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Theme

Conception of a Cogeneration System "Original Model of a Micro-Cogeneration"

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Dedication

To my Aunt
Remembrance in life’s passing
Is the truest form of love one can give
for memory should never die
and love should live forever in the heart of another
To my Parents
The reason for what I become Today. Thanks for your great support and continuous care

To my Siblings
I am grateful to both of you, you have been my inspiration, and giving me great support

Khennous Hadj Ghlam Alah

Dedication

To my parents
The reason for what I become Today. Thanks for your great support and continuous care
To my Siblings

Thank you for your everlasting love and encouragement throughout my research Without you, I couldn’t overcome my difficulties and concentrate on my studies

Hebri Ibrahim El Khalil

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I am deeply grateful to all members of the jury for agreeing to read the manuscript and to participate in the defense of this dissertation

I extend special thanks to all the teachers and students who helped me to collect much of the data.

Without their help and participation, this study could not have been done.
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Khennous Hadj Ghlam Alah

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Hebri Ibrahim El khalil

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List of Abbreviations

CHP: Cogeneration Heat Power.
PURPA: Public Utilities Regulatory Policy Act.
NUGs: Nonutility Generators.
KW: KiloWatts.
MW: Mega Watts.
GW: Giga Watts.
C°: Celsius.
CCGT's: Combined cycle gas turbines.
ORC's: Organic Rankine Cycle.
ACC: Air-Cooled Condenser.
BOP: Balance of Plant.
CFD: Computational Fluid Dynamics.
RE: Renewable Energy.
PV: Photovoltaic.
KToe: Kiloton Oil Equivalent.
Hab: Habitats.
Psig: Pounds Per Square Inch, Gauge.

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General Introduction

General Introduction

Humans convert energy from forms that are less desirable to those that are more desired i.e. from grass to meat, from wood to heat, and from fossil fuels to electricity. Throughout history, man has developed ways to expand his ability to harvest energy. The primitive man found in East Africa 1,000,000 years ago, who had yet to discover fire, had access only to the food he ate so his daily energy consumption has been estimated at 2,000 Kcal or 2,000 dietary calories. Energy consumption of the hunting man found in Europe about 100,000 years ago was about 2.5 times that of the primitive man because he had better methods of acquiring food and burned wood for both heating and cooking. Energy consumption increased again by almost 2.5 times as men evolved into the primitive agricultural man of about 5,000 years ago who harnessed draft animals to aid in growing crops. The advanced agricultural man of 1400 A.D. northwestern Europe again doubled the amount of energy consumption as he began inventing devices to tap the power of wind and water; it began to utilize small amounts of coal for heating and harnessed animals to provide transportation. The dawn of the age of industrialization, ushered in by the invention of the steam engine, caused a 3-fold increase in energy consumption by 1875. Among other things, the steam engine allowed man to unlock the Earth's vast concentrated storage deposits of solar energy - coal, gas, and oil so he no longer was limited to natural energy flows. Whereas increases in energy consumption had been gradual throughout history, once industrialization occurred, the rate of consumption increased dramatically throughout just a few generations.

As we, humans need more and more energy sources, due to the evolution that we are experiencing. We need to conserve the energy sources we have or at least reduce its consumption and find a way to consume it more efficiently. To achieve this, we need new technologies and develop those that already exist. Therefore, as we search for new sources of energy and develop technologies that allow us to harness them. We can within that time harness the energy that is already there, and that is being wasted.

We came across those chapters starting from the first, where we reviewed cogeneration, its uses in our lives as we talked also about the most commonly used combination, that is heat and power.to continue on the second chapter where we spoke at length about the different models of cogeneration with many details. To get by then to the third chapter where we introduced hydropower first time on this project. From its history to its types and uses, to its advantages and disadvantages, we included all of that here. To finally reach the forth and the last chapter, which contains a review of the wastewater treatment plants in Algeria, and in the world and the electricity consumption. To get finally to the simulation of the micro-cogeneration hydro turbine.

One of the new technologies that we can use to save electricity and benefit from its function and how it works is co-generation and micro-co-generation using a model of a hydropower plant. So, what is a co-generation? Moreover, what is the model that we are going to use?

Chapter I

State of the Art of Cogeneration Systems

I.1. Introduction

Since their existence, humans are always known as energy consumers. Within 30 years the world population could reach 9 to 10 billion people [1] (against 7.5 billion currently) with world energy consumption up to 50–70 % greater than the one we know today [2].

The major evolutions of humanity have occurred through harnessing energy. Very quickly, the individuals tamed fire, to warm up themselves, to light up, to heat objects, and to cook food … etc. Since then, the only two alternatives that have truly developed and been used are petroleum and nuclear energies. We must make a choice rapidly and develop other replacements. Thereby, it helps us save our fossil natural resources, through adopting new technologies based on energy management and the concepts of sustainable development, where the idea for cogeneration systems or combined heat and power (CHP) came from.

This production combination saves primary energy and diminishes greenhouse gas emissions, compared to separate installations. Excluding losses due to electricity transmission and distribution, conventional energy production has an average efficiency of 35%. Then up to 65% of the energy potential is released as waste heat. Whereas with cogeneration, the simultaneous generation of heat and electricity, lowers this loss by utilizing that heat. Cogeneration efficiency can reach 90% [3].Also, the electricity produced by a cogeneration system is mostly used locally. Consequently, transmission and distribution losses are negligible. Besides, cogeneration is one of the most cost-effective methods to generate energy while reducing greenhouse gas emissions.

I.2. History of combined heat and power system

The cogeneration system is a well-established concept with a long history. Indeed, itis one of the oldest forms of electricity generation. The potential to combine the production of electricity with the production of heat was recognized from the start of the development of the electricity generation industry. In the United States, for example, at the end of the 19th century, municipal authorities used the heat from the factories they had built to supply electricity for urban lighting to supply hot water and heating for homes and offices. Thus, it is impressive to mention that at the beginning of the 20th century, approximately 58% of the total electric power produced on-site in US industrial plants came from cogeneration systems [4].

Although the use of technology has decreased in recent years. These district heating systems, as they became known, were quickly replicated in other parts of the world. The fuel shortage after the First World War, followed by the Great Depression made district heating more attractive with the increase in electricity production in Europe during the 1920s and 1930s. Even here, however, the adoption was uneven. However, in the early 1950s, district heating systems were installed in some cities in the United States, in European countries like Germany Russia, and Scandinavia.

In other countries such as the United Kingdom, there has never been great enthusiasm for cogeneration, and it has gained few converts although several projects were built after World War II when regions devastated by the bombing were being rebuilt. This pattern of uneven exploitation has continued, and the situation is complicated by the fact that it is almost impossible, economically, to build district heating infrastructure in modern cities that lack it.

However, in the early 1950s, the idea gained ground that a manufacturing plant, like a city, could also benefit from cogeneration. If a factory uses large amounts of electricity and heat, installing its own power plant allows it to control the cost of electricity and use the waste heat produced, for considerable economic benefit.

While this idea slowly gained ground, the technological advances of the 80s and 90s allowed small factories, offices, and even residential developments to install cogeneration systems based on small piston engines or gas turbines. In many cases, this has been facilitated by the deregulation of the power industry and the introduction of legislation that has allowed small producers to sell the surplus electricity to the local grid. Since the mid-1990s, the concept of distributed generation has become popular and this has encouraged cogeneration.

The legislation of certain countries has also helped to encourage industrial and commercial cogeneration, e.g., in the United States, the government approved the Public Utilities Regulatory Policy Act (PURPA) on November 9, 1978. This act played a critical role in expanding cogeneration into the marketplace since it provided the only way for nonutility generators (NUGs) to sell excess electricity. That law forced electric utilities to buy power from other more efficient producers, such as cogeneration plants, if that cost was less than the utility's own "avoided cost1" rate to the consumer [5]. Moreover, the recent concern for the environment plays an important role to enhance energy efficiency from 30% to 70% or 80%. Thus, cogeneration is seen as a key strategy to control emissions for the 21st century. However, while environmentalists are calling for increased use, real growth has remained slow.

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[1] The avoided cost rate was the additional costs that the electric utility would incur if it generated the required power itself, or if available, could purchase its demand requirement from another source.

I.3. Definition of Cogeneration

Cogeneration is a range of technologies to produce two different types of energy simultaneously, in a single integrated system, and from a particular energy source. This energy source can be fossil fuels (coal, gas…), as well as nuclear or renewable fuel. e.g., whenever this fuel is consumed to generate electricity in power plants, waste heat is also produced. While this energy cannot be utilized to generate electricity, it can still be employed. Low-grade heat can be used to produce hot water or for space heating, while higher-grade heat will generate steam which can be exploited by some industrial processes.

Thus, the heat that is usually wasted in conventional power plants is recovered in the cogeneration system as useful energy, as a result, reduces losses that would otherwise occur from the separate production of heat and electricity.

The most typical combinations are electricity and space heating or electricity and hot water/steam production. These combinations of cogeneration are known as combined heat and power (CHP).

I.4. Components of CHP unit

A cogeneration unit consists of the following basic components:

- A prime mover in which fuel is converted into mechanical and/or thermal energy. It can be any of the following options: Steam turbines, gas turbines, internal combustion engines, solar systems, biomass external combustion systems, or Stirling engines.
- A Fuel System.
- A generator to transform the mechanical energy into electricity.
- A Heat Recovery System to collect the produced heat.
- A Cooling System for dissipating heat that is rejected from the locomotive.
- A Combustion and Ventilation Air Systems to supply clean air and carry waste gases left from the engine.
- A Control System is used for maintaining a secure and proficient operation.
- An Enclosure is used for achieving the protection for the engine as well as machinists, and for reducing noise.

I.5. Combined Heat and Power Principles and Technologies

CHP can be located at an individual facility or building, where there is a need for both electricity and thermal energy or be district energy or utility resource.

Each of the electricity and heat is an energy source; however, they own different properties. Electricity can be delivered to every household and facility in a nation because it is relatively easy to transport swiftly and efficiently. On the other hand, heat energy cannot conveniently and economically be transported with anywhere near the same ease.

This technology is based on the fact that the production of electricity releases a large amount of heat, often rejected in nature, and therefore lost. Recovering this heat allows it to be used and recovered as valuable thermal energy such as steam or hot water & that can be used for space heating, cooling, domestic hot water, and industrial processes. But also to increase the overall efficiency of the power plant or installation to reach 90% and even more [3].

Nearly two-thirds of the energy used by conventional electricity generation is wasted in the form of heat discharged to the atmosphere [6]. Additional energy is wasted during the distribution of electricity because of the Joule effect or what is also known as Joule heating, which is an increase in heat resulting from current flowing through a conductor. Essentially, when the electric current flows through a solid or liquid with finite conductivity, electric energy is converted to heat through resistive losses in the material.

The heat is generated on the microscale when the conduction electrons transfer energy to the conductor’s atoms by way of collisions, and this heat bleeds away as lost energy. Overall losses between power plants and users can be between 8 and 15% [7].

By capturing and using heat that would otherwise be wasted, and by avoiding distribution losses, CHP can achieve efficiencies of over 90%, compared to the average of 35% for typical technologies [3] (i.e., conventional electricity generation and an on-site boiler). Here is a simple diagram (Fig. I.1) that shows the efficiency of the combined heat and power system, compared to a conventional power plant.

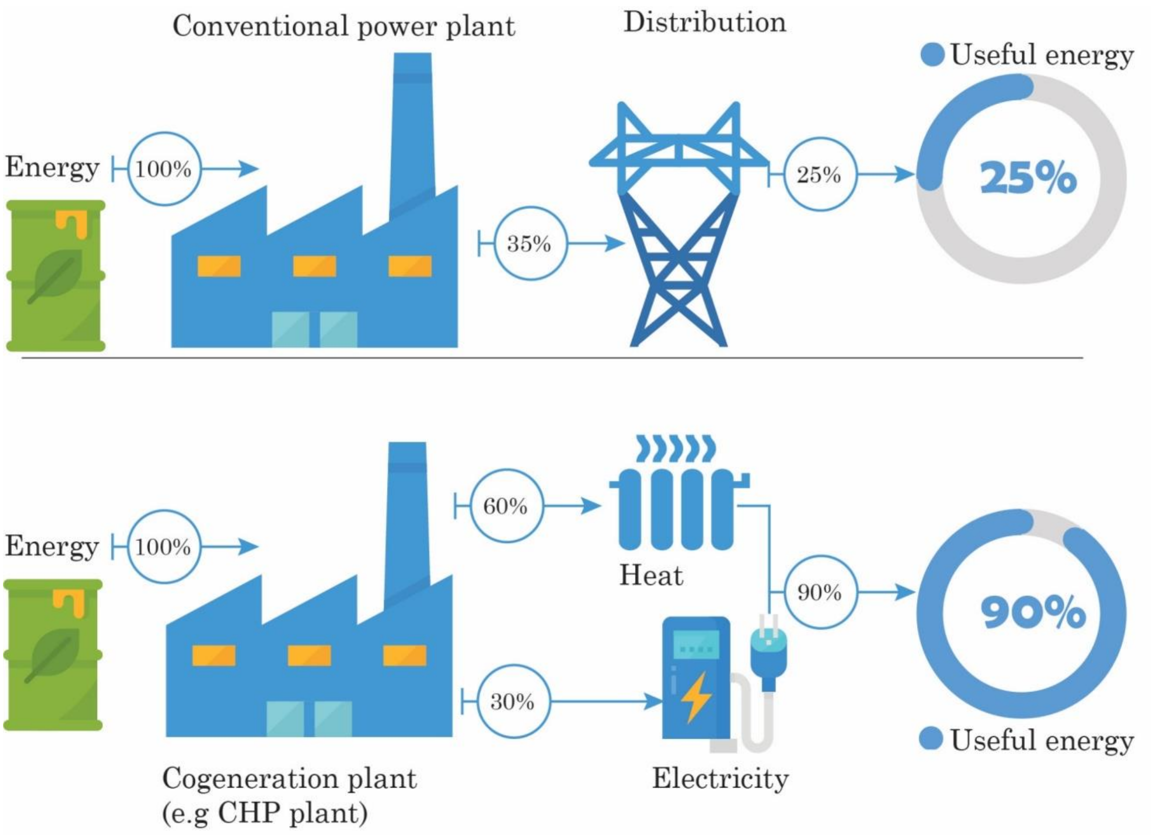

Fig. I.1 : Cogeneration power plant (CHP plant) vs. Conventional power plant.

A cogeneration installation consists of running an engine with a single energy source; that energy source can be a fossil (coal, natural gas…) or renewable fuel (geothermal energy, biomass, solar thermal power…). Different techniques can be used:

- A steam turbine.
- A gas turbine.
- An internal combustion engine.
- A Stirling engine.
- Fuel cells.

This engine in turn puts an alternator in motion, generating electricity that is recovered and stored. The movement of the alternator then creates heat; a coolant prevents it from overheating.

A heat exchanger recovers this heat and uses it to produce hot water for heating or sanitary installations. We can also recover heat from the condensation of combustion gases. The diagram below (Fig. I.2) shows a simple installation of a cogeneration system.

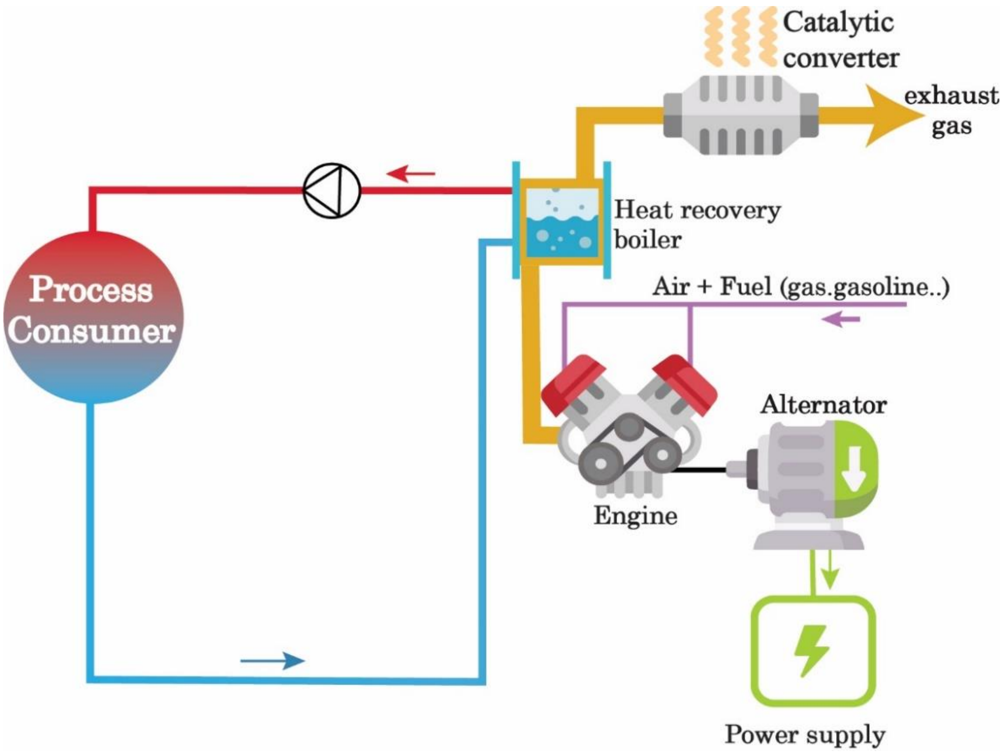

Fig. I.2 : Simplified diagram of cogeneration installation.

I.6. Classification of the CHP system

CHP systems are identified by the system's prime mover, the device that powers the generator. They can be further characterized either as topping-cycle or bottoming-cycle generation:

I.6.1. Topping cycle

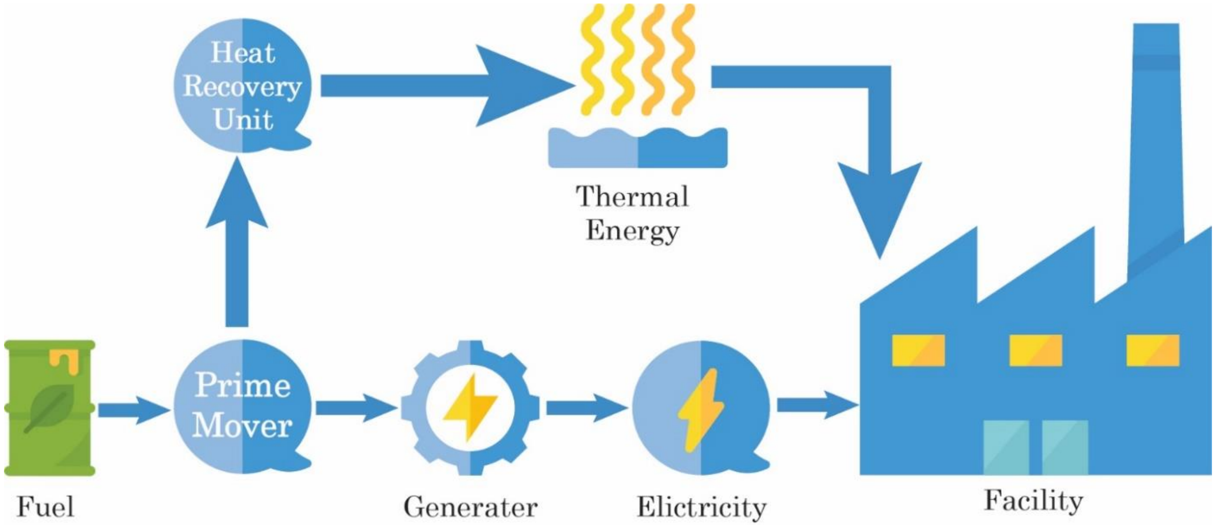

Fig. I.3 : Topping Cycle CHP system.

In this type of generator, the fuel supplied to the system is used primarily to generate electricity while the heat that is left after electrical power has been generated used in an ancillary application.

Depending upon the type of generating system, the heat energy from the electricity generating system might be high-grade heat that is suitable for raising steam or for use directly in an industrial process. As it might be lower grade heat that is only convenient for space heating and hot water production. There are four types of topping cycle cogeneration systems:

6.1.1. First type

It burns fuel in a gas turbine or diesel engine to produce power. The exhaust provides process heat or goes to a heat recovery boiler to create steam to drive the secondary steam turbine.

6.1.2. Second type

This system produces high-pressure steam by burning any type of fuel, which then passes through a steam turbine to generate electricity. The exhaust provides low-pressure process steam; this is called a steam-turbine topping system.

6.1.3. Third type

This system burns fuel such as natural gas, diesel, wood, gasified coal, or landfill gas. The hot water from the engine jacket cooling system flows to a heat recovery boiler, where it is converted to process steam and hot water for space heating.

6.1.4. Fourth type

This system is a gas-turbine topping system. A natural gas turbine drives a generator, and the exhaust goes to a heat recovery boiler that makes process steam and process heat.

I.6.2. Bottoming cycle

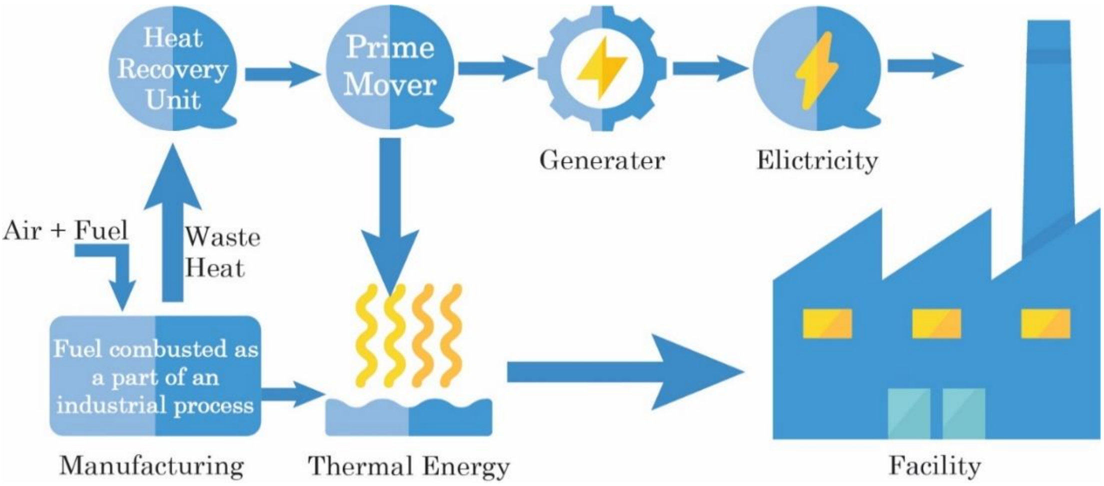

Fig. I.4 : Bottoming Cycle CHP systems.

The second type of CHP system is called a bottoming cycle. In this system, the fuel is used first to produce heat. The heat will normally be exploited in heavy industries such as glass—or metal manufacturing units where very high furnace temperatures are used. Any energy not used in the process is then used to generate electricity. Bottoming cycle CHP is also called waste heat recovery or waste energy recovery. The energy recovered for electricity generation may be in the form of heat, as it can be combustible gases such as those produced during iron production. Some electricity generating systems can also exploit high-pressure exhaust gases from a process, using the pressure drop to drive an engine. Bottoming cycle CHP systems are particularly attractive because they can provide electricity without the need to consume additional fuel. But they are much less common than topping cycle plants because electricity can easily be bought or sold when it is over site demand.

I.7. Combined heat and power applications

While the CHP system is ideally designed around heat demand. The availability of off-the-shelf components may also play a role in determining the final scheme of the system. In other cases, electricity may be the primary need and the use of heat is a secondary consideration. However, it is still the demand for the heat that will determine the location and outline of any CHP system. For without the demand for heat, there can be no CHP.

There are plenty of facilities in the industrial sector, which require a sufficiently large thermal load with a constant electrical load. Therefore, CHP is well suited for these types of establishments. These sites include chemical plants, refineries, pulp, and paper mills, wastewater treatment plants, food-processing sites, and many other locations with significant thermal and electric demands.

In the commercial sector, attractive CHP sites include, but are not limited to, hospitals, nursing homes, laundries, hotels, health clubs, universities, and prisons.

While most CHP systems have been installed in industrial, commercial, and institutional applications, residential applications, such as multi-family buildings, can also be a good match for CHP. Steam turbines used in CHP applications have relatively low power to heat ratios and are used primarily with solid fuel boilers. Rather than using low power to heat ratio steam turbines, sites that have access to gas fuels (e.g., natural gas or biogas) generally install prime movers with higher power to heat ratios, such as reciprocating engines or gas turbines. Of all these applications, domestic heat consumption remains the biggest challenge to the expansion of CHP.

Where district heating networks exist, a good balance between domestic heat and electricity demand is possible.

When there is no district heating network, the main options are either power stations meeting the electricity demand only, or domestic CHP systems, which cost a lot. If costs can be brought down then such systems, offer a real chance of a significant change in global energy usage.

Therefore, while CHP installations can range from single home heat-and-electricity units to municipal power stations supplying heat and power to a city, they all share one theme. Ideally, the heat and electricity from a CHP plant will be supplied to the same users. While this is not an absolute requirement, it is a pragmatic principle for a successful CHP scheme.

I.8. Benefits of CHP systems

CHP offers many benefits compared to conventional electricity and thermal energy production, including:

I.8.1. Efficiency Benefits

One of the key features of CHP is that inefficiencies in electricity generation increase the heat that can be utilized for thermal processes. Therefore, the combined electric and thermal energy efficiency remains in a range of 65–80 percent. However, every CHP system's efficiency depends on the technology used and the system design. The efficiency of the five most commonly installed CHP prime movers is [8]:

- Steam turbines: 80 percent.
- Reciprocating engines: 75–80 percent.
- Combustion turbines: 65–70 percent.
- Microturbines: 60–70 percent.
- Fuel cells: 55–80 percent.

Moreover, it avoids transmission and distribution losses, as we said earlier that it could reach 15%, increasing the efficiency of the system.

I.8.2. Environmental Benefits

Cogeneration technology not only achieves significant primary energy savings, but it also helps reduce greenhouse gas emissions to the atmosphere, such as carbon oxide (CO). e.g., for a small size gas-fired CHP the emissions of CO are cut by more than 50% [9], and other harmful combustion substances such as sulfur dioxide (SO_2), nitrogen oxides (NOx), CO…etc.

I.8.3. Economic Benefits

Cogeneration is most cost-effective where there are simultaneous demands for both heat and electricity. It offers several economic benefits. As indicated below.

- **Reduced energy costs:** By capturing and utilizing heat that would otherwise be wasted from the generation of electricity, CHP systems require less fuel to produce the same amount of energy. And by doing that cogeneration saves up to 20% of fuel [9]. That means cutting energy bills.
- **Reduced logistics cost:** By reducing the fuel supply needs, that brings about a reduction in the logistical needs to transport and store the fuel
- **Avoided capital costs:** CHP can often reduce the expense of replacing heating equipment.
- **Protection of revenue streams:** Through the on-site generation and improved reliability, CHP can allow facilities to continue running in the event of a disaster or an interruption of grid-supplied electricity.

I.8.4. Reliability Benefits

Unreliable electricity service represents a quantifiable business, safety, and health risk for some companies and organizations. CHP is an on-site generation resource and can support ongoing operations in the event of a disaster or grid disruption by continuing to provide reliable electricity.

Security of supply is crucial in many applications, such as in hospitals and at industrial plants where an interruption of the process can cause major disruption.

I.9. How to select a Cogeneration System

Many factors should be taken into consideration while selecting the most appropriate cogeneration system for a particular industry, such as:

- Maximum/minimum Electrical -load matching.
- Thermal- load matching.
- What is more critical - whether power or steam, to decide the backup plant.
- The quality of thermal energy required.
- Load outlines.
- Type of existing Fuels, and long-term availability of fuels and fuel pricing.
- Commercial availability of various system alternatives.
- Project cost and long-term benefits.
- Heat-to- Power ratio.

Typical Heat-to-Power ratios for certain energy-intensive industries are provided in Table 1.1 below [10].

Table I.1: Typical Heat-to-Power Ratios for Energy Intensive Industries.

Industry	Minimum	Maximum	Average
Breweries	1.1	4.5	3.1
Pharmaceuticals	1.5	2.5	2.0
Fertilizer	0.8	3.0	2.0
Food	0.8	2.5	1.2
Paper	1.5	2.5	1.9

I.10. Conclusion

Cogeneration is a technique for producing two types of energy (heat and electricity) in one process that can save considerable amounts of energy. Cogeneration is often associated with the combustion of fossil fuels but can also be carried out using some renewable energy sources and by burning waste.

In general, cogeneration is a potential area of energy management. However, it is more or less the economic aspects that govern the decision on going for cogeneration for a particular site. Therefore, it is very important to look for similar projects and address the necessary areas to bring the norm of cogeneration.

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Chapter II

Different Models of Cogeneration Systems

II.1. Introduction

Knowing the different types of cogeneration systems is essential to select the best cogeneration system for a particular type of industry. The cogeneration system suitable to one industry would not be found suitable for another industry, though both would be manufacturing the same product. Choosing the right type of cogeneration system would boost the industry’s economics, reliably provide energy, improve environmental performance, etc.

II.2. Different Cogeneration Systems

These days, several different cogeneration systems are widely used, we can classify them based on the CHP system capacity, the main prime mover of the system, and based on the conversion technology.

II.2.1. Based on capacity

II.2.1.1. Large-scale CHP

Large-scale CHP covers the widest range of thermal and power output and currently accounts for up to 90% of the installed capacity worldwide. Most large CHP installations are on industrial sites and include some very large installations in the range of 300 MW to over 01 GW at large oil refineries. As the definition of large-scale CHP embraces anything over 02 MW, both the number and variety of applications are significant.

The simplest form of large-scale CHP is found where the exhaust gas from an industrial gas turbine can be applied directly to heat a process, for example in the drying of bulk chemicals. The process must be tolerant of the products of combustion, which, from a modern gas turbine operating on natural gas, are exceptionally low in harmful emissions.

More common in large industrial processes is the need for steam as a flexible and easily transported heat medium. The natural provider of large quantities of steam from waste heat is again the industrial gas turbine which in some applications can be operated in a combined cycle with a steam turbine, the latter often receiving steam from the process or passing out to the process. A diminishing number of large-scale CHP systems have a steam turbine as the source of power. Exceptions to this are systems where heat can be recovered into steam from a high-temperature process, or more commonly now when renewable fuels are burnt in the steam raising plant. Reciprocating engines also have a place in large-scale CHP, in particular where the heat-to-power match is relatively low.

District heating systems will normally employ engines for that reason, to benefit not only from the low heat-to-power ratio but also from the much higher efficiency of the engine, which can extend operating periods against a seasonal heat demand.

When making comparisons between gas turbine and gas engine CHP solutions, there are additional factors that may benefit the latter technology. The gas turbine performance is affected directly by the ambient air temperature at the compressor inlet, and significant derating of the turbine takes place as temperatures rise. Both power and efficiency are affected by any temperature change, whereas for most gas engines, constant power and efficiency can be obtained at temperatures up to 30–35 °C. By actively cooling the intake air to the gas turbine, performance can be restored, generally at the cost of some thermal or electrical energy.

The other drawback of the gas turbine is its relatively poor efficiency against part-load, whereas the gas engine will lose only a few percentage points between full load and 50%. Therefore, the best application for the gas turbine is a constant load with a high heat-to-power ratio. A seldom deployed but highly effective solution for large-scale systems is to use a combination of a gas turbine with a number of gas engines. The turbine can be selected to provide the bulk of the heat demand whilst running at full load to provide a base level of power generation. The gas engines provide flexibility to cater for both electrical and heat demand fluctuations and serve to increase the electrical generating efficiency of the combined system. Many large-scale systems are installed where there is a very significant heat demand, greatly more than the electrical demand of the site or process. The efficient production of electrical power in these CHP installations makes it viable to export excess power to the grid thereby raising the overall efficiency of the network.

II.2.1.2. Small-scale CHP

Generally speaking, the concept ‘‘small-scale CHP’’ (combined heat and power) means combined heat and power generation systems, where an individual CHP unit size is typically less than 2 MW and greater than 200 kW of power output, and systems that are generally smaller than 10 MW where multiple power generators are installed. This category possibly contains the wildest range of technologies and applications for a CHP.

The prime mover technologies introduced for large-scale systems all find their place at a smaller scale, though reciprocating gas engines are predominant in this area where their relatively low cost and superior generating efficiency come to the fore. Indeed, the wide range of outputs available from modern engines employing essentially the same technology extends down into the micro-CHP sector.

At the higher end of the small-scale range, generating efficiencies over 40% have been achieved, and even at smaller sizes, the power efficiency closely matches that of delivered centrally generated power. So, in energy efficiency terms the heat recovered is a genuine bonus, and here again, the reciprocating engine has excelled in CHP applications, achieving total energy efficiencies of up to 95% when used to heat air. A further reason for the relative dominance of the reciprocating engine is the close thermal match it can achieve for applications in the commercial and public building sector, both as CHP and in trigeneration systems.

Turbines should not, however, be ignored, and there are now gas turbines available with good generating efficiency at around 2 MW power output. At the other end of the spectrum are several micro-turbine developments of up to 250 kW, which achieve respectable efficiency levels using the recuperated cycle where waste heat from the exhaust is recycled to the compressed air before combustion. Steam turbines also have their place, again mainly in heat recovery applications, but at low power, cycle efficiency remains low. There are even reciprocating and radial type steam engines appearing in the market, which, though exhibiting typically low electrical generating efficiencies, can find niche applications in small thermal plants burning renewable or waste fuels.

Developed decades ago, for the US space program, fuel cells are now beginning to find land-based power generation applications. There are many types of fuel cells either in the market or under development, and it is a technology that will still take many years to reach maturity and commercial viability. The principle of the fuel cell is simple, and indeed the antithesis of the process of electrolysis that uses electrical potential to split water into oxygen and hydrogen.

In the fuel cell, these elements recombine across a membrane to form water and in doing so release electrons that provide the power output of the cell.

As neither pure oxygen nor hydrogen is cheaply available, current fuel cells operate on-air and natural gas or similar hydrocarbon fuel from which the hydrogen is extracted in thermochemical processes. These processes account for the inefficiency of the fuel cell, which is largely recoverable as heat that makes the fuel cell a useful CHP technology.

II.2.1.3. Micro-CHP

At the smallest end of the CHP spectrum, some technologies can be applied to small buildings and individual homes. These are micro-CHP systems, not to be confused with the micro-turbines discussed earlier, though very small gas turbines could be employed in micro-CHP. More common technologies entering this part of the market are small reciprocating engines, Stirling engines, and fuel cells.

Reciprocating engines of similar output to a small family car can be used to provide CHP to small buildings in the private and public sectors and have been developed to operate not only on natural gas but both gas and liquid biofuels. Smaller engines with outputs below 5 kW might be applied to large homes, though very few houses will have a constant demand for this level of power generation. Small systems can also be applied to apartment blocks providing a miniature form of district heating, though where more than 15 homes are connected the technology is more appropriately small and not micro-scale.

In the more common domestic environment of the average family home, the Stirling engine has found its niche. Being an external combustion engine, there is a greatly reduced level of wear of the moving parts, so the potential for very high reliability. It also operates extremely quietly as the combustion system resembles that of the familiar domestic boiler. Several of the pioneering manufacturers in this field have adopted the Sterling engine to produce a direct replacement device for the domestic boiler in both floor and wall-mounted variants.

Small fuel cells have also been developed for use in this sector of the market, and though the technology is still expensive to install, in time viability and performance will improve making this clean, efficient, and virtually silent technology more widely applicable.

All micro-scale technologies suffer to an extent from lower power generation efficiencies making it crucial to ensure a good match to the thermal demand of the application when considering micro-CHP. To encourage uptake and further development of micro-CHP, it is common to find financial incentives from governments or utility companies and, in turn, wider uptake will allow manufacturers to invest to reduce the cost of their product.

II.2.2. Based on the main prime mover

There are three basic elements to most combined heat and power technologies. One of them is the ‘Prime mover’, which is effectively the ‘engine’ that creates mechanical motive power. The other two are the electrical generator (if it applies to the individual device), and the heat recovery unit(s).

There are currently seven distinct types of prime mover [11]**:**

1. Steam turbines.
2. Gas turbines.
3. Combined cycle gas turbines (CCGT’s).
4. Organic Rankine Cycles (ORC’s).
5. Internal combustion engines.

6. Stirling engines.
7. Fuel cells.

II.2.2.1. Steam turbine

Steam turbines are heat engines that convert the energy contained in high temperature and high-pressure steam into rotational, mechanical energy, or electrical energy in its simplest form, by turning an electrical generator using a shaft driven by the pre-generated mechanical energy. To operate, and unlike some heat engines, steam turbines do not, itself, burn fuel. Therefore, it needs a source of high temperature and high-pressure steam. Usually provided by an integrated furnace and boiler, as it can be provided in some cases from the exhaust of a gas turbine, or waste heat from another process in steam turbine-based CHP plants.

Steam turbines are a common feature of all modern and future thermal power plants. It provides mechanical power to drive generators in coal-fired, oil-fired, some gas-fired, and nuclear power plants across the globe. They can also be found in geothermal, solar thermal power plants, and in marine power plants that derive heat from the world’s oceans.

The steam turbines in large power plants such as central coal-fired and nuclear plants are usually made up of several cascaded units that extract energy in turn from high-pressure steam, medium pressure steam, and low-pressure steam. Smaller plants will have a single steam turbine and so will most steam turbine-based CHP plants.

The thermodynamic heat engine cycle upon which the steam turbine is based on called the Rankine cycle. The Rankine cycle is an idealized cycle of a heat engine that converts heat energy into work. Developed by Scottish engineer William J.M Rankine[2] in the 19th century [12]. It is used to predict and rate the performance of steam turbine power plants. Though the theoretical principle also applies to reciprocating engines such as steam locomotives. In this cycle, the heat is supplied externally to a closed loop, which usually uses water (in a liquid and vapor phase) as the working fluid. The working fluid in the Rankine cycle undergoes the phase change from a liquid to a vapor phase and vice versa.

Water is used as the working fluid in the Rankine cycle instead of other substances due to its favorable properties, such as its non-toxic and unreactive chemistry, abundance, and low cost, as well as its thermodynamic properties. For example, water has the highest specific heat of any common substance – 4.19 kJ/kg K [13].

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[2] William John Macquorn Rankine, (born July 5, 1820, Edinburgh, Scot—died Dec. 24, 1872, Glasgow), Scottish engineer and physicist and one of the founders of the science of thermodynamics, particularly in reference to steam-engine theory.

Moreover, it has a very high heat of vaporization[3], which makes it an effective coolant and medium in thermal power plants and other energy industries.

In the case of the Rankine cycle, the Ideal Gas Law can hardly be used (steam do not follow the law of p*V=n*R*T), therefore all-important parameters of water and steam are tabulated in the so-called "Steam Tables"[4].

In an ideal Rankine cycle, the system executing the cycle undergoes a series of four processes: two isentropic (reversible adiabatic) processes alternated with two isobaric processes:

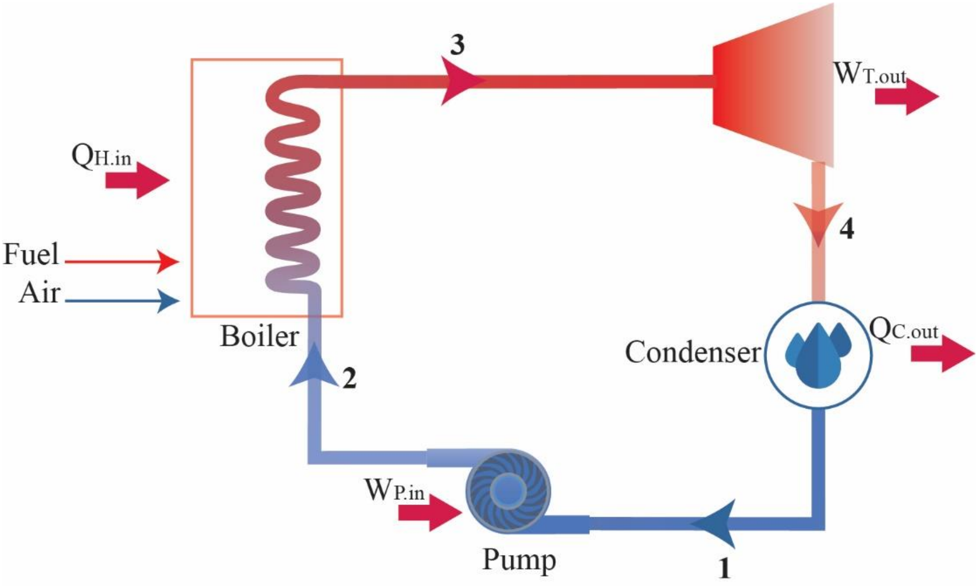

Fig. II.1 : Schematic representation of an ideal Rankine cycle.

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[3] When a material changes phase from solid to liquid, or from liquid to gas a certain amount of energy is involved in this change of phase. In case of liquid to gas phase change, this amount of energy is known as the enthalpy of vaporization, (symbol ΔH_{vap}; unit: J) also known as the (latent) heat of vaporization or heat of evaporation. Latent heat is the amount of heat added to or removed from a substance to produce a change in phase.

[4] In these tables, the basic and key properties, such as pressure, temperature, enthalpy, density and specific heat, are tabulated along the vapor-liquid saturation curve as a function of both temperature and pressure.

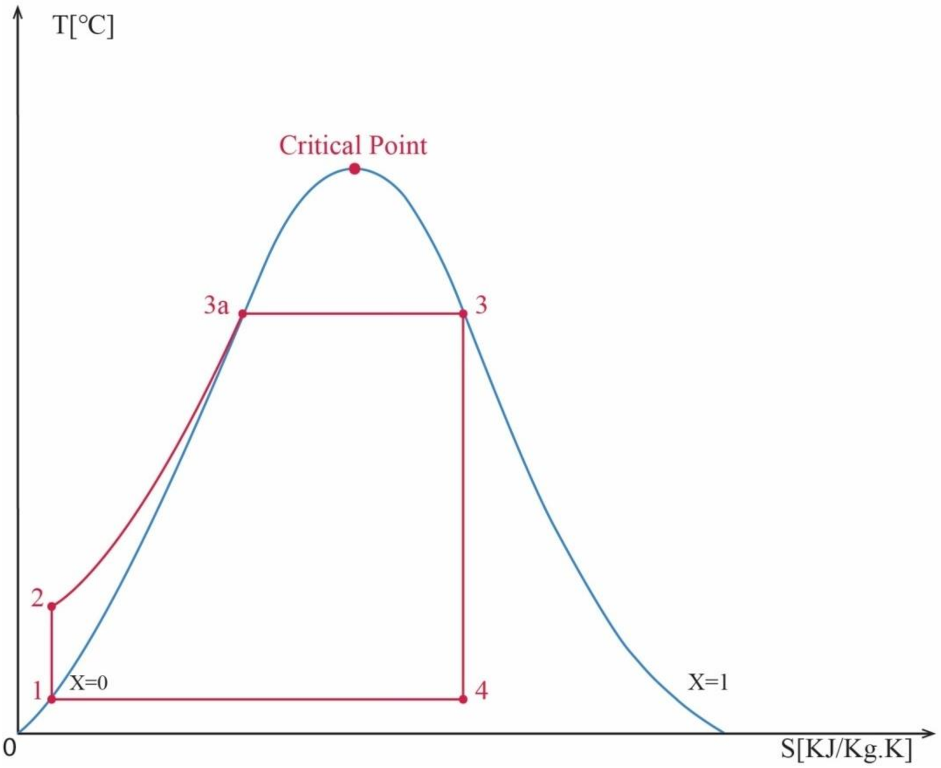

Fig. II.2 : T-s diagram of an ideal Rankine cycle.

- **Isentropic compression (process 1-2):** Pump pressurized the liquid water from the condenser before going back to the boiler. In this process, the surroundings do work on the fluid, increasing its enthalpy (h = u + pv) and compressing it (increasing its pressure). On the other hand, the entropy remains unchanged. Assuming no heat transfer with the surroundings, the energy balance in the pump is:

$$\mathbf{W_p = H_2 - H_1}. \tag{1}$$

- **Isobaric heat addition (process 2-3):** Liquid water enters the boiler and is heated (in a heat exchanger – boiler) at constant pressure by an external heat source to the boiling point (2 → 3a) of that fluid, and then evaporated (3a → 3) to become a dry saturated vapor. The net heat added is given by:

$$\mathbf{Q_{add} = H_3 - H_2}. \tag{2}$$

- **Isentropic expansion (process 3-4):** (expansion in a steam turbine) Steam from the boiler expands adiabatically from state '3' to state '4'in a steam turbine to produce work and then is discharged to the condenser (partially condensed). The steam does work on the surroundings (blades of the turbine) and loses an amount of enthalpy equal to the work that leaves the system. The work done by the turbine is given by:

$$\mathbf{W_T = H_4 - H_3}. \tag{3}$$

Again, the entropy remains unchanged.

- **Isobaric heat rejection (process 4-1):** (in a condenser) – In this phase, the cycle completes by a constant-pressure process in which heat is rejected from the partially condensed steam. There is heat transfer from the vapor to cooling water flowing in a cooling circuit. The vapor condenses and the temperature of the cooling water increases. The net heat rejected is given by:

$$Q_{re} = H_4 - H_1. \tag{4}$$

Steam turbines mostly can be found in topping cycle CHP systems, as it can be in bottoming CHP systems too. In the bottoming CHP systems, we can find one of the three basic types of steam turbine, which is **the condensing steam turbine**, which is a conventional steam turbine that condenses the steam exiting the turbine exhaust to provide the maximum energy capture. Then the waste heat or energy from an industrial process is used to raise steam to generate electricity. In this type of plant heat energy is exploited first, then the remaining heat is used to produce steam for electricity generation.

In the topping CHP systems, we find the other two types of steam turbines. The **backpressure steam turbine** and the **extraction steam turbine**. The first is so-called like that because the steam exiting the turbine exhaust will still contain a significant amount of energy and will be at relatively high temperature and pressure. This exhaust steam is used either to provide heat for an industrial process or to produce hot water as it is shown in Fig. II.3. Because there is no way of varying the steam output from the turbine exhaust while maintaining optimum operating conditions, this type of steam turbine CHP plants works with relatively constant heat demand [14].

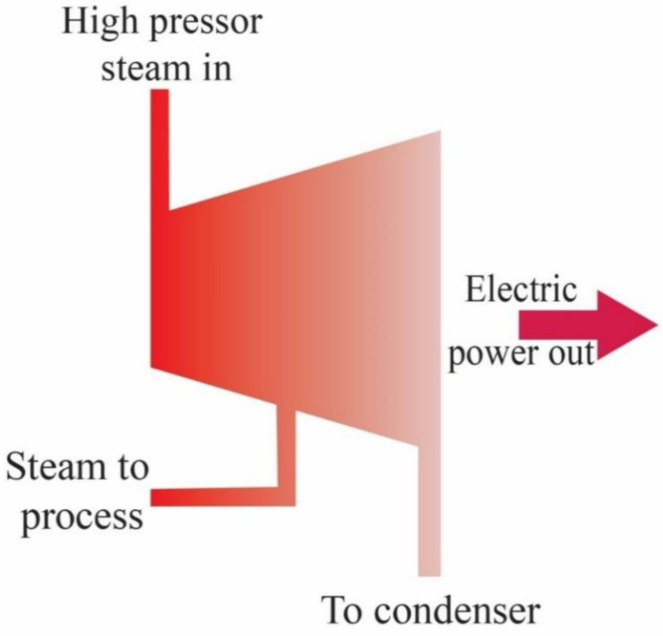

Fig. II.3 : Schematic of a backpressure steam turbine.

The third type that we find it in a topping cycle CHP plant, an **extraction steam turbine**, is a condensing steam turbine with a steam extraction port partway along with the steam turbine that can provide steam at an intermediate temperature and pressure for an industrial process (see Fig. II.4). The actual position of the extraction port will depend on the heat demand so this type of CHP plant will be tailored for each specific application. In an extraction steam turbine CHP plant, the amount of power that can be generated will vary, depending upon the amount of steam that is extracted. However, the turbine is more costly than backpressure or conventional condensing steam turbine.

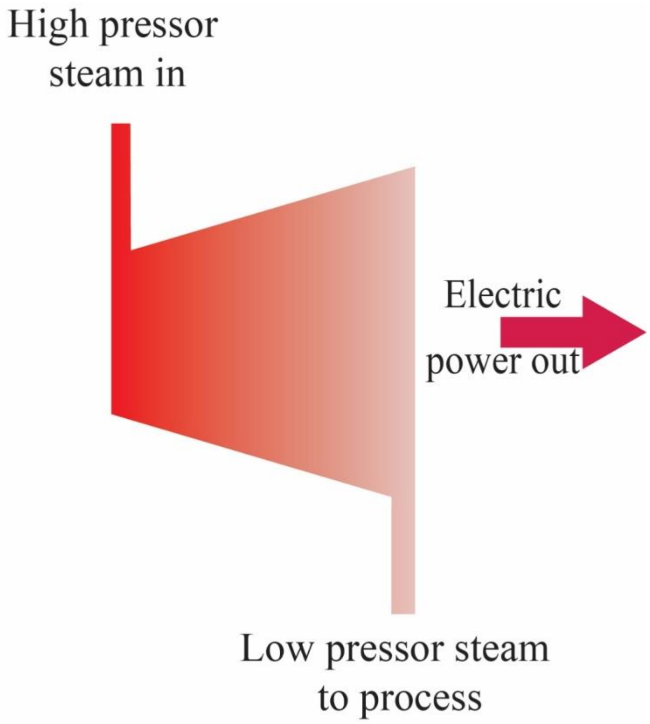

Fig. II.4 : Schematic of an extraction steam turbine.

Steam turbines are available in a wide range of sizes, but the complexity of steam turbine-based CHP plant make them relatively large. The smallest CHP steam turbines are likely to be several megawatts in generating capacity.

II.2.2.2. Gas turbines

Gas turbines are heat engines that use air as their working fluid. The modern gas turbine was developed in the early and mid-20th century, initially as an aero engine, and then adapted for power generation. Unlike gas turbine engines intended for power generation, which do not have weight limitations. Aero engines need to be very light and efficient. This has led to the evolution of a separate class of industrial gas turbines that are designed specifically for this market [15].

These turbines operate upon the thermodynamic cycle named the Brayton cycle. In general, the Brayton cycle describes the workings of a constant-pressure heat engine.

In an ideal Brayton cycle, the system executing the cycle undergoes a series of four processes: two isentropic (reversible adiabatic) processes alternated with two isobaric processes [16] as it is shown in the figure below.

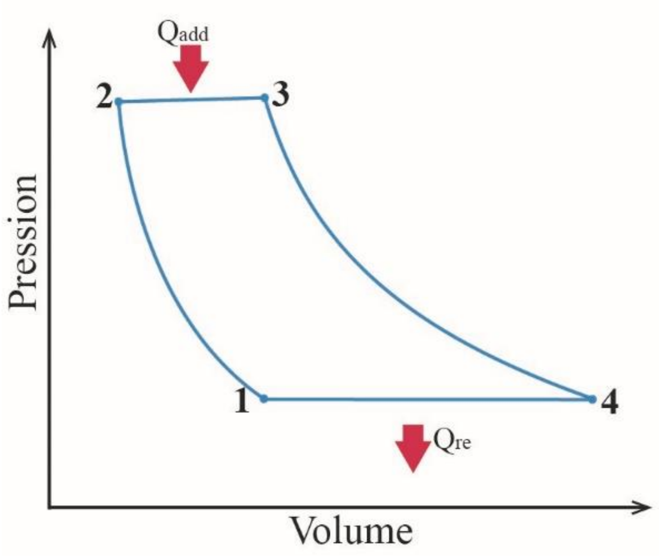

Fig. II.5 : PV diagram of a closed ideal Brayton cycle.

A modern gas turbine combines an air compressor, a combustion chamber and a power turbine in a single device with the compressor and turbine blades all mounted onto a single shaft. Therefore the gas turbine is considered a completely self-contained unit that only requires fuel and air to generate mechanical, rotational power [15].

In general, heat engines and gas turbines are categorized according to a combustion location as:

a) Turbines with internal combustion:

Most gas turbines are internal combustion engines. In these turbines, the high temperature is achieved by burning the fuel-air mixture in the combustion chamber as shown in Fig. II.6.

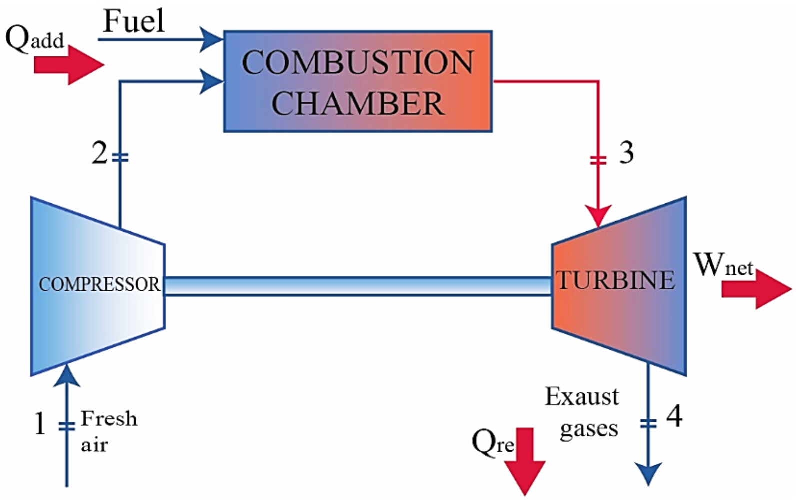

Fig. II.6 : Scheme of a turbine with internal combustion.

Since most gas turbines are based on the Brayton cycle with internal combustion, they are based on the open Brayton cycle. In this cycle, the compressor compresses the air from the ambient atmosphere (phase 1) to a higher pressure and temperature (phase 2). In the combustion chamber, the air is heated further by burning the fuel-air mixture in the airflow. Combustion products and gases (phase 3) expand in the turbine to near atmospheric pressure to produce mechanical energy then an electrical one. The open Brayton cycle means that the gases are discharged directly into the ambient atmosphere (phase 4).

b) Turbines with external combustion:

In these turbines, the closed Brayton cycle is used. Where a heat exchanger is usually used and only a clean medium with no combustion products travels through the power turbine as it is shown in Fig.II.7 Since the turbine blades are not subjected to combustion products, much lower quality (and therefore cheaper) fuels can be used. These turbines have usually lower thermal efficiency than turbines with internal combustion. The closed Brayton cycle is used, for example, in closed-cycle gas turbines and high-temperature gas-cooled reactors.

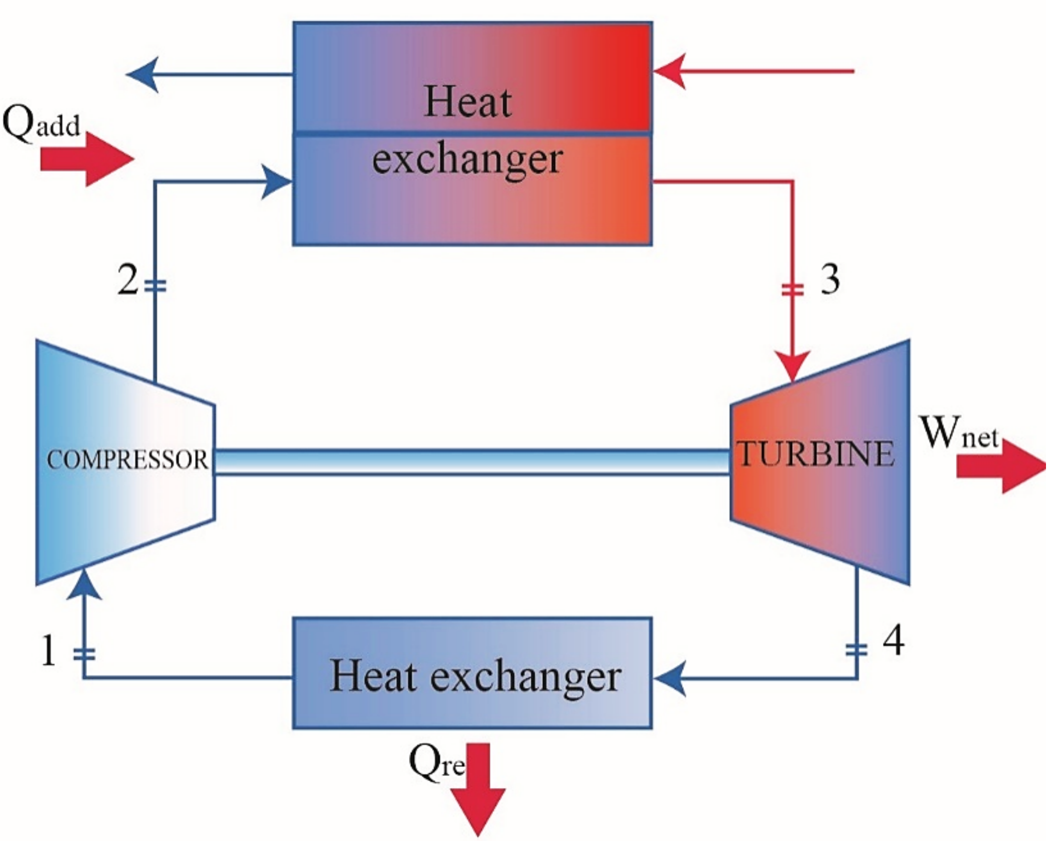

Fig. II.7 : Scheme of a turbine with external combustion.

Gas turbine power plants can be fired with natural gas and liquid fuels too. But they mostly burn natural gas because it is clean compared to coal, and since they started using combined cycle power plants, in which heat from the gas turbine exhaust is captured and used to raise steam to drive a steam turbine, which can raise the efficiencies to reach 62% [15].

The usage of natural gas and the high efficiency of the combined cycle plant leads to lower carbon dioxide emissions compared to coal plants

Gas turbines are usually used in the topping cycle configuration in a combined heat and power (CHP) application [15], with heat being recovered from the exhaust of the engine and used in an industrial process or to provide heating and hot water. Gas turbines could be used in the bottoming cycle when there is a stream of high-pressure, high-temperature air that is exiting from an industrial process. A power turbine can extract energy from this gas stream.

II.2.2.3. Combined cycle gas turbines (CCGT's)

The combined cycle is a combination of two thermal cycles in one plant. When two cycles are combined, the efficiency that can be achieved is higher than that of one cycle alone. Thermal cycles with the same or with different working media can be combined; however, a combination of cycles with different working media is more interesting because their advantages can complement one another. Normally, when two cycles are combined, the cycle operating at a higher temperature level is called the topping cycle. The waste heat it produces is then used in a second process that operates at a lower temperature level and is therefore called the bottoming cycle. Normally the topping and bottoming cycles are coupled in a heat exchanger [17].

Combined cycle gas turbines are among the most efficient, and cleanest technology to generate electric power from burning fossil fuel. It uses a gas topping cycle with a water/steam bottoming cycle. There are four major subsystems in a gas combined cycle power plant system as we can see in the Fig below, in which the exhaust heat of a simple cycle gas turbine is used to generate steam that will be expanded in a steam turbine:

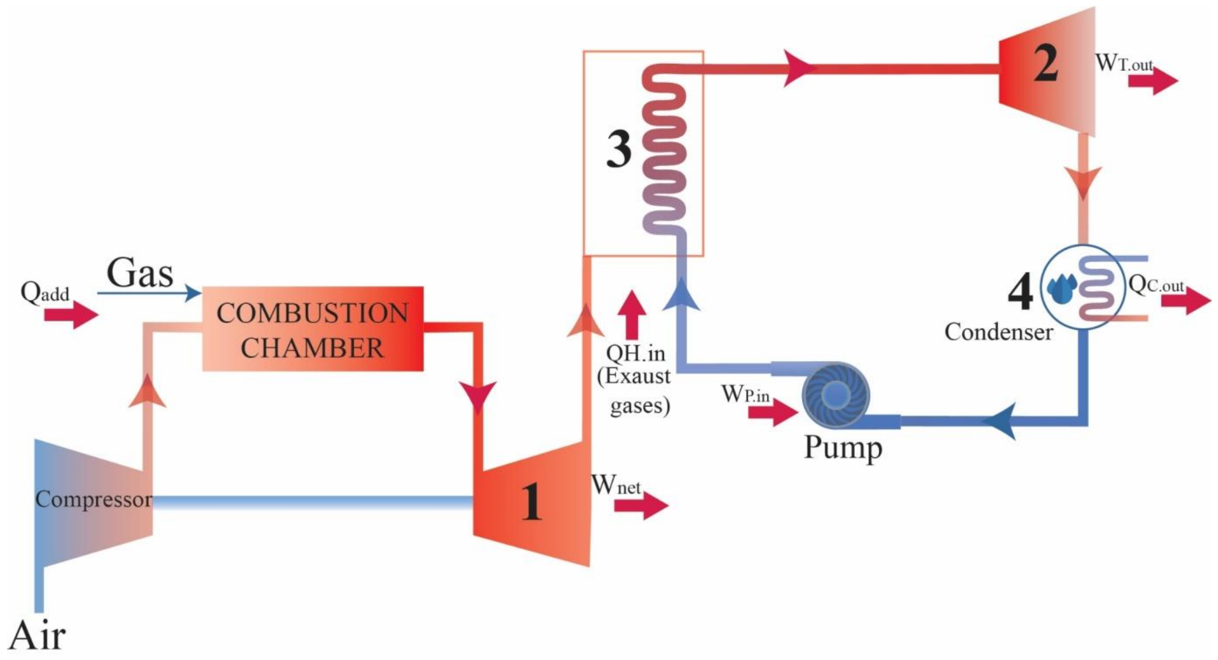

Fig. II.8 : Simplified flow diagram of a combined cycle gas turbine.

1. Gas turbine generator (operating in the Brayton cycle).
2. Steam turbine generator (operating in Rankine cycle).
3. Heat recovery boiler or using (the more common), Heat Recovery Steam Generator.
4. The heat rejection system comprising it can be:
    a. A water-cooled condenser (with or without a cooling tower).
    b. An air-cooled condenser (ACC).

In addition to these four major subsystems, there is a maze of condensate, cooling water, and steam piping with a large number of valves along with pumps (condensate, boiler feedwater, and circulating cooling water pumps) and myriad heat exchangers, which are lumped under the term “balance of plant” (BOP).

II.2.2.4. Organic Rankine Cycles (ORC)

An ORC turbine operates with the same thermodynamic principle (the Rankine cycle) as a steam turbine, except that it does not use water/steam as the working fluid used by the turbine. It uses an organic compound with a relatively low boiling point. Hence, Organic Rankine Cycles (ORCs) are a technology suitable for medium/low-temperature heat sources and/or for small available thermal power. It uses fluid with a low boiling point because it allows the liquid to be vaporized at a much lower temperature than water requires converting it into steam, and this allows a lower temperature heat source to be exploited [17].

There are three types of Organic cycles depending on where the four thermodynamic processes (compression, heat addition, expansion, and heat rejection) occur [18].

a) Subcritical Organic Rankine Cycle

In this cycle, the four processes occur at pressures lower than the critical pressures for the working fluid.

b) Trans-critical Organic Rankine Cycle

In this cycle, the process of heat addition occurs at a pressure higher than the critical pressure for the working fluid. The heat rejection process occurs at a pressure lower than the critical pressure for the working fluid. The compression and expansion processes occur between the two pressure levels.

c) Supercritical Organic Rankine Cycle

In this cycle, the four processes occur at pressures higher than the critical pressures for the working fluid.

II.2.2.5. Internal combustion engines

This system, and also known as the reciprocating engine is fired with fuel to drive the generator to produce electrical power. In reciprocating engine CHPs, there are two mechanisms for the recovery of heat. The first is the process steam generated by the recovery of waste heat available in engine exhaust. The engine jacket, which has a cooling water heat exchanger and lube-oil cooler, and they are the other sources of waste heat recovery to produce hot water or hot air. The reciprocating engines are available with low, medium, or high-speed versions. Most of these power plants are operated on diesel, while the prime mover’s efficiency is also enhanced with the use of natural gas or fuel oil, with efficiencies in the range of 35 - 42 % [10]. A simple reciprocating engine CHP is shown in the figure below.

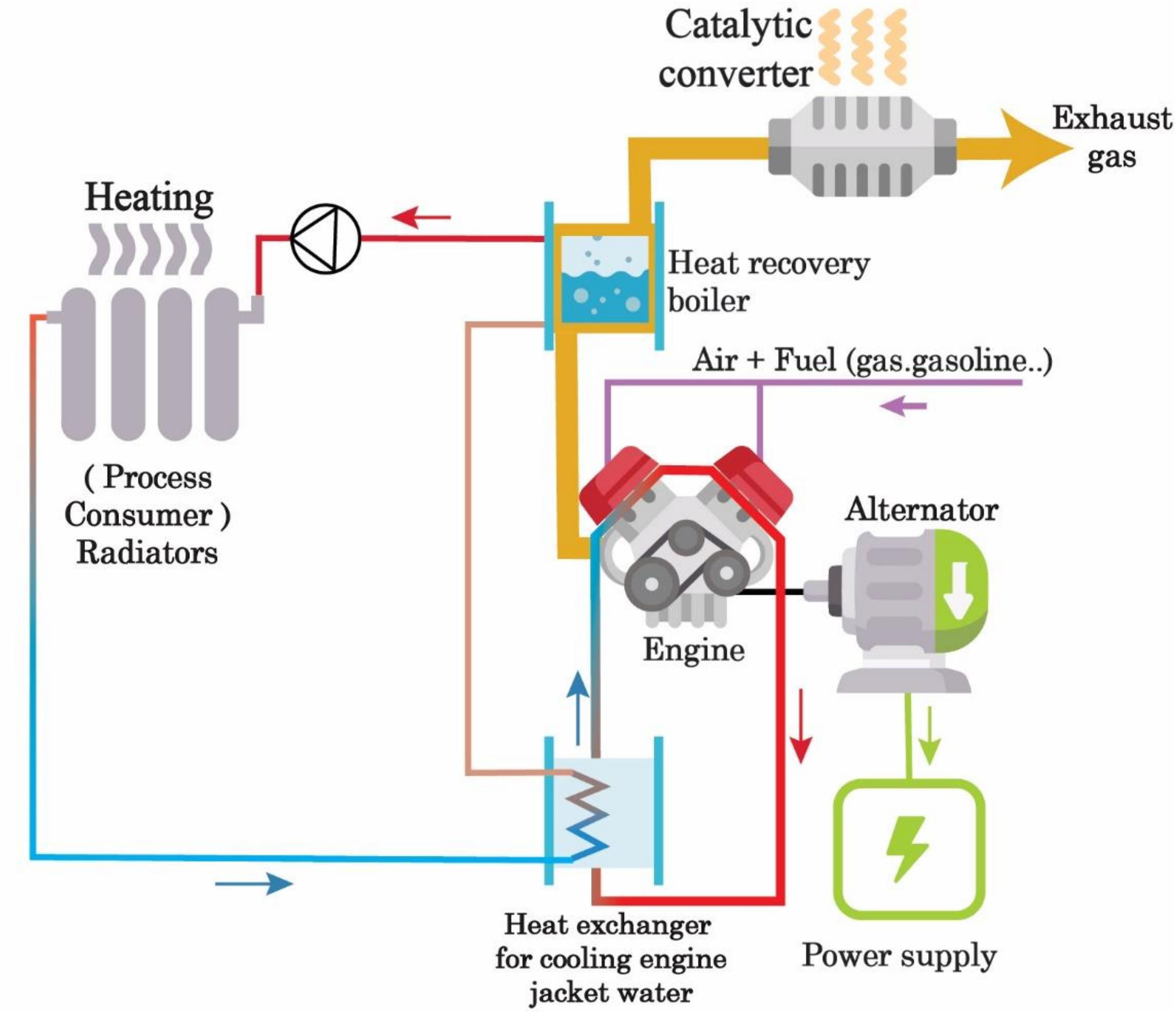

Fig. II.9 : Internal combustion engine CHP scheme with the two type of heat recovering unit.

II.2.3. Based on conversion technology

A conversion technology serves to convert chemical energy that is stored within a fuel into “useful” forms of energy, i.e. electricity and heat. Several different conversion technologies have been developed which have domestic CHP applications. The conversion process can be based on:

- Combustion and subsequent conversion of heat into mechanical energy, which then drives a generator for electricity production (e.g., reciprocating engines, Stirling engines, gas turbines, steam engines).
- Direct electrochemical conversion from chemical energy to electrical energy (i.e. fuel cell).
- Other processes include photovoltaic conversion of radiation (e.g., thermophotovoltaic devices) or thermoelectric systems.

II.3. Conclusion

As many cogeneration systems as there is, with their different capacity, different main prime movers, and different conversion technologies, and we saw all of that in this chapter with details explaining how it works and when we can use each of them. There is always a waste of energy. Therefore, we can say that whatever the cogeneration system is, and wherever it is, it is better than letting the energy be wasted when we need it most.

Cogeneration systems can be expensive and may require advanced technologies that we do not have, or we are not familiar with. Each case requires its system to benefit from the wasted energy in the best way, so if we study our case and know it well, it will not be difficult for us to determine which system works best in our case and if it is profitable for us or not, and this is

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Chapter III

Study of Hydraulic Turbine

III.1. Introduction

This chapter provides an overview of hydraulic turbines. A water turbine is a device that transforms the potential energy of a head of water into mechanical work. Turbines vary widely in form and application. At one extreme is the pure impulse machine where the flow is generally low, but the head is large. Reaction turbines, in which the pressure drop takes place in both fixed and rotating parts of the machine, cover the remaining types. The turbine-operating parameters of the head, flow, and rotational speed covers a wide range of combinations. To characterize them for comparison and selection purposes, the concept of specific speed is used. Cavitation is a very complicated physical phenomenon resulting from water flow in the passages of a turbine. It can occur whenever the local fluid pressure falls below a value corresponding to the water vapor pressure at the prevailing temperature. Under these conditions, boiling and steam bubble formation may occur. The chapter discusses different types of turbines: the Pelton turbine, the Francis turbine, the Kaplan turbine, and the tubular turbines.

III.2. Early History of Hydraulic Turbines

The word turbine was introduced by the French engineer Claude Burdin in the early 19th century, the hydraulic turbine has a long period of development, its oldest and simplest form being the waterwheel, first used in ancient Greece and subsequently adopted throughout medieval Europe, the use of hydraulic turbines for the generation of power has a very strong historical tradition. The first truly effective inward flow reaction turbine was developed and tested by Francis and his collaborators around 1850 in Lowell, Massachusetts [19]. Modern Francis turbines have developed into very different forms from the original, but they all retain the concept of radial inward flow. The modern impulse turbine was also developed in the USA and takes its name from Pelton, who invented the split bucket with a central edge around 1880. The modern Pelton turbine with a double elliptic bucket including a notch for the jet and a needle control for the nozzle was first used around 1900. The axial flow turbine with adjustable runner blades was developed by the Austrian engineer Kaplan in the period from 1910 to 1924. Hydraulic turbines are not only used to convert hydraulic energy into electricity but also in pumped storage schemes, which is the most efficient large-scale technology available for the storage of electrical energy. Separate pumps and turbines or reversible machines, so-called pump turbines, are used in such schemes. During their long history, there has been a continuous development of the design of hydraulic turbines, particularly concerning improvements in efficiency, size, power output, and head of water being exploited.

Recently, the use of modern techniques like computational fluid dynamics (CFD) for predicting the flow in these machines has brought further substantial improvements in their hydraulic design, in the detailed understanding of the flow and its influence on turbine performance, and the prediction and prevention of cavitation inception. The efficient application of advanced CFD is of great practical importance, as the design of hydraulic turbines is custom-tailored.

Turbines can be classified into four general types according to the fluids used: water, steam, gas, and wind. Although the same principles apply to all turbines, their specific designs differ sufficiently to merit separate descriptions.

Water wheels have been used for hundreds of years for industrial power. Their main shortcoming is size, which limits the flow rate and head that can be harnessed. The migration from water wheels to modern turbines took about one hundred years. Development occurred during the industrial revolution, using scientific principles and methods. They also made extensive use of new materials and manufacturing methods developed at the time.

The hydraulic turbine is used to convert the potential energy of water to mechanical energy. Flowing water is directed onto the blades of a turbine runner, creating a force on the blades. Since the runner is spinning, the force acts through a distance (a force acting through a distance is the definition of work).

In this way, energy is transferred from the flowing water to the turbine where Δp is the drop in total pressure across the turbine, $\dot{V}$ is the volumetric flow rate, and η the efficiency of the turbine. It is common practice to quote Δp in terms of the difference between the upstream and downstream total heads, called the turbine head which equals $\Delta p/g\rho$.

The basis of the design of the turbine hydraulic passages is the velocity diagrams at the entry and exit of the turbine rotating element (called the runner). These lead to the *Euler equation* for theoretical torque and to the theoretical *Euler efficiency* of the turbine (see Flow of Fluids). Although elemental velocity triangles are employed for the preliminary design of the hydraulic passages, for large turbines, model testing is necessary for verification of performance. Because of the cost and time involved in developmental model testing, more recently, a computerized finite element solution of the inviscid flow equations in the hydraulic passages (see Computational Fluid Dynamics), cross-correlated with general data from model test results, is employed for advanced design. In particular, the *efficiency of the hydraulic turbine* must be optimized and established for contractual purposes. The peak efficiency of properly designed large hydraulic turbines can be as high as 95%, with typically every point of improved efficiency involving considerable monetary benefits in operation.

Testing cannot model the losses due to hydraulic friction. Hence model test efficiencies are converted to full-scale values with established Reynolds Number based formulas. Confirmatory site efficiency testing of hydraulic turbines is possible using current meters, ultrasonic, salt velocity tracer, water column inertia (Gibson method), and thermodynamic methods to evaluate flow [IEC (1991)]. However, because of cost and the measuring inaccuracy inherent in site testing, there is a general trend to rely solely on model test results.

Depending on the use, the amount of water and level difference available, the power of hydraulic turbines can be a few kilowatts up to hundreds of Megawatts. However, regardless of size, their performance can be equated through similarity laws; hence the applicability of tests on models to predict the performance of large turbines. From nondimensional considerations the similarity laws are:

[20]

$$Head\ Coefficient = \Delta p/(\rho u^2) \tag{5}$$

[21]

$$Power\ Coefficient = \dot{V}/(uD^2) \tag{6}$$

[22]

$$Power\ Coefficient = \dot{\mathrm{W}}\ /(\rho u^3 D^2) \tag{7}$$

Where $\dot{\mathbf{W}}$ is the power, $\boldsymbol{\rho}$ is the water density, **u** is the water velocity, and **D** is a characteristic diameter of the runner from which all other dimensions of the hydraulic passages follow. Hydraulic turbines are classified according to a specific speed. Specific speed is defined as the rotational speed (revolutions per minute) at which a hydraulic turbine would operate at best efficiency under unit head (one meter) and which is sized to produce unit power (one kilowatt). The equation for specific speed derived from non- dimensional considerations is, therefore:

[23]

$$Specific\ speed = Speed.(\dot{\mathrm{w}}/1000)^{0.5}/(\Delta p/\rho \mathrm{g})^{1.25} \tag{8}$$

III.3. Types of Hydropower Turbines

III.3.1. Impulse Turbine

Let’s know the Impulse turbine in detail:

The impulse turbine changes the velocity of the water jet. The jet impinges on the turbine curved blade which changes the direction of the flow. The resulting change in momentum (impulse) causes a force on the turbine blades.

Since the turbine is spinning, the force act through a distance (work), and the diverted water flow is left with diminished energy. Before hitting the turbine blades, the water pressure (potential energy) is converted to kinetic energy by a nozzle and focused on the turbine. No pressure changes occur at the turbine blades, and the turbine doesn't require housing for operation.

- Newton's second law describes the transfer of energy for impulse turbine.
- Impulse turbines are most often used in a very high head application.
- This turbine works at atmospheric pressure.
- The Impulse turbines are Turgo, Jornal, Banki, Girad, and Pelton Turbine.

III.3.2. Reaction Turbine

Reaction turbines are acted on by water which changes pressure as it moves through the turbine and gives up its energy. They must be encased to contain the water pressure (or suction), there must be fully submerged in the water flow.

- Newton's third law describes the transfer of energy for the reaction turbine.
- Most water turbines used a reaction turbine.
- They are used in low and medium head applications.
- This turbine works above the atmospheric pressure.
- The Reaction turbines are Thompson, Francis, Kaplan, Fourneyron, and Propeller.

III.3.3. Pelton turbine

The historical development of hydraulic turbines has culminated in two distinct types namely *impulse* (or constant pressure) and *reaction*. Reaction turbines are further divided into radial and axial flow and variable and fixed runner blades. In the impulse turbine, flow is directed through a nozzle to impact a series of buckets attached to the periphery of the runner. The total transfer of energy is from the change of momentum of the fluid jet; there is no change in hydrostatic pressure once the fluid exits the jet. Impulse turbines (known as *Pelton turbines* after their inventor) are typically used for heads above 100 m and reasonably low flows. They can have up to six jets to better utilize larger flows, The Pelton wheel turbine, named after its American inventor, Lester A. Pelton, was brought into use in the second half of the nineteenth century. This is an impulse turbine in which water is piped at high pressure to a nozzle where it expands completely to atmospheric pressure. The emerging jet impacts onto the blades (or buckets) of the turbine, which produce the required torque and power output. A simplified diagram of a Pelton wheel turbine is shown in Fig. III.1.

The head of water used originally was between about 90 and 900 m (modern versions operate up to heads of nearly 2000 m), as shown in the figure below.

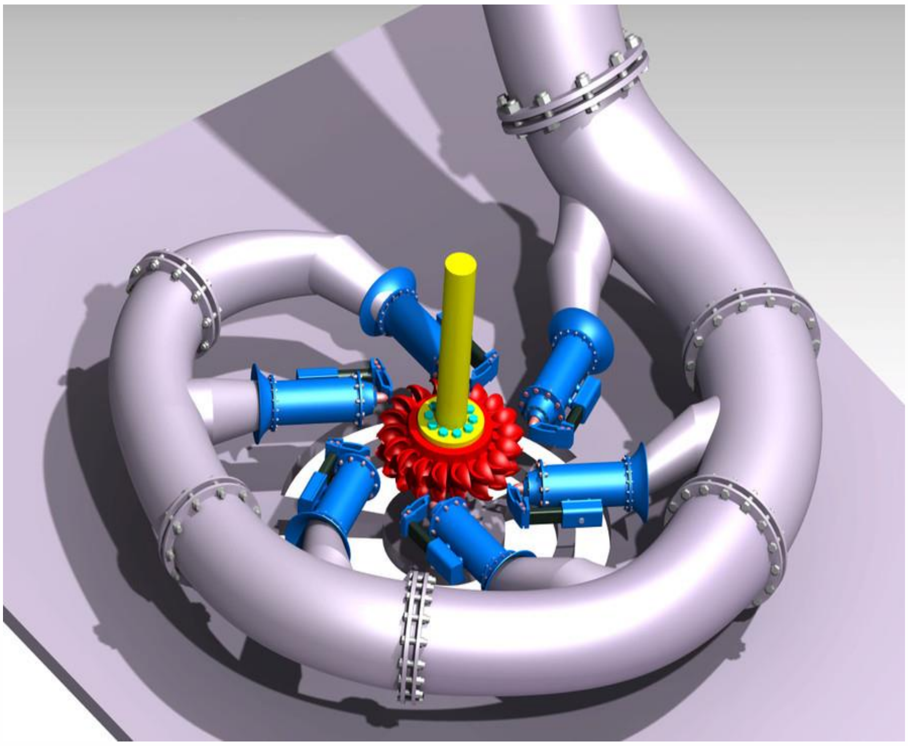


Fig. III.1 : Four jet Pelton turbines (with permission of Kvaerner-Boving Ltd).

III.3.4. Kaplan Turbine

The increasing need for more power during the early years of the twentieth century also led to the invention of a turbine suitable for small heads of water, i.e., 3 to 9 m, in river locations where a dam could be built. In 1913 Viktor Kaplan revealed his idea of the propeller (or Kaplan) turbine, see Fig. III.1, which acts like a ship's propeller but in reverse. At a later date, Kaplan improved his turbine utilizing swiveling blades, which improved the efficiency of the turbine appropriate to the available flow rate and head.

Kaplan turbines are widely used throughout the world for electrical power production. They cover the lowest head hydro sites and are especially suited for high flow conditions.

Inexpensive microturbines on the Kaplan turbine model are manufactured for individual power products designed for 3 m of the head which can work with as little as 0.3 m of the head at a highly reduced performance provided sufficient water flow.

Large Kaplan turbines are individually designed for each site to operate at the highest possible efficiency, typically over 90%. They are very expensive to design, manufacture, and install, but operate for decades.

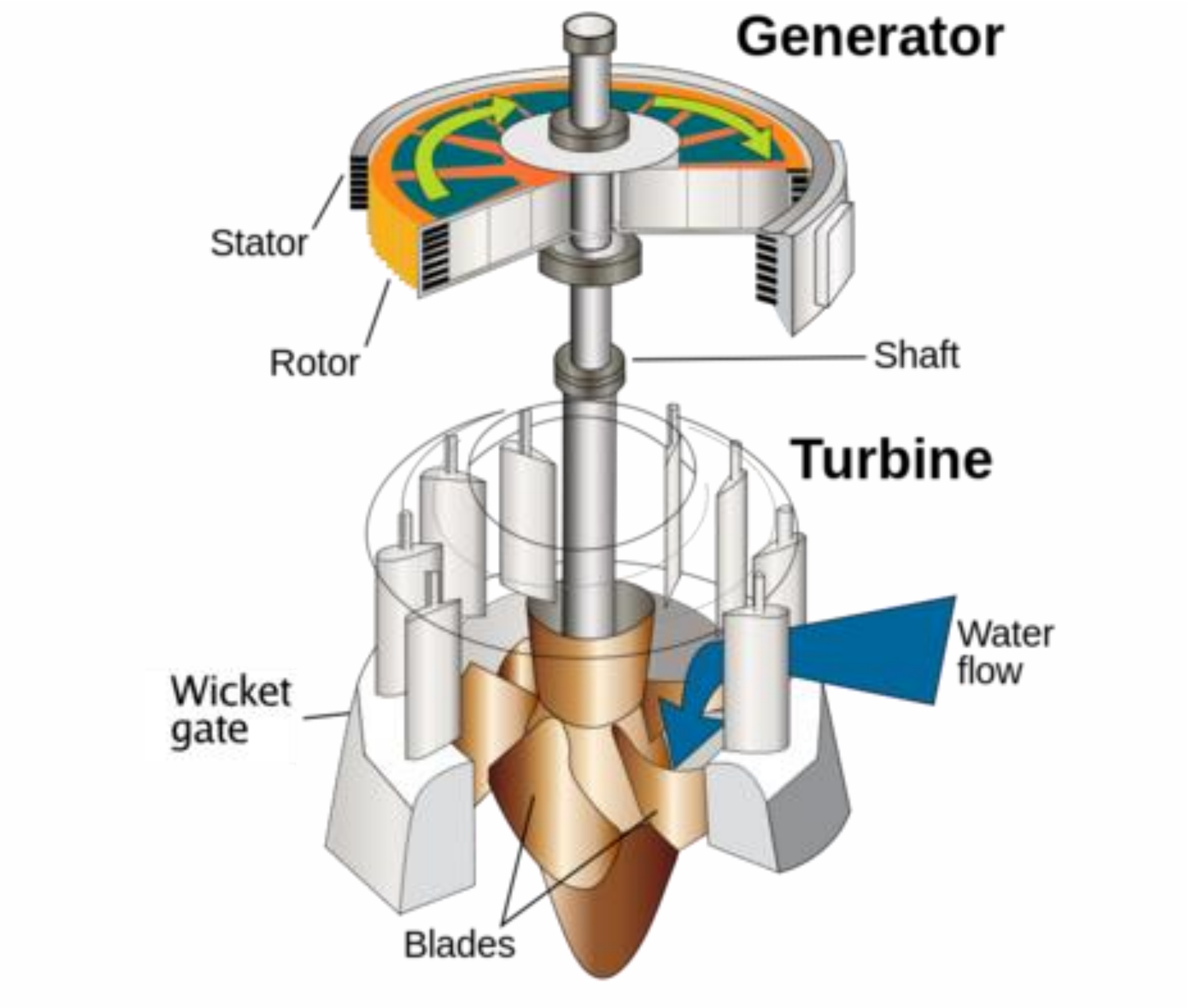


Fig. III.2 : Kaplan turbine.

III.3.5. Francis Turbine

Reaction turbines for heads in the range of 600 m to 30 m are known as *Francis turbines* (after their inventor). These are radial flow units in which the flow enters the runner radially and discharges axially, as illustrated in Figure.3. The runner of a reaction turbine is equipped with blades that direct the flow. Therefore, in addition to energy derived from the momentum changes of the fluid as it passes through the runner, it is also generated from the changes in hydrostatic pressure of the fluid within the runner passages.

Below design heads of approximately 50 m axial flow turbines are used, known as *propeller units* because of their similarity to a ship's propeller. A subsection of propeller units known as *bulb turbines* is used for heads below approximately 10 m. Small hydraulic turbines can be arranged with a horizontal shaft for ease of maintenance, but the larger units used for hydroelectric power installations are almost universally vertical. The exception is the bulb turbine, which is only arranged horizontally.

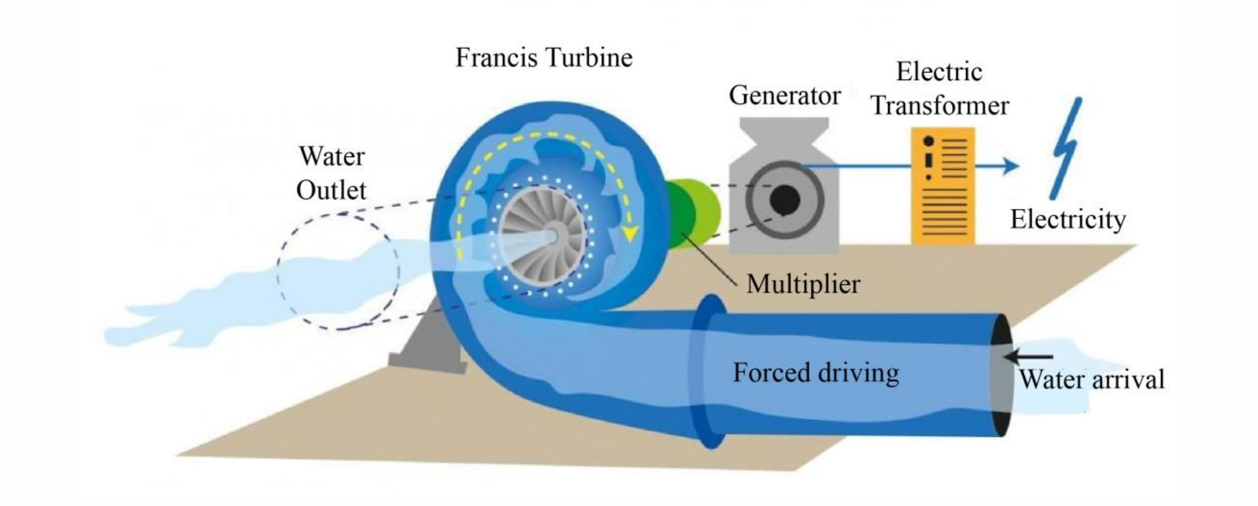


Fig. III.3 : Francis turbine with pressure relief valve (with permission of Kvaerner- BovingL Ltd).

III.4. The use of the basic turbine types

Utilization of the three basic turbine types are within the following ranges of specific speed (calculated from rpm, kW, and m):

- Single jet Pelton: $3 < \text{Specific Speed} < 36$.
- Multiple jet Pelton: $36 < \text{Specific Speed} < 60$.
- Francis: $60 < \text{Specific Speed} < 400$.
- Propeller: $300 < \text{Specific Speed} < 1200$.

Reversible pump turbines are a special type of reaction turbine. These change direction of rotation to operate both as a pump and a turbine and are used for pumped storage applications. Hydraulically, a reversible pump-turbine is designed as a pump with only minor modifications to accommodate its role as a turbine.

The stability of operation and the internal hydraulic forces (both static and dynamic), are directly dependent on the velocity of flow through the turbine. For a given design head and flow velocity, there is a unique specific speed. This leads to the relationship: [23]

$$Specific\ Speed = K/(\Delta p/\rho \mathrm{g})^{0.5} \qquad (9)$$

Where K is a constant.

There are strong commercial benefits in using as small a turbine (hence high flow velocities) as possible for any given application. However, this is restricted by the state of the art concerning vibration and performance. In 1994, the generally accepted maximum value for K was about 2300.

In all three general groups of hydraulic turbines, flow is directed to the periphery of the runner of the turbine via a spiral casing and discharges from the runner through a draft tube.

In reaction turbines, the rotation of the liquid commences as a free vortex in the spiral casing; it is directed through the fixed stay vanes and then through the adjustable turbine wicket gates, such that the angle of approach of the flow to the runner at the design conditions is precisely the runner blade angle (shockless entry). Flow-through the reaction turbine to obtain the required power is regulated by the turbine wicket gates. Thus, shockless flow is only obtained at the output for the best efficiency and the design head. In a reaction turbine, the draft tube is designed for maximum recovery of hydrostatic pressure. This is especially critical for low head turbines.

The efficiency and operational stability of turbines with low design heads are a strong function of the inlet approach angle, efficiency dropping rapidly with a decrease in output, and to a lesser extent, with a change in head. To maintain efficiency over the operating range, low head units often have adjustable runner blades, the runner inlet angle changing with wicket gate position, and if required, with operating head. These units are said to be double regulating and include the semi radial flow *Deriaz turbines*, axial flow *Kaplan turbines* (both named after their inventors), and bulb turbines.

Reaction turbine runners can suffer **Cavitation** at the blade inlet (due to off-design flow conditions), in the runner hydraulic channels at part load operation, and the runner exit on the suction side of the runner blades. The latter is the most critical and is a function of the back pressure on the runner. Suction side cavitation in a hydraulic turbine is accordingly related to downstream (tailwater) level through the *Thoma Coefficient* defined as:

$$\sigma_{Th} = \left(P_a - P_{vap} - z.\mathrm{g}.\rho\right)/\Delta p \qquad (10)$$

where z is the height of the runner exit plane above tailwater level, P_a is atmospheric pressure and P_{vap} vapor pressure of the fluid. Height z is commonly called the setting of the turbine. Typically, it is too expensive to set a large hydraulic turbine deep enough below the tailwater level to eliminate cavitation, and in any particular application, an economic balance between cavitation repair and the cost of excavation has to be established. For preliminary design, the operating experience is used to establish an acceptable σ_{Th}. One such criterion is:

$$\sigma_{Th} = 7.54 \cdot 10^{-5} \cdot (specific\ speed)^{1.41} \qquad (11)$$

For major installations, the cavitation performance of the hydraulic turbine should be established with model testing. Cavitation model testing of medium to towhead hydraulic turbines is often conducted with Froude Number similarity to the prototype. The wetted surfaces of hydraulic turbines are also prone to damage due to Erosion by transported silt and sand and corrosion from aggressive fluids.

Damage is particularly problematic when silt erosion, corrosion, and cavitation act in conjunction (synergistic effects). In applications where the silt content is extreme, the hydraulic design may sacrifice efficiency for partial immunity from silt erosion (contouring of surfaces and thickening of runner blades, for example). Stainless steel, which has far better resistance to cavitation and erosion than carbon steel, is extensively employed in susceptible areas.

The economic pressures to increase specific speed and hence flow velocities, for a particular head, have led to operational problems with flow-induced vibrations from runner blades and stay vanes. These are particularly problematic when their forcing frequency coincides with the natural frequency of any other part of the mechanical, hydraulic, or electrical system thus leading to resonance. Also, at part load operation reaction turbines suffer from draft tube pressure oscillations, which can result in unacceptable power swings. Air admitted naturally to areas of the low pressure or force-fed from compressors can be effective in curing oscillations due to part-load operation.

The speed of hydraulic turbines is regulated by a governor. The governor senses the speed of the turbine and adjusts the wicket gate opening to maintain speed within close limits. Speed-sensing and the associated feedback control systems are typically digital. On all other than very small hydraulic turbines, the amplification from the digital governor to the wicket gates (and runner blades if required) is through a high-pressure oil servomotor system. If the hydraulic turbine is operating on a large integrated network, then its speed is controlled by the network and the governor is used to change output via its permanent speed droop. The governor's feedback and gain have to accommodate the water column and generator inertias. The turbine and all equipment connected to it, both mechanically and electrically, are designed for runaway speed of the turbine (the speed at zero torque) resulting from governor failure. To aid regulation, high to medium head turbines are often equipped with pressure relief valves.

For the same reason, the jets of impulse turbines are often equipped with flow diverters. For security, isolation valves or hydraulic gates are commonly installed at spiral casing inlets.

III.5. Hydraulic Turbine Advantages

- This is a renewable energy source. The water-energy can be used again and again.
- This turbine having high efficiency.
- The running cost of the Hydraulic turbine is less as compared to other turbines.
- Since Dams are used. So, it is used for power generation.
- The environmental pollution system is negligible here.
- This is easy to maintain.

- The main advantages of the Hydraulic turbine are that in the turbine place, the people can visit and come across all the main parts in detail. This is like an open system.

III.6. Hydraulic Turbine Disadvantages

- The Installation or Initial cost is very high. This system or plant takes several decades to produces the profit.
- It can develop at only a few sites where the proper amount of water is available.

III.7. Conclusion

The potential of hydraulic power generation is immense, a historical source of energy, water can be used both as a source of electricity and for irrigation and agricultural uses. In today’s world, where a greener source of energy is the need of the hour, hydraulic energy is a promising resource, waiting to be harnessed to its true potential. The study of hydraulic turbines and their characteristics showed how it can be properly designed and used to get the maximum output, even with variable speeds.

« ------------------------------------ »

Chapter IV

Conception of Micro-Hydro Power Cogeneration System

IV.1. Introduction

Water is an economic, social, and environmental good. It is, therefore, necessary and important to guarantee its availability over time through sustainable forms of exploitation, which make it possible to cope with current demands without threatening the ecological balance. The scarcity of water resources in the Mediterranean is only increasing, particularly in the south area of the Mediterranean Sea. This region faces high levels of water stress.

Algeria is no different from those countries in the region. At the same time, our country has also experienced an impressive demographic growth, Where the population growth rate is 1.53% [1], a logical consequence of the economic and social development that our country has experienced since independence. For this reason, the state has spent a significant budget for the construction of wastewater treatment plants (WWTP). And the aim is to prevent the wasting of drinking water used in agriculture (irrigation), other industrialized and public uses, and to fight against pollution. The desired goal is above all the recycling of water, after purification, in agribusiness and industry to replace drinking water.

Therefore, the use of wastewater treatment plants is essential. And Algeria does not lack this as it has a good number of these factories, to be precise Algeria had one hundred seventy-two wastewater treatment plants operating across the country in 2016 [2]. Sewage treatment plants can be energy consuming and can also be used to produce energy. It should be noted that this form of energy production absents in Algeria.

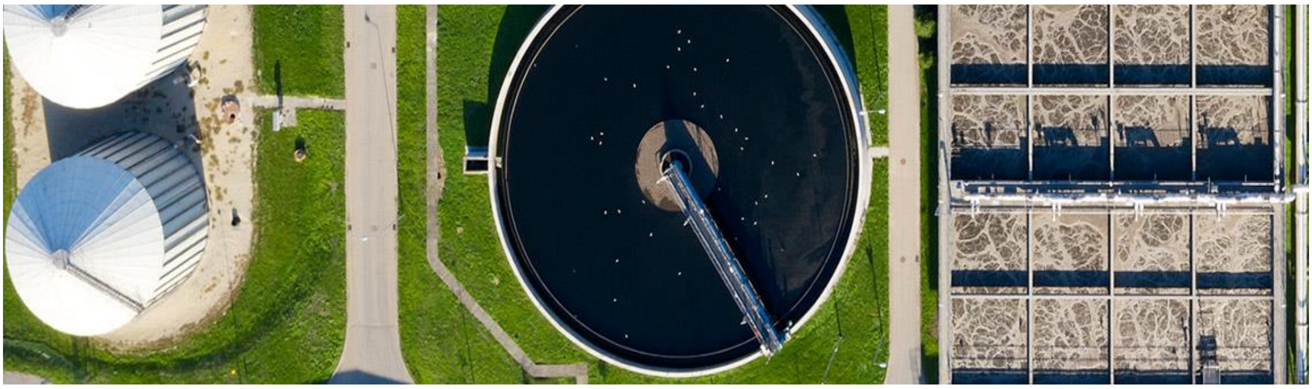


Fig. IV.1 : Wastewater treatment plants.

In this chapter, we will see an overview of wastewater treatment plants and how they can be used to produce energy and try to find another way to use these plants to produce energy besides those already existing methods.

IV.2. Electricity Consumption in Algeria

The residential sector is the biggest consumer in Algeria, representing 38.1% of the nationally consumed energy. Other important sectors are the tertiary sector (20.93%) and the manufacturing industry (17.83%). The details are outlined in table 1. [27]

Table IV.1: Electricity consumption by sector (2012).

Sector/ Product	**In KToe**	**In %**
Agriculture	89,865	2.42
Public works	17,742	0.48
Hydraulics	468,786	12.63
Mines and quarries	27,365	0.74
Manufacturing industry	661,555	17.83
Gas and oil industry	273,239	7.36
Residential	1,413,960	38.10
Tertiary	776,735	20.93
Transport	11,670	0.31
Total	3,710,917	100

IV.3. Renewable Energy Policy

In February 2015, the Algerian Government adopted an ambitious Renewable Energy outline. It envisions the installation of 22 GW of RE by 2030, which is almost double than what was set as a target before (12 GW) and equals a share of about 27% RE in total electricity production of these 22 GW, about 4.5 GW is supposed to be installed by 2020. The targets per technology are set according to two phases as outlined in the table below [28]:

Table IV.2: The Algerian renewable energy target.

Source	**1st phase 2015-2020 [MW]**	**2nd phase 2021-2030 [MW]**	**Total [MW]**
Solar PV	3000	10575	13575
Wind	1010	4000	5010
CSP	-	2000	2000
Cogeneration	150	250	400
Biomass	360	640	1000
Geothermal	5	10	15
Total	4525	17475	22000

IV.3.1. Trends for Wastewater Treatment Facilities

The interest in on-site cogeneration systems for wastewater treatment plants has been growing steadily during the last couple of years and is expected to grow further.

Some of the factors fueling this interest include the need for standby power (to provide reliability during utility power outages and shortages), availability of free fuel compared to high natural gas prices, interest in green or bioenergy from renewable resources, and significant grants and incentives being offered by state and federal governments.

Several energy companies have shown significant interest in the last couple of years in building cogeneration facilities for the municipal wastewater market either as design/build or as service contracts.

Grants offered by state and federal governments to encourage green energy from renewable resources make cogeneration projects more cost-effective, especially in California, where the current state grants are about 1000 $/ kW for a reciprocating internal combustion engine, 1300 $/kW for **microturbines**, and 4500 $/kW for fuel cells on renewable fuels like DG and landfill gas.

The need for standby power also makes the investment in cogeneration more cost-effective. In the economic analysis, it is possible to deduct the cost of a diesel standby generator system from the cost of cogeneration before evaluating the payback period, net present value, or cost per kilowatt-hour (kWh).

IV.3.2. The Wastewater Plants

One hundred and seventy-two wastewater treatment plants are in operation across the country, Minister of Water Resources and Environment said during a working visit to Laghouat. These infrastructures generate nearly one billion cubic meters of treated water intended for agricultural irrigation and make Algeria the leading African country in this area.

Fifty other stations are currently under construction, added the minister who wished to recall the preponderant role of these structures in the fight against diseases transmitted by water, environmental sanitation, and then uses part of the treated water for irrigation of agricultural land. On this last point, Mr. Nouri recalled that many hydraulic structures have been built to "increase the irrigated areas and bring them to one million hectares by 2020".

Works that have a cost, but the minister insisted on denying any consideration of recourse to foreign investment in the field: "Algeria has the means to take charge of all of its development programs", as he asserted.

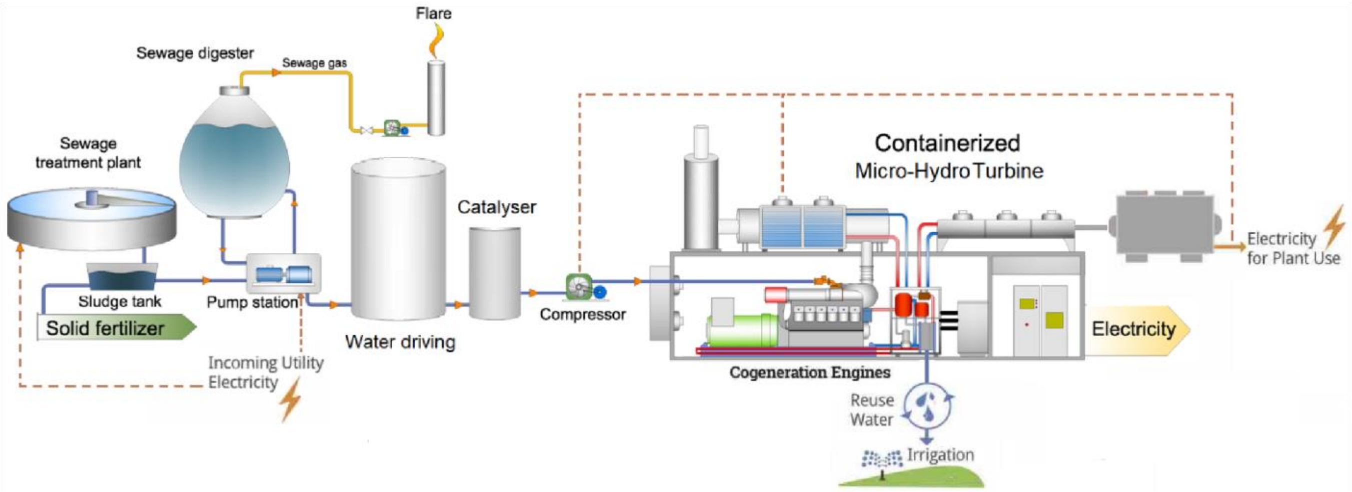


Fig. IV.2 : The proposed Wastewater plants based on hydropower turbine.

IV.3.2.1. Algeria Wastewater Treatment Station

The current Baraki WWTP has a purification capacity of 1,800,000 Hab (habitats). for a theoretical average flow of 300,000 m^3/d. Initially commissioned in 1989, this station did not operate for a long time, until its recent rehabilitation. An extension is underway to double its processing capacity. The program defined in the Master Plan provides for the connection of large collectors (Pointe Pescade) to the network supplying the Baraki WWTP. One subsequent extension is planned, which will bring its capacity to 3,600,000 Hab. Eq. By 2020.

This station received an average of 63,400 m3 / day in 2013 and produced 12,200 tons of sludge at 23.9% dryness. The treatment performance ensures discharge compliance greater than 99% and a pollution removal efficiency greater than 95%.

IV.3.2.2. Benefits of Cogeneration at Wastewater Power Plant

Cogeneration is a reliable, cost-effective option for wastewater treatment plants. The sewage water flow from the digester can be used as mechanical power to generate electricity in a combined hydropower system. The electrical energy produced by the cogeneration system can then be used for facility electricity.

- Produces power below retail electric prices.
- Generation of renewable energy from a waste material through cogeneration.
- Increases reliability and cost-effective,
- Produces useful energy and proven technology.
- Reduction in carbon emissions.
- Production of a low-carbon fertilizer/soil improver

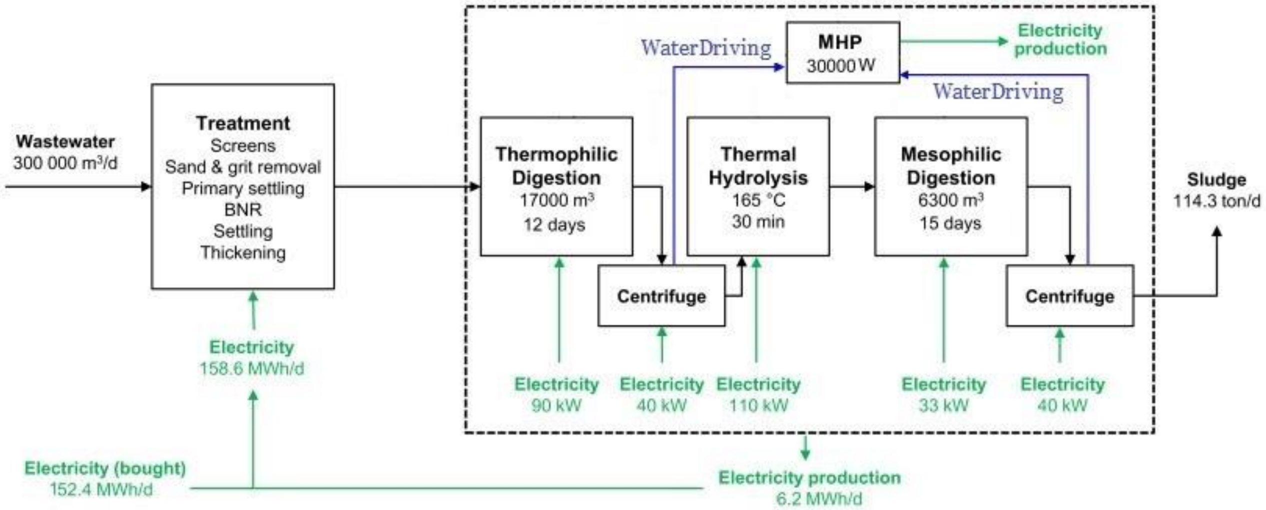


Fig. IV.3 : The Process of Electricity Production by the Wastewater Power Plant.

IV.3.3. The Hydro Power Plants

The energy sector is one of the most important sectors of the Algerian economy. Over 01% of the electric power is produced by hydropower plants, the situation in the Algerian transmission grid is characterized to this day by frequent interruptions every day.

In Algeria, although there is some installed capacity of hydropower, this energy source only plays a marginal role due to limited precipitation and high evaporation. [29]

Table IV.3: Electricity production by source (2012).

Production from	In GWh	In %
- Oil	3,727	6.49
- Gas	53,048	92.42
- Hydro	622	1.08
Total production	**57,397**	**100**

For the planning a safe and reliable operation in the future, it’s very important to have current simulation models, which can describe the static and dynamic behavior of the whole network including any elements. This contribution presents the most important steps for the creation of a reality-oriented model of the hydro power plant. Therefore, in the hydropower plant measurements were performed to obtain step response time signals of all-important functional parts. [30]

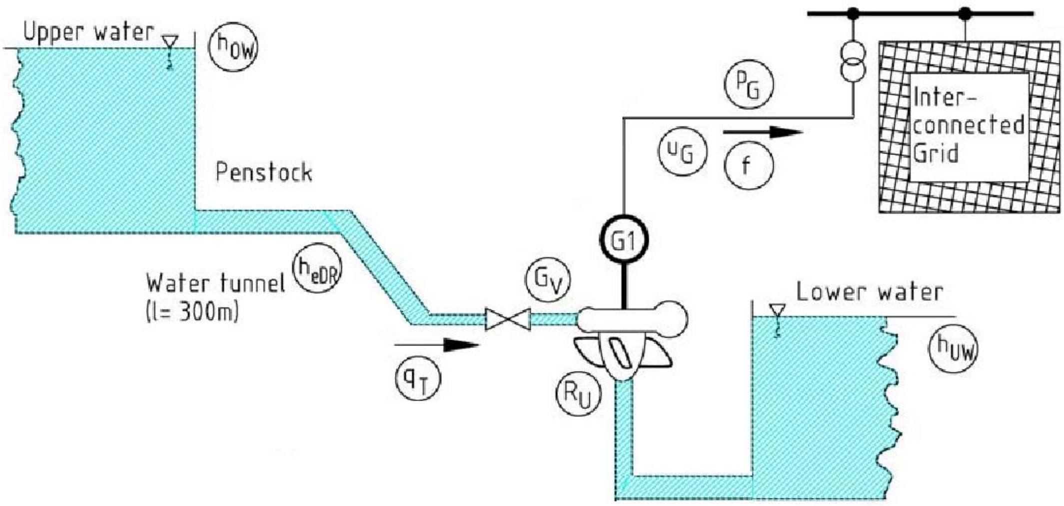


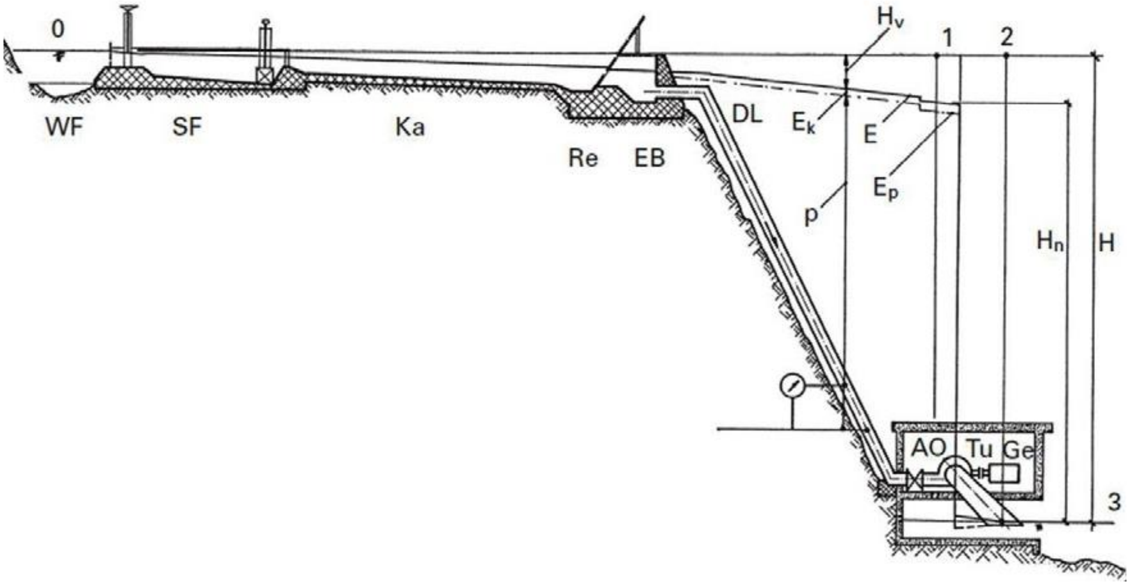
Fig. IV.4 : Model of the hydro power plant.

Based on available technical documentation and commissioning reports a general model including different submodules of the power plant was developed. Using the software MATLAB/Simulink it was possible to identify all the needed parameters of the mathematical model.

IV.3.3.1. Parameters of micro hydropower plants

IV.3.3.2. Operational parameter

Today, technically defined and available to engineers a larger number of turbines, which can be applied to mini and micro hydropower plants. For this reason, it is first necessary to show the most important components of a mini-hydropower plant with its operating parameters. Figure 2 shows the layout of the most important components and devices as well as the parameters of small and micro hydro power plants.



WF – water accumulation SF – crossing Ka – channel Re – grille EB – input workspace DL – input line AO – input body of the turbine	Tu - turbine Ge - generator 0 - ref. point of accumulation 1 - ref. point at the entrance to the turbine 2 - ref. point at the exit from the turbine 3 - ref. point of the drainage channel E - energy line	E_k – kinetic energy E_p – potential energy p – pressure H – gross height drops H_n – net height drops H_v – hydraulic energy losses

Fig. IV.5 : Profile of micro hydro power plant with components and devices [30].

The most important parameters of the hydroelectric power plant are [30]**:**

- *Flow* - the amount of water that passes through the turbine in the Q unit [m^3/s].
- *Gross height drops* - height difference between the water level in the accumulation (point 0) and the level of water at the exit from the turbine (point 3) H [m].
- *Net height drops* - which represents the available potential energy of the turbine Hn [m]
- *Hydraulic energy losses* - expressed through altitude difference represent losses inflow of water through grilles, channels, pipelines, and turbine H_v [m]. Determined according to:

$$\mathrm{H}_v = \mathrm{A} * \mathrm{Q}^2 \tag{13}$$

The hydraulic power of the turbine is determined according to [W]:

$$PP_{hyd} = \rho * Q * g * H_n \tag{14}$$

Mechanical power on the shaft is determined according to [W]:

$$P_{mech} = T * \omega = T * \frac{\pi * n}{30} = \frac{T * n}{9.549} \tag{15}$$

The efficiency of the turbine is determined as the ratio between the mechanical and hydraulic power of the turbine:

$$\eta = \frac{P_{hyd}}{P_{mech}} \tag{16}$$

The turbine mechanical power can be expressed as [31]:

$$P = Q * \eta * \mathrm{H} \tag{17}$$

where: H is effective turbine head, Q is water discharge flow and η is turbine efficiency. The turbine head H and turbine efficiency η are non-linear functions of gate position *p* and turbine blade angular position β:

$$\mathrm{H}(t) = f_h (p, \beta, Q) \tag{18}$$

$$\eta(t) = f_\eta (p, \beta, H) \tag{19}$$

In the normal conditions of the WWTP (our case) the rated head and flow are:

$$H = 3\text{m, and } Q = 3.49\ m^3/s \tag{20}$$

IV.3.3.3. Specific parameters

Table IV.4: The parameters of the hydro power plant model.

Feature of Power plant	
Rated Head	3 m
Rated Discharge Flow	3.49 m^3/sec
Rated Speed of Generator	1500 rpm
Kaplan Turbine Efficiency	0.95
Rated Electrical Power	30 KW
Rated Mechanical Power	0.989 p. u
Line-to-line voltage	380 V
Frequency	50 Hz
Excitation	1 p. u
Series RL Load Branch	150 Ω / 15 H

The entire model of the hydropower plant consists of separate models of hydraulic power plant parts, Kaplan turbine, voltage regulator with power system stabilizer (ELC), network model, and generator.

IV.3.3.3. Methodology

The proposed methodology is divided into two main phases: I) the estimation of energy production potential and II) the profitability assessment. In the first part, the essential available resources, i.e. head and water volume, are estimated based on topographic and demographic data. In the second part, the preliminary design of the identified hydropower schemes with potential is defined and the economic present value is calculated.

The first phase of the study is a screening of the potential sites; only the locations with a production bigger than a given threshold are retained for the economic analysis. The combination of the two parts gives results on energy production and economic feasibility, both major criteria for decision-makers to evaluate the interest in developing such hydropower schemes.

IV.3.3.4. Turbine Selection

We can distinguish two different groups for water turbines: impulse turbines and reaction turbines. The first group, which includes Pelton, Turgo, and Crossflow, uses the velocity of the water to move the runner and discharges to atmospheric pressure.

The water stream hits each bucket on the runner. There is no suction on the downside of the turbine, and the water flows out the bottom of the turbine housing after hitting the runner. An impulse turbine is generally suitable for high head, low flow applications. Conversely, reaction turbines such as Francis or Kaplan types develop power from the change in pressure experienced by the water as it moves through the turbine and gives up its energy. Reaction turbines are generally used for sites with lower head and higher flows.

Usually, the criterion to choose the type of turbine is based on the available water head, and less so on the available flow rate. As the figure below shows a typical chart which classifies most of the types of turbines according to their range of potential application.

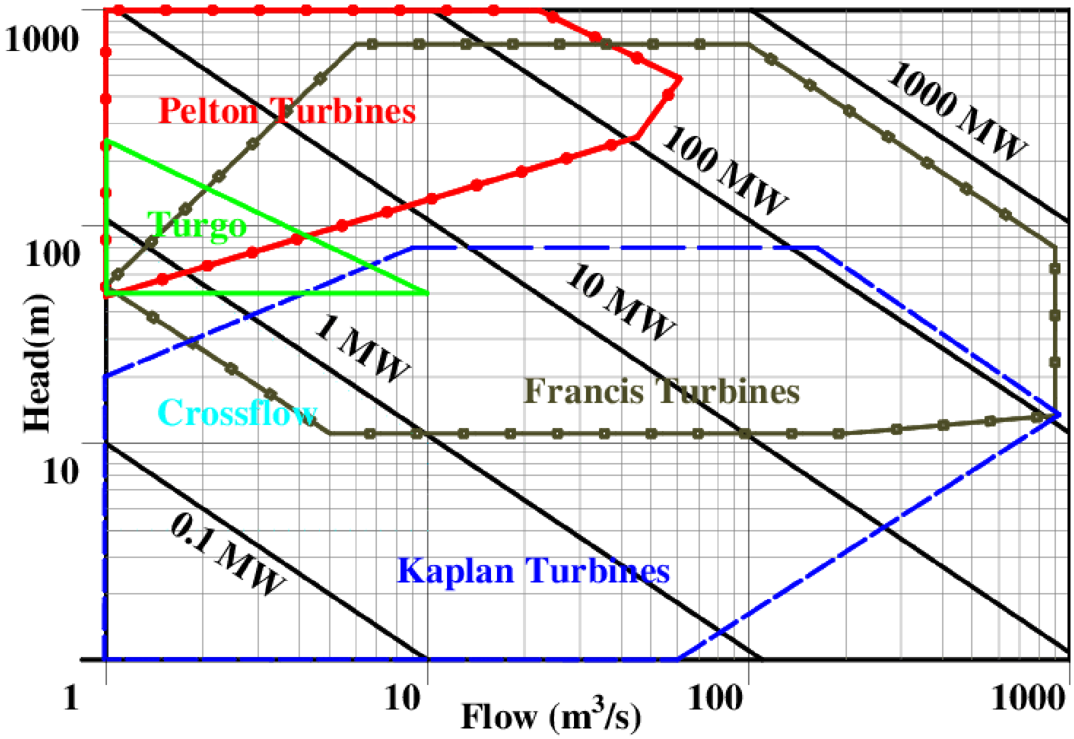


Fig. IV.6 : Turbine application chart.

Upon all these considerations and considering the head and flow characteristics of the potential locations where a water turbine could be installed in the WWTP, the type of turbine selected in this application is the Kaplan turbine.

IV.3.3.5. Microturbines

Another cogeneration technology that has become more common during the last few years is microturbines. Microturbines are miniature industrial turbines units currently available with DG experience are 30 and 60 kW (by Capstone) and 70 and 250 kW (by Ingersoll Rand). Electricity conversion efficiency is enhanced by the use of a recuperation cycle where most of the exhaust gas heat is used to preheat the combustion air charge. There is still plenty of heat that can be recovered as hot water for digester heating.

Microturbines' electricity conversion efficiency is between 25 to 30 percent. The overall efficiency, including heat recovery, could be as high as 65 to 70 percent.

Because of the small clearances and high speed of small rotor blades, fuel gas specifications require near-complete removal of all deposit forming siloxanes in the digester gas. Microturbines have very low emissions and permitting is relatively easy. Microturbines require over 50 psig (pounds per square in gauge) fuel pressure.

IV.4. Model Description

This section describes a generalized model that can be used to simulate a hydropower plant. The plant consists of a hydro turbine connected to a synchronous generator, which is connected to WWTP (Load). Simulation of the hydro turbine and synchronous generator can be done using various simulation tools, in this work, SIMULINK/MATLAB is favored over other tools in modeling the dynamics of a hydro turbine and synchronous machine. The SIMULINK program in MATLAB is used to obtain a schematic model of the hydro plant through basic function blocks. This approach is pedagogically better than using a compilation of program code as in other software programs.

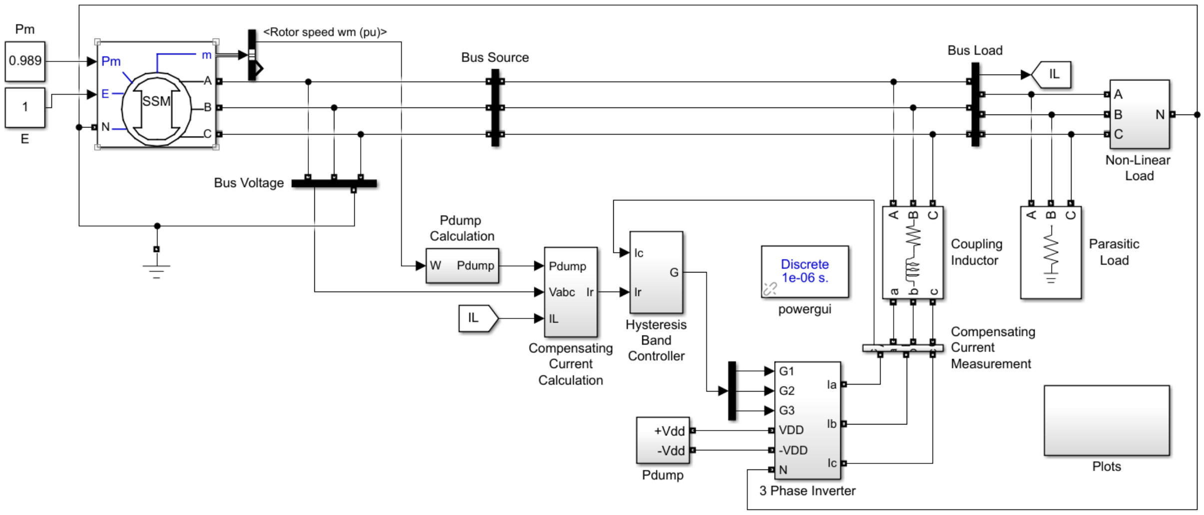


Fig. IV.7 : MATLAB simulation model of the micro-hydro-power plant.

The library of SIMULINK software programs includes function blocks that can be linked and edited to model. The main objectives of this model are aimed to achieve some operating modes of the hydro plant and some operating tests (harmonics and non-linear loads). The simulation results show a good correspondence between estimated and simulated values. The created model can be implemented as a part of an Algerian dynamic grid model.

IV.5. Simulations Results

In this simulation, the speed governor is not used because of its high cost. The Electronic Load Compensator (ELC) is preferred. This ELC regulates speed, compensates reactive power, and mitigates current harmonics. It senses deviation in speed and then calculates power to be dumped (Pdump). Then, its senses load current and voltage from which p and q are calculated

(Akagi pq theory) [31]. Then oscillating part of p is found using a digital filter. To compensates for reactive power and mitigate current harmonics, p and q should be injected.

To regulate speed, Pdump should be drawn. So, net power p - Pdump is to be injected along with q. With this value, the current to be injected is calculated. This reference current is fed to the hysteresis band current controller, which generates a gate signal for the inverter. The inverter injects the current. [32]

Pdump has drawn charges the capacitor C1 and C2. Therefore, the voltage across them increases. When the sum of their voltage exceeds a certain value, the MOSFET switch “S” is turned on. Therefore, the capacitor is discharged to the resistor. In this way, power is dumped in a resistor.

a)- Simulation Results of Power and Speed:

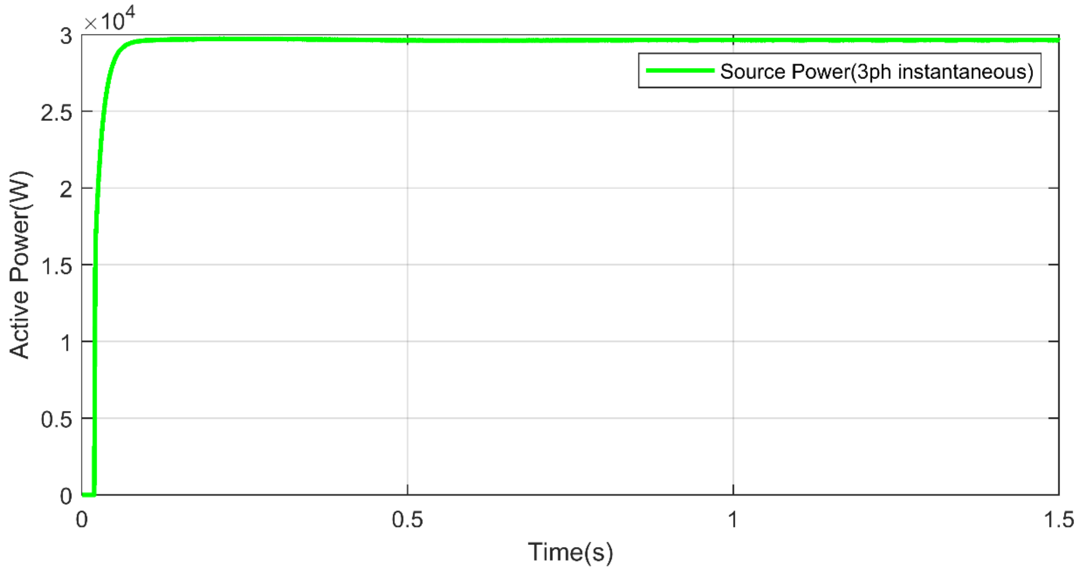


Fig. IV.8 : Simulation result of the injected active power.

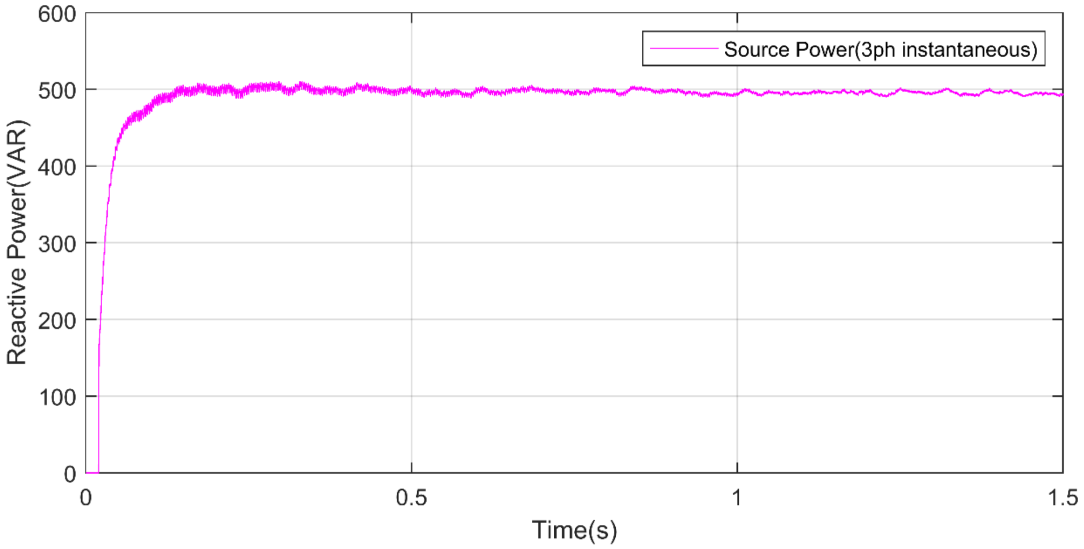


Fig. IV.9 : Simulation result of the injected reactive power.

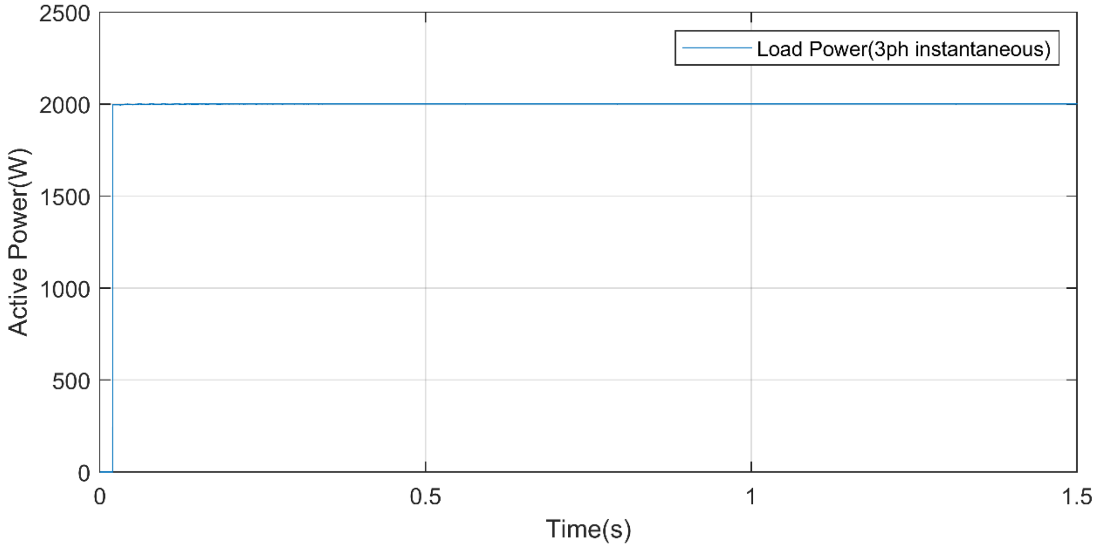


Fig. IV.10 : Simulation result of Load active power.

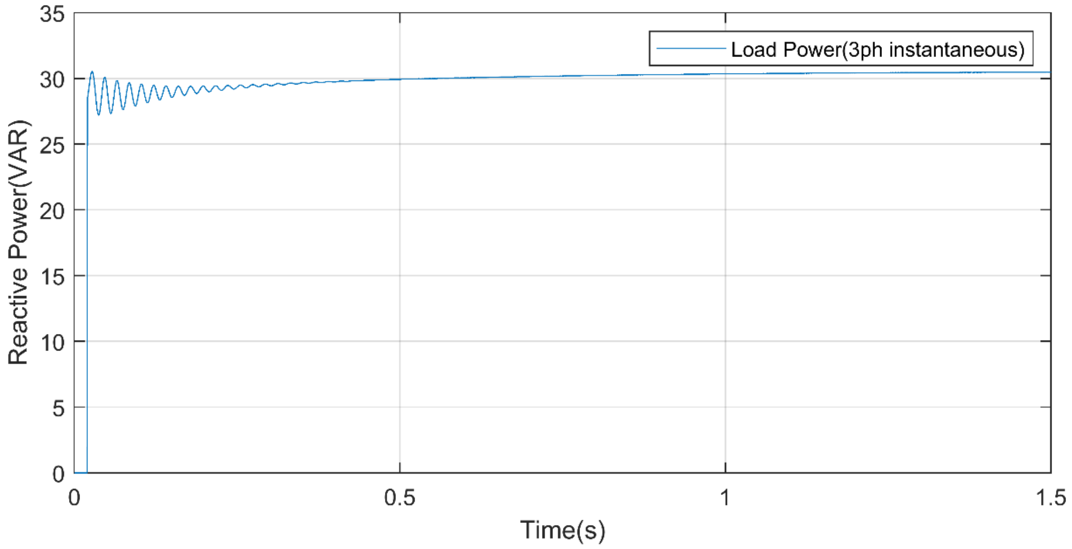


Fig. IV.11 : Simulation result of Load reactive power.

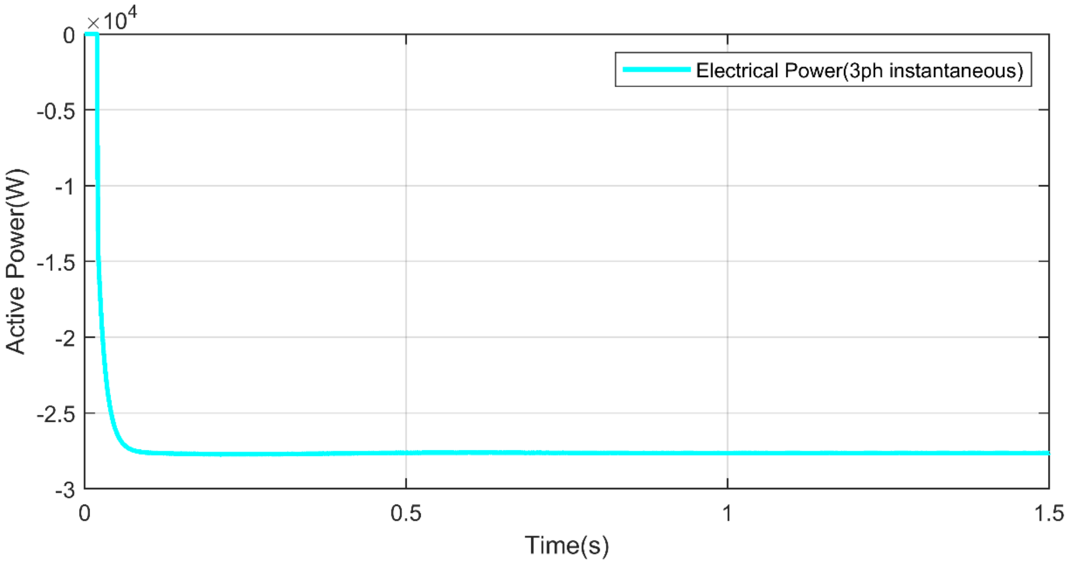


Fig. IV.12 : Simulation result of Electrical active power.

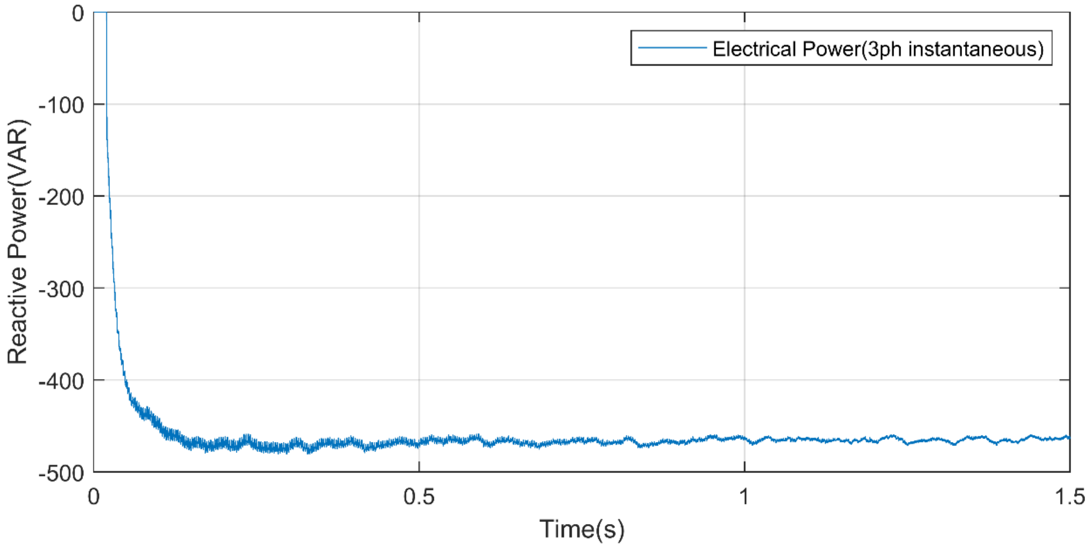


Fig. IV.13 : Simulation result of Electrical reactive power.

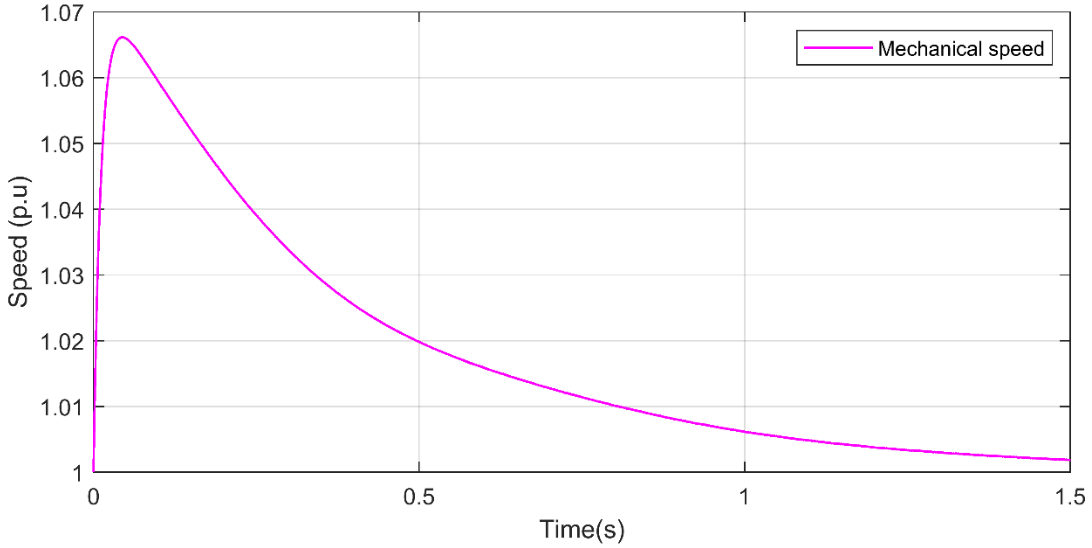


Fig. IV.14 : Simulation result of Synchronous generator speed.

b)- Simulation Results of Voltages and Currents:

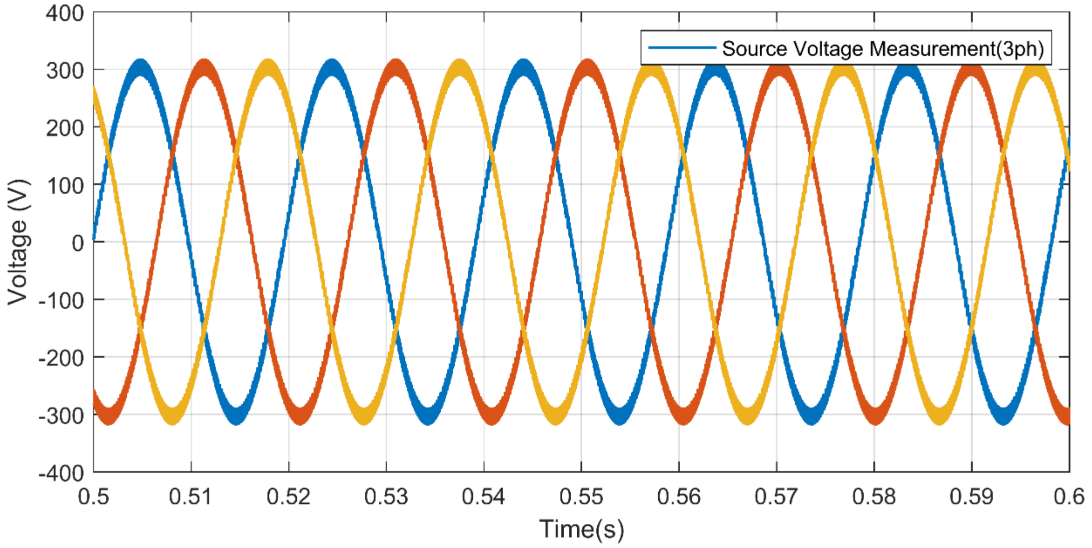


Fig. IV.15 : Simulation result of three phase voltages of the source.

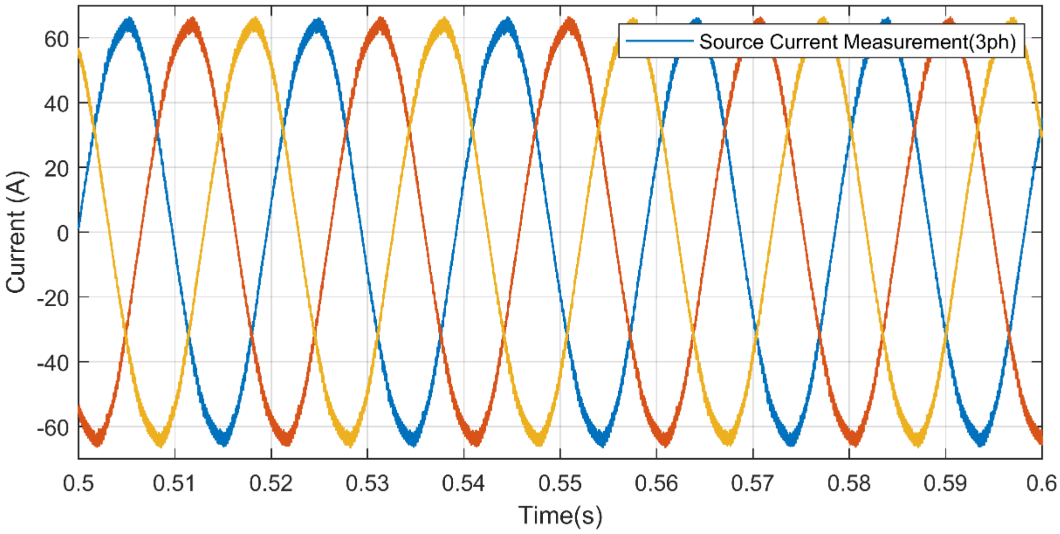


Fig. IV.16 : Simulation result of three phase currents of the source.

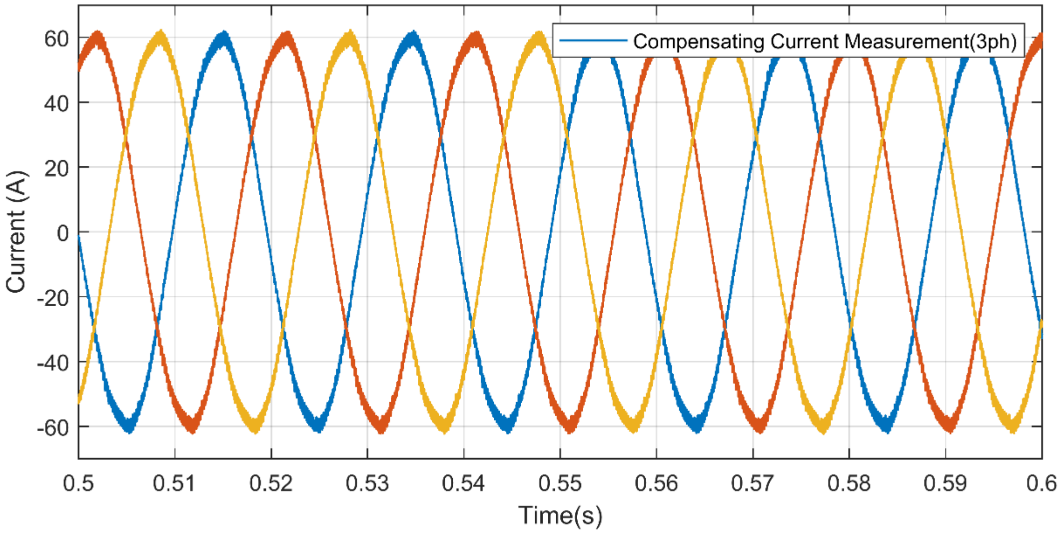


Fig. IV.17 : Simulation result of three phase compensating currents.

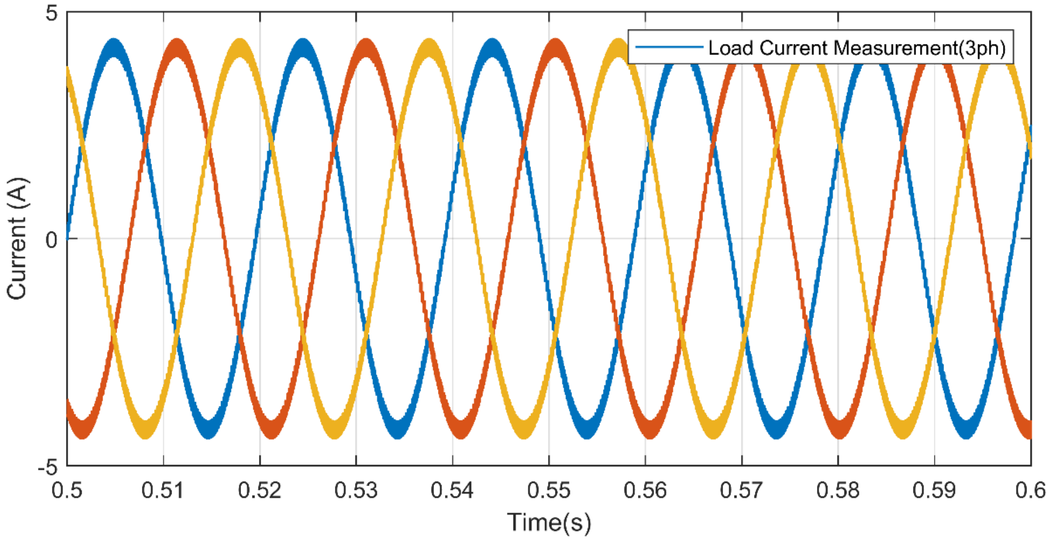


Fig. IV.18 : Simulation result of three phase currents of the Load.

IV.6. Conclusion

The main objectives of this chapter are aimed to achieve some operating modes of the hydro plant and some operating tests. The simulation results show a good correspondence between projected and simulated values. MATLAB is a powerful software package for the study of dynamic and nonlinear systems. Using SIMULINK, the simulation model can be built up systematically starting from simple sub-models. The hydropower plant model developed may be used alone, as in the direct-online starting example presented, or it can be incorporated in an advanced drive system. Several tests and operating conditions can be applied to the model.

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General Conclusion

During the last two decades, there has been a great deal of research on renewable energy technologies so it is very important to start thinking seriously about using new technologies such as Co-generation systems so that we can recover waste energy.

Electricity is the most versatile and easily controlled form of energy. At the point of use, it is practically loss-free and essentially non-polluting. At the point of generation, it can be produced clean with entirely renewable methods, such as water (hydropower system)

The use of these technologies will provide Sustainable development that embraces saving natural resources, economic growth, continued societal progress, and security of supply.

The interest in on-site cogeneration systems for wastewater treatment plants has been growing steadily during the last couple of years is expected to grow further. One of the factors that fueling this interest include the need for standby power (to provide reliability during utility power outages and shortages), availability of free fuel compared to high natural gas prices, interest in green or bioenergy from renewable resources, and significant grants and incentives being offered by state and federal governments.

There are several energy companies, which have shown significant interest in the last couple of years in building Cogeneration facilities for the municipal wastewater market either as design/build or as service contracts.

The need for standby power also makes the investment in cogeneration more cost-effective in the economic analysis; it is possible to deduct the cost of a diesel standby generator system from the cost of cogeneration before evaluating the payback period, net present value, or cost per kilowatt-hour (kWh).

Internal combustion engines, microturbines, gas turbines, fuel cells, and Stirling engines are the cogeneration technologies currently being considered for use with digester gas from wastewater treatment plants.

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ملخـــــص

يتمثل الهدف من هذا الإشراف المشترك بين قسم الهندسة الكهربائية وقسم الهندسة الميكانيكية، بشكل أساسي في تطوير منهجية لتصميم أنظمة التوليد المشترك في محطة معالجة وتنقية مياه الصرف الصحي، بهدف إنتاج كهرباء بعد دراسة ببليوغرافية مبنية على الأدب العالمي. تم اختيار هذا النموذج بناءاً على التركيب الفني للتوربينات الهيدروليكية. كما تحققنا من جدوى المولدات ومساهمة النظام في إنتاج الطاقة الكهربائية. من بين الأنظمة اللامركزية الحالية، تعد الشبكات الكهربائية الدقيقة من بين الحلول المفضلة لتزويد محطة معالجة مياه الصرف الصحي بالكهرباء؛ تكمن مشكلة هذا العمل في الحد من تأثير الطاقة وإدارة أنظمة التوليد المشترك الجزئي. تأخذ هذه الدراسة بعين الاعتبار السياقات الفنية والاقتصادية والبيئية.

الكلمات المفتاحية: الطاقويات، نظام التوليد المشترك المصغر، توربين، الاقتصاد، شبكة مصغرة، الكهرباء.

Résumé

L’objectif de ce travail en cotutelle entre département de génie électrique et département de génie mécanique, consiste principalement à développer une méthode de conception de système de cogénération sur une Station de traitement et d’épuration des eaux usées, en vue de production d’électricité. Après une étude bibliographique basée sur une littérature internationale. Le choix du modèle s’est porté sur les turbines hydrauliques et leur mise en place sur le plan technique. Nous avons vérifié la faisabilité du système micro Cogénérateur et l’apport du système sur la production d’énergie électrique. Parmi les systèmes décentralisés existants, les micro-réseaux électriques font partir des solutions privilégiées pour la fourniture d’électricité à la STEP ; La problématique de ce travail réside dans la réduction de l’impact énergétique et la gestion des systèmes de micro-cogénération. Cette étude tient compte des contextes techniques, économiques et environnementaux. Elle s’inclut dans le cadre du développement durable.

Mots-clés : Energétique, Micro-Cogénérateurs, Turbine, Economique, Microgrids, Electricité.

Abstract

The objective of this work in collaboration with the Electrical engineering department and Mechanical engineering department mainly consists of developing a method of designing a cogeneration system in wastewater treatment and purification stations to produce electricity. After a bibliographic study based on international literature, the choice of the model based on hydraulic turbines, and their technical implementation, we verified the feasibility of the micro Co-generator system and the system's contribution to the production of electrical energy. Among the existing decentralized systems Micro-grids. Micro-grids are one of the preferred solutions for the supply of electricity to WWTP (wastewater treatment and purification). The problem with this work lies in reducing the energy impact and managing micro-cogeneration systems. This study considers the technical, economic, and environmental contexts. It is included in the framework of sustainable development.

Keywords: Energy, Micro-Cogeneration, Turbine, Economic, Microgrids, Electricity.