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قسم الآلية والكهروميكانيك
Département de d'automatique et d'électromécanique

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Modeling and simulation of an electrical network with storage systems

Présenté par :
TEBBAKH Kacem

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Academic Year 2022/2023

Thankfulness

الحمد لله الذي هدانا لهذا وما كنا لنهتدي لولا ان هدانا الله

We thank above all ALLAH, our creator for giving us strength and courage to accomplish this work.

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To all our teachers, we express our deep gratitude

I would also like to thank all those who have helped us in any way to achieve this work

DEDICATION

First of all, I would like to thank God (ALLAH) for putting me on the right path to be able to carry out this work.

I dedicate this modest work, to the apple of my eye, to the two-dearest people in the world, who sacrifice all their life for me.

To my dearest father, who has encouraged and supported me throughout my life.

His fatherly warmth has been and always will be a great comfort and security for me; no words can suffice to thank you.

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To those who are dear to me and who have helped me in one way or another to carry out this work.

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Abstract

Hydropower has already proven to be a highly efficient means of electricity generation. One of the main challenges we face today is ensuring its stable and sustainable supply to meet the increasing demand. To address this, harnessing pumped water from tanks and converting it into energy has been proposed. Three solutions have been suggested: utilizing tank water, utilizing tank water upon completion of all planned tanks, and utilizing tank water with pump feed powered by solar energy. These solutions were simulated using the PSAT toolbox, and it was found that the second solution is the optimal one in terms of return on investment. Integrated hydropower systems provide significant gains in energy from small and diverse water sources. With significant growth potential, it is an important option for grid efficiency and reliability.

Keywords: Hydropower, electrical network, water reservoirs, PSAT toolbox.

Résumé

L'hydroélectricité s'est déjà révélée être un moyen très efficace de produire de l'électricité. L'un des principaux défis auxquels nous sommes confrontés aujourd'hui est d'assurer un approvisionnement stable et durable pour répondre à la demande croissante. Pour y répondre, il a été proposé d'exploiter l'eau pompée dans les réservoirs et de la convertir en énergie. Trois solutions ont été suggérées : utiliser l'eau des réservoirs, utiliser l'eau des réservoirs après l'achèvement de tous les réservoirs prévus, et utiliser l'eau des réservoirs avec une alimentation par pompe alimentée par l'énergie solaire. Ces solutions ont été simulées à l'aide de PSAT toolbox, et il a été constaté que la deuxième solution est la plus optimale en termes de retour sur investissement. Les systèmes hydroélectriques intégrés fournissent des gains significatifs en énergie à partir de sources d'eau petites et diverses. Avec un potentiel de croissance significatif, il s'agit d'une option importante pour l'efficacité et la fiabilité du réseau.

Mots clés : hydroélectricité, réseau électrique, réservoirs d'eau, PSAT toolbox.

ملخص

لقد أثبتت الطاقة الكهرومائية بالفعل أنها وسيلة عالية الكفاءة لتوليد الكهرباء، وأحد التحديات الرئيسية التي نواجهها اليوم هو ضمان إمداداتها المستقرة والمستدامة لتلبية الطلب المتزايد. لمحاولة تجسيد ذلك، تم اقتراح استغلال مياه المضخة من الخزانات وتحويلها إلى طاقة، وتم اقتراح ثلاثة حلول: استغلال مياه الخزانات، استغلال مياه الخزانات في حالة انجاز جميع الخزانات المخطط لها، استغلال مياه الخزانات مع تغذية المضخات بواسطة نظام الطاقة الشمسية، وتم محاكاتها باستخدام صندوق أدوات PSAT، ووجد أن الحل الثاني هو الأمثل من حيث العائد على الاستثمار. توفر نظم الطاقة الكهرومائية المدمجة مكاسب كبيرة من الطاقة من مصادر المياه الصغيرة والمتغيرة المتنوعة. مع إمكانات نمو كبيرة، فهو خيار مهم لكفاءة الشبكة وموثوقيتها.

كلمات مفتاحية: الطاقة الكهرومائية، الشبكة الكهربائية، الخزانات المائية، صندوق الأدوات PSAT.

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List of abbreviations

PSAT: Power System Analysis Toolbox .

IEA: International Energy Agency.

PV : photovoltaic.

General Introduction

Research and investment efforts are currently focused on improving the use of clean energy and renewable natural resources, driven by the escalating demand for energy and the associated increase in the cost of fossil fuels. [1]

Hydropower stands out as a key renewable energy source on a global scale, effectively meeting the electricity needs of communities and industries while adhering to sustainable and environmentally friendly practices.[2]

Our objective with this study is to assess the feasibility of a project that harnesses water energy from used water reservoirs in the area to generate electricity. This project aims to contribute to the reliability and stability of the power grid.

The first chapter can be divided into two parts. In the first part, we discussed the general overview of hydropower, its history, and its working principle. In the second part, we delved into the types of turbines and various types of hydroelectric power stations.

In the second chapter, we conducted simulations of an electrical grid for a region in southern Algeria using MATLAB toolbox. We incorporated hydropower energy from the reservoirs and presented the results. We also compared the results before and after the integration of hydropower.

In the third chapter, we proposed solutions to improve the outcomes of the project and achieve better utilization. We calculated the project's profitability in each case and presented the results. We compared the different scenarios and derived the optimal solution.

CHAPTER 01

Generalities on hydraulic storage

Chapter 1 : Generalities on hydraulic storage

1.1 Introduction

The overall structure of the electrical power system is currently undergoing a transition towards renewable energy resources, which are more sustainable and eco-friendlier, as opposed to fossil fuels which have been the primary source of energy. This shift is driven by several factors, including the increasing demand for electricity in both developed and developing countries, limited resources in some developing countries to construct power plants and distribution networks, insufficient power generation in some industrialized countries, and concerns over greenhouse gas emissions and climate change. The future power generation systems will incorporate various renewable energy sources such as wind turbines, photovoltaic solar systems, biomass power plants, and fuel cells, among others. However, the intermittent and variable nature of these renewable sources can pose challenges in power generation, resulting in sudden dips in system voltage due to factors such as wind fluctuations, lightning strikes, sudden load changes, or line faults. To address this, earlier studies have proposed the use of energy storage to compensate for the stochastic nature and sudden deficiencies of renewable energy sources during short periods without compromising on the load events or requiring additional generating plants to be started. **[3]**

Each of these technologies has different characteristics, advantages, and limitations, and the choice of technology depends on the specific application and the desired performance characteristics.

This study discusses hydraulic storage, which is an important form of electrical storage.

1.2 Pumped hydropower

Pumped storage hydroelectricity originated in the late 19th century but was first implemented on a large scale in the 1920s in Switzerland. The United States introduced the technology in the 1930s with the construction of the Ludington Pumped Storage Power Plant in Michigan. Since then, pumped storage hydroelectricity has become crucial for global energy systems, offering reliable and efficient energy storage for electrical grids. Many countries, including the United States, China, Japan, and several European nations, have adopted pumped storage hydroelectricity systems.[4]

This form of energy storage is flexible and efficient, and it has the potential to play a significant role in transitioning to a sustainable and renewable energy system. As the demand for renewable energy sources increases, pumped storage hydroelectricity is expected to become even more vital in the future. Hydropower, according to the International Energy Agency (IEA), contributes 17% of global electricity production, with an installed capacity exceeding 1200 GW. It is currently the largest source of renewable energy worldwide. Figure n°1 illustrates the hydropower generation and cumulative capacity by region. **[5]**

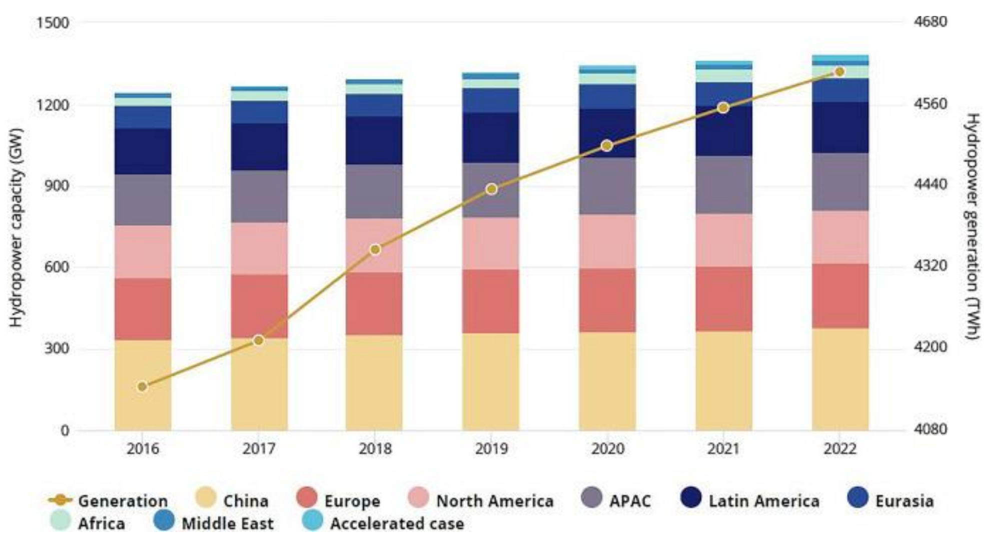

Figure 1.1: Hydropower generation and cumulative capacity by region (2016–2022)

1.3 Hydraulic power:

The flow rate and net head are used to calculate the hydraulic power with the formula :

$$P_{hydraulic} = Q_n * H_n * \rho * g \tag{1.1}$$

In SI Units:

$P_{hydraulic}$: Hydraulic power, in (W).

Q_n: Turbine flow, in (m^3/s).

H_n : Net drop, in (m).

ρ: Density of water in (kg/m3), 1000 kg/m3.

g : Acceleration due to gravity, 9.81 (m/s^2).[6]

1.4 Types of hydraulic turbines

The primary classification relies on the action of water on the turbine, resulting in two types: Impulse turbine and Reaction turbine. In the case of an impulse turbine, all the potential energy is converted into kinetic energy within the nozzles. The turbine wheel is rotated by the impulse generated by the jets, while the pressure inside the turbine remains atmospheric. This type, also known as tangential flow units, is suitable when there is a high amount of potential energy but comparatively low flow available. [7]

On the other hand, reaction turbines progressively convert the available potential energy within the turbine rotors. The rotation of the wheel is caused by the reaction of the accelerated water. Reaction turbines can be further divided into radial flow, mixed flow and axial flow machines. Radial flow machines are suitable for moderate levels of potential energy and medium flow rates. Axial machines are suitable for low levels of potential energy and high flow rates. Potential energy is commonly referred to as 'available head' and power stations are referred to as 'high head', 'medium head' or 'low head' on the basis of this terminology.[8]

1.4.1 Impulse turbine

1.4.1.1 Pelton turbines

The Pelton turbine is a type of water turbine that was developed by Lester Ella Pelton in the 1870s. It is generally used for high and low flow power plants. these are high-speed impulse turbines that use a jet of water to strike a series of buckets mounted around the perimeter of a wheel. the force of the water causes the wheel to rotate, which drives a generator to produce electricity the Pelton turbine is preferred for hydropower, when the available water source is at a relatively high elevation (10-2000 m) at low flows (0.04-1.5 m3/s). **[9]**

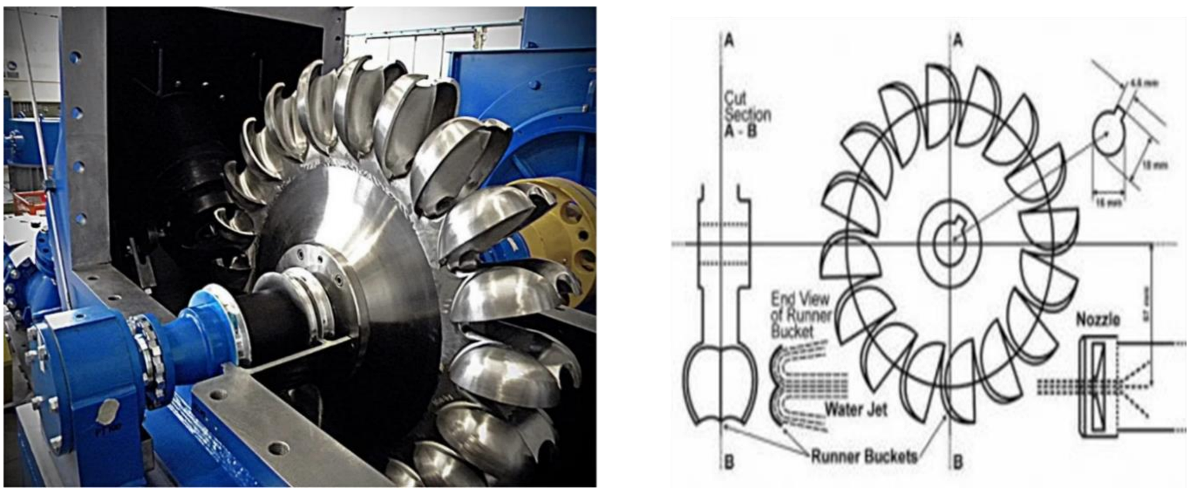

Figure 1.2 Pelton turbines[10]

1.4.1.2 Cross flow turbine

The Cross-flow turbine, also known as the Banki turbine, is specifically designed to operate within a flow rate range of 20 to 1000 liters per second and a vertical drop range of 2 to 200 meters. this turbine is often referred to as a flow-through turbine because the water passes through the turbine wheel twice. the unique feature of the cross-flow turbine is that it allows the water to flow through the blades in two stages. During the first pass, the water enters from the outer side of the blades and flows towards the inner side. In the second pass, the water reverses its direction and flows from the inner side back out. To control the flow, a guide vane positioned at the turbine's entrance directs the water to a specific portion of the runner. This design was developed to accommodate larger water flows and lower heads compared to the Pelton turbine. [11]

The cross-flow turbine can be divided into three main components or parts:

- An injector whose flow rate is adjusted using a rotary vane. In order to ensure a stop of the turbine without additional energy, closing is often carried out using a counterweight and opening by a hydraulic cylinder.
- A drum-shaped wheel with profiled cylindrical blades.
- A frame surrounding the wheel on which the turbine bearings are fixed

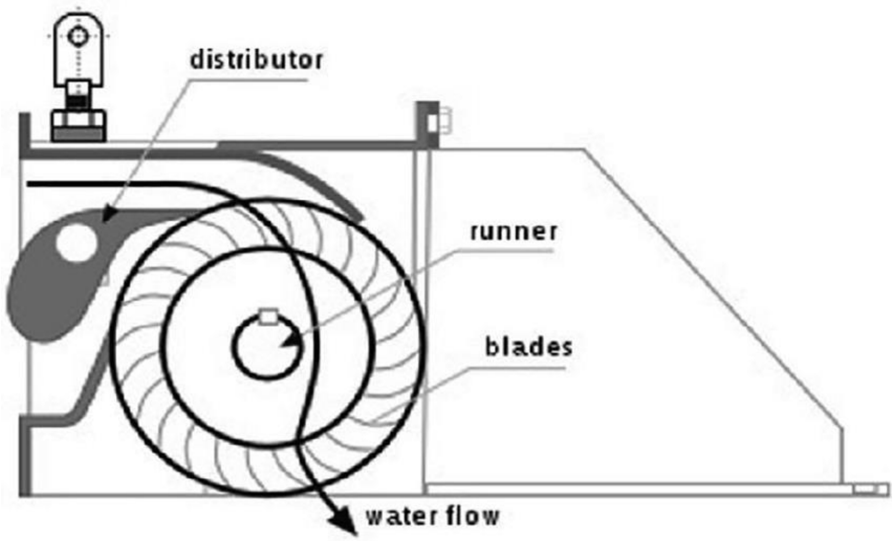

Figure 1.3: Cross flow turbine[12]

1.4.2 Reaction turbine

1.4.2.1 Francis turbines

The Francis turbine, invented by James Bichens Francis in 1855, is characterized by the change in water direction as it passes through. Water enters radially and exits along the turbine's axis, earning it the name "mixed-flow turbine." Flow is regulated by spiral valves or gates surrounding the turbine. To optimize energy extraction, the turbine is equipped with carefully shaped blades, requiring smooth water flow. The force exerted on the blades causes rotation, driving a generator for electricity production. Each turbine is custom-designed for specific water head height and flow volume. While suitable for various conditions, the Francis turbine performs best in medium to high head applications (100-300 meters). For extreme head conditions, other turbine designs like Pelton or Kaplan turbines may be more appropriate. Overall, the Francis turbine is a long-standing, efficient, and versatile solution for hydroelectric power generation. **[13]**

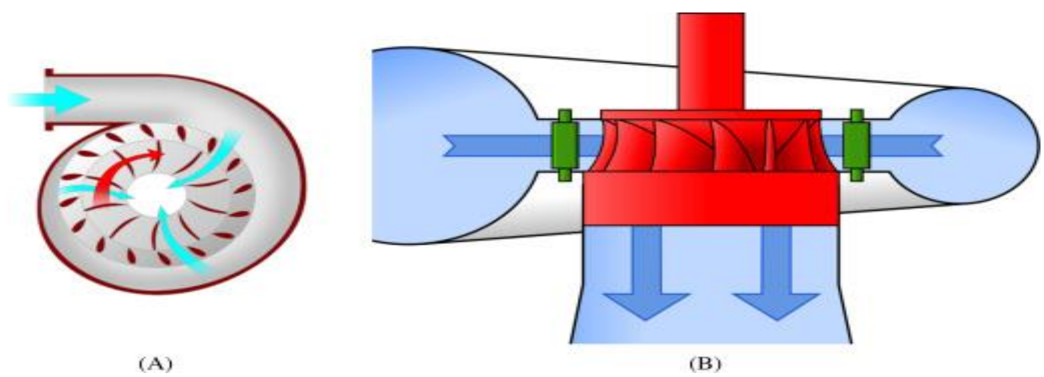

Figure 1.4: Francis turbines [13]

A: top views of Francis turbine .

B: side views of Francis turbine .

1.4.2.2 Kaplan turbines

The Kaplan turbine was developed in 1913 by the Austrian professor Viktor Kaplan. the Kaplan turbine is classified as a complete reaction turbine that operates on the principle of lift force generated on the impeller blades due to their aero foil shape. this turbine operates similarly to a propeller-type turbine, but with the added feature of adjustable runner blades that allow it to function smoothly in the presence of vortices and shocks during partial load conditions. the Kaplan turbine has shown significant advancements in small-scale hydropower plants by enabling high shaft speeds at low head levels. A double-regulated Kaplan turbine is capable of providing full discharge at 15% to 100% efficiency, while a single-regulated Kaplan turbine can achieve maximum discharge at 30% to 100% efficiency. **[14]**

Represents (figure 1.6) Schematic diagram of a Kaplan turbine

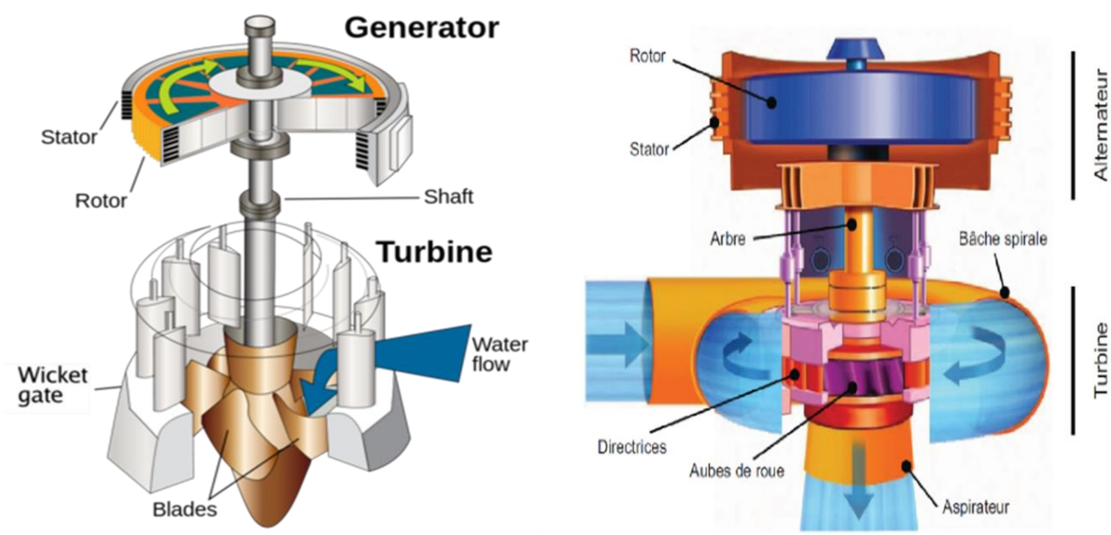

Figure 1.5: Kaplan turbines[15]

Table (Table1.1) shows the comparison among the Pelton, Francis, and Kaplan turbines based on a number of factors including flow types, head requirement, specific speed, and overall efficiency.

Table 1.1: Comparison of different types of turbines.[16]

Parameters	Pelton turbine	Francis turbine	Kaplan turbine	Cross flow turbine
Turbine type	Impulse turbine	Combination of impulse and reaction turbine	Purely reaction turbine	Impulse turbine
Flow type	Axial flow turbine	Mixed flow turbine	Axial flow turbine	radial flow turbine
Number of vanes and buckets	Wheel with 20–40 buckets	Impeller with 16–24 vanes	Impeller with 4–8 vanes	Impeller with 4–16 vanes
Head requires	Very high head (above 300–400 m)	Medium head (about 100–300 m)	Low head (below 100 m)	Low head (about 2 –200 m)
Flow rate	Low flow rate	Medium flow rate	Very large flow rate	large flow rate
Specific speed	Low specific speed	Medium specific speed (about 50–250 rpm)	High specific speed (about 250–1000 rpm)	Medium specific speed (about 50)
Adjustment of runner vanes	Fixed buckets at the periphery of the wheel	Runner vanes are fixed with the shaft so it can't be adjusted	Runner vanes are adjustable	Mechanized Adjustment
Overall efficiency	About 85%-95%	Above 90%	About 90%–93%	About 65%–85%

1.5 Types of hydropower plants

Hydropower sites with high head and high flow are considered ideal as they generate significant amounts of electricity at a lower cost. The choice of hydropower plants is influenced by both the cost considerations of current technologies and advancements in the field. There are three primary types of hydropower plants according to the IEA (2018): **[5]**

1.5.1 Run-of-river hydropower plants

This type of hydropower plant utilizes the flow of a river to generate electricity. It often includes short-term storage capacity to provide flexibility on a daily or hourly basis. These plants typically experience significant seasonal and annual variations in power production.**[5]**

Ex:

The Jimmie Creek Hydroelectric Project is a run-of-river hydropower plant located in British Columbia, Canada. The project has a capacity of 62 megawatt and generates enough electricity to power approximately 48,000 homes. The plant uses the natural flow of Jimmie Creek, a tributary of the Homathko River, to turn two 31-megawatt turbines. The project was designed to minimize environmental impacts, and features fish-friendly turbines that allow fish to pass through the plant safely. began operation in 2016.**[17]**

Figure 1.6: Jimmie Creek Hydroelectric Project[17]

1.5.2 Reservoir hydropower plants

In this type of hydropower plant, electricity is generated using water stored in a reservoir. The presence of a reservoir system offers the advantage of flexibility in electricity generation according to demand. It also helps to mitigate variations in water inflows. Larger reservoir systems can provide additional benefits such as irrigation services and flood protection. Moreover, they have the capability to maintain average water inflows over extended periods, ranging from months to even years.**[5]**

Ex:

The Hoover Dam located on the Colorado River between Arizona and Nevada in the United States. The Hoover Dam was completed in 1936 and has a total generating capacity of 2,080 megawatts.

The reservoir created by the dam, called Lake Mead, has a surface area of over 640 square kilometers and a maximum water storage capacity of 35.7 billion cubic meter. The stored water is used to generate electricity by flowing through turbines located in the dam's power plant.

there are fifteen 178,000 horsepower, one 100,000 horsepower, and one 86,000 horsepower Francis-type vertical hydraulic turbines in the Hoover powerplant. There are also thirteen 130,000 kilowatt, two 127,000 kilowatt, one 61,500 kilowatt, and one 68,500 kilowatt generators. All machines are operated at 60 cycles. The two 2,400-kilowatt station-service units are driven by Pelton water wheels. These provide electrical energy for lights and for operating cranes, pumps, motors, compressors, and other electrical equipment within the dam and powerplant.

The Hoover Dam provides power to over 1.3 million people in Arizona, California, and Nevada, as well as agricultural irrigation to the surrounding areas. **[18, 19]**

Figure 1.7: Hoover Dam, hydraulic turbines[20]

1.5.3 Pumped storage plants (PSPs)

In this type of hydropower plant, water is pumped from lower reservoirs to higher reservoirs during periods of low electricity demand. When electricity demand is high, the water is released from the higher reservoirs and passes through a turbine to generate electricity, flowing back into the lower reservoirs. This process allows for energy storage and helps balance electricity supply and demand. Pumped storage plants are currently a significant contributor to on-grid electricity storage.**[5]**

Ex:

The Dinorwig Power Station in Wales, UK. It has a capacity of 1,728 MW and is the largest pumped storage plant in Europe

The Din Orwig Power Station, also known as the Electric Mountain, is located in a former slate quarry in the Snowonia National Park. It comprises upper and lower reservoirs and an underground powerhouse. The upper reservoir is the pre-existing lake of Llyn Marchlyn Mawr, which is formed by a 36m-high rockfill dam. It is located 503m above the lower reservoir Llyn Peris, which is also a pre-existing lake.

The power station is accessible via 16km-long tunnels and its machinery is housed in nine 750m-deep man-made caverns. The turbine hall, which is 180m-long, 23m-wide, and 51m-high, lies 71m below the top level of Llyn Peris. The transformer hall measures 160m in length, 23m in width, and 17m in height.

Water is released from the upper reservoir to the lower reservoir through a 1.7km-long, 10.5m-diameter low-pressure tunnel during peak demand periods. From there, water flows to the six turbines through a 10m-diameter high-pressure tunnel. The force of this water turns the turbines at 500rpm.**[21]**

The six generating units can achieve maximum output of 1,728MW, from zero, within 16 seconds, The units are fixed vertically within the mountain, where the colossal generators – weighing at 445t each – can maintain maximum output for up to five hours.

Figure 1.8: Dinorwig Power Station in Wales[22, 23]

Hydropower, harnessed from dams, offers a stable and dependable energy source, particularly useful in areas prone to power outages or dependent on imported energy. The use of dams can also decrease greenhouse gas emissions, facilitating countries to meet their climate objectives. Additionally, dam construction can create job opportunities and stimulate local economies, particularly in rural areas where employment prospects may be scarce. Moreover, dams provide essential water management benefits such as water flow regulation, irrigation for agricultural activities, and enhanced food security in various regions of the world. Lastly, dams and reservoirs offer recreational opportunities, including fishing, boating, and camping, which promote local tourism and provide supplementary economic advantages.

1.6 The main characteristics of a storage system

An electrical storage system is a type of energy storage system that uses electrical energy to store and discharge energy as needed. Here are some of the main characteristics of an electrical storage system:

1. **Capacity:** The capacity of an electrical storage system refers to the amount of energy it can store. This is typically measured in units of watt-hours (Wh) or kilowatt-hours (kWh).
2. **Power:** The power rating of an electrical storage system refers to the maximum amount of power it can output at any given time. This is typically measured in units of watts (W) or kilowatts (kW).
3. **Efficiency:** The efficiency of an electrical storage system refers to how much of the energy put into the system can be retrieved as useful output. Some energy is lost during the charging and discharging process due to factors such as heat and resistance.
4. **Energy density:** Capacity divided by the size of the storage tank.
5. **Depth of discharge:** For technical reasons, it is sometimes necessary to limit the amount of energy exchanged during a cycle to a value lower than the theoretical capacity of a full load. The depth of discharge during operation sometimes has an impact on the service life. For example, an electrochemical battery that is deeply discharged at each cycle will experience a progressive decrease in capacity and a decrease in life expectancy in terms of cycles. This problem leads to the definition of a useful capacity, lower than the capacity defined above, which should not be exceeded during operation.
6. **Voltage:** The voltage of an electrical storage system refers to the electrical potential difference between the positive and negative terminals of the system. This is typically measured in units of volts (V).
7. **Cycle Life:** The cycle life of an electrical storage system refers to the number of charge and discharge cycles it can undergo before it starts to degrade. A longer cycle life means a longer lifespan for the system.
8. **Safety:** The safety of an electrical storage system refers to how well it can protect against hazards such as short circuits, overcharging, or thermal runaway. This is especially

important for larger systems that can pose a greater risk to people and property if safety measures are not properly implemented.

9. **Cost:** The cost of an electrical storage system is an important consideration for any application. Costs can vary widely depending on factors such as capacity, power rating, efficiency, and safety features. **[24]**

1.7 Conclusion

This chapter emphasized the concept of pumped storage and the importance of water resources in electricity generation. In addition, the main types of turbines used in this context were discussed, including their operating principles and illustrated with relevant examples.

CHAPTER 02

Study cases of hydraulic power integration by simulation

Chapter 2 : Study cases of hydraulic power integration by simulation

2.1 Introduction

In this chapter, a brief overview will be provided on the different applications of the PSAT toolbox, that will be used to study the network case. three integration cases will be selected in the electrical network of an area located in the south of the Algerian desert, and the results obtained in each case before and after integration.

2.2 Definition and some use of the toolbox (PSAT)

The Power System Analysis Toolbox (PSAT) is a powerful software tool used for studying and analyzing electrical networks. It provides a comprehensive set of functionalities and algorithms to simulate and evaluate the performance of power systems. PSAT allows users to model, simulate, and analyze the behavior of electrical networks, including power flow, voltage stability, transient stability, and optimal power flow. with PSAT, users can input network parameters, such as transmission lines, generators, loads, and transformers, and analyze the steady-state and dynamic behavior of the system. It enables the computation of power flow, voltage profiles, line losses, and reactive power flows within the network. Additionally, PSAT provides tools for transient stability analysis, which helps in assessing the system's ability to maintain stability during disturbances. one of the notable features of PSAT is its capability to perform optimal power flow analysis. It allows users to optimize power generation and control variables, considering constraints and objectives such as minimizing generation costs or maximizing system reliability. This functionality is valuable for studying and designing efficient and economically viable power systems.[25, 26]

The study area has been selected in the northern part of the Algerian desert during the summer season in the month of August, as it represents a period of high electricity consumption.

2.3 Characteristic of test network

The networks chosen in this work are the 60 kV distribution network, this network is fed by a source of 240 MVA, with a step-down transformer of 220/60 kV.

The networks are modeled using the PSAT toolbox, and its data are as follows:

- The number of Buses:28.
- The number of Lines:18.
- The number of Transformers:15.
- The number of Generators:1.
- The number of Loads:12.

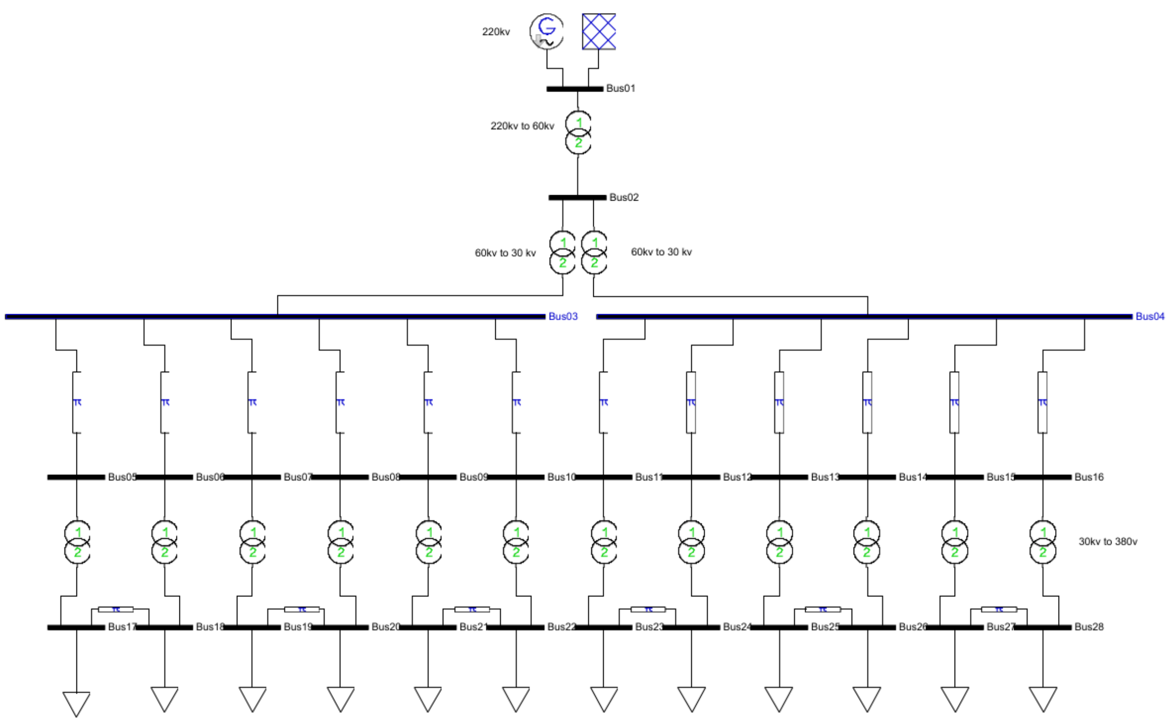

Figure 2.1: distribution network

2.4 Simulation results

2.4.1 Part I: before integrations

When the simulation starts, PSAT toolbox displays the power flow diagram in the network

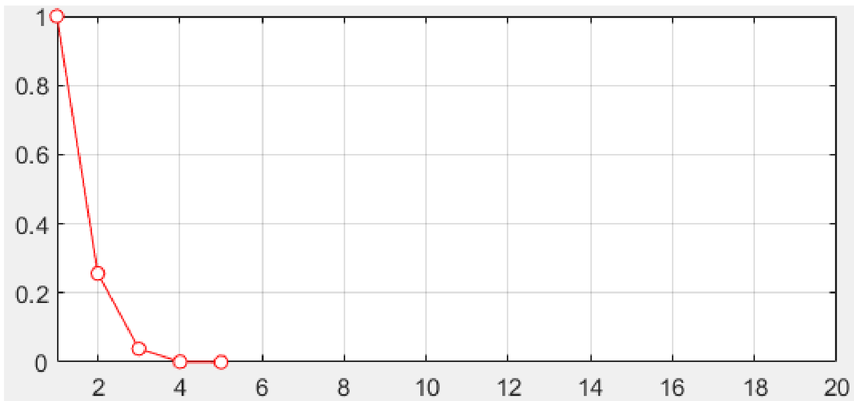

Figure 2.2: diagram of the power flow in the network

2.4.1.1 Results of simulation:

These figures show the voltages and phases as well as the active and reactive power of the generator and the loads on each bus.

This curve represents the transition phase at each bus:

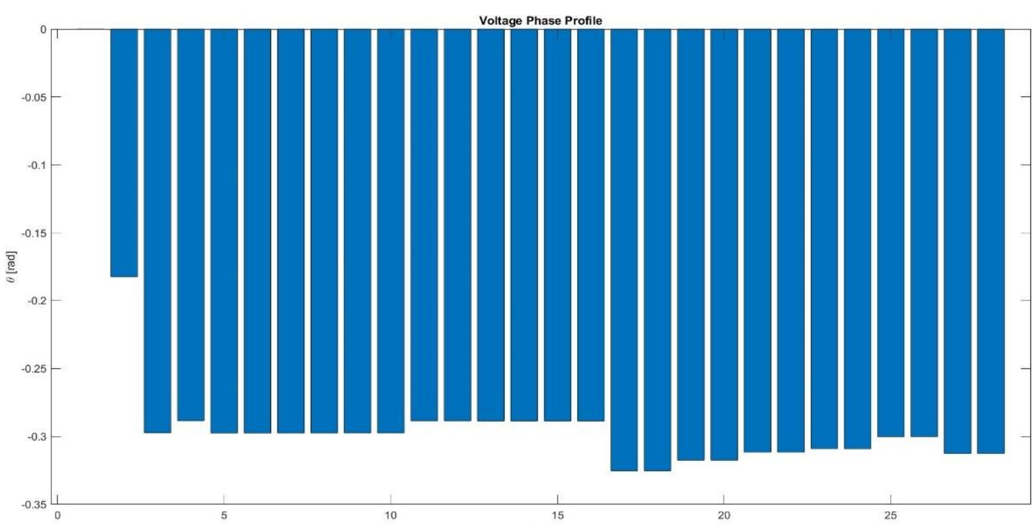

Figure 2.3: voltage phase on each bus (rad)

This curve represents voltage changes at each level of each bus:

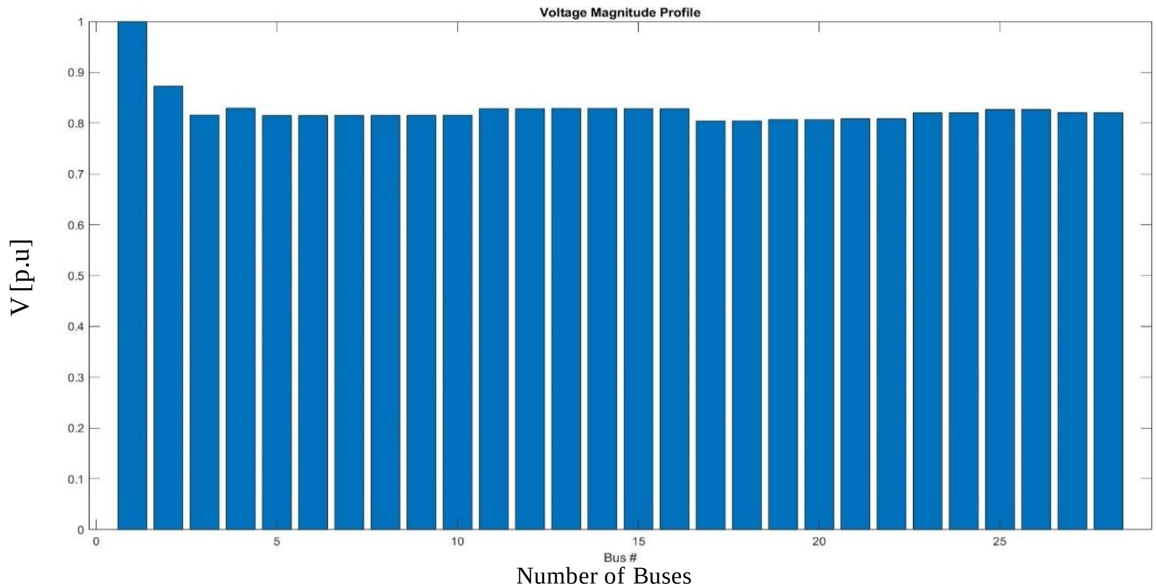

Figure 2.4: voltage profile on each bus

This curve represents the values of real power at each bus in the electrical generator and loads.

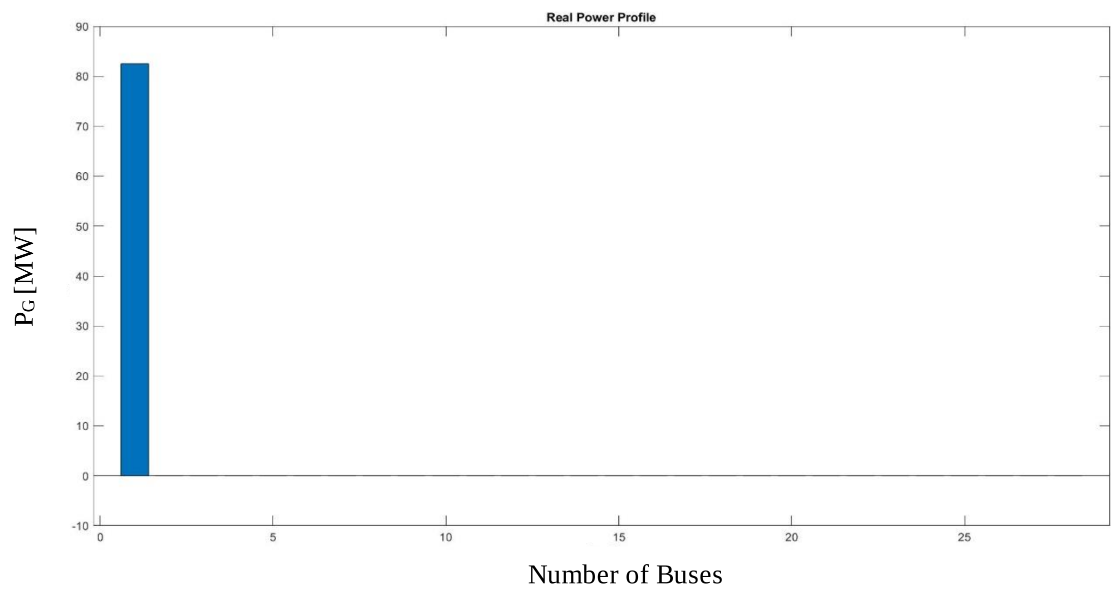

Figure 2.5: real power of generator

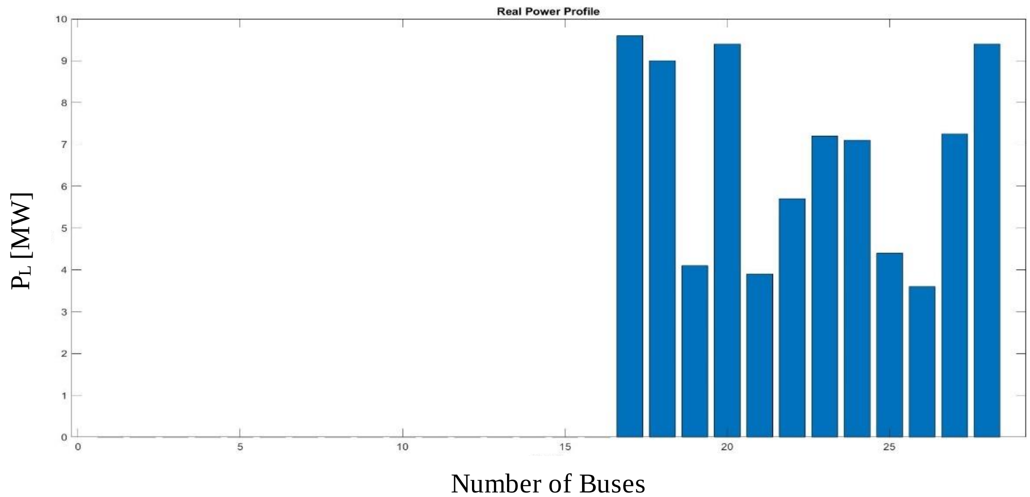

Figure 2.6: real power of loads

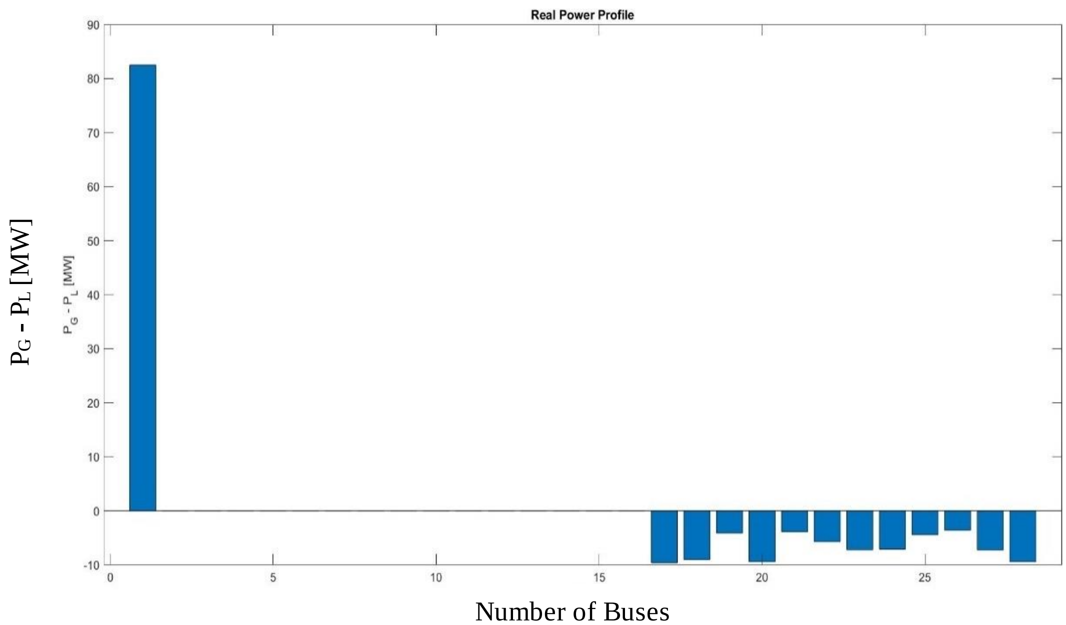

Figure 2.7: real power of generator - loads

This curve represents the values of reactive power at each buses in the electrical generator and loads.

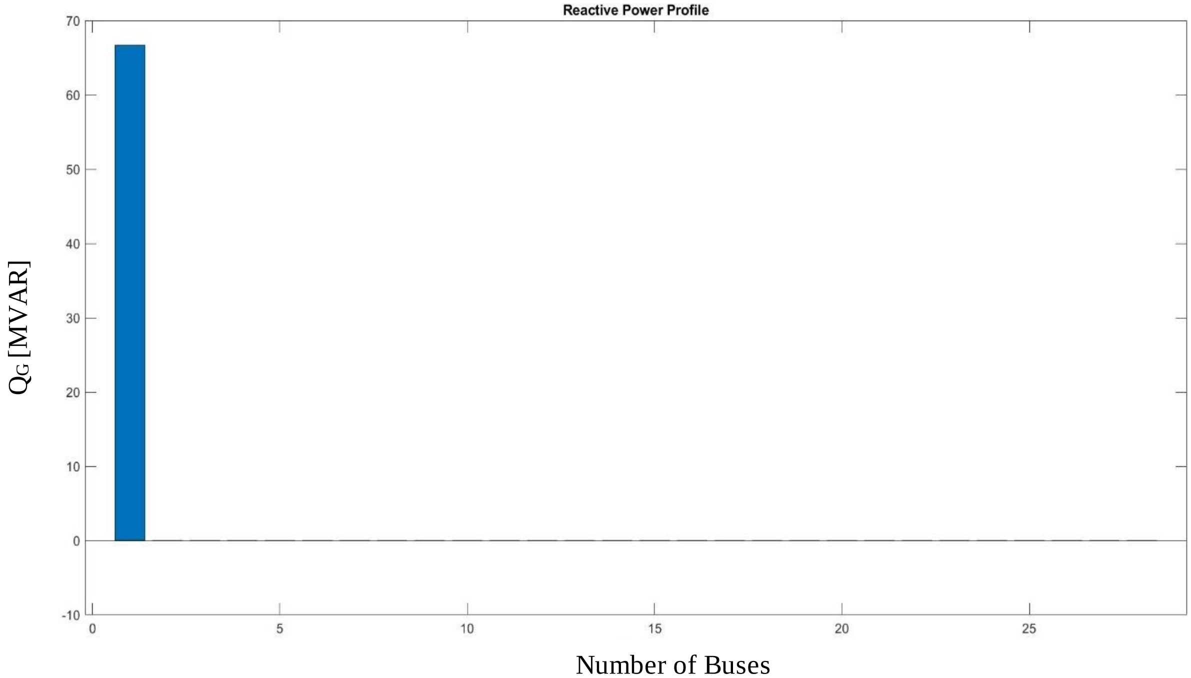

Figure 2.8: reactive power of generator

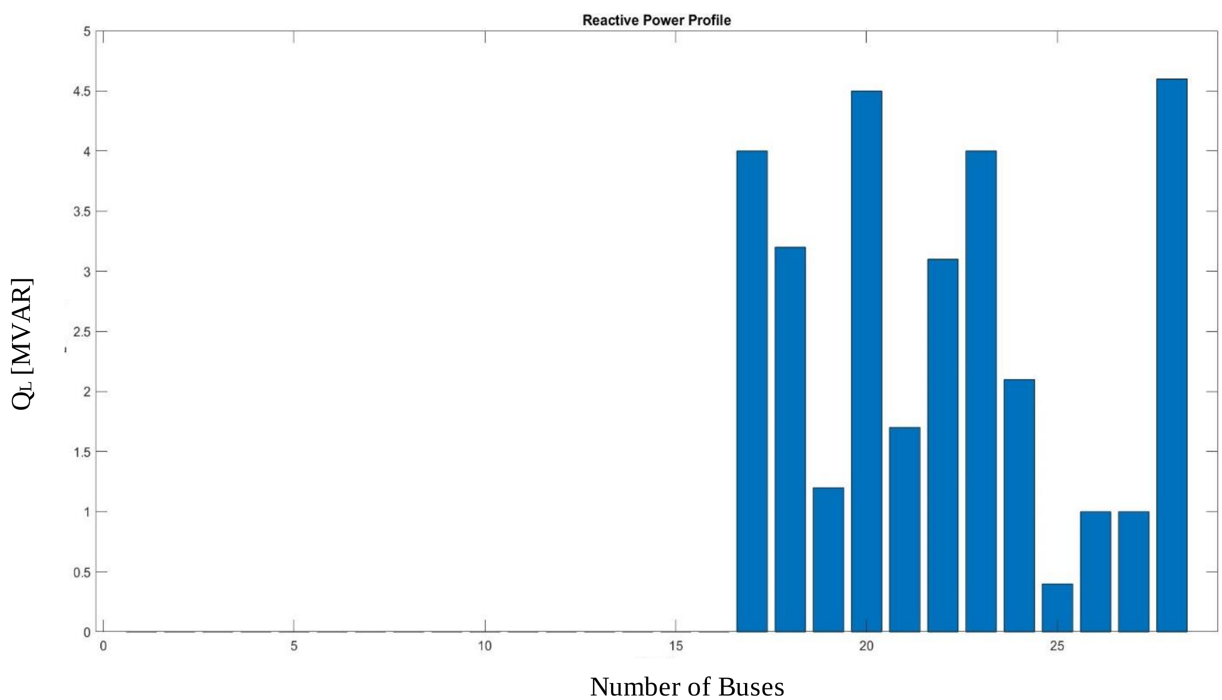

Figure 2.9: reactive power of loads

This curve represents the values of reactive power at each bus in the electrical generator - loads

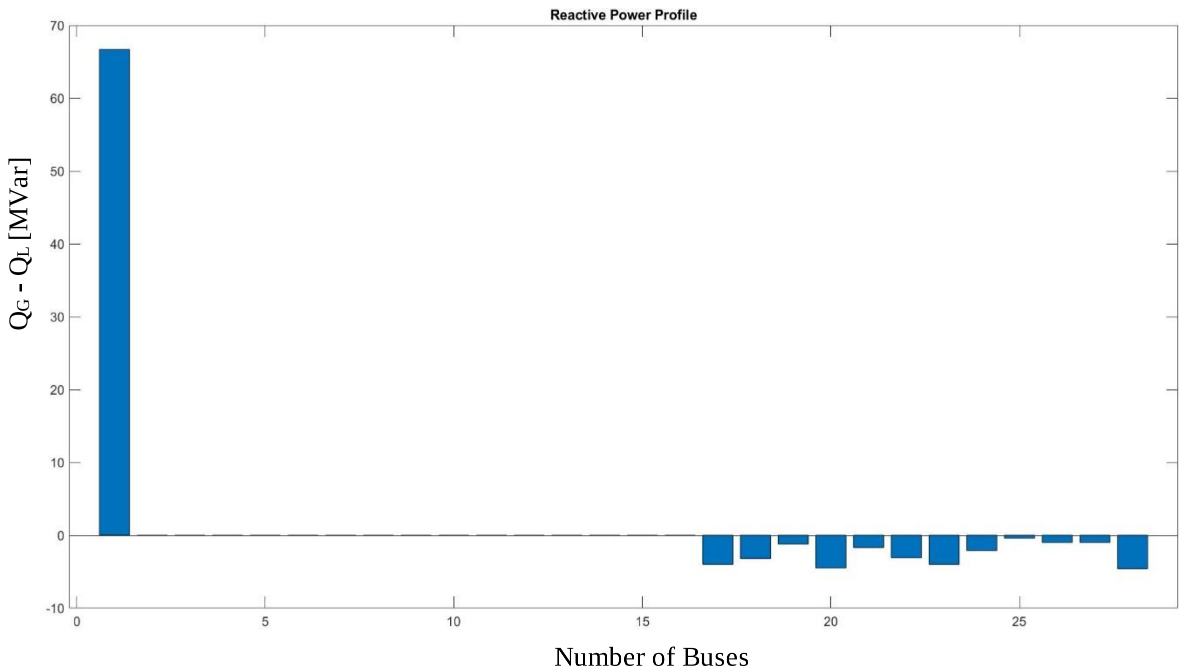

Figure 2.10: reactive power of generator - loads

This table shows the voltage, phase, active and reactive power of generator and loads on each bus.

Table 2.1: Power Flow Results before integration hydraulic power

Bus	V [p.u.]	phase [rad]	P gen [MW]	Q gen [MVar]	P load [MW]	Q load [MVar]
Bus01	1	0	82.4989	66.6832	0	0
Bus02	0.87286	-0.1824	0	0	0	0
Bus03	0.8158	-0.29737	0	0	0	0
Bus04	0.82943	-0.28846	0	0	0	0
Bus05	0.81504	-0.29748	0	0	0	0
Bus06	0.81504	-0.29748	0	0	0	0
Bus07	0.81524	-0.29744	0	0	0	0
Bus08	0.81524	-0.29743	0	0	0	0
Bus09	0.81539	-0.29739	0	0	0	0
Bus10	0.81539	-0.29739	0	0	0	0
Bus11	0.82885	-0.28851	0	0	0	0
Bus12	0.82885	-0.28852	0	0	0	0
Bus13	0.82914	-0.28857	0	0	0	0
Bus14	0.82914	-0.28857	0	0	0	0
Bus15	0.82878	-0.28859	0	0	0	0
Bus16	0.82878	-0.28858	0	0	0	0
Bus17	0.8046	-0.32529	0	0	9.6	4
Bus18	0.80463	-0.3253	0	0	9	3.2
Bus19	0.80729	-0.31753	0	0	4.1	1.2
Bus20	0.80706	-0.3175	0	0	9.4	4.5
Bus21	0.80882	-0.3116	0	0	3.9	1.7
Bus22	0.80873	-0.3116	0	0	5.7	3.1
Bus23	0.82034	-0.3091	0	0	7.2	4
Bus24	0.82038	-0.3091	0	0	7.1	2.1
Bus25	0.8269	-0.3002	0	0	4.4	0.4
Bus26	0.82692	-0.3001	0	0	3.6	1
Bus27	0.82077	-0.3127	0	0	7.25	1
Bus28	0.82063	-0.3126	0	0	9.4	4.6

The table **(Table 2.1)** shows the voltage values per unit and the phase in radians. The active and reactive power of the generator and the active and reactive power of the loads are measured in megawatts and megavolt-ampere reactive respectively. The active and reactive power of the generator is observed on busbar 01 and its absence is noted on the other busbars. The active and reactive power at busbars 17-28 is also recorded for the loads.

2.4.1.2 Powers transmitted in the power lines

The following two tables show the active and reactive powers transmitted in both directions 1 and 2

Directions 1: This table shows us the active, reactive and apparent force transmitted in the first direction between the buses:

Table 2.2: Powers transmit in the lines of model directions 1 before integration hydraulic power

From Bus	To Bus	Line	**P** Flow [MW]	**Q** Flow [Mvar]	S Flow [Mva]
Bus03	Bus05	1	9.321	3.919	10.1114
Bus03	Bus06	2	9.326	3.905	10.1106
Bus04	Bus15	3	8.357	3.004	8.88051
Bus04	Bus16	4	8.329	3.061	8.87367
Bus28	Bus27	5	-1.089	-1.771	2.07903
Bus26	Bus25	6	0.393	-0.302	0.49563
Bus24	Bus23	7	0.062	0.941	0.94304
Bus22	Bus21	8	-0.901	-0.683	1.13061
Bus20	Bus19	9	-2.649	-1.603	3.09626
Bus18	Bus17	10	0.303	0.393	0.49624
Bus03	Bus07	11	6.762	2.97	7.3855
Bus03	Bus08	12	6.764	3.065	7.42603
Bus03	Bus09	13	4.808	2.472	5.40626
Bus03	Bus10	14	4.805	2.507	5.41969
Bus04	Bus11	15	7.152	3.241	7.85208
Bus04	Bus12	16	7.176	3.224	7.86697
Bus04	Bus13	17	4.011	0.752	4.08089
Bus04	Bus14	18	3.997	0.746	4.06602
Bus01	Bus02	19	82.499	66.683	106.079
Bus12	Bus24	20	7.171	3.221	7.86118
Bus13	Bus25	21	4.01	0.751	4.07972
Bus14	Bus26	22	3.995	0.746	4.06405
Bus15	Bus27	23	8.351	3.001	8.87385
Bus16	Bus28	24	8.322	3.058	8.86606
Bus02	Bus04	25	39.271	19.026	43.6371
Bus02	Bus03	26	42.103	25.151	49.0432
Bus05	Bus17	27	9.313	3.914	10.102

Bus06	Bus18	28	9.318	3.9	10.1012
Bus07	Bus19	29	6.758	2.968	7.38103
Bus08	Bus20	30	6.759	3.063	7.42065
Bus09	Bus21	31	4.806	2.471	5.40402
Bus10	Bus22	32	4.803	2.505	5.41699
Bus11	Bus23	33	7.147	3.238	7.84629

The table **(Table 2.2)** shows that the lines connecting the transformer operate at 60/30kV and busbars 03 and 04 have high conversion power in terms of active and reactive power, while the power levels are lower in the lines connecting busbars 03 and 04 to the transformer, which operates at 30/380V. In addition, the power transfer between loads via the connecting lines is relatively low.

Directions 2: This table shows us the active and reactive force and the apparent force transmitted in the second direction between the buses:

Table 2.3: The powers transmit in the lines of model directions 2 before integration hydraulic power

From Bus	To Bus	Line	**P** Flow [MW]	**Q** Flow [Mvar]	S Flow [Mva]
Bus05	Bus03	1	-9.313	-3.914	10.102
Bus06	Bus03	2	-9.318	-3.9	10.1012
Bus15	Bus04	3	-8.351	-3.001	8.87385
Bus16	Bus04	4	-8.322	-3.058	8.86606
Bus27	Bus28	5	1.0893	1.7714	2.07953
Bus25	Bus26	6	-0.393	0.3024	0.49588
Bus23	Bus24	7	-0.062	-0.941	0.94304
Bus21	Bus22	8	0.9014	0.683	1.13093
Bus19	Bus20	9	2.6496	1.6037	3.09713
Bus17	Bus18	10	-0.303	-0.393	0.49624
Bus07	Bus03	11	-6.758	-2.968	7.38103
Bus08	Bus03	12	-6.759	-3.063	7.42065
Bus09	Bus03	13	-4.806	-2.471	5.40402
Bus10	Bus03	14	-4.803	-2.505	5.41699
Bus11	Bus04	15	-7.147	-3.238	7.84629

Bus12	Bus04	16	-7.171	-3.221	7.86118
Bus13	Bus04	17	-4.01	-0.751	4.07972
Bus14	Bus04	18	-3.995	-0.746	4.06405
Bus02	Bus01	19	-81.374	-44.178	92.5928
Bus24	Bus12	20	-7.162	-3.041	7.78087
Bus25	Bus13	21	-4.007	-0.702	4.06803
Bus26	Bus14	22	-3.993	-0.698	4.05355
Bus27	Bus15	23	-8.339	-2.771	8.78734
Bus28	Bus16	24	-8.311	-2.829	8.77929
Bus04	Bus02	25	-39.021	-14.028	41.4659
Bus03	Bus02	26	-41.787	-18.838	45.8369
Bus17	Bus05	27	-9.297	-3.607	9.97219
Bus18	Bus06	28	-9.303	-3.593	9.97274
Bus19	Bus07	29	-6.75	-2.804	7.30923
Bus20	Bus08	30	-6.751	-2.897	7.34633
Bus21	Bus09	31	-4.801	-2.383	5.35988
Bus22	Bus10	32	-4.799	-2.417	5.37329
Bus23	Bus11	33	-7.138	-3.059	7.76586

The table **(Table 2.3)** shows that the lines connecting the transformer operate at 60/30kV and busbars 03 and 04 have high conversion power in terms of active and reactive power, while the power levels are lower in the lines connecting busbars 03 and 04 to the transformer, which operates at 30/380V. In addition, the power transmission between the loads is relatively weak through the connecting lines, active and reactive power are negative due to a reverse direction.

2.4.1.3 Active and reactive power losses

The following table shows the active and reactive power losses in this network

Table 2.4: Active and reactive power losses before integration hydraulic power

From Bus	To Bus	Line	**P** loss [MW]	**Q** loss [Mvar]	S loss [Mva]
Bus03	Bus05	1	8.00E-03	5.00E-03	0.00943
Bus03	Bus06	2	8.00E-03	5.00E-03	0.00943
Bus04	Bus15	3	6.00E-03	3.00E-03	0.00671
Bus04	Bus16	4	6.00E-03	3.00E-03	0.00671
Bus28	Bus27	5	0	0	0
Bus26	Bus25	6	0	0	0
Bus24	Bus23	7	0	0	0
Bus22	Bus21	8	0	0	0
Bus20	Bus19	9	0	0	0
Bus18	Bus17	10	0	0	0
Bus03	Bus07	11	4.00E-03	2.00E-03	0.00447
Bus03	Bus08	12	4.00E-03	2.00E-03	0.00447
Bus03	Bus09	13	2.00E-03	1.00E-03	0.00224
Bus03	Bus10	14	2.00E-03	1.00E-03	0.00224
Bus04	Bus11	15	5.00E-03	3.00E-03	0.00583
Bus04	Bus12	16	5.00E-03	3.00E-03	0.00583
Bus04	Bus13	17	1.00E-03	1.00E-03	0.00141
Bus04	Bus14	18	1.00E-03	1.00E-03	0.00141
Bus01	Bus02	19	1.13	2.25E+01	22.5331
Bus12	Bus24	20	9.00E-03	1.80E-01	0.18022
Bus13	Bus25	21	2.00E-03	4.80E-02	0.04804
Bus14	Bus26	22	2.00E-03	4.80E-02	0.04804
Bus15	Bus27	23	1.10E-02	2.29E-01	0.22926
Bus16	Bus28	24	1.10E-02	2.29E-01	0.22926
Bus02	Bus04	25	2.50E-01	5.00	5.00525
Bus02	Bus03	26	3.16E-01	6.31	6.3219
Bus05	Bus17	27	1.50E-02	3.07E-01	0.30737
Bus06	Bus18	28	1.50E-02	3.07E-01	0.30737
Bus07	Bus19	29	8.00E-03	1.64E-01	0.1642
Bus08	Bus20	30	8.00E-03	1.66E-01	0.16619
Bus09	Bus21	31	4.00E-03	8.80E-02	0.08809
Bus10	Bus22	32	4.00E-03	8.80E-02	0.08809
Bus11	Bus23	33	9.00E-03	1.79E-01	0.17923

In the table **(Table 2.4)**, power losses are observed in all the lines connecting the busbars. Significant losses are observed between bus 01 and 02, while relatively low power losses are observed in the lines connecting bus 03 and 04 to the 30/380V transformer. On the other hand, no power dissipation is observed in the lines connecting the loads.

Total Generation:

- Real Power [MW]: 82.499
- Reactive Power [MVar]: 66.683
- Apparent Power [MVa]: 106.08

Total Load

- Real Power [MW]: 80.65
- Reactive Power [MVar]: 30.8
- Apparent Power [MVa]: 86.33

Total Losses

- Real Power [MW]: 1.849
- Reactive Power [MVar]: 35.883
- Apparent Power [MVa]: 35.93

There are many water tanks (Table 2.5) in the area. It will be used to generate electricity by means of a turbine fed by the tank's pump, below is a table of water tanks in the region:

Table 2.5: data of tanks in the region

number of the area	Names of hydraulic structure or installation, specifying type	Production capacity or volume m^3	Height in M	flow rate m^3/s	volume m^3/day
Area 01	tank	750	4.5	0.047	1570.667
Area 02	tank	800	4.5	0.047	1986
Area 03	tank	1500	4.5	0.047	2232
Area 04	tank	1500	4.5	0.047	1465.333
Area 05	tank	750	4.5	0.047	1130.533
Area 06	tank	1500	4.5	0.047	2086.333
Area 07	tank	1500	4.5	0.047	2480
Area 08	tank	1500	4.5	0.047	1857
Area 09	tank	1500	4.5	0.047	933.8667
Area 10	tank	800	4.5	0.047	1737
Area 11	water tower	1500	20	0.047	2199
Area 12	tank	350	4.5	0.047	2003.333
Area 13	tank	1400	4.5	0.047	1012.667
Area 14	tank	1000	4.5	0.047	1626.333
Area 15	tank	1500	4.5	0.047	2232
Area 16	tank	1500	4.5	0.047	1165.6
Area 17	tank	1500	4.5	0.047	1357.2
Area 18	tank	2000	4.5	0.047	2343.333
Area 19	tank	1500	4.5	0.047	2232
Area 20	tank	1500	4.5	0.047	1653.333
Area 21	tank	1500	4.5	0.047	1343.333

to calculate the hydraulic power in these cases we use the relation:

$$P_{hydraulic} = Q_n * H_n * \rho * g \quad (2.1)$$

$P_{hydraulic}$: Hydraulic power, in (W).

Q_n: Turbine flow, in (m^3/s).

H_n : Net drop, in (m).

ρ: Density of water in (kg/m3), 1000 kg/m3.

g : Acceleration due to gravity, 9.81 (m/s^2).

This table shows the values of active and reactive power produced by each tank in its region

Table 2.6: active and reactive power produced by generators of tanks in the region

Number Of the Area	Power (W)	Reactive (Var)
Area 01	2074.815	1285.855
Area 02	2074.815	1285.855
Area 03	2074.815	1285.855
Area 04	2074.815	1285.855
Area 05	2074.815	1285.855
Area 06	2074.815	1285.855
Area 07	2074.815	1285.855
Area 08	2074.815	1285.855
Area 09	2074.815	1285.855
Area 10	2074.815	1285.855
Area 11	9221.4	5714.910
Area 12	2074.815	1285.855
Area 13	2074.815	1285.855
Area 14	2074.815	1285.855
Area 15	2074.815	1285.855
Area 16	2074.815	1285.855
Area 17	2074.815	1285.855
Area 18	2074.815	1285.855
Area 19	2074.815	1285.855
Area 20	2074.815	1285.855
Area 21	2074.815	1285.855

This table **(table 2.6)** shows the values of active and reactive power produced by each tank in its region. Note that the power is the same for each tank because they have the same pumps.

2.4.2 Part II: After integration hydraulic power

The following results are obtained after feeding the electricity produced by the water tanks into the grid:

Simulation results (Table 2.7) show processing voltage on each bus

Table 2.7: Power Flow Results after integration hydraulic power

Bus	V [p.u]	phase [rad]	P gen [MW]	Q gen [MVar]	P load [MW]	Q load [MVar]
Bus01	1	0	81.5719	64.2892	0	0
Bus02	0.87737	-0.17958	0	0	0	0
Bus03	0.82269	-0.29141	0	0	0	0
Bus04	0.83518	-0.28372	0	0	0	0
Bus05	0.82194	-0.29151	0	0	0	0
Bus06	0.82194	-0.29151	0	0	0	0
Bus07	0.82215	-0.29147	0	0	0	0
Bus08	0.82214	-0.29147	0	0	0	0
Bus09	0.82229	-0.29143	0	0	0	0
Bus10	0.82229	-0.29142	0	0	0	0
Bus11	0.8346	-0.28377	0	0	0	0
Bus12	0.8346	-0.28378	0	0	0	0
Bus13	0.83489	-0.28383	0	0	0	0
Bus14	0.83489	-0.28383	0	0	0	0
Bus15	0.83454	-0.28385	0	0	0	0
Bus16	0.83454	-0.28384	0	0	0	0
Bus17	0.81187	-0.31855	0	0	9.5	3.9
Bus18	0.81191	-0.31857	0	0	8.9	3.1
Bus19	0.81454	-0.31093	0	0	4	1.1
Bus20	0.8143	-0.31092	0	0	9.3	4.4
Bus21	0.81604	-0.3051	0	0	3.8	1.6
Bus22	0.81596	-0.30508	0	0	5.6	3
Bus23	0.8263	-0.3039	0	0	7.1	3.9
Bus24	0.82633	-0.30397	0	0	7.1	2.1
Bus25	0.83267	-0.29526	0	0	4.4	0.4
Bus26	0.83268	-0.29522	0	0	3.6	1
Bus27	0.82684	-0.30742	0	0	7.2	0.9
Bus28	0.82671	-0.30732	0	0	9.3	4.5

The table **(Table 2.7)** shows the voltage values per unit and the phase in radians. The active and reactive power of the generator and the active and reactive power of the loads are measured in megawatts and megavolt-ampere reactive respectively. The active and reactive power of the generator is observed on busbar 01 and its absence is noted on the other busbars. The active and reactive power at busbars 17-28 is also recorded for the loads.

2.4.2.1 Powers transmitted in the power lines

The following two tables show the active and reactive powers that transmit in both directions 1 and 2.

Directions 1: This table shows us the active and reactive force and the apparent force transmitted in the first direction between the buses:

Table 2.8: The powers transmit in the lines of model directions 1after integration hydraulic power

From Bus	To Bus	Line	**P** Flow [MW]	**Q** Flow [Mvar]	S Flow [Mva]
Bus03	Bus05	1	9.21997	3.80553	9.97446
Bus03	Bus06	2	9.22532	3.79126	9.97398
Bus04	Bus15	3	8.28151	2.89565	8.77315
Bus04	Bus16	4	8.25278	2.95211	8.7649
Bus28	Bus27	5	-1.0642	-1.7715	2.06653
Bus26	Bus25	6	0.39292	-0.3024	0.49579
Bus24	Bus23	7	0.01149	0.89223	0.89231
Bus22	Bus21	8	-0.9013	-0.6829	1.13084
Bus20	Bus19	9	-2.6488	-1.6032	3.09617
Bus18	Bus17	10	0.30269	0.39288	0.49596
Bus03	Bus07	11	6.66151	2.86129	7.25001
Bus03	Bus08	12	6.66332	2.95618	7.28964
Bus03	Bus09	13	4.70775	2.36626	5.26898
Bus03	Bus10	14	4.70501	2.40075	5.28212
Bus04	Bus11	15	7.10195	3.1841	7.78307
Bus04	Bus12	16	7.12491	3.1692	7.79796
Bus04	Bus13	17	4.01078	0.75083	4.08045
Bus04	Bus14	18	3.99657	0.74574	4.06555
Bus01	Bus02	19	81.5719	64.2892	103.861
Bus12	Bus24	20	7.1202	3.16659	7.7926
Bus13	Bus25	21	4.00949	0.75011	4.07905
Bus14	Bus26	22	3.99529	0.74503	4.06416
Bus15	Bus27	23	8.27555	2.89234	8.76643
Bus16	Bus28	24	8.24684	2.94881	8.75818
Bus02	Bus04	25	39.0109	18.5452	43.1946
Bus02	Bus03	26	41.4823	24.1699	48.0101
Bus05	Bus17	27	9.21203	3.80112	9.96544

Bus06	Bus18	28	9.21739	3.78685	9.96496
Bus07	Bus19	29	6.65732	2.85896	7.24524
Bus08	Bus20	30	6.65908	2.95383	7.28481
Bus09	Bus21	31	4.70554	2.36503	5.26645
Bus10	Bus22	32	4.70279	2.39951	5.27957
Bus11	Bus23	33	7.09726	3.18149	7.77773

The table **(Table 2.8)** shows that the lines connecting the transformer operate at 60/30 kV, and busbars 03 and 04 have high conversion power in terms of active and reactive power, while the power levels are lower in the lines connecting busbars 03 and 04 to the transformer, which operates at 30/380V. In addition, the power transfer between loads via the connecting lines is relatively low.

Directions 2: This table shows us the active and reactive force and the apparent force transmitted in the second direction between the buses:

Table 2.9: The powers transmit in the lines of model directions 2 after integration hydraulic power

From Bus	To Bus	Line	**P** Flow [MW]	**Q** Flow [Mvar]	S Flow [Mva]
Bus05	Bus03	1	-9.212	-3.8011	9.96544
Bus06	Bus03	2	-9.2174	-3.7868	9.96496
Bus15	Bus04	3	-8.2755	-2.8923	8.76643
Bus16	Bus04	4	-8.2468	-2.9488	8.75818
Bus27	Bus28	5	1.06452	1.77165	2.06687
Bus25	Bus26	6	-0.3929	0.30237	0.49578
Bus23	Bus24	7	-0.0114	-0.8922	0.89227
Bus21	Bus22	8	0.90144	0.68299	1.13096
Bus19	Bus20	9	2.64955	1.60363	3.09706
Bus17	Bus18	10	-0.3027	-0.3929	0.49594
Bus07	Bus03	11	-6.6573	-2.859	7.24524
Bus08	Bus03	12	-6.6591	-2.9538	7.28481
Bus09	Bus03	13	-4.7055	-2.365	5.26645
Bus10	Bus03	14	-4.7028	-2.3995	5.27957
Bus11	Bus04	15	-7.0973	-3.1815	7.77773
Bus12	Bus04	16	-7.1202	-3.1666	7.7926
Bus13	Bus04	17	-4.0095	-0.7501	4.07905
Bus14	Bus04	18	-3.9953	-0.745	4.06416
Bus02	Bus01	19	-80.493	-42.715	91.1248
Bus24	Bus12	20	-7.1115	-2.9922	7.71535
Bus25	Bus13	21	-4.0071	-0.7024	4.06819
Bus26	Bus14	22	-3.9929	-0.6976	4.05341
Bus27	Bus15	23	-8.2645	-2.6717	8.68562
Bus28	Bus16	24	-8.2358	-2.7285	8.67604
Bus04	Bus02	25	-38.768	-13.698	41.1172
Bus03	Bus02	26	-41.183	-18.181	45.0177
Bus17	Bus05	27	-9.1973	-3.5071	9.84332
Bus18	Bus06	28	-9.2027	-3.4929	9.84326
Bus19	Bus07	29	-6.6496	-2.7036	7.17817
Bus20	Bus08	30	-6.6512	-2.7968	7.21533
Bus21	Bus09	31	-4.7014	-2.283	5.22643

Bus22	Bus10	32	-4.6987	-2.3171	5.23892
Bus23	Bus11	33	-7.0886	-3.0078	7.70031

The table **(Table 2.9)** shows that the lines connecting the transformer operate at 60/30 kV, and busbars 03 and 04 have high conversion power in terms of active and reactive power, while the power levels are lower in the lines connecting busbars 03 and 04 to the transformer, which operates at 30/380V. In addition, the power transfer between the loads through the connecting lines is relatively weak, the active and reactive power is negative due to a reverse direction.

2.4.2.2 Active and reactive power losses

The following table shows the active and reactive power losses in this network

Table 2.10: Active and reactive power losses after integration hydraulic power

From Bus	To Bus	Line	**P** loss [MW]	**Q** loss [Mvar]	S loss [Mva]
Bus03	Bus05	1	0.007938	0.00441	0.00908
Bus03	Bus06	2	0.007937	0.004409	0.00908
Bus04	Bus15	3	0.005959	0.00331	0.00682
Bus04	Bus16	4	0.005947	0.003304	0.0068
Bus28	Bus27	5	0.000337	0.000187	0.00039
Bus26	Bus25	6	1.91E-05	1.06E-05	2.2E-05
Bus24	Bus23	7	6.3E-05	3.5E-05	7.2E-05
Bus22	Bus21	8	0.000104	5.76E-05	0.00012
Bus20	Bus19	9	0.000781	0.000434	0.00089
Bus18	Bus17	10	2.01E-05	1.12E-05	2.3E-05
Bus03	Bus07	11	0.004194	0.00233	0.0048
Bus03	Bus08	12	0.00424	0.002355	0.00485
Bus03	Bus09	13	0.002215	0.001231	0.00253
Bus03	Bus10	14	0.002226	0.001237	0.00255
Bus04	Bus11	15	0.00469	0.002605	0.00536
Bus04	Bus12	16	0.004708	0.002615	0.00539
Bus04	Bus13	17	0.001289	0.000716	0.00147
Bus04	Bus14	18	0.00128	0.000711	0.00146
Bus01	Bus02	19	1.078707	21.57415	21.6011
Bus12	Bus24	20	0.008718	0.174355	0.17457
Bus13	Bus25	21	0.002387	0.047741	0.0478
Bus14	Bus26	22	0.00237	0.047393	0.04745
Bus15	Bus27	23	0.011035	0.220691	0.22097
Bus16	Bus28	24	0.011014	0.220275	0.22055
Bus02	Bus04	25	0.242376	4.847512	4.85357
Bus02	Bus03	26	0.29943	5.988596	5.99608
Bus05	Bus17	27	0.0147	0.293994	0.29436
Bus06	Bus18	28	0.014698	0.293965	0.29433
Bus07	Bus19	29	0.007766	0.155323	0.15552
Bus08	Bus20	30	0.007851	0.157026	0.15722
Bus09	Bus21	31	0.004102	0.082037	0.08214
Bus10	Bus22	32	0.004122	0.082447	0.08255
Bus11	Bus23	33	0.008684	0.17369	0.17391

In the table **(Table 2.10)**, power losses are observed in all the lines connecting the busbars. Significant losses are observed between bus 01 and 02, while relatively low power losses are observed in the lines connecting bus 03 and 04 to the 30/380V transformer. On the other hand, no power dissipation is observed in the lines connecting the loads.

Total Generation:

- Real Power [MW]: 81.571
- Reactive Power [MVar]: 65.749
- Apparent Power [MVa]: 104.770

Total Load

- Real Power [MW]: 79.67
- Reactive Power [MVar]: 29.9
- Apparent Power [MVa]: 85.09

Total Losses

- Real Power [MW]: 1.172
- Reactive Power [MVar]: 34.389
- Apparent Power [MVa]: 34.41

2.5 Comparison of results before and after integration

This table shows the voltage to be applied at each busbar level before and after integrating.

Table 2.11: voltage values of buses before and after integration

	Before		After		ΔV_2-ΔV_1	%
Bus	V [p.u.]	ΔV_1	V [p.u.]	ΔV_2		
Bus01	1	0	1	0	0	0
Bus02	0.87286	0.12714	0.87737	0.12263	-0.00451	-2.54
Bus03	0.8158	0.1842	0.82269	0.17731	-0.00689	-4.18
Bus04	0.82943	0.17057	0.83518	0.16482	-0.00575	-3.23
Bus05	0.81504	0.18496	0.82194	0.17806	-0.0069	-3.88
Bus06	0.81504	0.18496	0.82194	0.17806	-0.0069	-3.88
Bus07	0.81524	0.18476	0.82215	0.17785	-0.00691	-3.89
Bus08	0.81524	0.18476	0.82214	0.17786	-0.0069	-3.88
Bus09	0.81539	0.18461	0.82229	0.17771	-0.0069	-3.88
Bus10	0.81539	0.18461	0.82229	0.17771	-0.0069	-4.17
Bus11	0.82885	0.17115	0.8346	0.1654	-0.00575	-3.48
Bus12	0.82885	0.17115	0.8346	0.1654	-0.00575	-3.48
Bus13	0.82914	0.17086	0.83489	0.16511	-0.00575	-3.48
Bus14	0.82914	0.17086	0.83489	0.16511	-0.00575	-3.48
Bus15	0.82878	0.17122	0.83454	0.16546	-0.00576	-3.48
Bus16	0.82878	0.17122	0.83454	0.16546	-0.00576	-3.06
Bus17	0.8046	0.1954	0.81187	0.18813	-0.00727	-3.87
Bus18	0.80463	0.19537	0.81191	0.18809	-0.00728	-3.93
Bus19	0.80729	0.19271	0.81454	0.18546	-0.00725	-3.90
Bus20	0.80706	0.19294	0.8143	0.1857	-0.00724	-3.94
Bus21	0.80882	0.19118	0.81604	0.18396	-0.00722	-3.92
Bus22	0.80873	0.19127	0.81596	0.18404	-0.00723	-4.16
Bus23	0.82034	0.17966	0.8263	0.1737	-0.00596	-3.43
Bus24	0.82038	0.17962	0.82633	0.17367	-0.00595	-3.56
Bus25	0.8269	0.1731	0.83267	0.16733	-0.00577	-3.45
Bus26	0.82692	0.17308	0.83268	0.16732	-0.00576	-3.33
Bus27	0.82077	0.17923	0.82684	0.17316	-0.00607	-3.50
Bus28	0.82063	0.17937	0.82671	0.17329	-0.00608	-3.51

This table **(table 2.11)** shows the voltage values at each level of the buses before and after integration. The results show an increase in voltage on the buses after integration, with percentages ranging from 2.50% to 4.20%.

This table gives us the active and reactive power losses in this network before and after integration

Table 2.12: active and reactive power losses before and after integration

			before		after		difference	
From Bus	To Bus	Line	**P** loss [MW]	**Q** loss [Mvar]	**P** loss [MW]	**Q** loss [Mvar]	**P** loss [MW]	**Q** loss [Mvar]
Bus03	Bus05	1	8.00E-03	5.00E-03	0.007938	0.00441	-6.20E-05	-5.90E-04
Bus03	Bus06	2	8.00E-03	5.00E-03	0.007937	0.004409	-6.30E-05	-5.91E-04
Bus04	Bus15	3	6.00E-03	3.00E-03	0.005959	0.00331	-4.10E-05	-3.10E-04
Bus04	Bus16	4	6.00E-03	3.00E-03	0.005947	0.003304	-5.30E-05	-3.04E-04
Bus28	Bus27	5	0	0	0.000337	0.000187	-3.37E-04	-1.87E-04
Bus26	Bus25	6	0	0	1.91E-05	1.06E-05	-1.91E-05	-1.06E-05
Bus24	Bus23	7	0	0	6.3E-05	3.5E-05	-6.30E-05	-3.50E-05
Bus22	Bus21	8	0	0	0.000104	5.76E-05	-1.04E-04	-5.76E-05
Bus20	Bus19	9	0	0	0.000781	0.000434	-7.81E-04	-4.34E-04
Bus18	Bus17	10	0	0	2.01E-05	1.12E-05	-2.01E-05	-1.12E-05
Bus03	Bus07	11	4.00E-03	2.00E-03	0.004194	0.00233	-1.94E-04	-3.30E-04
Bus03	Bus08	12	4.00E-03	2.00E-03	0.00424	0.002355	-2.40E-04	-3.55E-04
Bus03	Bus09	13	2.00E-03	1.00E-03	0.002215	0.001231	-2.15E-04	-2.31E-04
Bus03	Bus10	14	2.00E-03	1.00E-03	0.002226	0.001237	-2.26E-04	-2.37E-04
Bus04	Bus11	15	5.00E-03	3.00E-03	0.00469	0.002605	3.10E-04	-3.95E-04
Bus04	Bus12	16	5.00E-03	3.00E-03	0.004708	0.002615	2.92E-04	-3.85E-04
Bus04	Bus13	17	1.00E-03	1.00E-03	0.001289	0.000716	-2.89E-04	-2.84E-04
Bus04	Bus14	18	1.00E-03	1.00E-03	0.00128	0.000711	-2.80E-04	-2.89E-04
Bus01	Bus02	19	1.13	2.25E+01	1.078707	21.57415	5.13E-02	-9.26E-01
Bus12	Bus24	20	9.00E-03	1.80E-01	0.008718	0.174355	-2.82E-04	-5.64E-03
Bus13	Bus25	21	2.00E-03	4.80E-02	0.002387	0.047741	-3.87E-04	-2.59E-04
Bus14	Bus26	22	2.00E-03	4.80E-02	0.00237	0.047393	-3.70E-04	-6.07E-04
Bus15	Bus27	23	1.10E-02	2.29E-01	0.011035	0.220691	-3.50E-05	-8.31E-03
Bus16	Bus28	24	1.10E-02	2.29E-01	0.011014	0.220275	-1.40E-05	-8.73E-03
Bus02	Bus04	25	2.50E-01	5	0.242376	4.847512	-7.62E-03	-1.52E-01
Bus02	Bus03	26	3.16E-01	6.31	0.29943	5.988596	-1.66E-02	-3.21E-01
Bus05	Bus17	27	1.50E-02	3.07E-01	0.0147	0.293994	-3.00E-04	-1.30E-02
Bus06	Bus18	28	1.50E-02	3.07E-01	0.014698	0.293965	-3.02E-04	-1.30E-02
Bus07	Bus19	29	8.00E-03	1.64E-01	0.007766	0.155323	-2.34E-04	-8.68E-03
Bus08	Bus20	30	8.00E-03	1.66E-01	0.007851	0.157026	-1.49E-04	-8.97E-03
Bus09	Bus21	31	4.00E-03	8.80E-02	0.004102	0.082037	-1.02E-04	-5.96E-03
Bus10	Bus22	32	4.00E-03	8.80E-02	0.004122	0.082447	-1.22E-04	-5.55E-03
Bus11	Bus23	33	9.00E-03	1.79E-01	0.008684	0.17369	-3.16E-04	-5.31E-03

The table (**Table 2.12**) shows the active and reactive losses before and after the integration of hydraulic power into the grid. A decrease in real and reactive power losses is observed after integration.

Table 2.13: Comparison of results before and after integration

		before	after	difference
Total Generation	Real Power [MW]	82.499	81.571	0.928
	Reactive Power[MVar]	66.68	65.749	0.931
	Apparent Power [MVa]	106.08	104.770	1.31
Total Load	Real Power [MW]	80.65	79.67	0.98
	Reactive Power[MVar]	30.8	29.9	0.9
	Apparent Power [MVa]	86.33	85.09	1.24
Total Losses	Real Power [MW]	1.849	1.172	0.677
	Reactive Power[MVar]	35.883	34.389	1.494
	Apparent Power [MVa]	35.93	34.41	1.52

The table **(Table 2.13)** shows the total power values of generators, loads and losses before and after the integration of hydraulic power into the grid. A decrease in real power is observed at the generator and the load, as well as losses ranging from 0.6 to 0.9 MW; a decrease in reactive power at the generator and the load, as well as losses, ranging between 0.9 and 1.4 MVar.

2.6 Conclusion

In this chapter, Simulations were conducted using the PSAT toolbox for an electrical network in a region located in the south of the desert. The results were divided into two sections: the first section before the generated energy was added through water tanks, and the second section where the results were compared after the addition.

CHAPTER 03

Comparison and interpretation of results

Chapter 3 : Comparison and interpretation of results

Introduction

In this chapter, the study will focus on analyzing the results of integrating hydropower into the grid and proposing supporting solutions to improve the results. It also assesses the feasibility and profitability of the investment and compares the results of different solutions.

3.1 solution: Utilization of hydraulic power during water descent

The table (Table 3.1) shows the proposed pumps for electricity generation

Table 3.1: active and reactive power produced by generators of tanks in the region

number of the area	Height in M	flow rate m^3/s	volume m^3/day	Power(W)	Reactive(VAR)
Area 01	4.5	0.047	1570.67	2074.815	1285.855
Area 02	4.5	0.047	1986	2074.815	1285.855
Area 03	4.5	0.047	2232	2074.815	1285.855
Area 04	4.5	0.047	1465.34	2074.815	1285.855
Area 05	4.5	0.047	1130.53	2074.815	1285.855
Area 06	4.5	0.047	2086.33	2074.815	1285.855
Area 07	4.5	0.047	2480	2074.815	1285.855
Area 08	4.5	0.047	1857	2074.815	1285.855
Area 09	4.5	0.047	933.87	2074.815	1285.855
Area 10	4.5	0.047	1737	2074.815	1285.855
Area 11	20	0.047	2199	9221.4	5714.910
Area 12	4.5	0.047	2003.33	2074.815	1285.855
Area 13	4.5	0.047	1012.67	2074.815	1285.855
Area 14	4.5	0.047	1626.33	2074.815	1285.855
Area 15	4.5	0.047	2232	2074.815	1285.855
Area 16	4.5	0.047	1165.6	2074.815	1285.855
Area 17	4.5	0.047	1357.2	2074.815	1285.855
Area 18	4.5	0.047	2343.33	2074.815	1285.855
Area 19	4.5	0.047	2232	2074.815	1285.855
Area 20	4.5	0.047	1653.33	2074.815	1285.855
Area 21	4.5	0.047	1343.33	2074.815	1285.855

The values of active and reactive power generated by each tank within its region are presented in (**Table 3.1**). It is important to observe that the power remains consistent across all tanks due to the identical nature of their pumps.

3.1.1 Energy value generated by tank pumps

The table shows the energy values produced by the tank pumps and the following relation is used to calculate the energy:

$$T_{time} = \frac{\text{volume } (m^3)}{\text{flow rate } (\frac{m^3}{s})} \tag{3.1}$$

$$E_{electrical} = P_{hydraulic} \times T_{time} \tag{3.2}$$

Table 3.2: Energy value generated by tank pumps

Number Of the Area	Power(W)	Time	$E_{electrical}$ (Wh)	$E_{electrical}$ (KWh)
Area 01	2074.815	9h 16min	19260.3	19.2603
Area 02	2074.815	11h 44min	24353.325	24.35333
Area 03	2074.815	13h 11min	27369.9	27.3699
Area 04	2074.815	8h 39min	17968.65	17.96865
Area 05	2074.815	6h 40min	13863.165	13.86317
Area 06	2074.815	12h 19min	25583.6625	25.58366
Area 07	2074.815	14h 39min	30411	30.411
Area 08	2074.815	10h 58min	22771.4625	22.77146
Area 09	2074.815	5h 31min	11451.54	11.45154
Area 10	2074.815	10h 15min	21299.9625	21.29996
Area 11	9221.4	12h 59min	119845.5	119.8455
Area 12	2074.815	11h 50min	24565.875	24.56588
Area 13	2074.815	5h 59min	12417.825	12.41783
Area 14	2074.815	9h 36min	19942.9125	19.94291
Area 15	2074.815	13h 11min	27369.9	27.3699
Area 16	2074.815	6h 53min	14293.17	14.29317
Area 17	2074.815	8h 1min	16642.665	16.64267
Area 18	2074.815	13h 50min	28735.125	28.73513
Area 19	2074.815	13h 11min	27369.9	27.3699
Area 20	2074.815	9h 46min	20274	20.274
Area 21	2074.815	7h 56min	16472.625	16.47263

This table **(Table 3.2)** shows the energy values produced by the tank pumps at each area level. The results show the variation in energy.

Total energy produced in the day :

generator efficiency η = 85%

$$E_{electrical\ eff} = E_{electrical} \times \eta \quad (3.3)$$

$$542.2625 \times 0.85 = 460.92 KWh$$

Total energy produced in the year :

$$460.92 \times 365 = 168236.94 KWh$$

The price of electricity in Algeria is calculated by 1KWh = 5.4796 Da

The price per day is :

$$\text{Price per day} = E_{electrical\ eff} \times 5.4796 \text{ Da} \quad (3.4)$$

$$460.92 \times 5.4796 = 2525.66 \text{ DA}$$

In year :

$$168236.94 \times 5.4796 = 921871.14 \text{ DA}$$

The monetary return generated from the energy production per year is 921871.14 DA.

3.1.2 Cost of hydraulic pump installation

Given the characteristics of the tanks available in the region, high 4.5 meters and debut 0.047 m3/s, for these characteristics the most suitable turbine is a Kaplan turbine generating from 3kW to 5kW.

The installation of a Kaplan impeller for a hydraulic pump includes several essential components. The main basic components are as follows:

1. Kaplan turbine: This is the turbine itself, which converts hydraulic energy into mechanical energy. The Kaplan turbine consists of a central hub and adjustable blades, allowing its performance to be optimized according to the flow and head conditions.

2. Generator: The generator is the element that converts the mechanical energy supplied by the turbine into electricity. It consists of a rotor and a stator and uses the principles of electromagnetic induction to produce electricity.

3. Penstock: This is the channel or pipe that carries water from the source to the turbine. The penstock is usually made up of specific pipes or ducts, designed to withstand the pressure of the water.

4. Control valve: The control valve controls the flow of water into the turbine. It regulates the speed of the turbine and therefore the amount of energy produced.

5. Filtration device: To avoid damage caused by solid particles in the water, a filtration device is often installed upstream of the turbine. This may be a screen system, grids or other suitable filtration device.

6. Control and monitoring system: A control and monitoring system is used to supervise and regulate the performance of the plant. It may include pressure, flow and temperature sensors, and a user interface to monitor and control operating parameters.

The total cost of installing a small Kaplan turbine with an output of 3 kW to 5 kW is approximately 400000 DA .

3.1.3 Rate of return on investment

$$\boldsymbol{Ec \times 5.4796t = C_{invst} + E_{CRE} \times 5.4796t} \tag{3.5}$$

$\boldsymbol{Ec}$: total energy of grid in the region **.**

$\boldsymbol{C_{invst}}$ **:** total cost of investment .

$\boldsymbol{E_{CRE}}$ **:** Ec - E_{hyd}

$\boldsymbol{E_{hyd}}$ **:** total energy of hydraulic pumps

$$t = \frac{C_{invst}}{Ec \times 5.4796 - E_{CRE} \times 5.4796} \tag{3.6}$$

$\boldsymbol{C_{invst}}$ = 400000 × 21 = 8400000 DA (3.7)

$\boldsymbol{Ec}$ = 81571 × 365 = 29773415 kwh / year (3.8)

$\boldsymbol{E_{hyd}}$ = 168236.94Kwh / year

$\boldsymbol{E_{CRE}}$ **:** 29773415 - 168236.94 = 29605178.06 (3.9)

$$t = \frac{8400000}{29773415 \times 5.4796 - 29605178.06 \times 5.4796}$$

$t = 9.111902$ year

$t =$ 9 years 1 month 20 hours 15 minutes

Rate of return on investment is 9 years 1 month 10 days 20 hours 15 minutes.

3.2 Solution: Utilization of pumps that do not store their water

There are several pumps in the area that directly serve customers without storage tanks. It is proposed that if these pumps are used, they can pump water into storage tanks. The water can then be distributed around the area and used to generate electricity through turbines when it is released during consumption.

The table (Table 3.3) shows the proposed pumps for electricity generation.

Table 3.3: active and reactive power produced by generators of tanks in the region

number of the chain/transfer	Height in M	flow rate m^3/s	volume m^3/day	Power(W)	Reactive(VAR)
Area 22	4.5	0.047	1577.333	2074.815	1285.855
Area 23	4.5	0.047	1165.600	2074.815	1285.855
Area 24	4.5	0.047	1240.000	2074.815	1285.855
Area 25	4.5	0.047	1722.000	2074.815	1285.855
Area 26	4.5	0.047	2202.000	2074.815	1285.855
Area 27	4.5	0.047	1438.400	2074.815	1285.855
Area 28	4.5	0.047	920.000	2074.815	1285.855
Area 29	4.5	0.047	1550.000	2074.815	1285.855
Area 30	4.5	0.047	1519.433	2074.815	1285.855
Area 31	4.5	0.047	1607.500	2074.815	1285.855
Area 32	20	0.047	1649.667	9221.4	5714.910
Area 33	4.5	0.047	1461.600	2074.815	1285.855
Area 34	4.5	0.047	2495.667	2074.815	1285.855
Area 35	4.5	0.047	1984.000	2074.815	1285.855
Area 36	4.5	0.047	1607.667	2074.815	1285.855
Area 37	4.5	0.047	2728.000	2074.815	1285.855
Area 38	4.5	0.047	1984.000	2074.815	1285.855
Area 39	4.5	0.047	1276.333	2074.815	1285.855
Area 40	4.5	0.047	1688.400	2074.815	1285.855
Area 41	4.5	0.047	1387.767	2074.815	1285.855
Area 42	4.5	0.047	1092.567	2074.815	1285.855
Area 43	4.5	0.047	1160.000	2074.815	1285.855
Area 44	4.5	0.047	1064.000	2074.815	1285.855
Area 45	4.5	0.047	1488.000	2074.815	1285.855
Area 46	4.5	0.047	1457.667	2074.815	1285.855
Area 47	4.5	0.047	347.600	2074.815	1285.855
Area 48	4.5	0.047	728.500	2074.815	1285.855

This table **(Table 3.3)** shows the values of active and reactive power produced by each tank in its region. Note that the power is the same for each tank because they have the same character pumps.

3.2.1 Comparison of results before and after integration

This table shows the voltage to be applied at each busbar level before and after integrating

Table 3.4: tension values of busbars before and after integration all hydraulic power

	Before		After		ΔV_2-ΔV_1	%
Bus	V [p.u.]	ΔV_1	V [p.u.]	ΔV_2		
Bus01	1	0	1	0	0	0
Bus02	0.87286	0.12714	0.87834	0.12166	-0.00548	-3.11
Bus03	0.8158	0.1842	0.82374	0.17626	-0.00794	-4.87
Bus04	0.82943	0.17057	0.83681	0.16319	-0.00738	-4.17
Bus05	0.81504	0.18496	0.823	0.177	-0.00796	-4.50
Bus06	0.81504	0.18496	0.823	0.177	-0.00796	-4.50
Bus07	0.81524	0.18476	0.8232	0.1768	-0.00796	-4.50
Bus08	0.81524	0.18476	0.8232	0.1768	-0.00796	-4.51
Bus09	0.81539	0.18461	0.82334	0.17666	-0.00795	-4.50
Bus10	0.81539	0.18461	0.82334	0.17666	-0.00795	-4.85
Bus11	0.82885	0.17115	0.83625	0.16375	-0.0074	-4.52
Bus12	0.82885	0.17115	0.83625	0.16375	-0.0074	-4.53
Bus13	0.82914	0.17086	0.83653	0.16347	-0.00739	-4.52
Bus14	0.82914	0.17086	0.83654	0.16346	-0.0074	-4.52
Bus15	0.82878	0.17122	0.83618	0.16382	-0.0074	-4.52
Bus16	0.82878	0.17122	0.83618	0.16382	-0.0074	-3.96
Bus17	0.8046	0.1954	0.81294	0.18706	-0.00834	-4.46
Bus18	0.80463	0.19537	0.81297	0.18703	-0.00834	-4.52
Bus19	0.80729	0.19271	0.8156	0.1844	-0.00831	-4.50
Bus20	0.80706	0.19294	0.81536	0.18464	-0.0083	-4.54
Bus21	0.80882	0.19118	0.8171	0.1829	-0.00828	-4.53
Bus22	0.80873	0.19127	0.81702	0.18298	-0.00829	-4.82
Bus23	0.82034	0.17966	0.82809	0.17191	-0.00775	-4.51
Bus24	0.82038	0.17962	0.82812	0.17188	-0.00774	-4.68
Bus25	0.8269	0.1731	0.83445	0.16555	-0.00755	-4.56
Bus26	0.82692	0.17308	0.83446	0.16554	-0.00754	-4.40
Bus27	0.82077	0.17923	0.8285	0.1715	-0.00773	-4.50
Bus28	0.82063	0.17937	0.82837	0.17163	-0.00774	-4.51

This table **(Table 3.4)** shows the voltage values at each level of the buses before and after integration. The results show an increase in voltage on the buses after integration, with percentages ranging from 3.10% to 4.90%.

This table gives us the active and reactive power losses in this network before and after integration

Table 3.5: active and reactive power losses before and after integration

			before		after		difference	
From Bus	To Bus	Line	**P** loss [MW]	**Q** loss [Mvar]	**P** loss [MW]	**Q** loss [Mvar]	**P** loss [MW]	**Q** loss [Mvar]
Bus03	Bus05	1	8.00E-03	5.00E-03	0.007917	0.004398	8.30E-05	6.02E-04
Bus03	Bus06	2	8.00E-03	5.00E-03	0.007916	0.004398	8.37E-05	6.02E-04
Bus04	Bus15	3	6.00E-03	3.00E-03	0.005935	0.003297	6.51E-05	-2.97E-04
Bus04	Bus16	4	6.00E-03	3.00E-03	0.005924	0.003291	7.63E-05	-2.91E-04
Bus28	Bus27	5	0	0	0.000336	0.000187	-3.36E-04	-1.87E-04
Bus26	Bus25	6	0	0	0.000019	0.000010	-1.87E-05	-1.04E-05
Bus24	Bus23	7	0	0	0.000070	0.000039	-7.01E-05	-3.89E-05
Bus22	Bus21	8	0	0	0.000103	0.000057	-1.03E-04	-5.75E-05
Bus20	Bus19	9	0	0	0.000779	0.000433	-7.79E-04	-4.33E-04
Bus18	Bus17	10	0	0	0.000020	0.000011	-2.01E-05	-1.12E-05
Bus03	Bus07	11	4.00E-03	2.00E-03	0.004183	0.002324	-1.83E-04	-3.24E-04
Bus03	Bus08	12	4.00E-03	2.00E-03	0.004229	0.002349	-2.29E-04	-3.49E-04
Bus03	Bus09	13	2.00E-03	1.00E-03	0.002209	0.001227	-2.09E-04	-2.27E-04
Bus03	Bus10	14	2.00E-03	1.00E-03	0.002220	0.001233	-2.20E-04	-2.33E-04
Bus04	Bus11	15	5.00E-03	3.00E-03	0.004591	0.002550	4.09E-04	4.50E-04
Bus04	Bus12	16	5.00E-03	3.00E-03	0.004608	0.002560	3.92E-04	4.40E-04
Bus04	Bus13	17	1.00E-03	1.00E-03	0.001247	0.000693	-2.47E-04	3.07E-04
Bus04	Bus14	18	1.00E-03	1.00E-03	0.001238	0.000688	-2.38E-04	3.12E-04
Bus01	Bus02	19	1.13	2.25E+01	1.068628	21.372560	6.14E-02	1.13E+00
Bus12	Bus24	20	9.00E-03	1.80E-01	0.008533	0.170660	4.67E-04	9.34E-03
Bus13	Bus25	21	2.00E-03	4.80E-02	0.002310	0.046200	-3.10E-04	1.80E-03
Bus14	Bus26	22	2.00E-03	4.80E-02	0.002293	0.045858	-2.93E-04	2.14E-03
Bus15	Bus27	23	1.10E-02	2.29E-01	0.010990	0.219810	9.52E-06	9.19E-03
Bus16	Bus28	24	1.10E-02	2.29E-01	0.010970	0.219396	3.02E-05	9.60E-03
Bus02	Bus04	25	2.50E-01	5	0.238384	4.767689	1.16E-02	2.32E-01
Bus02	Bus03	26	3.16E-01	6.31	0.298648	5.972966	1.74E-02	3.37E-01
Bus05	Bus17	27	1.50E-02	3.07E-01	0.014661	0.293223	3.39E-04	1.38E-02
Bus06	Bus18	28	1.50E-02	3.07E-01	0.014660	0.293195	3.40E-04	1.38E-02

Bus07	Bus19	29	8.00E-03	1.64E-01	0.007746	0.154919	2.54E-04	9.08E-03
Bus08	Bus20	30	8.00E-03	1.66E-01	0.007831	0.156617	1.69E-04	9.38E-03
Bus09	Bus21	31	4.00E-03	8.80E-02	0.004091	0.081825	-9.12E-05	6.18E-03
Bus10	Bus22	32	4.00E-03	8.80E-02	0.004112	0.082233	-1.12E-04	5.77E-03
Bus11	Bus23	33	9.00E-03	1.79E-01	0.008501	0.170019	4.99E-04	8.98E-03

The table (**Table 3.5**) shows the active and reactive losses before and after the integration of hydraulic power into the grid. A decrease in real and reactive power losses is observed after integration all hydraulic power of the region.

Comparison of results before and after integration all hydraulic power

Table 3.6: Comparison of results before and after integration all hydraulic power

		before	after	difference
Total Generation	Real Power [MW]	82.499	81.356	1.143
	Reactive Power[MVar]	66.68	63.777	2.903
	Apparent Power [MVa]	106.08	103.370	2.71
Total Load	Real Power [MW]	80.65	79.6	1.05
	Reactive Power[MVar]	30.8	29.7	1.1
	Apparent Power [MVa]	86.33	85.09	1.24
Total Losses	Real Power [MW]	1.849	1.756	0.093
	Reactive Power[MVar]	35.883	34.0769	1.8061
	Apparent Power [MVa]	35.93	34.41	1.52

The table **(Table 3.6)** shows the total power values of generators, loads and losses before and after the integration of hydraulic power into the grid. A decrease in real power is observed at the generator and the load, as well as losses ranging from 0.9 to 1MW; a decrease in reactive power at the generator and the load, as well as losses, ranging between 1and 2 MVar.

3.2.2 Energy value generated by tank pumps

The table shows the energy values produced by the tank pumps and the following relation is used to calculate the energy:

Table 3.7: Energy value generated by tank pumps

Number Of the Area	Power(W)	Time	$E_{electrical}$ (Wh)	$E_{electrical}$ (KWh)
Area 22	2074.815	9h 19min	19342.05	19.34205
Area 23	2074.815	6h 53min	14293.17	14.29317
Area 24	2074.815	7h 19min	15205.5	15.2055
Area 25	2074.815	10h 10min	21116.025	21.116025
Area 26	2074.815	13h	27002.025	27.002025
Area 27	2074.815	8h 30min	17638.38	17.63838
Area 28	2074.815	5h 26min	11281.5	11.2815
Area 29	2074.815	9h 10min	19006.875	19.006875
Area 30	2074.815	8h 58min	18632.05125	18.63205125
Area 31	2074.815	9h 30min	19711.96875	19.71196875
Area 32	9221.4	9h 44min	89906.83333	89.90683333
Area 33	2074.815	8h 38min	17922.87	17.92287
Area 34	2074.815	14h 44min	30603.1125	30.6031125
Area 35	2074.815	11h 43min	24328.8	24.3288
Area 36	2074.815	9h 30min	19714.0125	19.7140125
Area 37	2074.815	16h 07min	33452.1	33.4521
Area 38	2074.815	11h 43min	24328.8	24.3288
Area 39	2074.815	7h 32min	15651.0375	15.6510375
Area 40	2074.815	9h 58min	20704.005	20.704005
Area 41	2074.815	8h 12min	17017.48875	17.01748875
Area 42	2074.815	6h 27min	13397.59875	13.39759875
Area 43	2074.815	6h 51min	14224.5	14.2245
Area 44	2074.815	6h 17min	13047.3	13.0473
Area 45	2074.815	8h 47min	18246.6	18.2466
Area 46	2074.815	8h 36min	17874.6375	17.8746375
Area 47	2074.815	2h 03min	4262.445	4.262445
Area 48	2074.815	4h 18min	8933.23125	8.93323125

This table **(Table 3.6)** shows the energy values produced by the tank pumps at each area level. The results show the variation in energy.

Total energy produced in the day :

generator efficiency η = 85%

$$E_{electrical\ eff} = E_{electrical} \times \eta \qquad (3.10)$$

$$1109.1074 \times 0.85 = 942.74129 \text{ KWh} .$$

Total energy produced in the year :

$$942.74129 \times 365 = 344100.5709 \text{ KWh}$$

The price of electricity in Algeria is calculated by 1KWh = 5.4796 DA

The price per day is :

$$\text{Price per day } = E_{electrical\ eff} \times 5.4796 \text{ Da} \tag{3.11}$$

$$942.74129 \times 5.4796 = 5156.845173 \text{ DA}$$

In year :

$$344100.5709 \times 5.4796 = 1885533.488 \text{ DA}$$

The monetary return generated from the energy production per year is 1885533.488 DA.

3.2.3 Cost of hydraulic pump installation

The total cost of installing a small Kaplan turbine with an output of 3 kW to 5 kW is approximately 400000 DA ,total are 48 turbines.

$\boldsymbol{C_{invst}}$ **:** 400000 DA × 48 pumps = 19200000 DA

3.2.4 Rate of return on investment

$$\boldsymbol{Ec \times 5.4796t = C_{invst} + E_{CRE} \times 5.4796} \tag{3.12}$$

$\boldsymbol{Ec}$: total energy of grid in the region **.**

$\boldsymbol{C_{invst}}$ **:** total cost of investment .

$\boldsymbol{E_{CRE}}$ **:** Ec - E_{hyd}

$\boldsymbol{E_{hyd}}$ **:** total energy of hydraulic pumps

$$t = \frac{C_{invst}}{Ec \times 5.4796 - E_{CRE} \times 5.4796} \tag{3.13}$$

$\boldsymbol{C_{invst}}$ **:** 400000 DA × 48 pumps = 19200000 DA

Ec = 81356 kwh × 365 = 29694940 kwh

E_{hyd} = 1885533.46 kwh

E_{CRE} = 29694940 – 1885533.488 = 27809406.54 kwh

$$t = \frac{400000 \times 48}{Ec \times 5.4796 - E_{CRE} \times 5.4796}$$

$$t = \frac{400000 \times 48}{29694940 \times 5.4796 - 27809406.54 \times 5.4796}$$

$t = 1.85831$

$t =$ 1 years 10 month 13 days 6 hours 47 minutes

Rate of return on investment is 1 years 10 month 13 days 6 hours 47 minutes.

3.3 Solution : Powering the pumps using solar panels

After a thorough review and research with the relevant authorities, it was found that the water distribution department is one of the largest consumers of electricity in the country due to its pumping activities, and the proposed solution is to power the pumps with solar energy, Photovoltaic pumping system and this Pumping system using DC motor.

3.3.1 Dimensioning of the photovoltaic (PV) system

In the calculation relied on solar panel characteristics of the type YL250P-29b powered by YINGLI, the price of the solar panel is 32800 DA.

YGE 60 CELL SERIES

Powered by YINGLI

ELECTRICAL PERFORMANCE

Electrical parameters at Standard Test Conditions (STC)							
Module type			YL270P-29b	YL265P-29b	YL260P-29b	YL255P-29b	YL250P-29b
Power output	P_{max}	W	270	265	260	255	250
Power output tolerances	ΔP_{max}	%			0 / +3		
Module efficiency	η_m	%	16.6	16.3	16.0	15.7	15.4
Voltage at P_{max}	V_{mpp}	V	30.7	30.5	30.3	30.0	29.8
Current at P_{max}	I_{mpp}	A	8.80	8.70	8.59	8.49	8.39
Open-circuit voltage	V_{oc}	V	37.9	37.8	37.7	37.7	37.6
Short-circuit current	I_{sc}	A	9.27	9.18	9.09	9.01	8.92

STC: 1000W/m² irradiance, 25°C cell temperature, AM 1.5G spectrum according to EN 60904-3.

Electrical parameters at Nominal Operating Cell Temperature (NOCT)							
Power output	P_{max}	W	196.9	193.3	189.7	186.0	182.4
Voltage at P_{max}	V_{mpp}	V	28.0	27.8	27.6	27.4	27.2
Current at P_{max}	I_{mpp}	A	7.04	6.96	6.87	6.79	6.71
Open-circuit voltage	V_{oc}	V	35.0	34.9	34.8	34.8	34.7
Short-circuit current	I_{sc}	A	7.49	7.42	7.35	7.28	7.21

NOCT: open-circuit module operation temperature at 800W/m² irradiance, 20°C ambient temperature, 1m/s wind speed.

Figure 3.1: Electrical Performance of YL250P-29b [27]

3.3.1.1 Daily energy supplied by a module

$$E_{PV} = P_{hyd} \times T_{time} \tag{3.15}$$

3.3.1.2 Total number of modules making up the generator

$$N_t = \frac{P_{pv}}{P_{module}} \tag{3.16}$$

In order to ensure continuous and sufficient pumping to all reservoirs when the pumps run for 09 hours a day, the flow rate is determined based on the volume of water stored.

The results of the dimensioning of the photovoltaic system are shown in the tables (table 3.8) below .

Table 3.8: Dimensioning of photovoltaic system

Number Of the Area	flow rate m3/s	Power(W)	Time	N_{PV}	E_{PV}	$C_{INVST(DA)}$
Area 01	0.048	2140.033	9h	9	19260.30	295200
Area 02	0.061	2705.925	9h	11	24353.33	360800
Area 03	0.069	3041.100	9h	13	27369.90	426400
Area 04	0.045	1996.517	9h	8	17968.65	262400
Area 05	0.035	1540.352	9h	7	13863.17	229600
Area 06	0.064	2842.629	9h	12	25583.66	393600
Area 07	0.077	3379.000	9h	14	30411.00	459200
Area 08	0.057	2530.163	9h	11	22771.46	360800
Area 09	0.029	1272.393	9h	6	11451.54	196800
Area 10	0.054	2366.663	9h	10	21299.96	328000
Area 11	0.068	13316.167	9h	54	119845.50	1771200
Area 12	0.062	2729.542	9h	11	24565.88	360800
Area 13	0.031	1379.758	9h	6	12417.83	196800
Area 14	0.050	2215.879	9h	9	19942.91	295200
Area 15	0.069	3041.100	9h	13	27369.90	426400
Area 16	0.036	1588.130	9h	7	14293.17	229600
Area 17	0.042	1849.185	9h	8	16642.67	262400
Area 18	0.072	3192.792	9h	13	28735.13	426400
Area 19	0.069	3041.100	9h	13	27369.90	426400
Area 20	0.051	2252.667	9h	10	20274.00	328000
Area 21	0.041	1830.292	9h	8	16472.63	262400
TOTAL					542262.47	8298400

The table(**table 3.8**) shows the flow rate , power, time, number of panels energy and cost of solar panels for each region. It also shows the total cost.

3.3.2 Comparison of results before and after integration

This table shows the voltage to be applied at each busbar level before and after integrating

Table 3.9: tension values of busbars before and after integration PV system

	Before		After		ΔV_2-ΔV_1	%
Bus	V [p.u.]	ΔV_1	V [p.u.]	ΔV_2		
Bus01	1	0	1	0	0	0
Bus02	0.87286	0.12714	0.87767	0.12233	-0.0048	-3.93
Bus03	0.8158	0.1842	0.82318	0.17682	-0.0074	-4.17
Bus04	0.82943	0.17057	0.8355	0.1645	-0.0061	-3.69
Bus05	0.81504	0.18496	0.82243	0.17757	-0.0074	-4.16
Bus06	0.81504	0.18496	0.82243	0.17757	-0.0074	-4.16
Bus07	0.81524	0.18476	0.82264	0.17736	-0.0074	-4.17
Bus08	0.81524	0.18476	0.82263	0.17737	-0.0074	-4.17
Bus09	0.81539	0.18461	0.82278	0.17722	-0.0074	-4.17
Bus10	0.81539	0.18461	0.82278	0.17722	-0.0074	-4.17
Bus11	0.82885	0.17115	0.83492	0.16508	-0.0061	-3.68
Bus12	0.82885	0.17115	0.83492	0.16508	-0.0061	-3.68
Bus13	0.82914	0.17086	0.83521	0.16479	-0.0061	-3.68
Bus14	0.82914	0.17086	0.83521	0.16479	-0.0061	-3.68
Bus15	0.82878	0.17122	0.83486	0.16514	-0.0061	-3.68
Bus16	0.82878	0.17122	0.83486	0.16514	-0.0061	-3.68
Bus17	0.8046	0.1954	0.81239	0.18761	-0.0078	-4.15
Bus18	0.80463	0.19537	0.81243	0.18757	-0.0078	-4.16
Bus19	0.80729	0.19271	0.81506	0.18494	-0.0078	-4.20
Bus20	0.80706	0.19294	0.81482	0.18518	-0.0078	-4.19
Bus21	0.80882	0.19118	0.81655	0.18345	-0.0077	-4.21
Bus22	0.80873	0.19127	0.81647	0.18353	-0.0077	-4.22
Bus23	0.82034	0.17966	0.82662	0.17338	-0.0063	-3.62
Bus24	0.82038	0.17962	0.82665	0.17335	-0.0063	-3.62
Bus25	0.8269	0.1731	0.83299	0.16701	-0.0061	-3.65
Bus26	0.82692	0.17308	0.833	0.167	-0.0061	-3.64
Bus27	0.82077	0.17923	0.82717	0.17283	-0.0064	-3.70
Bus28	0.82063	0.17937	0.82704	0.17296	-0.0064	-3.71

This table **(Table 3.10)** shows the voltage values at each level of the buses before and after integration. The results show an increase in voltage on the buses after integration, with percentages ranging from 3.60% to 4.30%.

This table gives us the active and reactive power losses in this network before and after integration

Table 3.10: *active and reactive power losses before and after integration PV system*

			before		after		difference	
From Bus	To Bus	Line	**P** loss [MW]	**Q** loss [Mvar]	**P** loss [MW]	**Q** loss [Mvar]	**P** loss [MW]	**Q** loss [Mvar]
Bus03	Bus05	1	8.00E-03	5.00E-03	0.007907	0.004393	-9.30E-05	-6.07E-04
Bus03	Bus06	2	8.00E-03	5.00E-03	0.007906	0.004392	-9.40E-05	-6.08E-04
Bus04	Bus15	3	6.00E-03	3.00E-03	0.005947	0.003304	-5.30E-05	3.04E-04
Bus04	Bus16	4	6.00E-03	3.00E-03	0.005936	0.003298	-6.40E-05	2.98E-04
Bus28	Bus27	5	0	0	0.000338	0.000188	3.38E-04	1.88E-04
Bus26	Bus25	6	0	0	0.000019	0.000011	1.90E-05	1.10E-05
Bus24	Bus23	7	0	0	0.000063	0.000035	6.30E-05	3.50E-05
Bus22	Bus21	8	0	0	0.000104	0.000058	1.04E-04	5.80E-05
Bus20	Bus19	9	0	0	0.000780	0.000433	7.80E-04	4.33E-04
Bus18	Bus17	10	0	0	0.000020	0.000011	2.00E-05	1.10E-05
Bus03	Bus07	11	4.00E-03	2.00E-03	0.004173	0.002318	1.73E-04	3.18E-04
Bus03	Bus08	12	4.00E-03	2.00E-03	0.004219	0.002344	2.19E-04	3.44E-04
Bus03	Bus09	13	2.00E-03	1.00E-03	0.002203	0.001224	2.03E-04	2.24E-04
Bus03	Bus10	14	2.00E-03	1.00E-03	0.002214	0.001230	2.14E-04	2.30E-04
Bus04	Bus11	15	5.00E-03	3.00E-03	0.004685	0.002603	-3.15E-04	-3.97E-04
Bus04	Bus12	16	5.00E-03	3.00E-03	0.004703	0.002613	-2.97E-04	-3.87E-04
Bus04	Bus13	17	1.00E-03	1.00E-03	0.001288	0.000716	2.88E-04	-2.84E-04
Bus04	Bus14	18	1.00E-03	1.00E-03	0.001279	0.000710	2.79E-04	-2.90E-04
Bus01	Bus02	19	1.13	2.25E+01	1.075423	21.508466	-5.46E-02	-9.92E-01
Bus12	Bus24	20	9.00E-03	1.80E-01	0.008710	0.174197	-2.90E-04	-5.80E-03
Bus13	Bus25	21	2.00E-03	4.80E-02	0.002385	0.047704	3.85E-04	-2.96E-04
Bus14	Bus26	22	2.00E-03	4.80E-02	0.002368	0.047356	3.68E-04	-6.44E-04
Bus15	Bus27	23	1.10E-02	2.29E-01	0.011012	0.220247	1.20E-05	-8.75E-03
Bus16	Bus28	24	1.10E-02	2.29E-01	0.010992	0.219838	-8.00E-06	-9.16E-03
Bus02	Bus04	25	2.50E-01	5	0.242049	4.840984	-7.95E-03	-1.59E-01
Bus02	Bus03	26	3.16E-01	6.31	0.298042	5.960842	-1.80E-02	-3.49E-01
Bus05	Bus17	27	1.50E-02	3.07E-01	0.014642	0.292846	-3.58E-04	-1.42E-02

Bus06	Bus18	28	1.50E-02	3.07E-01	0.014641	0.292818	-3.59E-04	-1.42E-02
Bus07	Bus19	29	8.00E-03	1.64E-01	0.007728	0.154562	-2.72E-04	-9.44E-03
Bus08	Bus20	30	8.00E-03	1.66E-01	0.007813	0.156256	-1.87E-04	-9.74E-03
Bus09	Bus21	31	4.00E-03	8.80E-02	0.004079	0.081579	7.90E-05	-6.42E-03
Bus10	Bus22	32	4.00E-03	8.80E-02	0.004099	0.081985	9.90E-05	-6.01E-03
Bus11	Bus23	33	9.00E-03	1.79E-01	0.008677	0.173532	-3.23E-04	-5.47E-03

The table (**Table 3.10**) shows the active and reactive losses before and after the integration of hydraulic power into the grid. A decrease in real and reactive power losses is observed after integration all hydraulic power of the region.

Comparison of results before and after integration PV system

Table 3.11 : Comparison of results before and after integration PV system

		before	after	difference
Total Generation	Real Power [MW]	82.499	81.494	1.005
	Reactive Power[MVar]	66.68	64.132	2.548
	Apparent Power [MVa]	106.08	103.70	2.37
Total Load	Real Power [MW]	80.65	79.728	0.922
	Reactive Power[MVar]	30.8	29.849	0.951
	Apparent Power [MVa]	86.33	85.13	1.19
Total Losses	Real Power [MW]	1.849	1.766	0.083
	Reactive Power[MVar]	35.883	34.283	1.6
	Apparent Power [MVa]	35.93	34.32	1.60

The table **(Table 3.11)** shows the total power values of generators, loads and losses before and after the integration of hydraulic power into the grid. A decrease in real power is observed at the generator and the load, as well as losses ranging from 0.1 to 1MW; a decrease in reactive power at the generator and the load, as well as losses, ranging between 0.9 and 2.5 MVar.

3.3.3 Energy value generated by tank pumps

The table shows the energy values produced by the tank pumps and the following relation is used to calculate the energy:

Table 3.12: Energy value generated by tank pumps

Number Of the Area	Power	Time	$E_{electrical}$ Wh	$E_{electrical}$ KWh
Area 01	2074.815	9h 16min	19260.3	19.2603
Area 02	2074.815	11h 44min	24353.325	24.35333
Area 03	2074.815	13h 11min	27369.9	27.3699
Area 04	2074.815	8h 39min	17968.65	17.96865
Area 05	2074.815	6h 40min	13863.165	13.86317
Area 06	2074.815	12h 19min	25583.6625	25.58366
Area 07	2074.815	14h 39min	30411	30.411
Area 08	2074.815	10h 58min	22771.4625	22.77146
Area 09	2074.815	5h 31min	11451.54	11.45154
Area 10	2074.815	10h 15min	21299.9625	21.29996
Area 11	9221.4	12h 59min	119845.5	119.8455
Area 12	2074.815	11h 50min	24565.875	24.56588
Area 13	2074.815	5h 59min	12417.825	12.41783
Area 14	2074.815	9h 36min	19942.9125	19.94291
Area 15	2074.815	13h 11min	27369.9	27.3699
Area 16	2074.815	6h 53min	14293.17	14.29317
Area 17	2074.815	8h 1min	16642.665	16.64267
Area 18	2074.815	13h 50min	28735.125	28.73513
Area 19	2074.815	13h 11min	27369.9	27.3699
Area 20	2074.815	9h 46min	20274	20.274
Area 21	2074.815	7h 56min	16472.625	16.47263

This table **(Table 3.12)** shows the energy values produced by the tank pumps at each area level. The results show the variation in energy.

Total energy produced in the day by the tank pumps :

generator efficiency η = 85%

$$E_{electrical\ eff} = E_{electrical} \times \eta \quad (3.17)$$

542.2625×0.85 = 460.92KWh .

Total energy produced in the year :

460.92 × 365 = 168236.94KWh

The price of electricity in Algeria is calculated by 1KWh = 5.4796 Da

The price per day is :

$$\text{Price per day} = E_{electrical\ eff} \times 5.4796\ \text{Da} \quad (3.18)$$

460.92 × 5.4796 = 2525.66 DA

In year :

168236.94 × 5.4796 = 921871.14 DA

Total energy produced in the day by generator PV :

DC/AC converters efficiency η = 95%

$$E_{electrical\ eff} = E_{electrical} \times \eta \quad (3.19)$$

542.2625 × 0.95 = 515.149 KWh .

Total energy produced in the year :

515.149 × 365 = 188029.5219 KWh

The price of electricity in Algeria is calculated by 1KWh = 5.4796 Da

The price per day is :

$$\text{Price per day} = E_{electrical\ eff} \times 5.4796\ \text{Da} \quad (3.20)$$

515.149 × 5.4796 = 2822.813 DA

In year :

$$188029.5219 \times 5.4796 = 1030326.568 \text{ DA}$$

The monetary return generated from the energy production per year is 1952197.708 DA

3.3.4 Cost of hydraulic pump and PV installation

photovoltaic (PV) system: $\boldsymbol{C_{invst}}$ = 8298400 DA

$\boldsymbol{C_{invst}}$ **:** 350000 DA × 21 pump = 15750000 DA

Total $\boldsymbol{C_{invst}}$ = 24048400 DA

3.3.5 Rate of return on investment

$$\boldsymbol{Ec \times 5.4796t = C_{invst} + E_{CRE} \times 5.4796t} \quad (3.21)$$

$\boldsymbol{Ec}$: total energy of grid in the region **.**

$\boldsymbol{C_{invst}}$ **:** total cost of investment .

$\boldsymbol{E_{CRE}}$ **:** Ec - E_{hyd} -E_{PV} **.**

$\boldsymbol{E_{hyd}}$ **:** total energy of hydraulic pumps.

$\boldsymbol{E_{PV}}$ **:** total energy of generator PV.

$$t = \frac{C_{invst}}{Ec \times 5.4796 - E_{CRE} \times 5.4796} \quad (3.22)$$

Total $\boldsymbol{C_{invst}}$ = C_{invst} hydraulic pumps + C_{invst} generator PV (3.23)

There are a total of 21 stations : **Total** $\boldsymbol{C_{invst}}$ = 24048400DA

$\boldsymbol{Ec}$ **=** 81494 × 365 = 29745310 KWh / year

E_{hyd} = 168236.94 KWh / year

E_{PV} = 188029.5219 KWh / year

E_{CRE} = 29745310 - 168236.94 - 188029.5219 = 29389043.54 KWh

$$t = \frac{24048400}{29745310 \times 5.4796 - 29389043.54 \times 5.4796}$$

t = 12.3186294458 years

$t = 12\ years\ 3\ month\ 24\ days\ 16\ hours\ 57\ minute$

Rate of return on investment is 12 years 3 month 24 days 16 hours 57 minute.

3.4 Comparison of results before and after integration

The table shows the total power values of generators, loads and losses in each of solution

Table 3.13: Comparison of results before and after integration in the three solutions

		before	after		
			solution 1	solution 2	solution 3
Total Generation	Real Power [MW]	82.499	81.571	81.356	81.494
	Reactive Power[MVar]	66.68	65.749	63.777	64.132
	Apparent Power [MVa]	106.08	104.77	103.37	103.702
Total Load	Real Power [MW]	80.65	79.67	79.6	79.728
	Reactive Power[MVar]	30.8	29.9	29.7	29.849
	Apparent Power [MVa]	86.33	85.09	84.96	85.13
Total Losses	Real Power [MW]	1.849	1.172	1.756	1.766
	Reactive Power [MVar]	35.883	34.389	34.0769	34.283
	Apparent Power [MVa]	35.93	34.41	34.41	34.33

The table **(Table 3.14)** shows the total power values of generators, loads and losses before and after the integration in the three solutions

Rate of return on investment

- Solution 01 : is 9 years 1 month 10 days 20 hours 15 minutes.
- Solution 02 : is 1 year 10 month 13 days 6 hours 47 minutes.
- Solution 03 : is 12 years 3 month 24 days 16 hours 57 minutes.

Based on the results obtained, it can be said that the second solution is the best in terms of results as well as considering the optimal return on investment.

Conclusion

In this chapter, three solutions have been proposed to improve the results of using water reservoirs for electricity generation. These solutions were simulated using MATLAB and the results obtained were presented along with a feasibility study for each solution with a demonstration of the energy value obtained in each solution. A comparative analysis of the results was also carried out to evaluate their effectiveness and the second solution was selected as the optimal one.

General conclusion

General conclusion

Indeed, as time progresses, the demand for energy especially electrical energy, increases due to the growing requirements of modern life. This increased demand puts pressure on electrical grids, resulting in challenges related to their reliability and stability. These challenges are particularly prominent in areas with weak infrastructure.

This work includes strategies for better utilization of renewable energy resources, especially water resources, in order to reduce costs and negative impacts on the environment, and ensure greater stability and reliability of the network.

First Chapter focuses on presenting different types of turbines and their suitability for each case based on the location.

Second Chapter focuses on the simulation of an electrical grid for a region in southern Algeria using the PSAT toolbox in MATLAB, and also calculates the electrical energy that can be produced by using water reservoir pumps during distribution by converting hydraulic energy into electrical energy through turbines. Comparing the results before and after integration, significant improvements can be seen. In terms of total network losses, there is a reduction in active power of around 0.5 MW and in reactive power of around 1.5 MVA. In addition, in terms of total loads, there is a reduction in active power of approximately 1 MW and a reduction in reactive power of approximately 0.9 MVA.

Third Chapter two additional solutions were proposed to improve the results. The first solution suggests introducing pumps that do not have reservoirs, meaning they pump directly to customers, considering that they will have reservoirs in the future as part of a government project. The electrical energy that can be produced in this case was calculated, resulting in significant improvements in total loads and network losses. The real power ranged from 0.9 MW to 1.2 MW, and the reactive power reached up to 1.9 MVA.

The second solution proposes to power the pumps using solar panels, considering them as loads in the grid. Since water distribution company branches are among the customers with high electricity consumption, this solution was explored. The results obtained were similar to the previous proposal, but there was a noticeable difference in the payback period for the investment. It was concluded that the first solution is the preferred option.

Finally, compact hydropower systems can provide significant energy gains from various small and variable water sources. They have considerable scope for development and can be one of the key options proposed to improve grid efficiency and reliability. They are an essential element in energy sustainability plans.

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