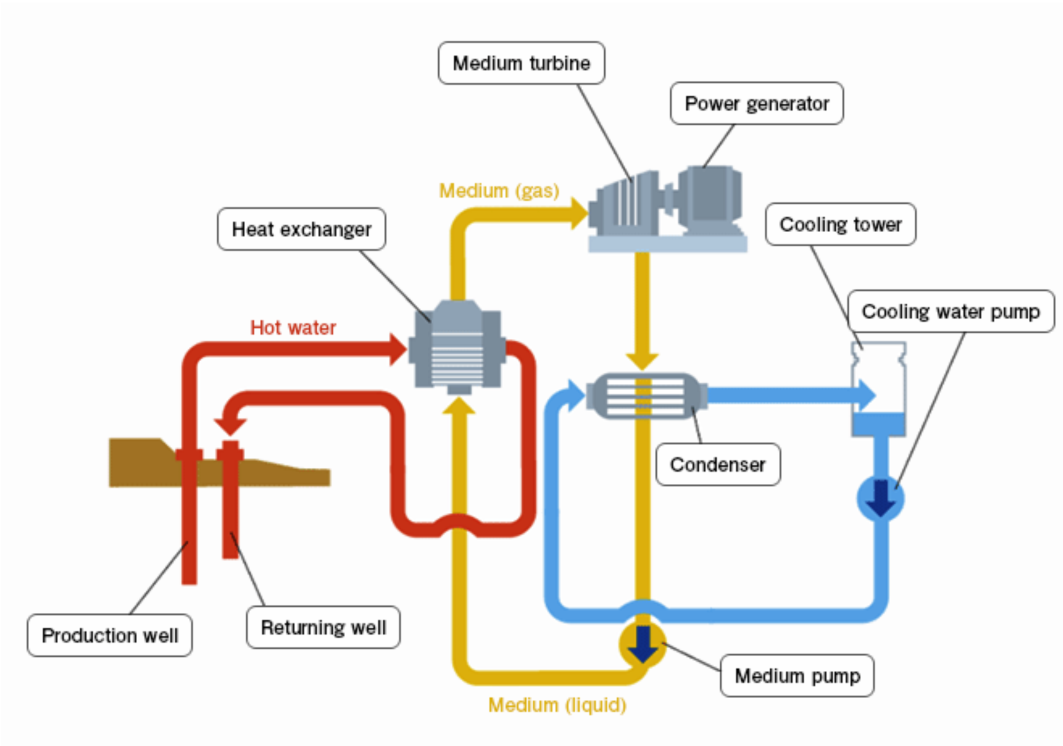

Figure 10 — Binary Cycle Power Plant diagram [adapted] | source: Agency for Natural Resources (Japan)

A major disadvantage of this power plant is that it consumes close to 30% of the output power by boiling the working fluid, however, is proven very efficient using geothermal resources with low temperature.

---

[20] By Conserve Energy Future | under the section Main Types of Geothermal Power Plants , available at: https://www.conserve-energy-future.com/geothermalenergy.php

3.4.2. Dry Steam Power Plant

The dry steam cycle power plant uses water vapor resources (or water in a gaseous state) where the steam produced is not in contact with any liquids. This power plant works with two wells: the production well and the injection well, which are separated and link to the reservoirs under the soil.

The reservoir contains hot water and produces superheat (180 degrees Celsius to 225 degrees Celsius) that is extracted with the help of the production well. This steam then expands passing through the turbines, resulting in a movement of blades and shafts to power an electric generator that pass along the electricity through the distribution network. After that, the remaining steam is transformed back to the liquid state by means of a condenser and reenter the reservoir through the injection. Usually, this type of powerplant is simple and most commercially used in the market[21].

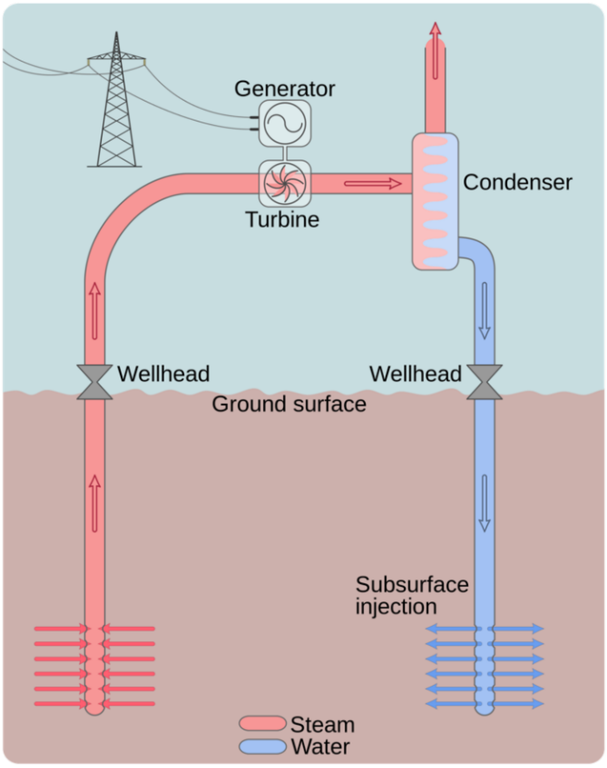

Figure 11 — Dry Steam Power Plant diagram | source: Wikimedia Common

These power plants are very inefficient and most of the time is used when a new steam field is open.

---

[21] By "Renewable energy, POWER FOR A SUSTAINABLE FUTURE", 2ND EDITION, edited by Godfrey Boyle, Chapter 9: Geothermal Energy by Geoff Brown and John Garnish. NTK code: b13932a pp. 360

3.4.3. Flash Steam Power Plant

The process that consists of vaporizing hot water using a thermal expansion valve in a tank at high pressure is called flashing. After the flash, the steam is captured and feed the turbine that is closely connected to an electric generator. In these power plants, a separation part is common to retain the brine (salt substances at the earth surface).

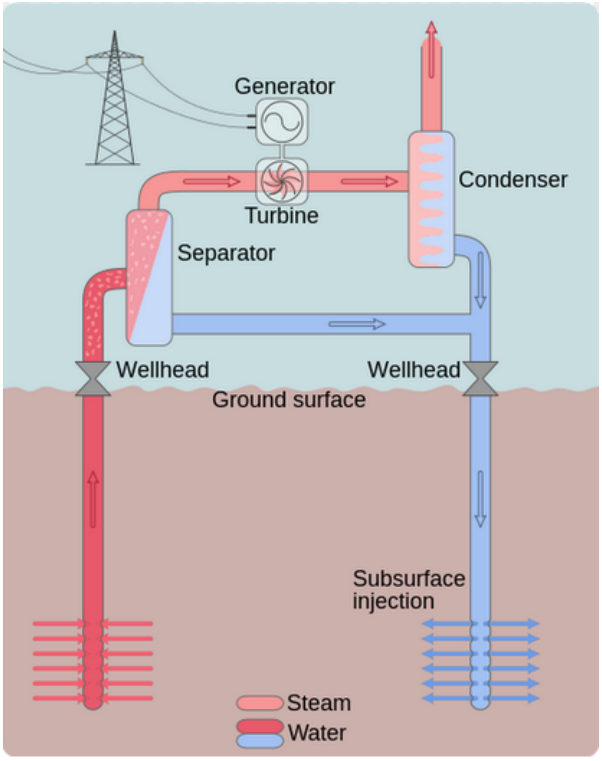

Figure 12 — Flash Steam Power Plant diagram | source: Wikimedia Commons

Usually, at this type of power plant, the temperature of the hot water reservoir is 230 degrees Celsius and can be enhanced by a double or multiple flash systems.

The double flash system avoids parasitic power, so the remain unflushed liquid goes to a second flash tank were steam if formed. This steam is then fed to the second turbine, increasing by 20 to 25% the power generated on the output versus an increase of 5% of the investment cost[22]. In a domestic level, we can also find geothermal heat pumps for domestic applications that are used for heating and cooling with a not so deep drilling process, these pumps are often called ground source heat pumps.

---

[22] By “Renewable energy, POWER FOR A SUSTAINABLE FUTURE”, 2ND EDITION, edited by Godfrey Boyle, Chapter 9: Geothermal Energy by Geoff Brown and John Garnish. NTK code: b13932a pp. 363

4. Chapter III — Energy Generated by Water

Our planet is majorly composed of water, close to 71% of the earth surface is made of water with a significant amount found submerged on the earth. Water itself has a vital importance in our lives, we have a strong dependence on water, and we have been using this resource to produce our food, to feed plants, to refresh ourselves and not less important we are using water to produce energy.

The concept of using energy to generate power is not new to humanity, 2000‘s years ago the Greeks were using water wheels to transform and process wheat into flour by grinding them. It is not possible to talk about the beginning of waterpower without mention the Nora. The Nora was a wheel composed of irrigation channel, paddle and clay jar, design to raise water to a storage tank or aqueduct system to be used later for irrigation. These constants technologies were evolving with time giving born to the earliest Watermills that in some mountain location are still used to mixed corn through mechanical power applications.[23]

Water can be turned into energy by means of tidal power, wave energy and hydroelectricity. These types of waterpower generation utilize mechanical, kinetic and gravitational energy to generate power. A new modern approach to generating power using heat engines that are powered by small differences in temperature of the ocean surface and water in a different depth is becoming popular.

Water turbines, similar to wind turbines are essentially the main component of these systems because they are responsible for capturing the energy of the water.

These water turbines come in different sizes and specs depending on the head (difference in levels of water elevation), the volume of water flowing, and the desired operation. Through history, different types of water turbines were made and optimize to serve better the purpose of producing power.

The most notorious turbines developed are Francis Turbine, Pelton turbine, Kaplan Turbine and the Ossberger Turbine or cross-flow turbine.

The Francis Turbine is used in systems with heads up to 600 m using the pressure difference of water and its made of Spiral Casting allowing the water to intrude the runners blade, Stay Vanes

---

[23] By “Renewable energy Power for A Sustainable Future”, 1ST EDITION, edited by Godfrey Boyle, Chapter 5: Hydroelectricity, by Janet Ramage., ISBN 10: 0198564511 NTK code: A33394 pp. 190

which transforms the pressure of the water into motion energy, runner blades and the draft tube responsible for reducing the velocity of water discharge.

They are designed in such a way that the blades are shaped to create different pressure states when the water is flowing through one of the faces of the blade.

The other face of the blade uses the force of the water leaving the blade and originate a resulting force, at this process very little kinetic or potential energy is lost; this working principle allows this turbine to be used also as a pump turbine.[24]

The Pelton Turbine reaches high efficiencies (90% to 95%) and it is suitable for large heads used in high mountains with a low flow of water.

Their working principle is based on a gate that controls the water flow (penstock) that is feed to the turbine, after that, high velocity water is flowing through the cylindrical end of the pipe (nozzle) to the spoon-shaped buckets[25].

The Kaplan Turbine and the Ossberger turbine are used in small heads and are very effective in low heads. The Kaplan use the forces of the water exiting the draft tube to make the blades of the runner spin.

The Ossberger among its pairs has the advantage of having the same efficiency over small variations of water flow making it suitable for small run-of-the-river plants.

In general, energy generated by water is predominantly reliable but have a significant impact on the environment, like the destruction of many species habitats by flooding water, and the existing risk of damage by entering in the turbines. Another concerning scenario is the cost of building these solutions which affect the price of energy production. Even with these setbacks, we can consider one of the most effective ways of producing energy.

---

[24] By Francis Turbine via Wikipedia in English | https://en.wikipedia.org/wiki/Francis_turbine

[25] By “Renewable Energy and Climate Change”, by Volker Quaschning, Chapter 9: Hydropower plants — Wet Energy, ISBN 978-0-470-74707-0 NTK code: B15785 pp. 196

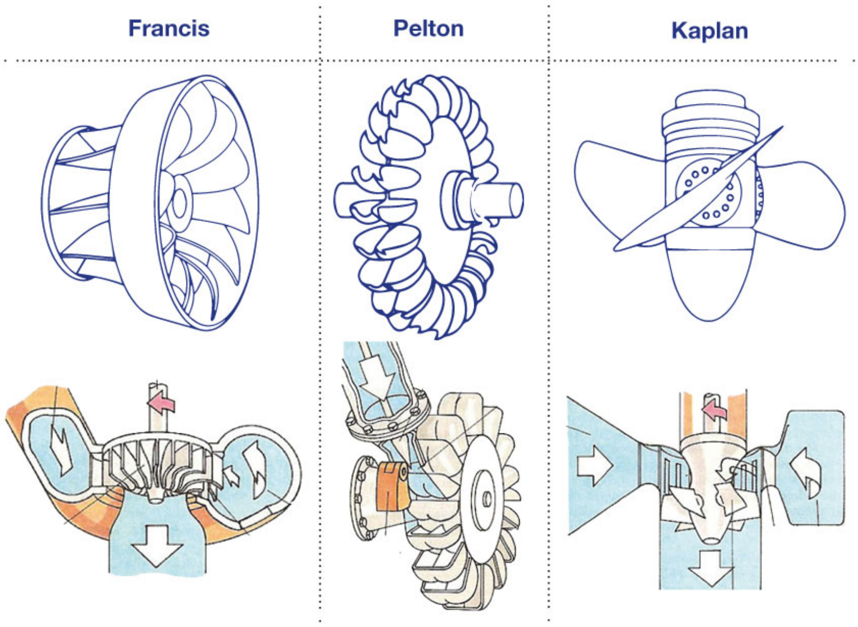

Figure 13 — Different Types of Turbines | source: ENERGOCONSULTANT

4.1. Wave Energy

The wind passing through the surface of seas and oceans transfers its energy to water forming waves, this energy is then measured by means of wave speed and height, which is, consider to be wave energy is turned into mechanical energy to be later converted into electric energy. The sites that lay at the end of the Atlantic Ocean were the wind blows with high velocities are the richest in wave energy potential.

Wave power technologies have emerged on the 70's but until this date is not being commercially used but have a huge potential. The world energy Council estimates that the power generated by waves is a little over 2000 GW. Countries like France, Portugal, UK and USA are the well-known pioneers of wave energy production.

Due to the lack of sores, this solution is impossible to be implemented in the Czech Republic or countries that do not have ocean or sea access with low water depths. Similar to the most types of renewables wave energy also as a large initial investment cost, and a difficult process of energy capturing due to the constant change of wave direction, this constant change is the result of wind changing its direction.

In contrast, the harness of wave energy does not affect the environment with the exception of a small risk of spillage of substances during operation.

This type of renewable is consistent and can be gathered in different ways. Many devices (water converters) were created and developed to harness the power of waves by using their kinetic energy and must handle extreme environmental conditions and balance the operational costs.

Usually we can divide these converters into three main systems (Float ball, Chamber and Tapered Chanel) based on the principle used in their operation.

Float Ball Systems uses a floating ball that imitates the movement of the water. A vibrant application of potential energy is established by keeping track of the buoyant force of the floating ball, this movement is then used to power a turbine that feeds an electric generator.

Chamber systems in the market can be encountered for example, as an oscillating water column that compresses and decompresses the air in the chamber due to the movement of water resulting on air displacement. The airflow passes through an opening to rotate an air turbine connected to a generator.

Tapered Chanel systems are usually used in coastal installations in which the waves are elevated in a narrow channel into a reservoir, returning them to the ocean, but first, they pass through a turbine powering a generator.

Another way of classifying these devices is by means of their orientation. The orientation is related to the direction of which they are capturing the energy of the waves.

These devices can have their axis lay in parallel to the wave physically intercepting these waves (terminators) or have their mains axis facing perpendicular (attenuators) to the wave drawing energy to them. Terminators due to their shape and working movement rise a risk of pinching sea creatures. Another device that also carries a risk of disturbing marine life is the point absorbers.[26]

Point Absorbers also absorb energy while operating but the difference between them and the attenuators is that they extract wave energy from all distinct directions using the buoyant force. There exist many ways in which the point absorbers can capture the power depending on the dimensions and configurations of the device, but unfortunately is also dependent on the wavelength.

---

[26] By Wave Power via Wikipedia in English | available at: https://en.wikipedia.org/wiki/Wave_power#Surface_attenuator

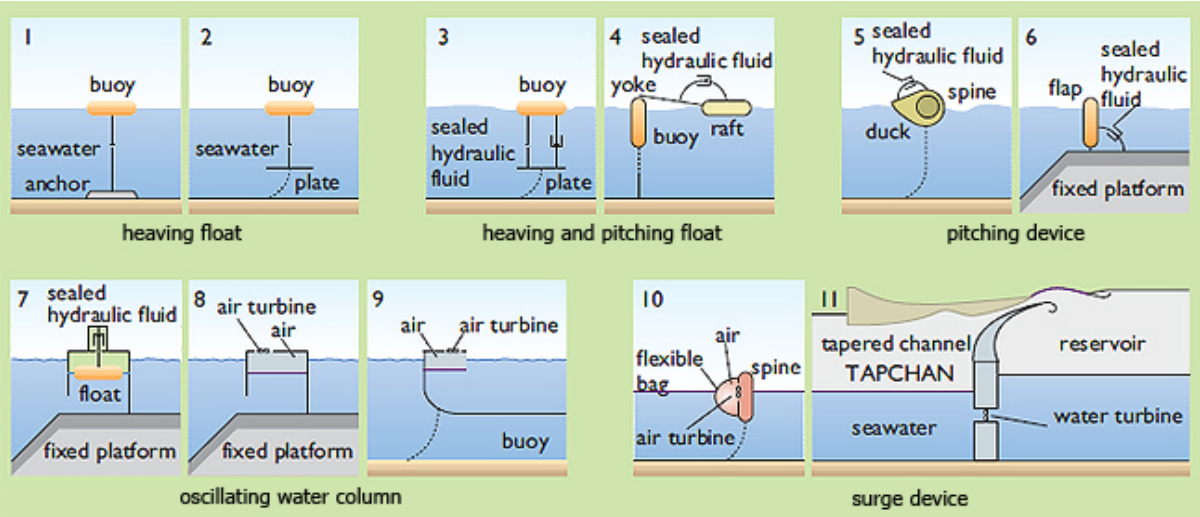

Figure 14 — Different Types of wave converters | source: Based on Falnes and Lovseth, 1991

4.2. Tidal Energy

The gravitational force exerted by the Sun and the moon added to the rotation of earth results in a periodic variation of the sea water levels causing tides, this process happens twice a day. These tides have an energy potential contained in their flow, which is used to generate electricity.

The tidal energy differs from the hydro energy since the last one uses the earth water cycle and suffers a direct interference of the solar energy. The solar energy has a small degree of interference on the tides.

In general, we harness tidal power by placing an artificial barrier through the width of a river or estuary. The difference in water levels present across this barrier (barrage) creates a potential energy that is then transformed into kinetic energy by means of the water flow passing the blades of the turbine, which gives place to a rotational Kinect energy that is used to power a generator.

Usually, when we have a rise in water levels due to the moon gravitational pulling forces tidal currents are generated. These same currents can flow rapidly and this same flow can be used to harness energy. The average power of this tidal barrage can be estimated by means of the tidal range (almost proportional to it)[27].

[27] By "Renewable energy, POWER FOR A SUSTAINABLE FUTURE", 2ND EDITION, edited by Godfrey Boyle, Chapter 6: Tidal Power by David Elliott. NTK code: b13932a pp. 199 & 203

Table 3 — World Biggest Tidal Power Station | source: POWER TECHNOLOGY

Name of the Tidal Power Station	Description	Country
Sihwa Lake Tidal Power Station	As an output capacity of 254 MW and is located on Lake Sihwa. Built in a period of 7 years (2003-2010) and has an estimated output capacity of 552.7 GWh per year.	South Korea
La Lance Tidal Power Plant	This power plant has been operational since 1996 and is considered to be the second biggest tidal power station with 240MW and an annual generation capacity of 540 GWh.	France
MeyGen Tidal Energy Project	This energy project received a first plan phase approval for 86 MW and it is planned to reach a total installed capacity in 398MW by 2020.	Scotland

In *Table 3* the Swansea Bay Tidal Lagoon was not considered because till this date is not in construction yet.

Usually, these type of tidal power stations is placed in a lagoon apart from the ocean and when the tide rises the lagoon is filled up and when the tide falls the water is evacuated through an opening making the turbines spin and are attached to an electric generator by a shaft.

We can also generate energy from tides using a similar technology as wind energy turbines. The tidal turbines are stronger and shorter than the ones used to harness wind but it presents high maintenance costs which makes tidal barrages the most cost-efficient option among tidal energy solutions[28].

Tidal power requires a huge upfront cost investments, and presents a few environmental impacts due to the barrier placed on the mouth of a river or ocean but even so is a reliable alternative to fossil fuels.

---

[28] By Conserve Energy Future | under the section How tidal Energy is Converted into Electricity? , available at: https://www.conserve-energy-future.com/tidalenergy.php

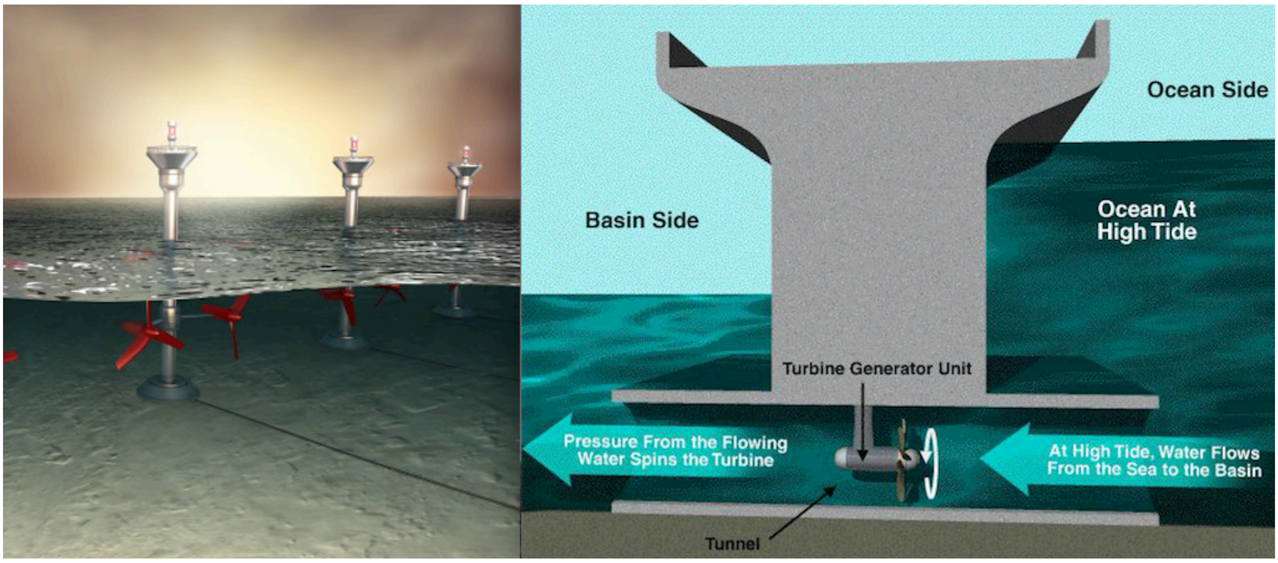

Figure 15 — Tidal Turbine (At Left) and Tidal Barrage (At Right) | source: Infogram and SMRU CONSULTING [adapted]

4.3. Hydro Energy

Contrary to the Tidal Energy the Hydro energy uses the hydrological cycle of water and its associated with the height in which the water falls or where it is found and the amount of water flowing.

Hydro energy can be considered a form of solar power since the hydrological water cycle is a natural consequence of the water evaporation by the wind and the solar radiation. The water vapor with other gases forms the clouds, which gives place to precipitation that feeds the rivers and their downstream flows.

We capture hydro energy generally by first placing a barrier across a river to form a reservoir, second we open the floodgates of the dam and release the water via gravity to pass ducts powering turbines attached to a generator.

The hydroelectric power plants are usually smaller than the tidal power plants and besides from generating electricity they can also be used as storage facility for electricity, that is the case of the run-of-the-river power plants.

The hydropower is vastly used by humankind, with high cost-effect advantages for that reason alone is been used in many countries, but lately are facing criticism over their huge environmental impact on nature.

Table 4 — Hydropower Capacity in 2015 | source: REN21, IHA(2015), World Energy Council (2016)

Country	Total Capacity end of 2015 (GW)	Added Capacity In 2015 (GW)	Production (GWh)
China	319	19	1126000
USA	102	0.1	259000
Brazil	92	2.5	382000
Canada	79	0.7	376000
India	52	1.9	120000
Russia	51	0.2	180000

We have four main distinct hydro energy systems being: run-of-the-river, water diversion, water impoundment and pump storage.

Run-of-the-river among its pairs as a relatively cheap and simple setup. At this system, a cross-flow turbine is placed into a fast-flowing river with a significant difference in elevation. This turbine rotates with the natural flow of the river and powers a generator, sufficient speed and flow are crucial to this system, and is implemented in areas with little or no storage reservoir.

Water impoundment reflects direct human interaction, which uses a dam or weir to collect large volumes of water in a reservoir to store their potential energy later converted to electrical energy.

This system requires a large dam and a deep reservoir and it is common in high mountain regions.

Water diversion like the name suggests it deviates portion of the river through an aqueduct (penstock) to move an overshot waterwheel at the bottom. The water flows through the penstock carrying potential energy that is then transformed into electrical energy.[29]

[29] By Alternative Energy Tutorials | under the section Hydro energy using the power of Water , available at: http://www.alternative-energy-tutorials.com/hydro-energy/hydro-energy.html

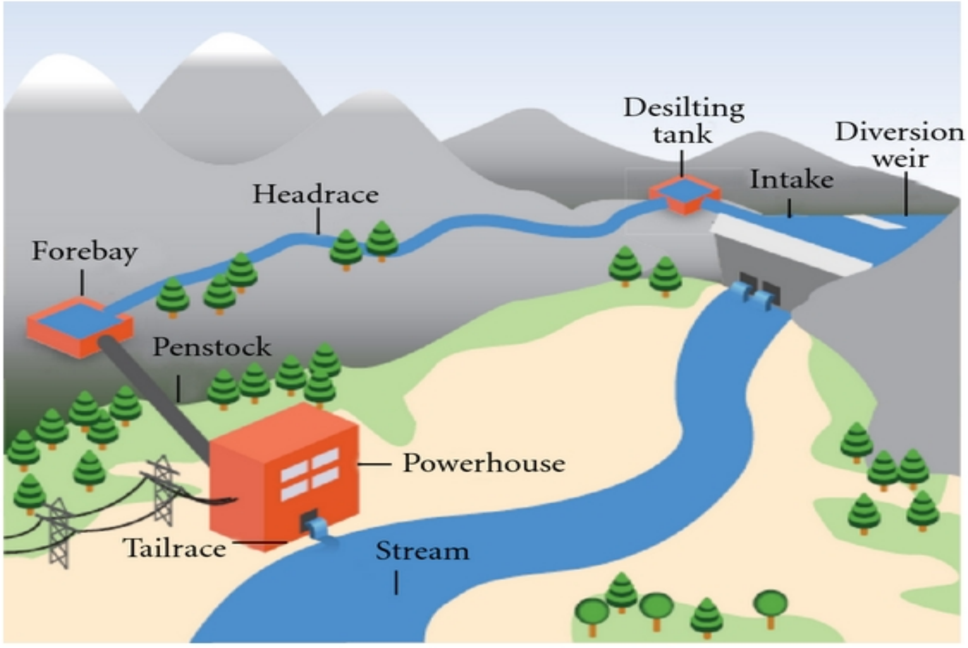

Figure 16 — Run of the River Hydropower plant using Diversion | source: Energypedia

The diversion and run of the river method are often used at the same time and are suitable for small and micro hydropower facilities.

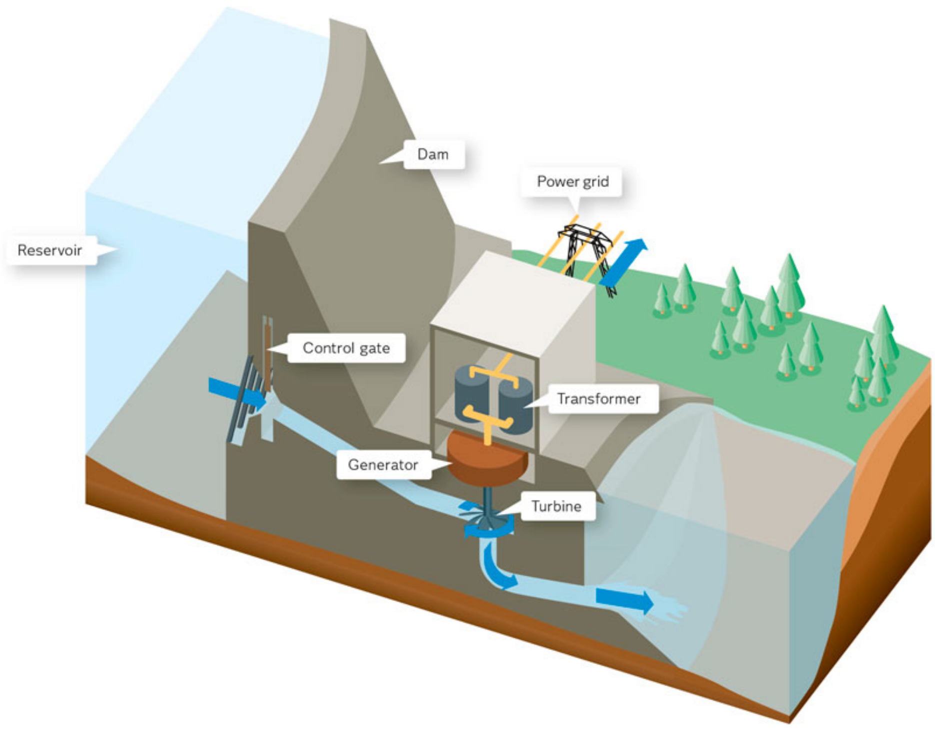

Figure 17 — Impoundment system | source: Corporate Vattenfall

Impound systems are the most common type of hydroelectric systems because they present constant levels of energy production which makes them more efficient than run-of-the river facilities.

Pump storage power plants have usually two basins or reservoirs with a big difference in altitude between them. The water is pumped from the low reservoir to a higher reservoir at periods of low electricity demand and reversely when energy is needed. In between the reservoirs, we encounter turbines with a shaft to a generator.

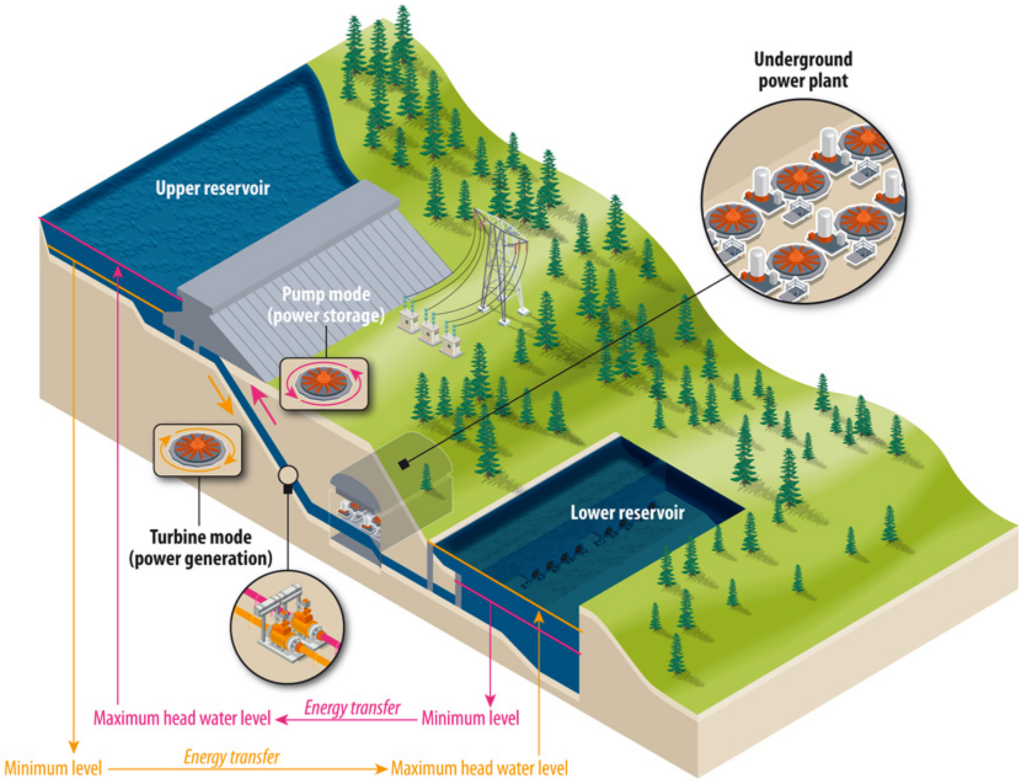

Figure 18 — Pump Storage Systems | source: Think Grid

Ideally, the power of water present on these turbines can be calculated from the efficiency of the turbine (n), the density of water in cubic meters (ρ), the water flow in cubic meters (Q), the acceleration due to gravity (g), and the head height (h).

$$\boldsymbol{P = n \cdot \rho \cdot Q \cdot g \cdot h} \ \ [W]^{30} \qquad (3)$$

Size wise, these different systems can be classified according to their power output. A hydropower plant with capacity up to 10 MW is considered a Small Power Plant, less than 1 MW is in the Micro

[30] By Hydropower via Wikipedia in English | available at: https://en.wikipedia.org/wiki/Hydropower

category. The medium power plants range from 10 MW until 100 MW and the large have more than 100MW.

Another alternative in classifying these hydropower systems is by their head; in operation, we have low (until 30 m), medium (range between 30 to 300 m) and high heads (from 300 m).

4.4. Hradištko Power Plant

The Czech Republic stands on the division of the three seas north-south axis (Baltic Sea, Adriatic Sea, and Black sea) and has considerable water resources and suitable geographic location for the use of hydropower and special predisposition for small hydropower plants.

The Hradištko power plant is located at the 887.6 km of the Elbe River one of the largest in the Central Europe.

This power plant was constructed taking into consideration all the necessary depts, navigation conditions, and assuring a common area for water sports. This power plant maintains the water level in the lake ridge at 177.59 m above the sea level.

The weir has three clearance brackets of 24 m with a Stoney lifting gate valves with angled flaps attached. The weir pillars are 3.70 m wide and 20 m long with a fishway built in the right weirs pillar.

The Small Hydropower Plant is located in the left part of the coast and is equipped with two vertical Kaplan turbines that are installed in the spiral fountains. Each of these turbines has a power of 0.96MW with humidity of 40 m^3/s and gradient of 2.90 m.

These turbines have a minimum gradient of 1.5 m. On the right part of the coast, we have the Sluice gate, with dimensions of 85×12×3 m. An electrohydraulic servo valve controls both axes of the buckling doors. By emptying and filling this canal, we can have a long vault bypass profile.[31]

[31] By Povodí Labe v češtině | available at: http://www.pla.cz/planet/public/vodnidila/zsl_hradistko.pdf

Table 5 — Hradistko Characteristic and Ratio | source: Povodí Labe [adapted]

Hydrological Ratios	Value	Weir Characteristics	Value
River Basin Area	10 889.21 km^2	Total Basin Volume	1012 m^3
Average flow Q_a	74.89 m^3/s	Nominal headwater level	177.59 m
Flow Q_{355}	14.20 m^3/s	Weir distance	3.84 km
Flow Q_{100}	1 220.00 m^3/s	Falling height level	3.70 m

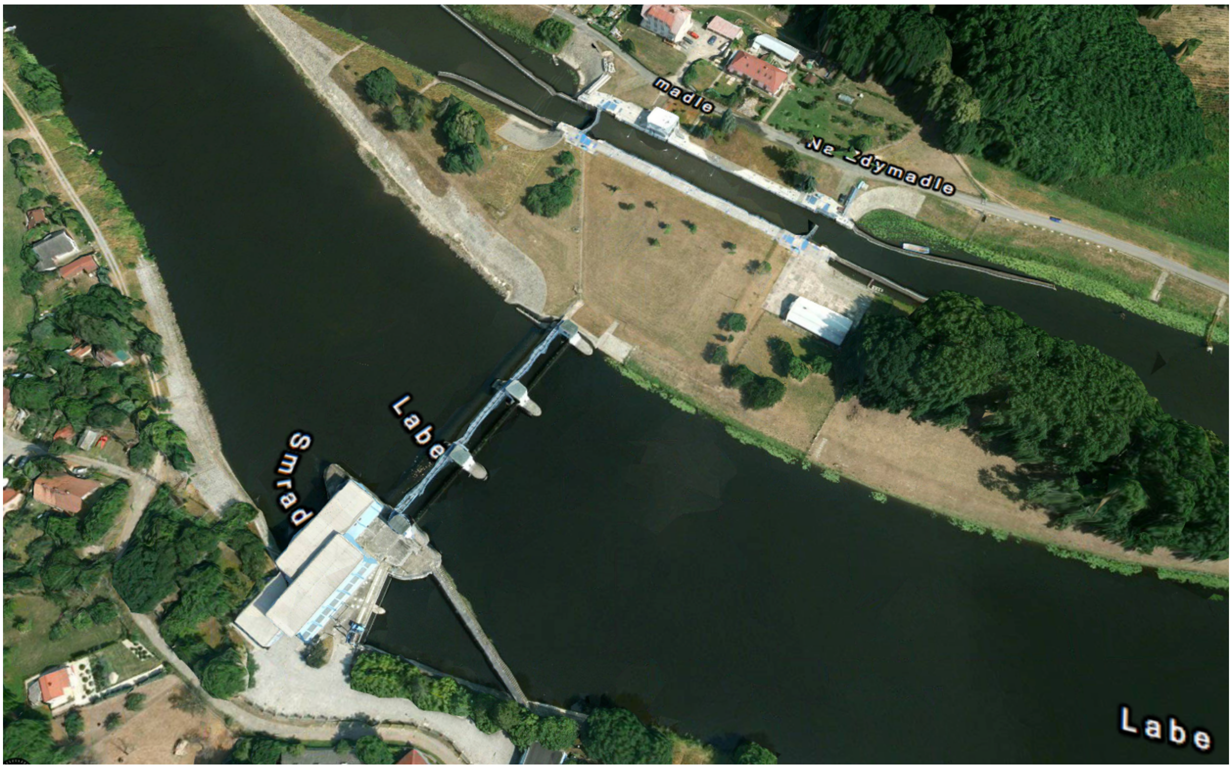

Figure 19 — Hradistko Hydropower Plant | source: Mapy.cz

5. Chapter IV — Integration to Distribution Network

Renewables like the others energy resources use a distribution network to be delivered to us for consumption. This consumption varies in terms of daily use application and we can divide it into categories like industry, transport, personal domestic use and others. Between these categories, we can extract them for heat, power or electricity.

It is a common trend to use renewable energy systems to release pressure on the use of fossil fuels, this leads to a change on our distribution energy systems, meaning these new renewable solutions will have to work with the existing Grid structure, which carries advantages, or work parallel to the grid.

Been connected to the grid offers the advantage of having a roundly supply of electricity using the grid as a natural backup which leads to a price reduction on energy consumption on the consumer side. Other exemptions on regulations are granted to consumers who adopt these types of solutions like money incentives, fixed prices for electricity (generated by renewable sources).

The power fed to the grid by renewable sources as to guarantee normal operation to the devices connected to the grid, and we can evaluate the power quality by observing the power factor, harmonic distortion, unbalance voltage, frequency oscillation, reactive power and others. If the power quality of a network is not god, is almost certain that the connected loads will have a reduced lifetime and efficiency, which will lead to an increase on running costs and in some drastic cases may not even run.

While connecting these systems to the grid we need to take into account the different types of necessary equipment for connection to the grid, grid regulation and requirements (from the provider side), and national guides and regulations. The distribution system operators provide the technical requirements of grid-connected systems.

Safety is also a major factor to take into the account while connecting these solutions to the Grid, before connecting we should make sure we have a way of dealing with a power failure or power surge and differences in frequency (need to be matched to the grid).

In Czech Republic the distribution system has 110 kV devices connected to a set of lines, apart from that and devices that are part of the transmission lines it has devices with 0.4/0.23 kV, 3 kV, 6 kV, 10 kV, 22 kV and 35 kV suitable for electricity distribution, which includes measuring, protection, signaling, control, information and telecommunication systems. This system ensures the distribution of electricity from the transmissions line to the final consumers and at the same time connects low-power plants up to 10 MW. The main distribution operators in The Czech Republic are CEZ Distribuce that operates mainly in the Bohemian Region (West, North, Central, and East Bohemia) and North Moravia followed by E.ON Distribuce, which operates in the South Bohemia and North Moravia Region. In Prague and Roztoky, PREdistribuce operates the distribution network.[32]

These low-power plants can be connected to the distribution network at a medium (22 kV & 35 kV) or low voltage level (0.4 kV). The right level of connecting voltage is determined by different factors like the nominal power of the generator, operation mode and the total power of the power plant. The status and characteristics of the distribution network are also important on the determine the right voltage level.

In a low-voltage network, we can connect different types of power plants,

- For Power Plants up to 50 kW, we connect to a voltage line or low voltage buses of 22/0.4 kV substation.

- For Power Plants up to 100 kW, we connect to a medium voltage network (22 kV & 35 kV).

- For Power Plants up to 1000 kW, we connect to a medium voltage line.

- For Power Plants over 1000 kW, we connect to a medium or high voltage line, or to an IO system.

Renewable energy sources have a few environmental setbacks like we discuss in the previous chapters, so a detailed cost-benefit analysis accompany to an environmental impact study should be carried to determine the best way to implement them into the distribution network. This study should predict changes in the development of the distribution network and seasonal changes in electricity demand versus production in order to suppress a few of the problems encountered.

After a thorough analysis including the calculation of voltage drops, load flow, short circuit current and total harmonic voltage distortion a recommendation is made concerning the adequate capacity and mode of connection of distributed sources to the distribution network, doing that provides reliability.

---

[32] By Distribuční soustava via Wikipedie v češtině | available at: https://cs.wikipedia.org/wiki/Distribučn%C3%AD_soustava

While building a power plant, there is some important technical information that must be provided to the distribution system operator in order to match the grid connection conditions in normal and special regime from the desired connection point to the distribution network.

This information should include:

- Updated Available Capacity
- Insulation and Coordination Data
- Protection Information (fault clearance with quick reaction time on the user side, with primary and backup protection, this includes disconnectors.)
- Maximum and Minimum Short Circuit Power
- Maximum and Minimum Continuous Operating Voltage
- Typical Load profiles
- Grounding information
- Breaking Capacity to the corresponding nominal voltage of the transmission network
- Higher harmonics and flicker information (determines the effect of the power plant on the distributed system)
- Parallel operation information with electric power systems
- Telecommunication system integration
- Remote Control system integration
- Measurement and Calculation Method
- Defense System Plan (this includes under frequency load shedding, under voltage shedding, manual and automatic control)
- Participation in services needed for supporting electric power transmission. (ancillary services)
- Large Scale disturbances behavior (the ability to pass through a state of failure)
- Reactive Power Information

The reactive power information should mention the nature and extent of reactive power exchange, and its reserve destined for energy delivery and production, meaning a necessary amount of reactive power should be generated, with production power factor ranging between 0.85 until 1. However, in certain renewables power plants, this variation does not occur. (Ex: solar power plants, and wind farms).

5.1. Connection Criteria between electricity generating power plants and distribution network Operator CEZ Distribuce

Is already establish that the distribution network operator is responsible for determining the best way of connecting generating electricity power plants to the distribution network. Nevertheless, even in an optimal case, we can experience stress during the switching process, long-term flicker, voltage changes while operating a generating electricity plant, current harmonics and influence on short-circuit conditions and on centralized ripple control devices. In the Czech Republic, these devices use frequencies like 183.33 Hz and 1060 Hz.

The points of a common connection are suitable for voltage variations due to connection or disconnection to the electricity generating facility (power plant). This Variation cannot exceed the medium voltage level of 22 kV. A voltage change in the distribution of medium voltage occurs due to a connection between generating facility and the point of common connection. This voltage change should not exceed 2%.

In low voltage systems, the voltage change in distribution due to a connection between generating facility and the point of common connection should not exceed 3%. A 3% voltage change rate is also admitted during the switching process.

In the point of common connection, the voltage variation should not exceed a 10% variation rate or under the connection or disconnection process to a generating facility or be connected to a low voltage system of 0.4 kV. In general, these conditions are suitable for all power plants with frequent switching (usually once every 1.5 min), that is the case of almost every power plant using renewable energy sources.

In low voltage systems, the power quality is mostly affected by harmonic distortion, reactive power, unbalanced load and fast voltage variations. The harmonic distortion in grid connections appears when we connect asynchronous generators to the grid. The asynchronous generators are implemented with the use of special electronic frequency converters, which generates many harmonics causing Voltage drops on the distribution line and a significant decrease in efficiency.

In various cases, the Total Harmonic dispersion affects the network by increasing the current on the conductors and consequently increases the temperature of the loads on the network causing an increase in heat losses.

$$\text{The Total Harmonic Dispersion} = \frac{\sqrt{V_{RMS}^2 - V_1^2}}{V_1} = \frac{\sqrt{\sum_{k=2} V_k^2}}{V_1} \quad (4),$$

Where V_k is the harmonic component of order k-th of the fundamental signal (V).

A simple filter circuit can solve the problem of unwanted harmonics.

The phase shifting in current from the supply voltage in alternated current creates different power definitions like the active power [P] which is the only one capable of doing Work, the reactive Power [Q] which is produced from capacitive elements and consumed by inductive elements, and the Total Power also known as the Apparent Power [S].

These different powers can be represented by vectors and with the help of the theorem of Pythagoras; we can establish a relation between them.

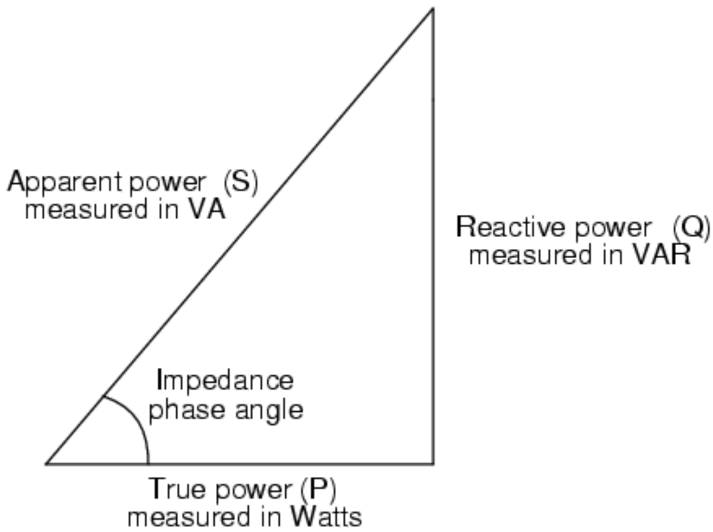

Figure 20 — Power Triangles in AC | source: ApparentPowerBlog

From the triangle, is established that:

$$S^2 = P^2 + Q^2 \quad (5)$$

Another important characteristic that can be obtained from this power triangle is the power factor that indicates the efficiency of the electrical energy in the network. The power factor is the cosine of the impedance phase angle or the ratio between the active and apparent power.

$$\frac{P}{S} = \cos(\text{impedance phase angle}) \quad (6)$$

A Power Factor of 1 implies that the quality of energy is optimal. The power factor is inversely proportional to the total harmonic distortion hence; zero Total harmonic distortion is an indicator of maximum energy transformation quality.

Even though the Reactive Power does not express any work like the Active Power, it is imperative for normal operation of certain machines. The amount of reactive power on the electric systems should be limited in order to avoid losses on the distribution network. A well-known solution is the use of capacitor banks for storing reactive power limiting this power to the necessary devices.

Ideally, a three-phase supply should be composed by a system of three balanced sinusoidal voltages with the same amplitude and a total difference of phases of 120 degrees between them. When a deviation occurs this leads to an asymmetric distribution of loads through the system due to the appearing of a negative phase component.

The voltage unbalanced can be calculated from[33]:

$$K_u(\%) = \frac{\sqrt{1-\sqrt{3-6\times\beta}}}{\sqrt{1+\sqrt{3-6\times\beta}}} \times 100 \tag{7}$$

β is calculated from the effective values of voltage between the phases.

$$\beta = \frac{V_{AB}^4 + V_{BC}^4 + V_{CA}^4}{(V_{AB}^2 + V_{BC}^2 + V_{CA}^2)^2} \tag{8}$$

Another phenomenon that causes discomfort is the flicker. The flicker is a visual phenomenon that manifests in the consumer side caused by rapid changes in voltage supply and it is closely related to the equipment used in electricity generation and the short-circuit current at the point of common connection.

The flicker can also be considered an effect of harmonic distortion and can be affected by the weather in the particular case of the supply of electricity by wind energy (the wind velocity is always changing in a short period, these changes cause different voltage fluctuations), for that reason the equipment manufacturer should include the flicker factor.

Not all equipment has a source of flicker that is the case of the hydro and turbo generators. Renewable sources that have a flicker factor of 40 harmonics while producing electricity are considered problematic.

[33] By Silva, 2009 available at: https://saturno.unifei.edu.br/bim/0046316.pdf

6. Chapter V — Case Study

The main goal of this bachelor project as mentioned on the introduction is to address all the aspects related to renewable energy resources, from sources until integration to the distribution network hoping to contribute on the creation of new research materials focusing on renewable energy resources.

Due to the complexity of the matter in discussion a case study is a right approach, because it takes into account in numerous factors, as a higher flexibility, extended comprehension and different scenarios can be explored.

The proposed case study takes into account the rules and guidelines currently in use in the Czech Republic and will be focusing on a small hydropower plant located in Hradištko that uses two synchronous generators and a thorough analysis of the integration of this renewable energy solution into the distribution network.

For educational purposes, a simulation environmental was used with conditions close to the reality and power quality parameters were observed. A consulting specialist of the EEC consulting provided the data used in this case study.

The installation consists of three transformers, two of them working in parallel to each other and are linked to their respective synchronous generator. The other one is linked to an overhead MV line leading to a transform station in Nymburk. At this installation, overhead lines will guarantee the connection between the distributed network and the small hydropower plant in Hradištko. For consumption purposes, loads have been added to the network.

The hydro generators used in the small hydropower plant are three-phase synchronous generators + linked to hydroelectric turbines. They are easy to install and have short delivering cycles, which make them very popular for this type of installation.

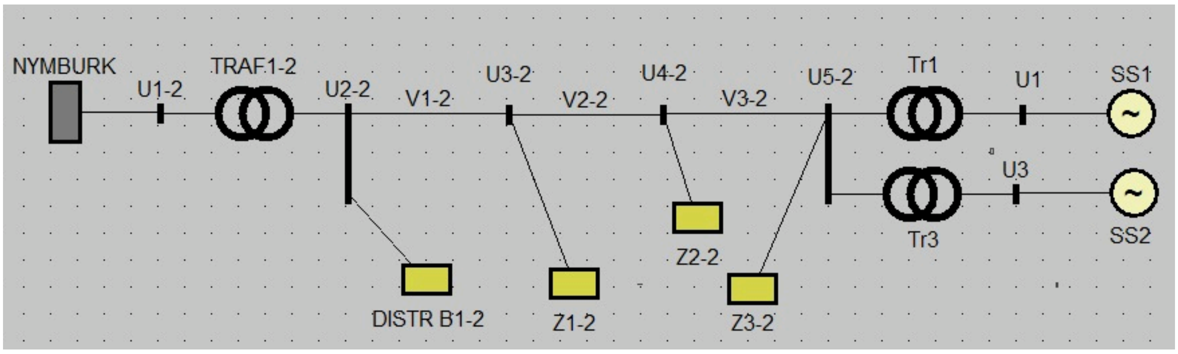

Figure 21 — Network Topology

Table 6 — Transformer input parameters

Transformer	U_{n1} [kV]	U_{n2} [kV]	S[MVA]	P_k [kW]	U_k [%]	I_0 [%]	P_0 [kW]
TRAF 1-2	110	23	40	212	12	0.22	31
Tr1	22	6.3	1.6	2.4	6	0	0
Tr3	22	6.3	1.6	2.4	6	0	0

Commentary: *The transformer TRAF1-2 is a TP 8103-40 transformer manufactured by Milen. In the last two columns of table 6, we encountered the no-load losses and current. These losses are intrinsic related to the iron losses on the core of the transformer and losses on the insulating material (dielectric). The no-load current in transformer generates copper losses.*

Table 7 — Generator Parameters

Generator	U_n [kV]	S_n [kV]	X''d[%]	Frequency [Hz]
SS1	6.3	1165	14	50
SS2	6.3	1165	14	50

Table 8 — Input Parameters for OH

Line Title	Type	Wire type	R $[\Omega/km]$	X $[\Omega/km]$	B $[\mu S/km]$	Length [km]	I_{max} [A]	U_n [kV]
V1-2	OH	95AIFe6	0.301	0.374	1.448	1.5	289	22
V2-2	OH	95AIFe6	0.301	0.374	1.448	5.2	289	22
V3-2	OH	95AIFe6	0.301	0.374	1.448	3	289	22

Commentary: *The line V1-2 starts on the node U2-2 and ends on the node U3-2; the line V2-2 starts on the node U3-2 and ends on the node U4-2; the line V3-2 starts on the node U4-2 and ends on the node U5-2.*

Table 9 — Load Consumption

Load	Network Node	U_n [kV]	Q_k [kVAr]	S [kVA]	Power Factor [-]
DISTR B1-2	U2-2	22	0	12000	0.92
Z1-2	U3-2	22	0	400	0.95
Z2-2	U4-2	22	0	500	0.95
Z3-2	U5-2	22	0	630	0.92

6.1. Calculated Results

Table 10 — Voltage difference before and after Connection using a power factor equal to 1

Node	dU before [%]	dU after [%]	Difference	Total difference
U1-2	-6.164	-6.170	-0.005	-0.010
U2-2	-9.276	-9.290	-0.034	-0.068
U3-2	-9.193	-9.301	-0.115	-0.230
U4-2	-9.063	-9.496	-0.440	-0.880
U5-2	-9.102	-9.723	-0.629	-1.258
U1	-14.557	-15.240	-0.960	-1.920
U3	-14.587	-15.240	-0.671	-1.342

Table 11 — Voltage difference before and after Connection using a power factor equal to 0.98

Node	dU before [%]	dU after [%]	Difference	Total difference
U1-2	-6.170	-6.181	-0.012	-0.024
U2-2	-9.341	-9.432	-0.096	-0.192
U3-2	-9.275	-9.484	-0.213	-0.426
U4-2	-9.203	-9.823	-0.624	-1.248
U5-2	-9.275	-10.132	-0.862	-1.724
U1	-14.739	-16.472	-1.860	-3.720
U3	-15.577	-16.472	-0.906	-1.812

Table 12 — Voltage difference before and after Connection using a power factor equal to 0.96

Node	dU before [%]	dU after [%]	Difference	Total difference
U1-2	-6.173	-6.187	-0.014	-0.028
U2-2	-9.374	-9.497	-0.127	-0.254
U3-2	-9.318	-9.570	-0.255	-0.510
U4-2	-9.284	-9.983	-0.703	-1.406
U5-2	-9.378	-10.335	-0.962	-1.924
U1	-14.846	-17.029	-2.285	-4.570
U3	-16.032	-17.029	-1.006	-2.012

Commentary: *From the tables 10, 11 and 12 we can see the difference in voltage before and after connection using different power factors. This difference is a voltage variation with respect to the nominal voltage and for medium voltage networks, should not exceed the 2% mark according to the*

Czech Republic guidance. However, since we are using two generators we have a total difference taking into account both of them, and if we look closer we can see that these difference exceeds in the nodes U1 and U3, but does not raise a concern because it is an internal problem of our power plant and has a very little influence on the distribution network.

Table 13 — Voltage Profile on Line

Power Factor	U2-2 in [kV]	U3-2 in [kV]	U4-2 in [kV]	U5-2 in [kV]
1	24.044	24.046	24.089	24.139
0.98	24.075	24.086	24.161	24.229
0.96	24.089	24.105	24.196	24.274
Without Generator	24.034	23.992	23.884	23.847

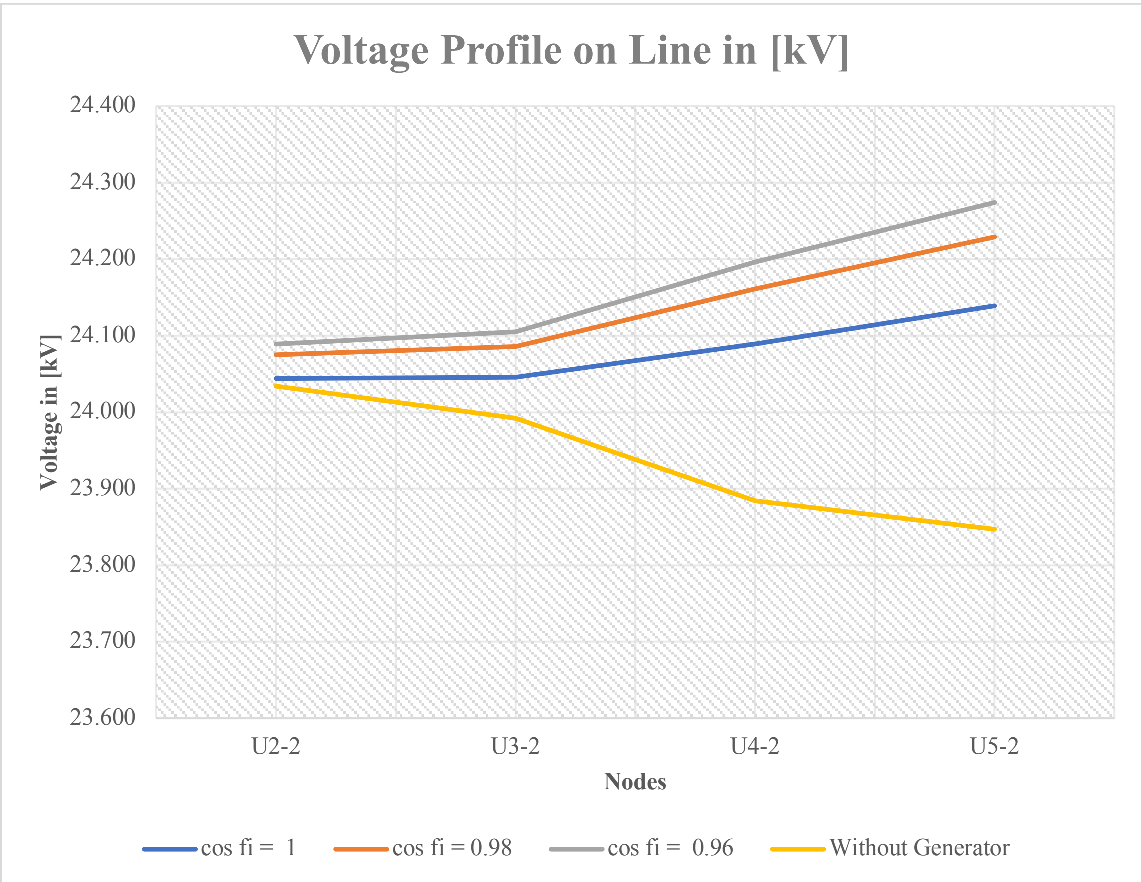

Figure 22 — Voltage Profile on Line

Table 14 — Current and Powers in load using power factor equal to 1

Load	Network Node	P [kW]	Q [kVAr]	S [kVA]	I [A]
DISTR B1-2	U2-2	11039.9	4703	11999.9	288.1
Z1-2	U3-2	380	124.9	400	9.6
Z2-2	U4-2	475	156.1	500	11.9
Z3-2	U5-2	579.6	246.9	630	15

Table 15 — Current and Powers in load using power factor equal to 0.98

Load	Network Node	P [kW]	Q [kVAr]	S [kVA]	I [A]
DISTR B1-2	U2-2	11040	4703	12000	287.7
Z1-2	U3-2	380	124.9	400	9.6
Z2-2	U4-2	475	156.1	500	11.9
Z3-2	U5-2	644	274.3	700	16.7

Table 16 — Current and Powers in load using power factor equal to 0.96

Load	Network Node	P [kW]	Q [kVAr]	S [kVA]	I [A]
DISTR B1-2	U2-2	11040	4703	12000	287.6
Z1-2	U3-2	380	124.9	400	9.5
Z2-2	U4-2	475	156.1	500	11.9
Z3-2	U5-2	644	274.3	700	16.6

Table 17 — Active Power Losses on the distribution line

Regime	V1-2 Losses in [kW]	V1-2 Losses in [kW]	V1-2 Losses in [kW]	Total Losses in [kW]
With power factor equal to 1	0.903	4.974	4.902	10.779
With power factor equal to 0.98	0.546	3.895	4.384	8.825
With power factor equal to 0.96	0.524	3.949	4.504	8.977
Without Generator	2.014	3.949	0.777	6.740

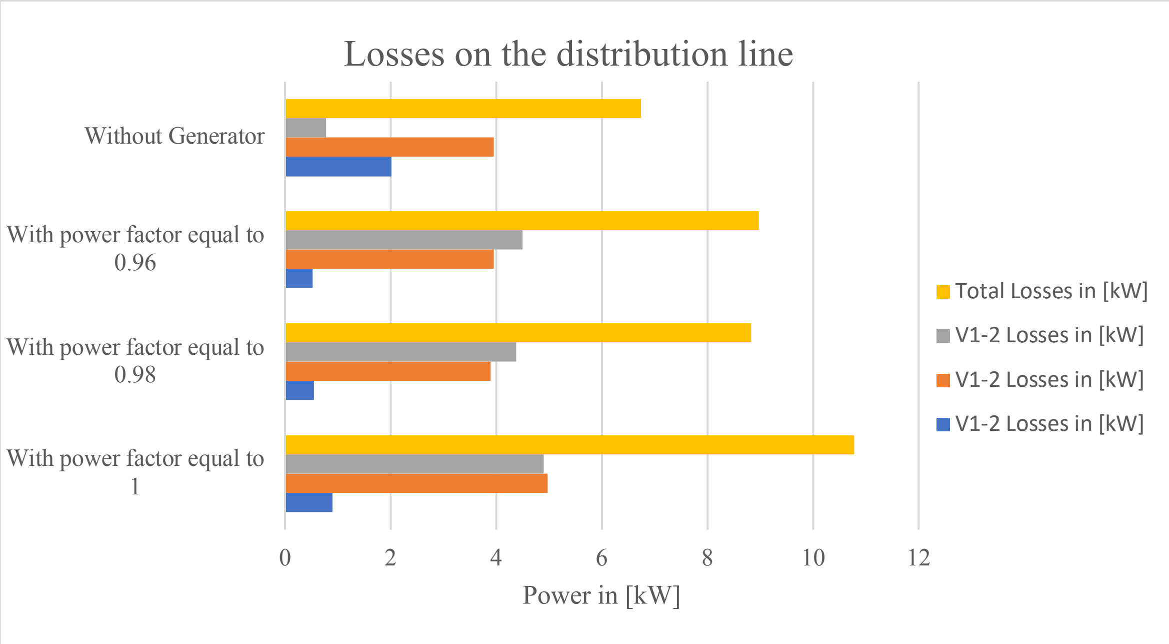

Figure 23 — Losses on the distribution line

Commentary: *From the table 16 along with the figure 23, we can observe that if we increase our power factor we are increasing the losses in Active Power in the network. The power factor in our generator is influencing the losses on the line and therefore can establish a power loss/ power factor relation where an increase on power factor results on an increase of loss on the distribution line.*

7. Chapter VI — Conclusion

Renewable energy solutions are in most of the cases reliable and sustainable to some extent a significantly negative impact on the environment, nevertheless is largely necessary for the actual energy panorama.

In the case study simulation chapter, I can easily point that the integration of the hydropower plant as well pointed effects on the distribution network clearly affecting the power of the system. The obtained data showed that for the nodes U1-2, U2-2, U3-2, U1-4, U5-2 the Voltage Variation before and after connection to distribution network complies with the Czech Standards and Czech distribution network code, however, is not true for the nodes U1 and U3 in the internal installation of the hydropower plant. This presented problem can be solved by adjusting the excitation of the generators SS1 and SS2 or by regulating the transformers Tr1 and Tr3.

Losses on the distribution do not have a direct bearing on the integration process approval, it has been observed in *Table 17* and in *figure 23* that the largest losses on the distribution occur when the generators have a power factor equal to 1, and the smallest losses when the generators are disconnected, therefore being in a passive configuration; the increase in losses is a clear effect of the integration of the hydropower plant.

The future of Renewable energy solutions from my perspective should be carefully expand taking into consideration the geographic area, type of solution, investment costs and socio-environmental impact.

References

Energia, Wikipedia em Português, from *https://pt.wikipedia.org/wiki/Energia* [accessed 27 March 2018].

The Paris Agreement, from *https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement* [accessed 12 April 2018].

Distributed Energy Resources (DER) from *https://www.wbdg.org/resources/distributed-energy-resources-der* [accessed 13 April 2018].

Independent Study Climatescope 2016, Bloomberg New Energy Finance, from *http://2016.global-climatescope.org/en/summary/* [accessed 13 April 2018].

Energia Solar, Wikipedia en Español, from
https://es.wikipedia.org/wiki/Energ%C3%ADa_solar#cite_note-13 [accessed 13 April 2018].

"Renewable energy, POWER FOR A SUSTAINABLE FUTURE", 2ND EDITION, edited by Godfrey Boyle NTK code: b13932a.

Efeito fotovoltaico, Paginas PT, from *https://paginas.fe.up.pt/~ee97234/efeito_fotovoltaico.htm* [accessed 17 April 2018].

Bioenergy Conversion Technologies, Chemical Conversion, Thermal Conversion from *http://www.wgbn.wisc.edu/conversion/bioenergy-conversion-technologies* [accessed 17 April 2018].

"RENEWABLE ENERGY ,a first course" by Robert Ehrlich , ISBN 978-1-4398-6115-8, NTK code: b16816.

Conserve Energy Future, what is Wind Energy ?, from *https://www.conserve-energy-future.com/wind_into_energy.php* [accessed 20 April 2018].

Cleanenergyideas, A history of Geothermal Energy , from *https://www.clean-energy-ideas.com/geothermal/geothermal-energy/history-of-geothermal-energy* [accessed 20 April 2018].

REN21(2016), World Energy Council, from
https://www.worldenergy.org/wpcontent/uploads/2017/03/WEResources_Geothermal_2016.pdf [accessed 20 April 2018].

Conserve Energy Future, Main Types of Geothermal Power Plants , from *https://www.conserve-energy-future.com/geothermalenergy.php* [accessed 23 April 2018].

"Renewable energy Power for A Sustainable Future", 1ST EDITION, edited by Godfrey Boyle, ISBN 10: 0198564511 NTK code: A33394.

Francis Turbine, Wikipedia in English, from https://en.wikipedia.org/wiki/Francis_turbine [accessed 24 April 2018].

"Renewable Energy and Climate Change", by Volker Quaschning, ISBN 978-0-470-74707-0 NTK code: B15785.

Wave Power, Wikipedia in English from https://en.wikipedia.org/wiki/Wave_power#Surface_attenuator [accessed 26 April 2018].

Conserve Energy Future, How tidal Energy is Converted into Electricity?, from https://www.conserve-energy-future.com/tidalenergy.php [accessed 27 April 2018].

Alternative Energy Tutorials, Hydro energy using the power of Water, from http://www.alternative-energy-tutorials.com/hydro-energy/hydro-energy.html [accessed 4 May 2018].

Hydropower, Wikipedia in English, from https://en.wikipedia.org/wiki/Hydropower [accessed 4 May 2018].

Povodí Labe v češtině ,from http://www.pla.cz/planet/public/vodnidila/zsl_hradistko.pdf [accessed 12 May 2018].