School of Information Technology and Engineering at the ADA University

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Energy-saving technology for increasing efficiency of energy production.

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By
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THESIS ACCEPTANCE

This Thesis by: Islam Mammadov
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ABSTRACT

When battery storage system incorporate into modern power system began a critical answer to problems such as voltage instability, energy imbalances, and the increasing use of renewable energy. This thesis investigates the impact of incorporating a lithium-ion batteries into Absheron 500/330/220 kV substation and compares its performance with and without batteries. To establish the system's total efficiency, the study conducts thorough simulations and evaluations of changes in voltage stability, load flows, and energy losses.

The analysis begins by providing a complete overview of how the Absheron substation operates, emphasizing the importance of its 500 kV, 330 kV, and 220 kV buses in the regional power system. The thesis uses a combination of theoretical models and simulation tools to predict load flows and voltage profiles for two scenarios: one in which the battery is not incorporated and one in which the system is supported. The battery-integrated scenario contains parameters such as 6,000 full charge-discharge cycles at 100% efficiency and an additional 1,500 cycles at 80% efficiency, reflecting the battery's real-world performance.

The results demonstrate that integrating the battery improves voltage stability significantly across all busbars. For example, the voltage on the 500 kV busbar rises from 484.8 kV to 485.7 kV, resulting in improved dependability and operational stability. Similarly, load balancing on important transmission lines improves, lowering voltage on overcrowded lines while enhancing power distribution. The battery also decreases energy losses, which provides long-term economic benefits. The cost-benefit analysis reveals that, while the initial investment for the battery system is over US$35 million, the annual energy savings and reduced fuel use at the Solar Power Plant give a 5-year payback period.

Furthermore, the report cites limitations such as lithium-ion batteries' short lifespan and high initial cost, while emphasizing their potential to improve grid resilience and incorporate renewable energy sources. Recommendations include optimizing charge-discharge cycles to increase battery life and using renewable sources like wind or solar to lessen rely on natural fuels.

This thesis finds that incorporating BESS into high-voltage substations is a feasible and successful technique for improving grid performance. The findings are useful for politicians, utility operators, and engineers looking to increase efficiency and stability in modern power systems as they transition to sustainable energy sources.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
DC	Direct Current
AC	Alternating Current
GND	Ground
BESS	Battery Energy Storage System
PHS	Pumped Hydro Storage

CHAPTER ONE

INTRODUCTION

The energy industry, being a strategically important component the country's economy is currently characterized by low energy efficiency, one of the reasons for which is increasing wear and tear of power equipment. It should be taken into account that in in the coming years there may be unfavorable changes due to the release of failure of extremely worn out technical systems.

Currently innovation activity is the basis for increasing efficiency functioning of the country's energy sector. In this regard, replacement physically and morally worn-out equipment should be carried out with application.

Mastering energy-saving technologies in production and transmission energy requires significant capital investment, which determines the importance assessing their effectiveness. In order to rationally spend investments assessment of the effectiveness of the introduction of energy-saving technologies in production and transmission of energy must be carried out at every stage mastering scientific developments.

Introduction of innovations into the economy and transition to an innovative path development of the country is one of the primary tasks. Increase in share innovative technologies in the total volume of energy used equipment requires the creation of favorable investment conditions and developing methods for supporting and stimulating innovation. Support can be carried out using government regulation innovation activities and improvement of the regulatory framework, based on global experience and economic development trends.

Investment activity represents the investment and implementation of a set of practical actions for their implementation in order to making a profit and (or) achieving another beneficial effect. You can go here include the construction of new energy facilities, reconstruction and modernization of existing fixed assets.

CHAPTER TWO
LITERATURE REVIEW

Traditional Energy Systems

Currently, primary energy sources have already been identified and it is unlikely that they will be added in the near future. In the early nineteenth century until Industrial Revolution, wood and various forms of natural biomass were used to produce primary energy. Wind energy was used for sea and river transport. Then coal was used to generate energy, and since then coal has played an important role in energy production. In addition, internal combustion engine vehicles began to be widely used and petroleum and petroleum products were used to obtain energy. After 1950, natural gas was used for electricity production.

Depending on the depth, these fuels are found in the earth's crust. These fuels are organic materials exposed to high pressure and temperature for 100 years and are formed as a result of natural processes. Due to these characteristics, they are known as fossil fuels. According to world statistics, about 36% of the energy produced today is oil, 29% coal, and 24% natural gas. [1] Thus, they make up 89% of the total. There are many reasons why these sources cannot be continued in the near future for various reasons that will be discussed below. The remaining 10-12% comes from alternative sources. Wind and solar energy are a type of alternative sources, have become more widespread in some countries.

A large part of all these primary energy sources is converted into electricity, but the other part is used in the transport sector and also in households.

Innovative Technologies in Energy Systems for energy saving

Renewable Energy Sources

Biomass energy (such as ethanol), geothermal energy, hydropower, wind energy, solar energy.

Biomass sources include organic remains of animals or plants. Biomass sources include wood, sewage, and ethanol. Biomass can be used as an energy source because it absorbs energy from the sun. During biomass burning, thermal energy is released and this energy is also used.

Hydropower is the earliest renewable energy source and has been used for over 1,000 years. Today, hydroelectric power plants are widely used to generate electricity in all American states. In hydropower, the mechanical energy of water is used to obtain electrical energy. In hydropower plants, the flow direction of rivers is used to increase the production energy of the generator and to turn the turbine more easily.

Geothermal energy is used due to the heat generated in the nuclear layer, which is the 3rd layer of the earth. Geothermal energy is more easily found in active volcanic areas or tectonic zones. Wells are drilled in geothermal power plants to use steam or hot water in the power plants. That energy is useful to produce heat and electricity.

Wind energy is one of the most common types of renewable energy and wind turbines use to produce electricity. The wind drives the blades of the turbine and creates mechanical energy, mechanical energy convert into eletrrical energy in generator. The energy obtained provides electricity to houses and other buildings and can be transferred to the grid when needed.

Solar power plants use radiation from the sun. Photovoltaics are used to convert solar energy into electricity. Generally, the energy produced by these photovoltaics is used to power a calculator, but by connecting solar panels together, larger arrays are created and more electricity is obtained. Considering the decrease of non-renewable energy sources, finding the right way to use renewable energy sources becomes more important. Renewable sources are important not only to provide electricity to whole world, but also to create healty and clean environment.

Energy Storage Technologies

Battery Storage: Battery storage technology is important because it can provide electricity to homes and businesses even when power is not being produced. For example, Great Britain has the greatest power in obtaining energy using the power of offshore wind, but it is necessary to increase production and obtain cleaner energy by reducing the production costs of energy, and to store and use this energy in a targeted manner.

Every day, electricity grids around the world must balance supply and demand. These are difficult to manage when it comes to achieving net zero carbon output. In the past, conventional fuel-fired plants were used to manage these challenges, but the widespread use of battery energy storage devices will increasingly replace these generators.

Prescott Hartshorne, director of National Grid Ventures in the US, says: “Storage increases the need for renewable energy sources from a reliability perspective. This is one of the main parts of the transition to renewable energy sources.”[2]

Thermal storage:. Using various technologies, TS can store heat energy for months or weeks. Depending on the scale of storage and use, storage districts, regions, small and large differ. It is used to balance the energy balance and is useful for heating in winter and cooling in summer. Storage environments are also different, as for example these ice tanks can be local earth masses with heat exchangers introduced through boreholes. For example, shallow lined pits filled with gravel and insulated on top are also used.

Pumped Hydro Storage (PHS): Walawalkar and Apt in the article "Market Analysis of Emerging Electric Energy Storage Systems" (Energy Policy Journal, 2008) analyzed the wide application areas and economic efficiency of pumped hydro storage (PHS) [1]. In this article, it has been shown that PHS plays an important role and is effective in providing energy during peak demand times. According to their research, the use of PHS prevents network fluctuations and helps in reliable control. PHS technology based on law converting the kinetic energy convert electrical energy generated during the transfer of water to a lower level after collecting it at a higher level. It has been noted that the application of PHS in effective areas in terms of geographical compatibility is effective for the stability of the network.

Flow Batteries: Flow batteries are designed to store large amounts of energy and can provide long-term energy reserves. In the article "Vanadium Redox Flow Battery for Power Storage (Journal of Power Sources, 2011)", Skyllas-Kazacos and colleagues noted that vanadium redox flow batteries are ideal for storing solar and wind energy, especially[2]. stored in tanks and offers high flexibility and endurance. One of some advantages of this technology is that it has a long life and reduces greenhouse gas emissions. It is also noted that flow batteries can be used in combination of renewable sources and ensure the maintenance of balance in energy systems.

Supercapacitors: Supercapacitors are designed to store and discharge energy quickly. In his article "Electrochemical Supercapacitors: Scientific Fundamentals and Technological Applications" (1999), Conway noted that supercapacitors store electrical energy at a high power density, which can only be used to control short-term fluctuations in the grid because the storage is short-term and the energy density is low. Supercapacitors are mainly important in systems that require fast power and are therefore more commonly used in the transportation sector. The work principle of supercapacitors based on electrochemical double layer principle. The article notes that despite their high power density, Supercapacitors are limited in their use for long-term energy store due to their relatively low energy density.

Hydrogen Energy Storage: Hydrogen technologies are efficient for long-term energy storage and clean energy provision. Parra and colleagues in their article "Hydrogen as a Long-Term Energy Storage Solution" (International Journal of Hydrogen Energy, 2019) point out that hydrogen has long-term storage properties and is then converted back into electricity in fuel cells [5]. Using hydrogen can reduce carbon emissions and increase the sustainability of energy systems. Hydrogen technologies have a wide range of possibilities to provide long-term energy storage and to be used in combination with renewable energy sources.

Economic and Environmental Impacts: Energy storage technologies are economically and environmentally efficient. The researchers noted in their paper that these technologies reduce energy costs and minimize carbon emissions. Gonzalez "Economic and Environmental Impact of Energy Storage Systems" (Renewable Energy Journal, 2022) notes that with the application of Energy Storage Technologies, it is possible to reduce the total energy consumption in energy systems by up to 20% [6]. The environmental benefits of EST include reducing carbon emissions and protecting the environment from greenhouse gases when integrated with renewable energy sources.

The articles provide extensive information about the growing importance of energy storage technologies in modern energy systems. Researchers Blomgren "The Development and Future of Lithium Ion Batteries." (Journal of The Electrochemical Society, 2017), Goodenough and Park, “The Li-Ion Rechargeable Battery: A Perspective.” (Journal of the American Chemical Society, 2013), noted that lithium-ion batteries are more effective in energy storage and grid stability due to their high energy density and conversion efficiency. . The characteristics of lithium-ion batteries allow them to be used not only for mobile devices, but also in large powerful energy systems.

The analysis provides an overview of the efficiency, economic benefits, and environmental benefits of lithium-ion batteries in large-scale energy storage applications. However, existing studies have not analyzed more precisely the economic benefits and ecological systems when lithium-ion batteries are connected to the power system. In order to make a more accurate analysis, this study will analyze the economic and environmental impacts of the integration of a 250 MW lithium-ion battery into the energy system on a specific energy system. Specifically, the study will analyze the technical and economic effects caused by this technology in real application conditions by simulating the integration of a 250 MW lithium-ion battery into the system, and by conducting a simulation in the DigSilent Power Factory software, it will analyze the impact of the battery on voltage, frequency and load balance in the power network after connection.

CHAPTER THREE

METHODOLOGY

1. The Current Situation of Azerbaijan's Energy System

The energy map of Azerbaijan reflects the country's abundant energy resources and their distribution across territories. The main part of the produced energy is due to natural gas. Thermal energy production and gas turbines provide the main part of Azerbaijan's energy supply. Mingachevir TPP, Shimal power station, South and Sumgait power stations are the largest power stations in the country and the main energy production falls on the share of these stations. Combined production technologies are also used to increase the efficiency of heat and electricity production.

In recent years, the renewable energy potential has also increased in Azerbaijan. Garadagh solar power plant, Sharur and Kangarli solar power plants in Nakhchivan, Balakhani and Gobustan Bioenergy can be examples of them. Nakhchivan and western zones are ideal places for solar power plants. The construction of small and medium-scale hydropower plants in Karabakh and Eastern Zangezur is the basis of the transition to green energy.

Fig3.1 Azerbaijan Energy system [ref. 5]

3.1 Installed Capacities of Power Plants in Azerbaijan

Electricity production in Azerbaijan is achieved through various sources. The most common of these include thermal, water and solar power plants. So, these sources cover 99% of total energy consumption. Other consumers, some special plants have their own independent power plant. An example of this is Azerbaijan Sugar Production Union (24 MW) or Balakhani Solid Waste Incineration Plant (37 MW).

The demand for electricity in Azerbaijan is increasing day by day. Therefore, it is necessary to build new power plants and integrate them into the energy system. To meet this demand, the country uses sources such as heat, hydroelectricity and solar.

Thermal Power Station

Thermal power plants are the basis of Azerbaijan's electricity sector. More than 60% of the total power is accounted for by thermal power plants. Currently, Azerbaijan power system capacity is 5,782.9 MW. The largest of them is the Azerbaijan Thermal Power Station with a capacity of 2400 MW. The power plants with the largest capacity are thermal power plants and are extremely important for maintaining stability.

Table3.1 Thermal Power Station [ref.10]

Power Plant	Installed Capacity (MW)
Azerbaijan TPP	2400.0
Shimal TPP	800.0
Janub TPP	780.0
Sumgayit TPP	525.3
Qobu TPP	385.0
Sangachal TPP	299.3
Baku TPS	107.0
Baku TPP	104.4
Shahdag TPP	104.4
Astara TPP	87.0
Sheki TPP	87.0
Khachmaz TPP	87.0
Lerik TPP	16.5
Total	5782.9

Hydroelectric Power Stations

Hydropower plants are very important for the energy landscape of Azerbaijan. Total hyrdopower capacity of Azerbaijan is 1,232,798 MW. The largest hydroelectric power plant is Mingachevir HPP with a capacity of 424 MW.

In addition, there are a large number of small hydropower plants in Karabakh and other areas. From an environmental and economic point of view, hydropower plants are important in the energy sector because they decrease greenhouse gas emissions and dependence on non-renewable resources.

Table3.2 Hydroelectric Power Stations [ref.11]

Power Plant	Installed Capacity (MW)
Mingachevir HPP	424.6
Varvara	17.0
Shamkir	380.0
Yenikend HPP	150.0
Fuzuli HPP	25.0
Taxtakorpusu	25.0
Shamkirchay	24.42
Tartar	50.0
Qusar 1	0.96
Ismayilli 1	1.581
Goychay 1	3.1
Ismayilli 2	1.581
Balakan	1.44
Masalli	0.3
Gulebird	8.0
Suqovushan 1	4.8
Suqovushan 2	3.0
Oguz 1	1.341
Oguz 2	1.341
Oguz 3	0.894
Astara	0.26
Kalbajar 1	4.4
Chirag 1	8.3
Chirag 2	3.6
Soyuqbulaq	5.3
Meydan	3.4
Qamishli	6.3
Sus	4.0
Alxasli	6.0
Mishni	8.25
Cahangirbeyli	10.5
Agbulag	14.25
Hasanriz	10.0
Toragay 1	3.0
Toragay 2	5.9
Toragay 3	5.0
Toragay 4	0.8
Mugan	4.05
Chichekli	3.0
Sheki	1.3
Nugadi	0.83
Total	1232.798

Solar Power Stations in Azerbaijan

Solar power plant capacity of Azerbaijan is 238,222 MW. Currently, large powerful solar and wind power plants are being built. The largest solar plant is located in Garadag and it is 230 MW.

Decrease greenhouse emissions: By investing in solar energy, Azerbaijan can reduce its reliance on fossil fuels, lowering greenhouse gas emissions related with electricity production.

This transition is critical to meeting international climate commitments and promoting sustainable development.

The use of solar energy is important for achieving energy security, supporting economic growth and contributing to environmental sustainability. On the other hand, it reduces energy dependence and greenhouse gases and creates energy independence. The potential of solar energy in Azerbaijan is quite high.

Table3.3 Solar Power Stations [ref.20]

Power Plant	Installed Capacity (MW)
Qaradağ	230.0
Qobustan	2.863
Suraxanı	1.559
Samux	2.803
Pirallahı	1.1
Sumqayıt	2.072
Sahil	1.927
Total	242.32399999999998

s

Total Installed Energy Capacity

The total installed energy capacity in Azerbaijan is 7,258,022 MW. The diagram below shows the share of heat, water and solar power plants in the total energy system.

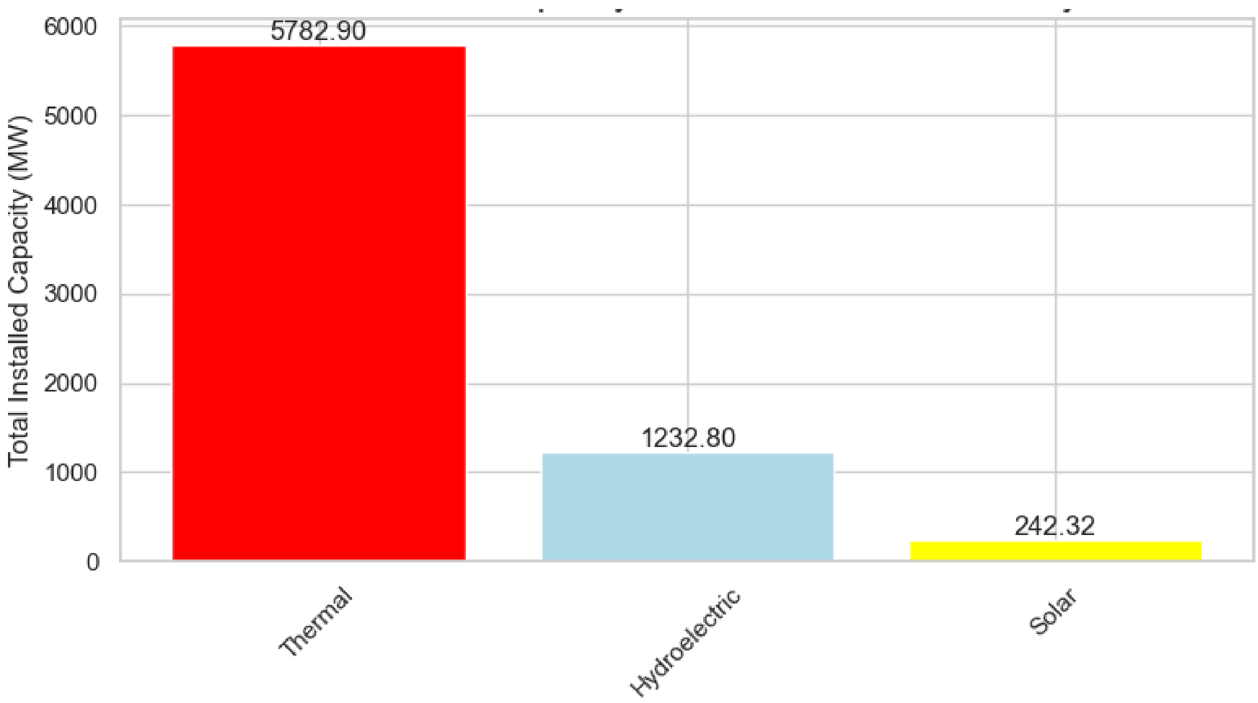

Fig3.2 Total İnstalled Capacity

In 2022, the production of electricity across the country was 29000 million kWh, and in 2023, this indicator increased to 29,282 mln kWh. Last year, 2,716 mln kWh of electricity was obtained in thermal power plants, 1,763 mln kWh in hydropower plants, and 303 million kWh of electricity was obtained due to solar and bioenergy. 26,447 million kWh of electricity was produced and sold to consumers by Azerenerji OJSC and 42 million kWh by Azerishiq.

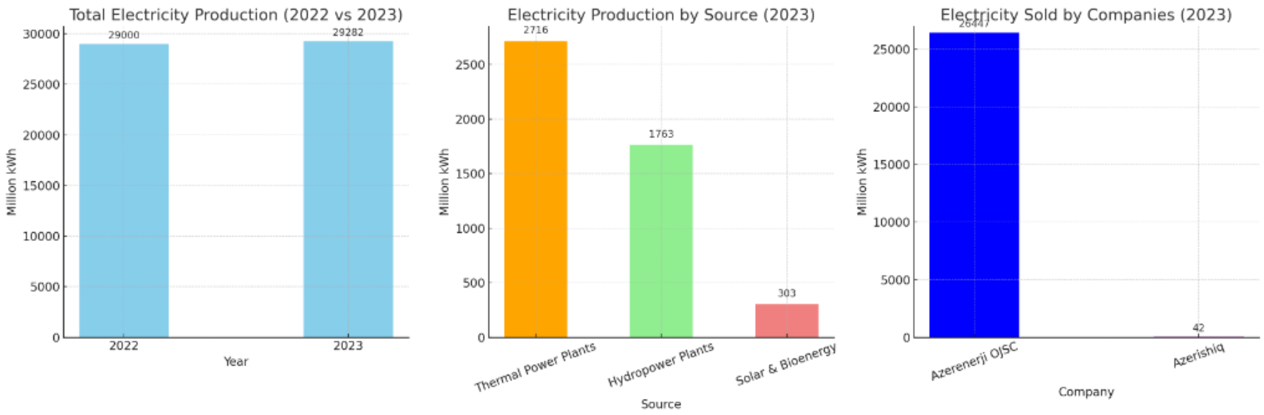

Fig3.3 Annual energy production [ref.12,13,15]

In 2023, 5502 million m3 of natural gas was used for the production of electricity. And in 2023, the average amount of fuel for the production of 1 kWh of electricity was 255.3 grams, which is 3.8 grams less than in 2022. Last year, the consumption of electricity in the republic increased by 5.7 million kWh to 23196 million kWh.

Conventional fuel such as natural gas is widely used in Azerbaijan's electric power industry. Electricity produced in natural gas-fired power plants accounts for more than 70% of the country's energy demand. Coal consumption is relatively low.

In 2023, the electricity produced in the country was mainly due to conventional fuel. The use of conventional fuels increases greenhouse gases and causes environmental problems. Currently, the amount of energy obtained from alternative and renewable energy sources is increasing in Azerbaijan in order to reduce greenhouse gases and eliminate environmental problems.

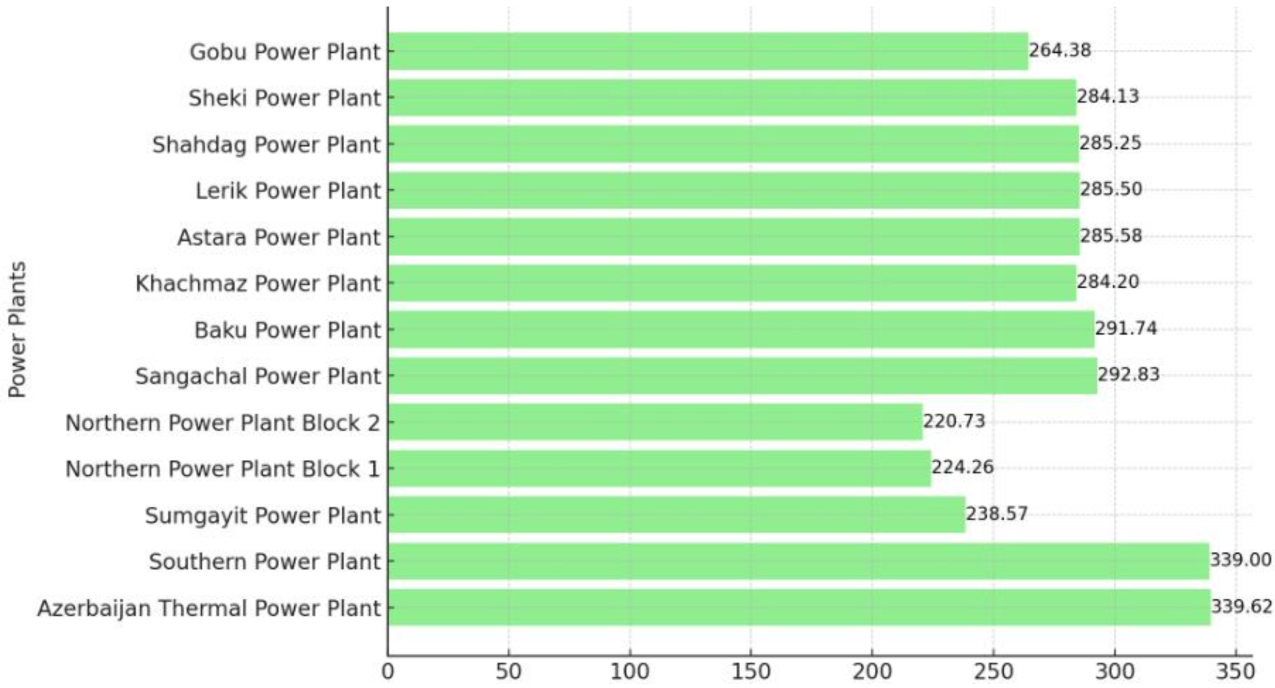

Fig3.4 Electricity production in 2023 [ref.31]

In 2023, a total renewable energy sources were 2116.2 million kW, and 1757.2 million kWh of energy was generated by hydropower plants, 56.6 million kWh by wind power plants, and 79.4 million kWh by solar energy , 223 million kWh are accounted for by bioenergy. In 2023, 29282.6 million kWh of electricity was produced in Azerbaijan, which means that 7.22% of the produced energy was due to renewable energy sources. The total renewable energy potential in Azerbaijan is estimated at 29,000 mln MW. Currently, renewable install energy capacity is 1304.5 MW. This means that the number and power of renewable energy sources will increase in the future.

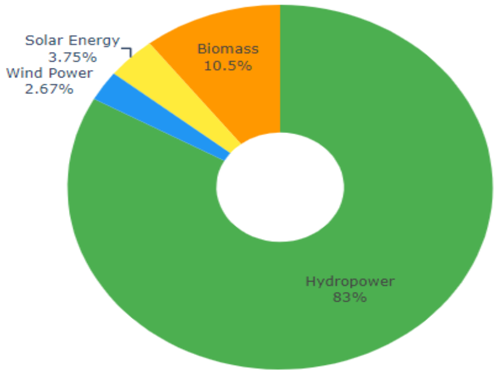

Fig3.5 Electricity production by renewable energy sources in Azerbaijan for 2023 [ref.31]

In January, daily, weekly and 1-month load charts are provided and these charts are important to visually show the dynamic patterns of electricity consumption. On the other hand, these graphs are important for improving energy efficiency, optimizing production and predicting consumption.

The daily load curve for January 7 reflects the changes in electricity consumption during the hourly day. On this curve, 9am to 9pm is typically the peak time for residential and commercial activity, so demand is at its peak. On the contrary, off-peak hours at night reflect lower consumption levels.

The change of load during the day depends on various factors. Thus, these factors include many factors such as weather conditions, industrial operations and household use. For example, in cold weather, due to increased heating requirements, it leads to an increase in the use of electricity. This load schedule minimizes wasted energy during off-peak hours throughout the day.

Fig3.6 Load curves on 7th of January in 2024

The monthly load curve shows how electricity demand changes over a longer period from December 22 to January 22. Weekly and seasonal trends can be determined by analyzing this curve. And with this graph we can get the following results:

- Seasonal changes: The period between December and January is characterized by increased electricity consumption as it is the winter season. This is clearly reflected in the higher parts of the load curve as the demand for heating increases in the residential, commercial and industrial sectors during cold weather. Understanding these seasonal trends is critical to planning electricity generation and distribution.

- Holiday Impact: The load curve for this period includes significant fluctuations due to public holidays such as New Year celebrations. Electricity consumption these days can vary significantly. For example, industrial and commercial activities may decrease during holidays, but residential consumption may increase due to prolonged use of heating, lighting, and cooking appliances. Identifying these variations allows energy providers to adjust production schedules accordingly.

- Weekend and Weekday Trends: There is a difference in electricity demand between weekdays and weekends. Consumption is usually higher on weekdays due to industrial and commercial operations, while production is lower on weekends due to reduced demand in these sectors. These charts help in forecasting.

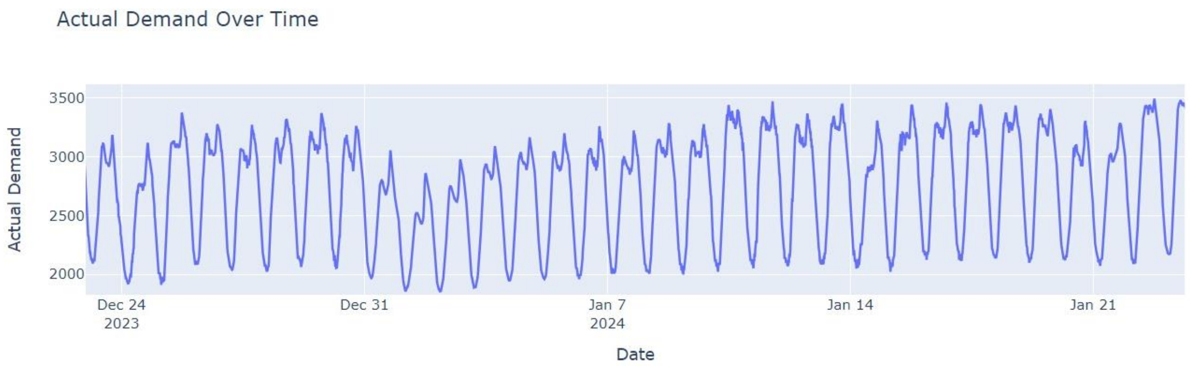

Fig3.7 Daily load curves in January

Looking at the annual energy consumption for 2023, the total energy load in January was 82,667 MW, which is the peak demand for the year. The reason for this increase is primarily due to heating in the winter months. The lowest consumption figure is in April and is 61,235 MW.
During the winter months, the energy demand is at its maximum due to heating systems, and in July and August, the consumption is at its maximum due to cooling.

Table3.4 Total Power

Month	Energysystem total power(MW)
January	82667
February	73094
March	80309
April	61235
May	61542
June	62090
July	68359
August	74017
September	66940
October	67587
November	81962
December	67287

The annual load curve shows the change in electricity demand in Azerbaijan for 2023. Analyzing the curve, it is clear that the demand is at its highest during the cold or warm months, while the demand is relatively low during the cold seasons. By understanding and analyzing this graph, it is possible to optimize energy production and ensure stable operation of the grid.

The annual load curve provides important information about energy consumption throughout the year in months. Significant fluctuations between winter and summer months highlight the need for adaptive power generation strategies. In addition, analysis of load graphs is important for energy storage, efficiency improvement and integration of renewable sources, grid stabilization.

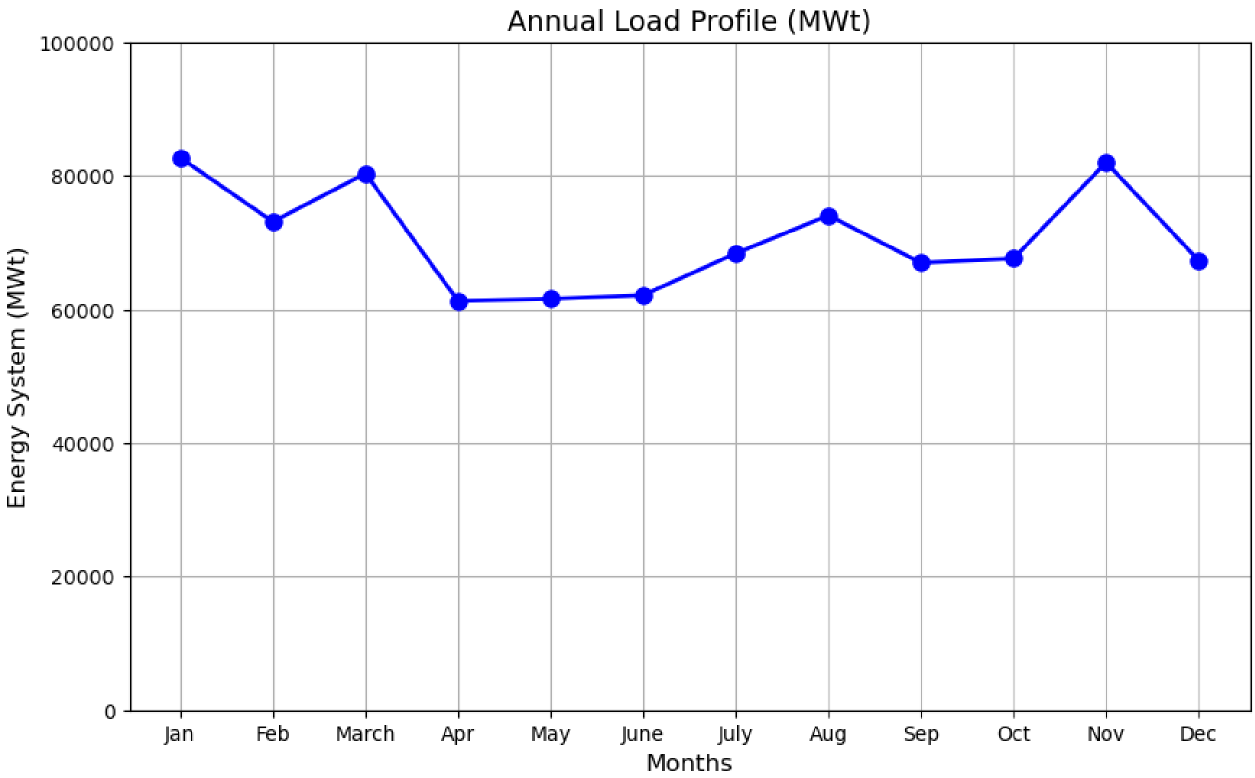

Fig3.8 Annual load curves in 2023

In the energy system of Azerbaijan, 6.3 million tons of natural gas were used for the production of electricity and heat energy in 2023. Considering the density of natural gas, this is about 8.8 billion m^3. Although the use of natural gas in energy production has increased in recent years, it has many negative aspects. Thus, when natural gas is burned, the waste emitted into the air increases the emission of greenhouse gases. It is not environmentally friendly. On the other hand, it is not a prospect because it is transportable and a depleting resource. It is not economically efficient. In Azerbaijan, the volume of carbon dioxide emissions should be reduced by 40% by 2050, but the use of natural gas prevents this.

In the evening hours of the day, between 18.00 and 21.00, energy demand increases. The average daily increase for 2023 was 500 MW. And to meet this demand, during those hours either the generators currently in use are overloaded or additional generators are started. In addition, using natural gas pollutes the environment, creates energy losses, and results in equipment failure. This situation is not economically beneficial either.

This is shown visually in the graph below. Therefore, the energy to be consumed during these hours should be the reserve energy of the system. We can use the energy stored in the batteries during these hours to avoid overloading the generators or starting additional generators.

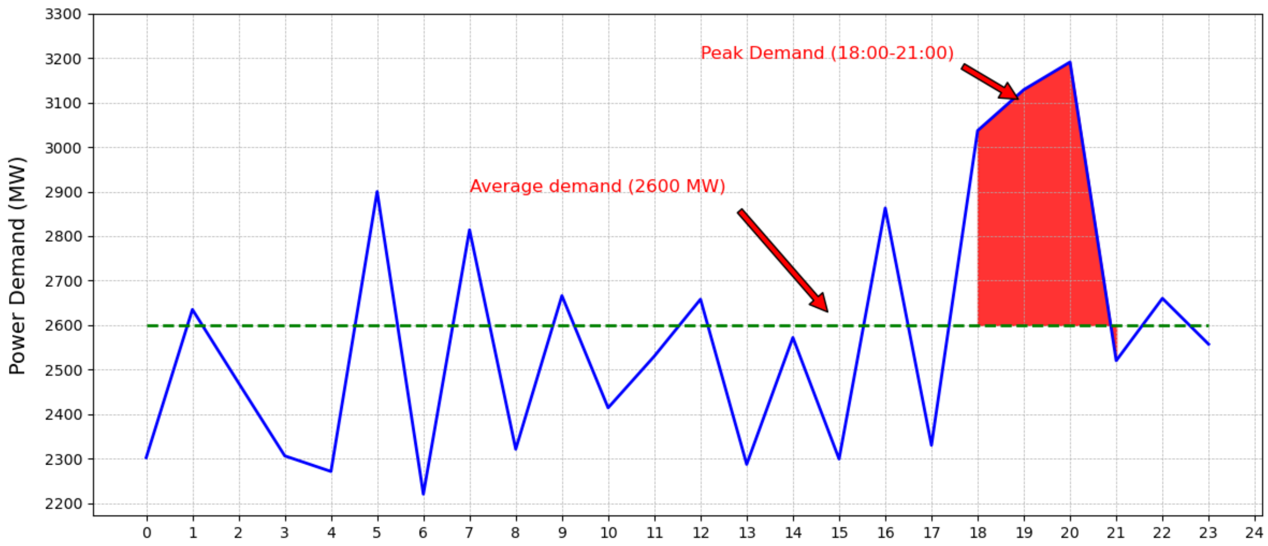

Fig3.9 Energy demand during the day

CHAPTER FOUR

RESULTS

History of Battery Storage

Battery technology has grown in importance in the energy system in the twenty-first century, particularly in the process of integrating renewable energy sources. The invention of the battery first started in 1800 when Alessandro Volta used the battery called "Voltaic pile". This battery stored electrochemical energy for continuous power supply.

Gaston Plante invented the first rechargeable battery in 1859. These lead-acid batteries were inexpensive and utilized in autos. But it was short-lived.

Smaller, more efficient batteries were developed in the mid-twentieth century. Examples are nickel-cadmium (Ni-Cd) and nickel-metal hydride. At the close of the twentieth century, the era of lithium-ion battery technology arrived. Lithium-ion batteries have higher energy density and last longer.

Energy storage technologies fall into five main categories: mechanical, electrochemical (or batteries), thermal, electrical, and hydrogen storage technologies.

Modern and efficient energy storage technologies are capable of transferring electrical energy within milliseconds or seconds. These energy storage technologies can provide energy continuously for several minutes to several hours. Storage time and power (MW) depend on the type of technology and this is necessary to choose the right technology according to application requirements. Figure 2 below shows the classifications of energy storage technologies.

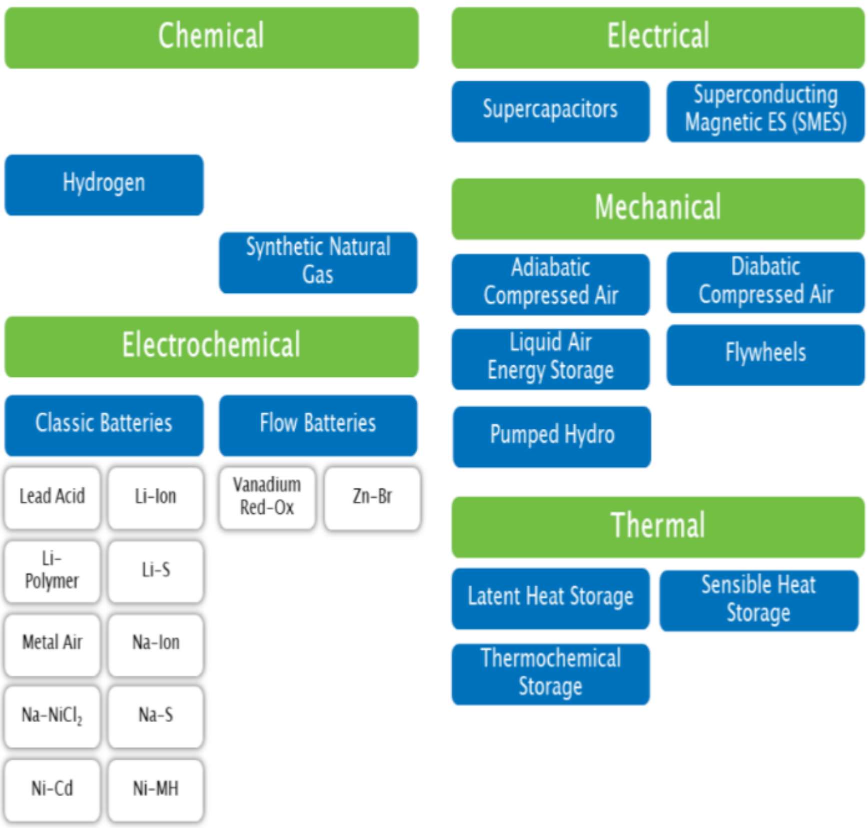

Fig4.1. Classsification of energy storage technologies

4.1 Advantages and disadvantages of various energy storage systems

The application of energy storage technologies is important during the integration of renewable energy sources into the system. Energy storage systems store excess energy from renewable energy sources and connect to the system when demand increases or when a renewable energy source is unavailable. Thus, energy storage technologies increase the reliability and stability of the energy system. Below is information on the pros and cons of various energy storage technologies including thermal, mechanical, electrochemical, magnetic and electrical systems.

Thermal energy storage systems: These storage systems collect heat from solar or geothermal energy sources. Solar thermal energy storage captures the sun's rays and uses them to heat the phase change material and heat the liquid. Thermal energy storage technologies have a number of advantages and disadvantages:

Advantages:

- It is possible to integrate renewable sources into the grid and have a more sustainable energy supply.
- They increase the efficiency of renewable energy systems, as they provide energy to consumers immediately and also the energy is not lost during storage.

Using heat pumps or electric boilers, energy is stored and efficient and important for the integration of renewable energy sources such as wind, solar.

Disadvantages:

- Thermal energy storage systems require frequent maintenance and monitoring to ensure proper operation and extend service life.

Electrochemical energy storage systems: These systems use chemical energy to store electrical energy for later use. The most commonly used technology for electrochemical energy storage is lithium-ion batteries. The advantages and disadvantages of employing lithium-ion batteries to integrate renewable energy into your system are listed below.

Advantages:

- The production of these batteries in different forms allows them to be adapted to different applications. This battery has a low self-discharge rate.
- Lithium-ion batteries have high energy density and therefore allow storing more energy in a small area.
- Lithium-ion batteries can last for a long time, that is, they can be charged and discharged several times.

Disadvantages:

- They have a very high internal resistance, which increases over time.

- Lithium-ion batteries are very expensive, making it difficult for all renewable energy sources to be used for energy storage.
- Lithium-ion batteries can be destructive when overcharged, creating a safety issue.
- The negative effects of lithium-ion batteries on the environment pose a problem for their long-term use.

Mechanical energy storage systems: Turbines and compressors are used in mechanical energy storage devices to store gravitational and electrical energy. One example is compressed air energy storage, which compresses air and stores it in underground caverns or tanks, creating energy when needed. In general, the benefits and drawbacks of adopting mechanical energy storage for renewable energy sources are:

Advantages:

- The storage capacity is large.
- Technological maturation
- A long life
- Fast deployment time in the case of a flywheel.
- It is kept simple (energy storage using compressed air)

Disadvantages:

- Pumped hydropower storage systems may be dependent on nearby terrain (elevation
- change) and pose environmental problems.
- Compressed air energy storage is constrained by a lack of appropriate subsurface caverns, may require combustion fuel (depending on the system type), and has seen limited deployment.
- The difficulty of a flywheel to tolerate dynamic loads or external shocks is compounded by its limited discharge capacity and short discharge durations.

Electric energy storage systems: Supercapacitors store energy in an electric field rather than using a chemical process like batteries. The following are the benefits and drawbacks of employing them in renewable energy-based systems.

- Faster charge and discharge times,higher power density, low maintenance costs and less environmental pollution are the advantages of electric energy storage systems.
- Compared to batteries, low energy density, short service life, temperature sensitivity and high cost of energy storage per kWh are the disadvantages of energy storage batteries.

Different Types of some Battery Storage Technologies

Each of the energy storage technologies has its own characteristics, advantages and disadvantages.

Lead-acid batteries: These batteries are rarely used today and are one of the oldest batteries. Due to its relatively low cost, it is used in UPS and cars. In addition to its low cost, energy density is low, and the disposal of lead is an environmental concern, limiting its use due to its disadvantages.

Nickel-cadmium (Ni-Cd) batteries: Nickel-cadmium batteries are used in extreme areas, but cadmium is toxic and the energy density is low, which are the main reasons limiting its use.

Nickel-Metal Hydride (NiMH) batteries: NiMH batteries have high energy density and low environmental problems. These batteries are used in households, but lag behind lithium-ion batteries.

Lithium-ion batteries (Li-ion): In the twenty-first century, Li-ion batteries are the greatest option for energy storage systems, big grids, and electric vehicles. These batteries offer great energy density and a long lifespan. These batteries are available in three different chemistries: lithium iron phosphate ($LiFePO_4$), lithium nickel manganese cobalt oxide (NMC), and lithium cobalt oxide (LCO), each with advantages and disadvantages.

Advantages of Lithium-Ion Battery Batteries

Lithium-ion battery systems have many advantages, and due to these advantages, they are widely used in power systems. These advantages are discussed in detail in the following paragraphs.

Energy Density: Lithium-ion batteries have a high energy density, which is the most important advantage for these batteries. Energy density is the energy a battery can store for its volume and weight. Energy density of lithium-ion batteries are 150-25 watt hours (Wh/kg), depending on their chemical composition. According to this indicator, it is significantly superior to other batteries. The high energy density of lithium ion batteries makes it more efficient to use and allows for more energy storage. Therefore, energy is widely used in networks and cars.

Low self-discharge rates: Self-discharge is one of the most commonly used concepts in all batteries. A battery loses its charge over time when not in use, and this is called the self-discharge rate. Lithium-ion batteries have a self-discharge rate of about 2-3% per month, which significantly increases the importance of these batteries as they are much lower than other batteries. The self-discharge rate ensures that the stored energy can be stored for a long time and supply consumers with this energy when needed.

In grid applications, these batteries are used to store excess energy produced by renewable sources such as wind and solar provide power to consumers when solar and wind are not available. The fast response time and quick discharge capability of lithium-ion batteries increase the possibility of being used in frequency regulation, peak shaving and load shifting applications when the power loss in the grid is large.

In addition, lithium-ion batteries can be combined with other technologies such wind turbines or as solar photovoltaic (PV) systems to increase overall grid reliability and decrease dependence on fossil fuels.

4.2 Lithium-ion Battery working principle

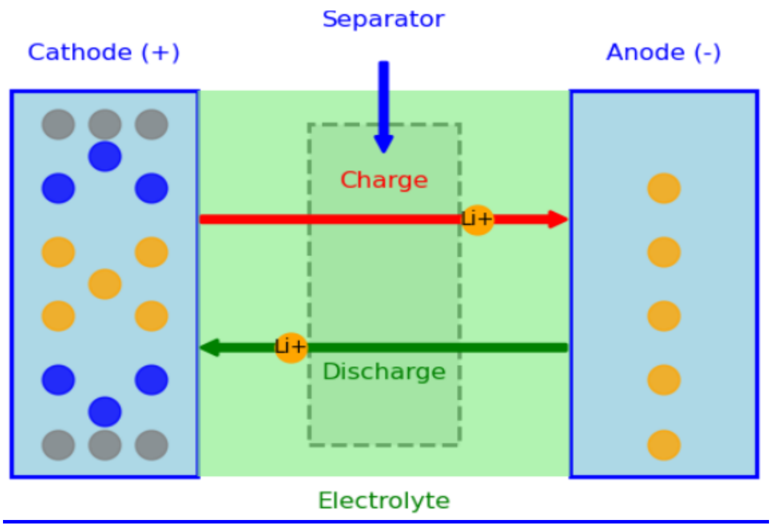

Fig4.2 Basic working principle of lithium-ion batteries

Lithium-ion batteries are important, because they help to the integration of renewable energy into energy systems. Renewable energy sources such as wind and solar operate seasonally, and the use of lithium-ion batteries is essential to overcome these negative aspects and ensure uninterrupted power. When the energy produced by lithium-ion batteries is greater than the energy required, they store this extra energy and use it when there is a break in production at these energy sources or during peak times.

Energy storage and subsequent use in lithium-ion batteries is based on an electrochemical process. The process consists of 2 stages.(Figure 3)

Charging Process: Surplus energy produced during sunny or windy times is charged by converting electrical energy into chemical potential through lithium-ion batteries. Lithium ions (Li^+) transfers to anode from cathode using electrolyte. The cathode is mainly composed of materials such as cobalt oxide and lithium iron phosphate and the anode is mainly graphite. Electrons pass through the external circuit, balancing the ionic movement. Lithium ions are "intercalated" from the cathode to the anode, where the energy is stored until needed.

Discharge Process: When the energy provided by renewable energy sources drops at night or during calm, windless weather, the process of utilizing the energy stored in the batteries begins. At this point, the process is reversed: lithium ions migrate from the anode to the cathode. Electrons flow back through the external circuit, generating power in the grid. The energy output is changed from direct current (DC) to alternating current (AC) via an inverter. Lithium-ion batteries efficiently store and use renewable energy that might otherwise be lost.

4.3 Essential Characteristics of Lithium-Ion Batteries

Lithium-ion batteries are an important energy storage technology due to their favorable properties, including high energy density, efficiency, and long cycle life. Understanding these key characteristics is critical to evaluating their performance and suitability in renewable energy storage applications.

Energy density: To determine the energy density of lithium-ion batteries used in renewable energy integration, you must take into account both theoretical and practical elements of battery performance. Energy density is often represented as energy per unit mass (volumetric energy density or gravimetric energy density).

Gravimetric energy density is defined as the quantity of energy stored per unit mass of the battery. It may be calculated using the following formula:

$$E_{density,\ gravimetric} = \frac{E_{total}}{M} \tag{4.1}$$

To find E_{total}:

$$E_{total} = \frac{1}{M}\int_0^{t_d} V(t) * I_{input}(t)\, dt \tag{4.2}$$

Volumetric energy density is the amount of energy stored per unit volume of battery. The formula for calculating it is as follows:

$$E_{density,\ volumetric} = \frac{E_{total}}{V_{battery}} \tag{4.3}$$

When lithium ion batteries were first used for renewable energy storage, the energy density was 80-100 Wh/kg, and this quantity has been increased to 300 Wh/kg in the 2020s.

Efficiency of batteries: Currently, the most common battery in the world is lithium-ion batteries, accounting for about 90%. Environmental impact, operating conditions and service life are factors that affect battery efficiency. If these factors are taken into account, the efficiency of the battery is 85-95%. For long-term use, lithium-ion batteries are more efficient.

Depth of discharge(DoD): The proportion of a battery's overall capacity that has been utilized is what it really means. For instance, a battery's DoD is 80% if it is 80% drained.

- **Low DoD (20%–30%):** Recharging a battery after using a lesser portion of its capacity extends its life and enables it to withstand more charge cycles.
- **High DoD (80%–100%):** The battery's lifespan may be shortened by using a higher percentage of its capacity since deeper discharges put greater strain on the battery's components and accelerate their deterioration.

A DoD of 80% is generally advised for lithium-ion batteries in order to balance cycle time and power consumption. Even while many contemporary systems can manage DoDs as low as 90%–95%, using a high DoD often might shorten battery life overall. Certain chemistries, such Lithium-Iron Phosphate (LFP), may withstand deeper discharges better than others, although Nickel Manganese Cobalt (NMC) batteries can deteriorate more quickly in situations with a high DoD.

The installed cost of batteries in energy systems: Although the installation cost of lead-acid batteries is 80-150$ per 1 kWh, the energy density and lifespan are small. And due to these negative characteristics, the installation of large powerful lead-acid batteries is effectively unsuitable.

Installation of nickel-cadmium (Ni-Cd) batteries costs $400 per kWh. The fact that these batteries are expensive and have low energy density means that their use is less efficient.

Nickel-Metal Hydride (NiMH) batteries are installed for $250 per 1 KWh. The cost of installation is high and therefore not efficient.

The most efficient batteries in terms of energy density, environmental impact and installation costs are lithium-ion batteries. Installation cost is $139 per 1 kWh. And the energy density is greater than other batteries, so it is 95%. Lifespan depends on the place of installation of the battery, the number of charging and discharging. Currently, the developed countries of the world such as America, Canada, Germany, Japan use lithium-ion batteries in the energy system.

Calculation of Total Installitaion Cost of lithium ion batteries:

$$\begin{gathered} 250 \text{ MWh} = 250000 \text{ KWh} \\ 1 \text{ KWh} = 139\$ \\ \text{Total cost} = 250000 * 139\$ = 34.750.000 \ \$ \end{gathered} \tag{4.4}$$

So, total cost for 250 MWh is about 35 million dollars.

4.4 Charging batteries due to various sources

In order to calculate the economic efficiency of batteries, it is necessary to compare the charge values of their charging from different sources. In order to save energy, it is necessary to calculate the charging of batteries from 3 types of power stations. Since the life of the batteries depends on the number of times they are charged and discharged, the number of charges and discharges will be considered as 2 and 3 times a day. The cost of recharging lithium-ion batteries from traditional fuel stations, hydroelectric power plants and renewable energy sources will be calculated.

4.4.1 Analysis of battery charging using a Shimal power plant

- **Charging the batteries twice a day**

The power station that uses the least fuel per 1 KWh of traditional stations is the Shimal Power Station. Thus, 223 grams of natural gas is used for 1 KWh of electricity at the Shimal Power Station. To use the battery twice a day, 500,000 kWh of energy is needed.

Daily gas consumption =500,000*223 grams = 111,500,000 grams = 111,500 kg

Convert kg to cubic meter = $\frac{111{,}500}{0.8} = 139{,}375\ m^3$

Annual gas = 139,375 * 365 = 50,871,875 m^3

Annual price = 50,871,875 * $\frac{300}{1000}$ = $15,261.562 (4.5)

Considering that $23 million is required to charge a 250 MW battery during the day using the Azerbaijan Thermal Power Plant, according to reports, this is $15,261,562 at the Shimal power plant. That is, with this method, we will save $7,733,438 in annual funds. And if we consider that the cost of installing the batteries is $35 million, it can be payback in 5 years.

- **Charging the batteries three times a day**

Azerbaijan Thermal Power Station uses 336 grams of fuel for 1 KWh of electricity. The cost of using the battery 3 times a day, 2 hours each, for a total of 6 hours, was calculated at the Azerbaijan Thermal Power Station.

The amount of energy needed during the day:

250 000 KWh * 3 = 750 000 KWh (4.6)

Battery is charged 3 times a day by Azerbaijan Thermal Power Station:

Daily gas consumption = 750 000 KWh * 336 grams = 252 000 000 grams

Daily gas consumption = 252 000 000 gram/ 1000 = 252 000 kg (4.7)

The price of 1000 cubic meters of gas is $300. 0.8 kg/m^3 is the density of natural gas. To find cubic meters, you need to divide by 0.8.

Convert kg to cubic meter = $\frac{252\ 000}{0.8} = 315\ 000\ m^3$ (4.8)

Now, monetary value of annual amount of natural gas :

Annual gas = 315 000 * 365 = 114,975,000 m^3

Annual price = 114,975,000 * $\frac{300}{1000}$ = 34,492,500 $ (4.9)

Therefore, 1 generator with a capacity of 250 MW at the Azerbaijan Thermal Power Station requires about $34.5 million for 1 year to operate for 3 hours a day. If we charge and use the lithium ion batteries during these 3 hours using the Shimal Power Station, let's calculate how much cost we will save during the year.

It should be noted that the amount of fuel at the Shimal Power Station is 223 grams.

$$\text{Daily gas consumption} = 750{,}000*223 \text{ grams} = 167{,}250{,}000 \text{ grams} = 167{,}250 \text{ kg} \quad (4.10)$$

At the Azerbaijan Thermal Power Station, it was 252,000 kg per day, and thus we save 84,750 kg of natural gas per day at the expense of the Shimal Power Station.

Now, monetary value of annual saving natural gas :

$$\text{Convert kg to cubic meter} = \frac{84750}{0.8} = 105{,}937.5\ m^3$$

$$\text{Annual gas} = 105{,}937.5 * 365 = 38{,}667{,}187.5\ m^3 \quad (4.11)$$

$$\text{Annual saving price} = 114{,}975{,}000 * \frac{300}{1000} = 11{,}600{,}150\ \$$$

Based on the results of the calculations, the Azerbaijan Thermal Power Station, which uses 336 grams of fuel per 1 kWh, instead of using 1 generator for 6 hours a day, using a lithium-ion battery charged at the expense of the Shimal Power Station, which uses 223 grams of fuel per 1 kWh, will cost approximately $11.6 million can be saved per year. Considering the cost of installing the batteries is $35 million, we will payback the cost of these batteries for 3 years, and they will be profitable for the next few years.

4.4.2 Analysis of charging of batteries with the energy obtained from Hydroelectric Power Stations

- **Charging the batteries twice a day**

Here, calculations are made about the feasibility and financial savings of using hydropower to charge lithium-ion batteries, which is an energy storage technology. Purchase of 1 kWh of electricity for hydropower in Azerbaijan is $0.0294 Since hydropower is a type of renewable energy sources, it reduces the dependence on fossil fuels and the amount of carbon dioxide. This is its ecological advantage. Hydropower is more ecologically efficient than conventional plants due to the use of water to generate electricity. However, hydro potential is not enough.

In order to charge the batteries twice a day using hydro energy, it should be taken into account that 1 kWh of energy is sold for 0.05 AZN. That is, we need 500,000 kWh of energy during the day, and the cost of this is 25,000 AZN, in other words, $14,705,882.

$$\text{Annual price} = \$14{,}705{,}882*365 = \$5{,}367{,}646$$

$$\text{Annual Savings} = \$23{,}000{,}000 - \$5{,}367{,}646 = \$17{,}632{,}354 \quad (4.12)$$

That is, as a result, we save $17,632,354 per year by charging the batteries twice a day using hydropower. This means that the cost of installing batteries can be payback within 2 years.

- **Charging the batteries three times a day**

Daily and annual energy consumption needs to be calculated for financial reporting. During the financial reporting of the Shimal Electric Station, the daily energy demand for batteries was found to be 750,000 kWh.

$$\text{Daily price} = 750{,}000\ \text{kWh} * \$0.0294 = \$22{,}050$$
$$\text{Annual price} = \$22{,}050*365 = \$8{,}048{,}250 \quad (4.13)$$

Thus, the power required by the batteries during the year costs $9,170,625. Natural gas costs about $34 million of this energy, so the annual financial savings can be calculated based on these prices.

$$\text{Annual Savings} = \$34{,}500{,}000 - \$8{,}048{,}250 = \$26{,}480{,}750 \quad (4.14)$$

In addition, Reduced usage of fossil fuels reduces greenhouse gas emissions and, on the other hand, increases the reliability and service life of equipment.

Hydropower generation transfers minimal carbon emissions to the environment and therefore significantly reduces greenhouse gases. Therefore, both financial savings and environmental goals can be achieved in this way.

Considering the reports, it is found that about $26 million is saved annually, and from this it can be concluded that if hydropower is used to charge the batteries, the payback will be in 1.4 years.

4.4.3 Reports of charging batteries using a solar power plant

- **Charging the batteries 2 times a day**

Inverters or converters are used to transfer the electricity obtained from solar energy to the batteries at the appropriate voltage and current. The converted electricity is stored in the batteries for efficient use after being charged. The energy obtained from the solar power plant is currently sold for 0.057 AZN, i.e. $0.0335. The report of charging the batteries 2 times a day is as follows:

$$\text{Daily price} = 500{,}000\ \text{kWh} * \$0.0335 = \$16{,}750$$
$$\text{Annual price} = \$14{,}925*365 = \$6{,}113{,}750 \quad (4.15)$$

According to reports, we save $16,886,250 compared to the Azerbaijan Thermal Power Station, which uses the most fuel per 1 kWh, and on the other hand, we save $9,147,812 compared to the Shimal Power Station, which uses the least fuel per 1 kWh.

- **Charging the batteries 3 times a day**

Solar energy is an environmentally friendly energy source as it does not require fuel consumption. It has many advantages compared to natural gas-fired plants. No fuel is used because the energy of the sun is used. This means fuel savings.

It is also environmentally friendly, as it reduces greenhouse gas emissions as there is no fuel. Currently, solar power plants are the most ideal choice due to long-term fuel savings and more environmentally friendly use.

The following report found annual funding to charge the batteries 3 times a day using a solar power plant.

$$\text{Daily price} = 750{,}000 \text{ kWh} * \$0.0335 = \$25{,}125$$
$$\text{Annual price} = \$25{,}125*365 = \$9{,}170{,}625 \quad (4.16)$$

Apparently $9,170,625 in annual funding is needed. If we consider that a plant using 336 grams of fuel per 1 kWh requires $34,530,000. Then

$$\text{Annual Savings} = \$34{,}530{,}000 - \$9{,}171{,}125 = \$25{,}358{,}875 \quad (4.17)$$

We will save $25,358,875 in 1 year. This indicator allows us to say that it is possible to payback with this method within 1.5 years.

5 Analysis and simulation of reports

According to the results of the reports, it seems more efficient to charge batteries 3 times a day using hydropower. However, it should be noted that currently, the hydro potential in Azerbaijan is not sufficient, so it will not be possible to charge batteries using this method. On the other hand, work is being done all over the world to reduce carbon emissions due to climate change, and it is planned to reduce carbon emissions by 40% by 2050. This is the goal of COP29, which will be held in Azerbaijan in 2024. Considering this, charging batteries at the expense of the Shimal Power Plant is not environmentally friendly. Because 223 grams of conventional fuel are used here per 1 kWh.

It should also be noted that the life of lithium-ion batteries is about 20 years and they work with 80% efficiency for the next 5 years. Therefore, by using them 3 times a day, we reduce their life and get less economic profit. Considering all these shortcomings, it was decided to charge and use batteries 2 times a day using a solar power plant.

The table below provides more clear information on charging batteries by all three methods.

Table 5.1 Charging batteries by all three methods

Charge Method	Daily Energy (kWh)	Energy Cost per kWh ($)	Daily Cost ($)	Annual Cost ($)	Comparison to Azerbaijan Thermal Power Plant ($)	Payback Period (years)
Shimal Power Plant (2 times)	500,000	0.027	13,500	4,927,500	7,733,438	5
Shimal Power Plant (3 times)	750,000	0.027	20,250	7,391,250	11,600,150	3
Hydroelectric Power Plant (2 times)	500,000	0.0294	14,705	5,367,646	17,632,354	2
Hydroelectric Power Plant (3 times)	750,000	0.0294	22,050	8,048,250	26,480,750	1.4
Solar Power Plant (2 times)	500,000	0.0335	16,750	6,113,750	16,886,250	2.1
Solar Power Plant (3 times)	750,000	0.0335	25,125	9,170,625	25,358,875	1.5

For more optimal management of energy consumption, it is more effective to use the battery twice a day. Using the battery during periods of high energy demand reduces fuel consumption. Charging twice a day allows for more effective management of the battery cycle count. Batteries can operate with a longer life when charged once a day, charging three times a day drastically reduces the number of battery cycles and increases operating costs. Using the battery once a day increases the payback period. Using it three times a day complicates operational management and increases operating costs. On the other hand, using it three times a day is not possible because the solar potential is not sufficient. All these factors show that using it twice a day increases energy savings, battery life and financial efficiency. In this way, it is possible to increase the long-term use of the battery, reduce fuel costs and increase the overall financial efficiency of the system. This is important for both reducing operating costs and protecting long-term revenues.

5.1 Analysis of Load Flow with and without Battery Integration at Absheron 500/330/220 kV Substation

The analysis of load flows with battery connection at Absheron 500/330/220 kV substation is an important step, as this analysis is important for the efficiency of energy distribution and voltage stabilization. On the other hand, the determination of loads on all lines and buses allows for the complex determination of loads and the analysis of the effects caused by batteries.

By writing the loads on all lines and buses in a complex manner, it is possible to analyze the changes in the battery connection state.

This research compares load flow at the Absheron 500/330/220 kV substation in two scenarios: without and with battery integration. The primary goal is to investigate the effects of battery storage systems on voltage stability and load balancing across various buses and transmission lines. The figure below shows a single-line diagram of the 500 KV bus of the Absheron 500/330/200 substation in normal condition. The system was simulated using the DigSilent Power Factory program and the load analysis was performed when the 250 MW generator of the Azerbaijan Thermal Power Plant was operating. The loads on the lines connected to the 500 KV bus at the Absheron 500/330/220 substation when the power system was operating without a battery are shown in the graph.

1. 500 kV Busbar

- **Voltage without battery**: 484.8 kV
- **Voltage with battery**: 485.7 kV

The voltage increased by 0.9 kV after battery integration, suggesting better voltage stability. The load flows over the lines linked to the 500 kV busbar are shown below.

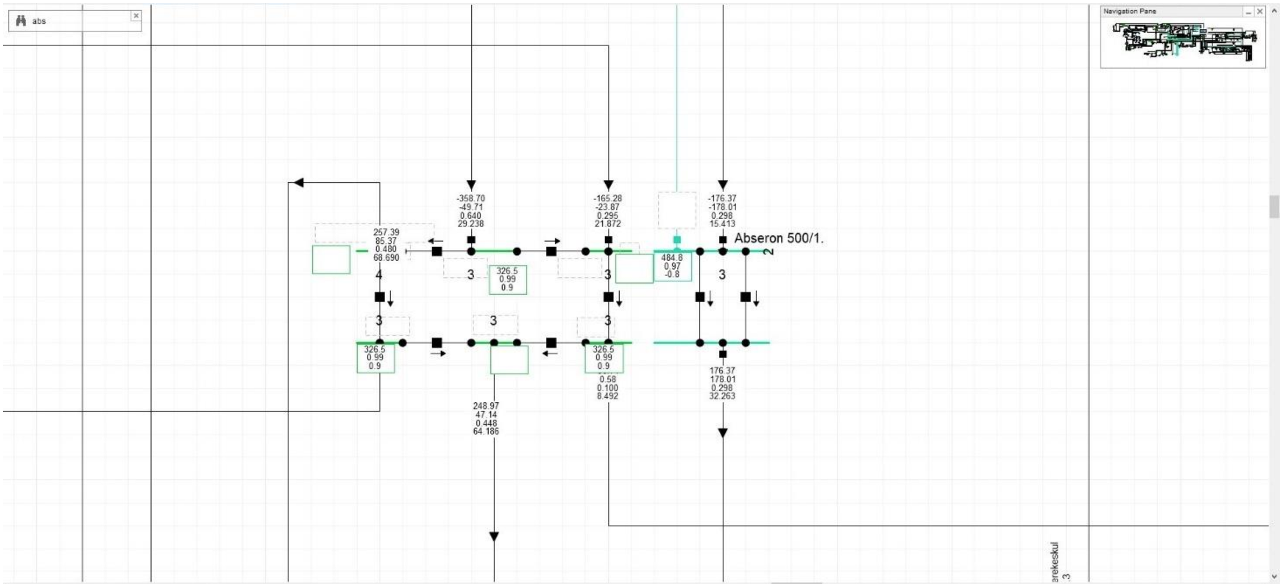

Fig5.1 500 kV busbar

After the battery was connected, generator 1 of Azerbaijan Thermal Power Plant was stopped and the system was restarted. When the system was running, the loads on the same bus were re-analyzed. The value of the loads is shown in the figure below. This is the case when a 250 MW battery is connected to the Absheron 500/330/220 substation.

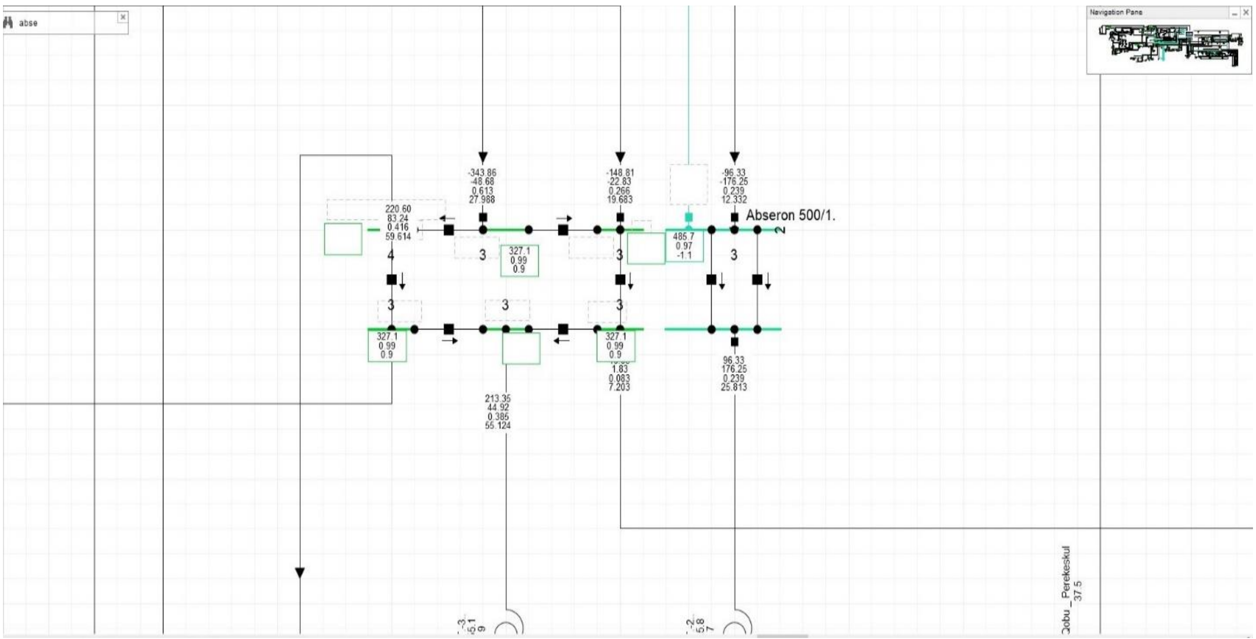

Fig5.2 The value of the loads

The voltage for a 500 kV busbar with and without batteries is shown in the graph below. The graph shows that in the battery case, the voltage increased from 484.8 kV to 485.7 kV due to the reduction in losses.

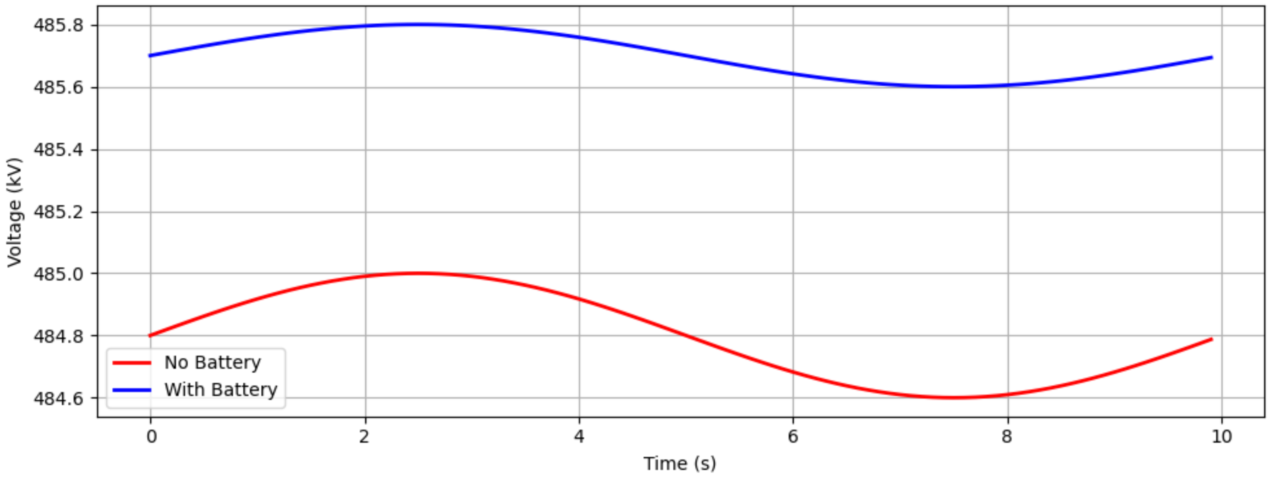

Fig5.3 500 kV busbar with and without batteries

The complex loads of the lines connected to the 500 kV bus are listed in the table.

Table 5.2 Lines connected to the 500 kV bus

Line	**Without Battery (MVA)**	**With Battery (MVA)**	**Change (MVA)**
2nd Absheron	-176 - j178	-96.33 - j176.25	Decrease
Autotransformer 2 Input	176.23 + j166.54	96.33 + j176.25	Decrease

2. 330 kV Busbar

- **Voltage without battery**: 326.5 kV
- **Voltage with battery**: 327.1 kV

With battery integration, the voltage rose by 0.6 kV. This enhancement demonstrates how well the battery can maintain voltage stability at the 330 kV busbar. The following are the load flows across the linked lines:

Table 5.3 Lines connected to the 330 kV bus

Line	**Without Battery (MVA)**	**With Battery (MVA)**	**Change (MVA)**
6th Janub	-165.28 - j23.87	-148.81 - j22.83	Decrease
Autotransformer 1	257.39 + j85.37	220.6 + j83.24	Decrease
Navahi-Absheron	-358.7 - j49.7	-343.86 - j48.68	Decrease
Autotransformer 3	248.97 + j47	213.35 + j44.92	Decrease
8th Absheron	56.71 + j0.58	46.85 + j1.83	Decrease

The change in voltage level on a 330 kV busbar is shown in the graph below. It is clear from the graph that the voltage has increased by 0.6 kV due to the reduction in losses.

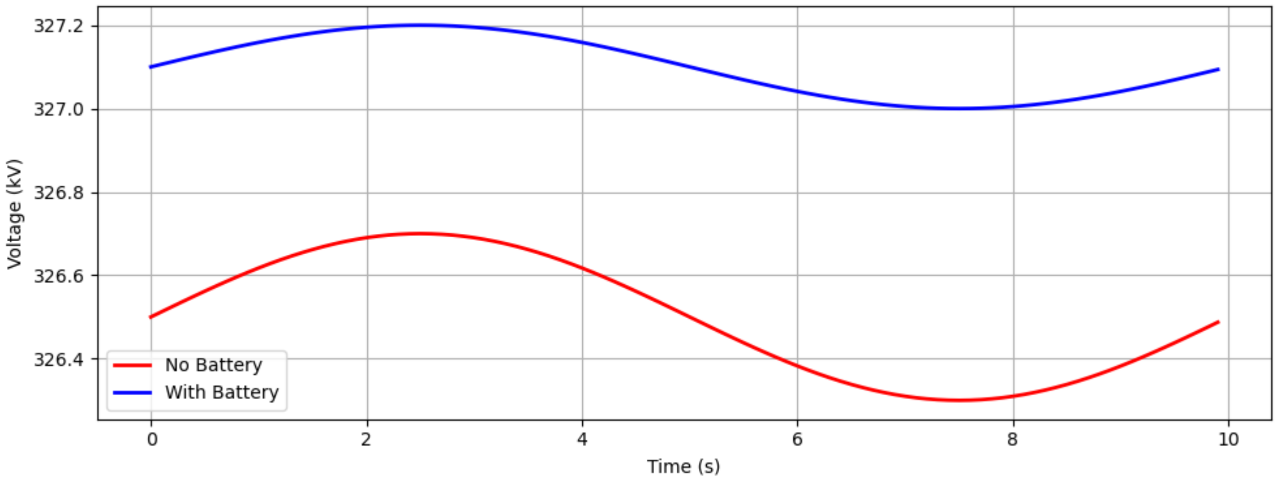

Fig 5.4 Voltage level on a 330 kV busbar

3. 220 kV Busbar

- **Voltage without battery**: 223.6 kV
- **Voltage with battery**: 224 kV

The voltage increased by 0.4 kV when the battery was integrated. The lines connected to the 220 KV bus and their loads for the battery-free situation are given in the graph below.

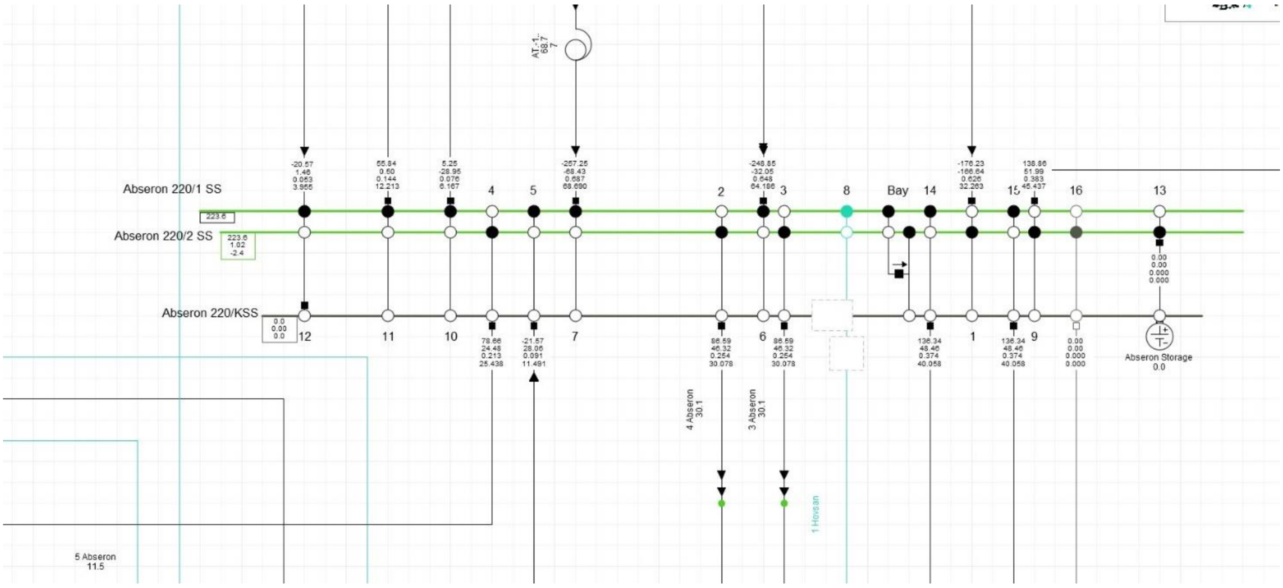

Fig5.5 Lines connected to the 220 KV bus

After the battery was connected, the voltage on the 220 KV bus increased. This means that the losses decreased after the battery was installed.

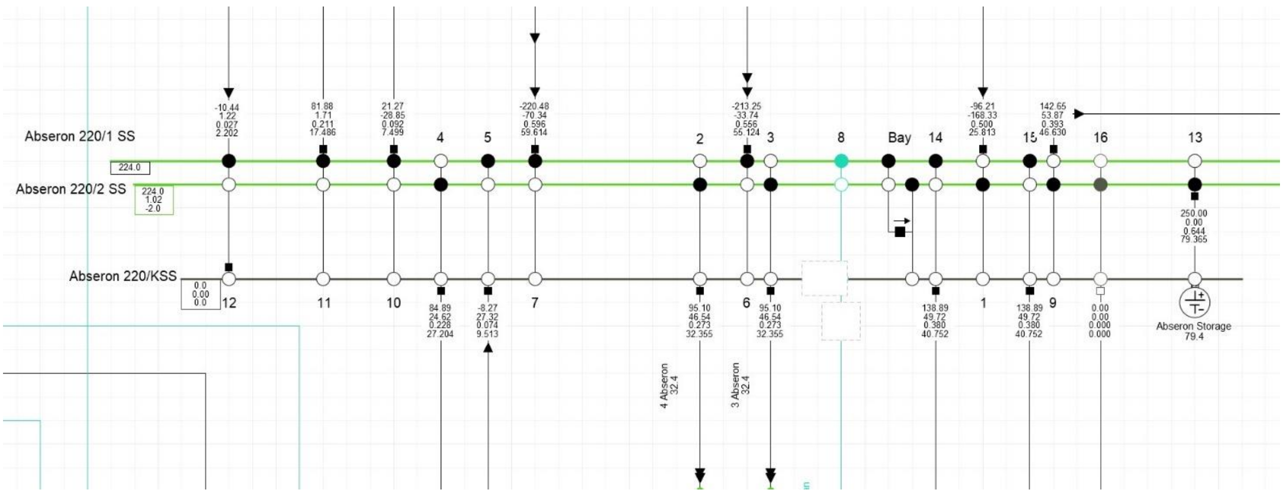

Fig5.6 The voltage on the 220 KV bus with battery

The complex loads of the lines connected to the 220 kV bus are listed in the table.

Table 5.4 Lines connected to the 220 kV bus

Line	Without Battery (MVA)	With Battery (MVA)	Change (MVA)
1st Abseron	-39 + j31	11.86 + j33.73	Increase
3rd Abseron	86.59 + j46.32	95.1 + j46.54	Increase
4th Abseron	86.59 + j46.32	95.1 + j46.54	Increase

5th Abseron	-21.57 + j28.06	-8.87 + j27.32	Decrease
6th Abseron	78.66 + j24.46	84.89 + j24.62	Increase
7th Abseron	138.86 + j51.99	142.65 + j53.87	Increase
Absheron-Novkhany	136.34 + j48.46	138.99 + j49.72	Increase
Sangachal-Absheron	-20.57 + j1.46	-10.44 + j1.22	Decrease
Akhsu-Absheron	55.84 + j0.5	81.88 + j1.71	Increase
Qabala-Absheron	5.25 - j28.95	21.27 - j28.85	Increase

The change in voltage level on a 220 kV busbar is shown in the graph below. It is clear from the graph that the voltage has increased by 0.4 kV due to the reduction in losses.

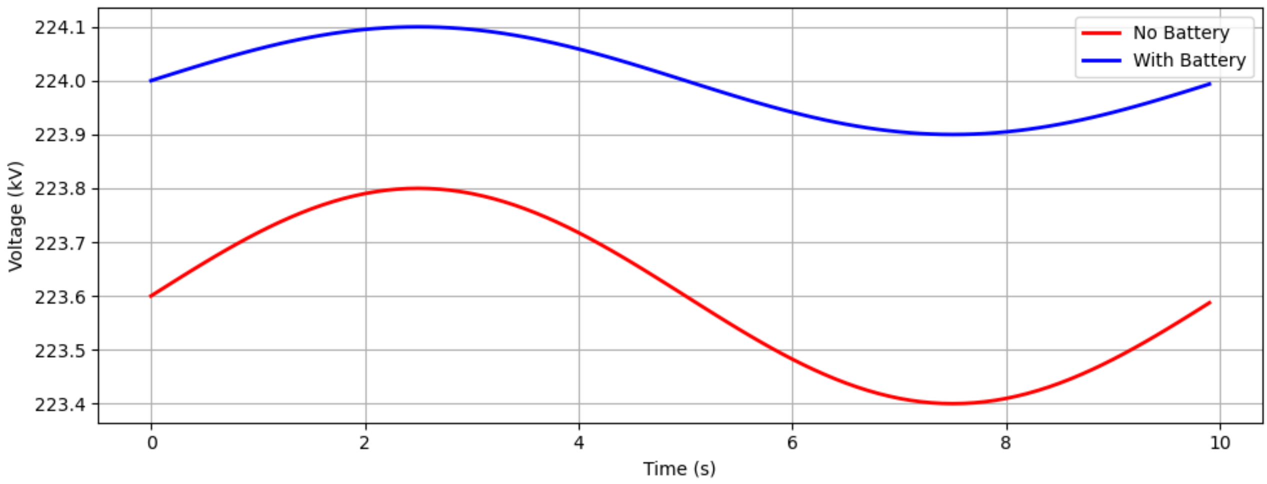

Fig5.7 Voltage level on a 220 kV busbar

Based on the general comparison, it has been proven through simulation that there are many advantages of using batteries. Thus, by using batteries, it was possible to reduce losses, that is, energy losses were reduced, which also increased efficiency. On the other hand, the loads in the network are balanced, which increases the efficiency of the system in long-term use.

The following graphs show the simulation results obtained using the DigSilent Power Factory program. According to the results obtained, the Battery Storage System (BSS) significantly improves the stability of the voltage in the power system during a short circuit when connected to the substation. The results are given below for the case of Absheron 500/220/ substation with and without a battery.

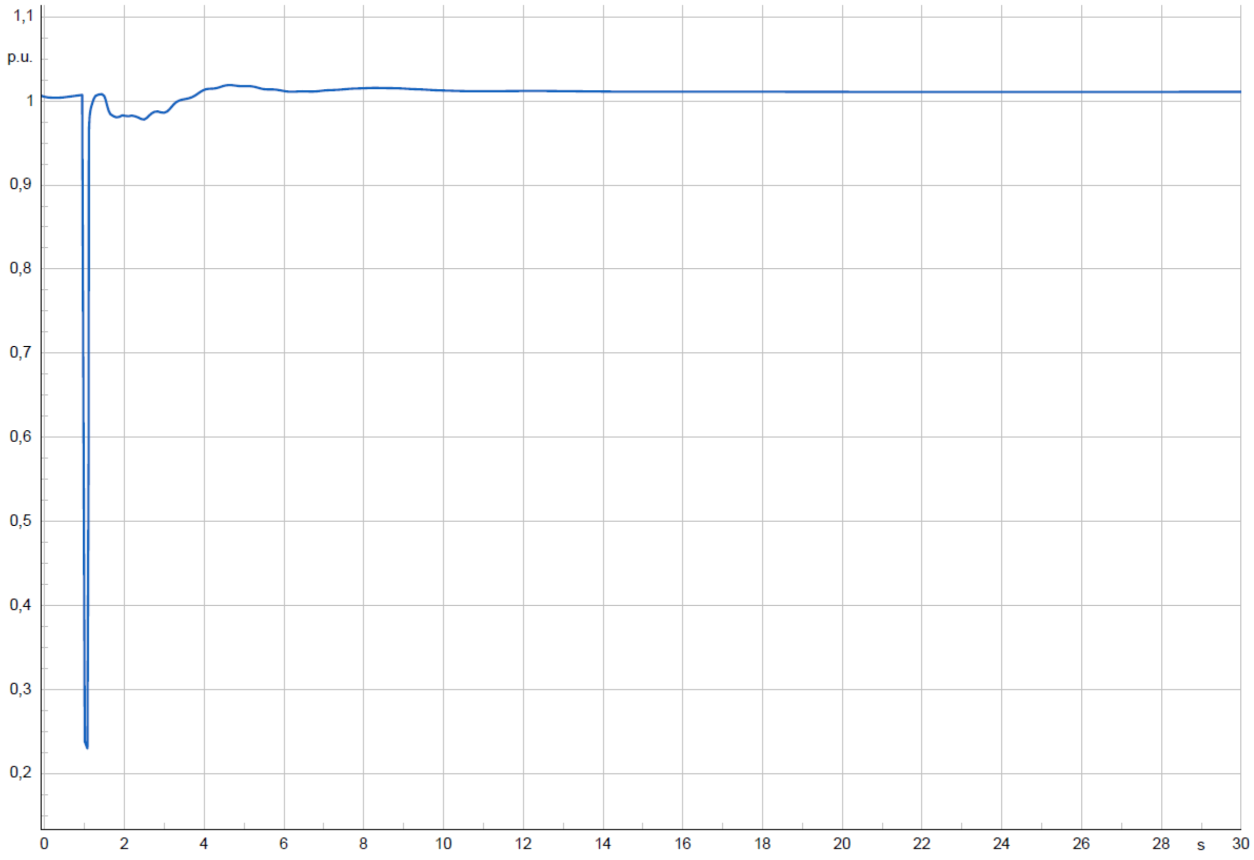

Fig5.8 Short circuit in 1.1 seconds without battery

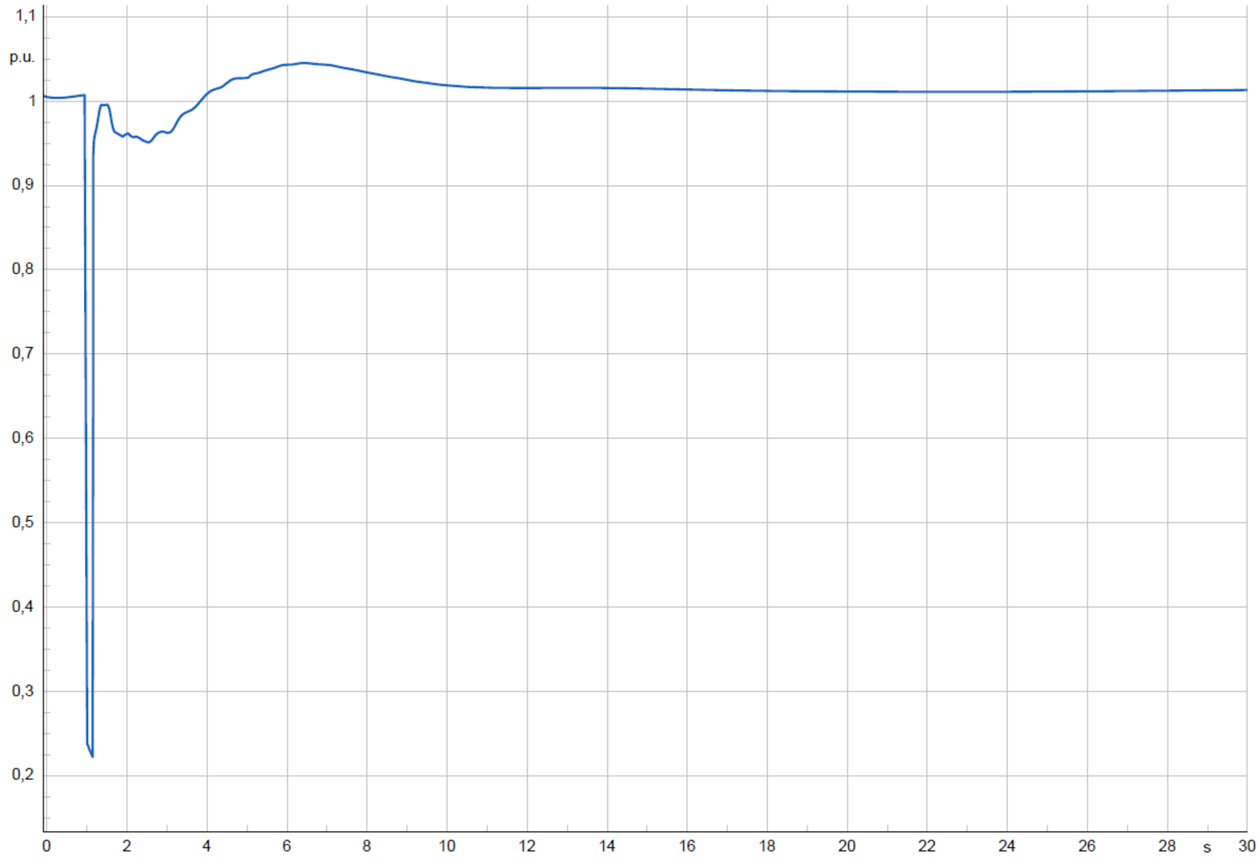

Fig5.9 Short circuit in 1.15 seconds without battery

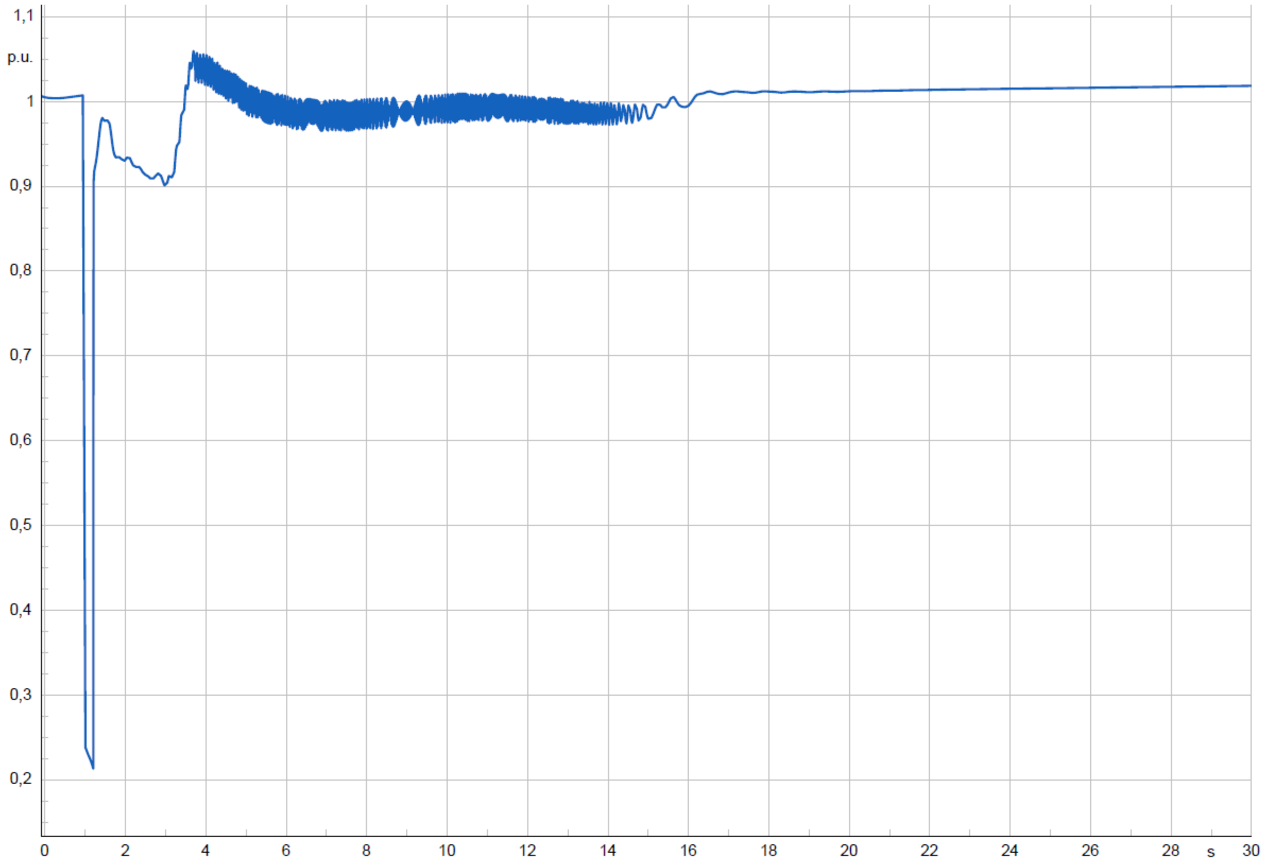

Fig5.10 Short circuit in 1.2 seconds without battery

According to the simulation results, if there is a short circuit at 1.1, 1.15 and 1.2 seconds in the absence of a battery, serious problems arise in maintaining the voltage stability. In the general system, voltage recovery takes longer.

In the absence of a battery during short circuits of 1.1 and 1.2 seconds, the voltage approaches the nominal value, but it takes longer to achieve full stability. And the voltage level remains lower. Such changes in voltage result in fluctuations and disrupt the overall stability.

During a short circuit of 1.15 seconds, the voltage stabilizes at 0.93-0.94 p.u. However, on the other hand, instability has increased due to the absence of a battery. Therefore, total load losses in the system also increase.

The fact that the voltage remains at such a low level negatively affects the reliability of the system and creates additional costs, because voltage disruptions cause fluctuations, and equipment fails more quickly, requiring additional technical measures. This is also not good from an economic perspective and requires additional funding.

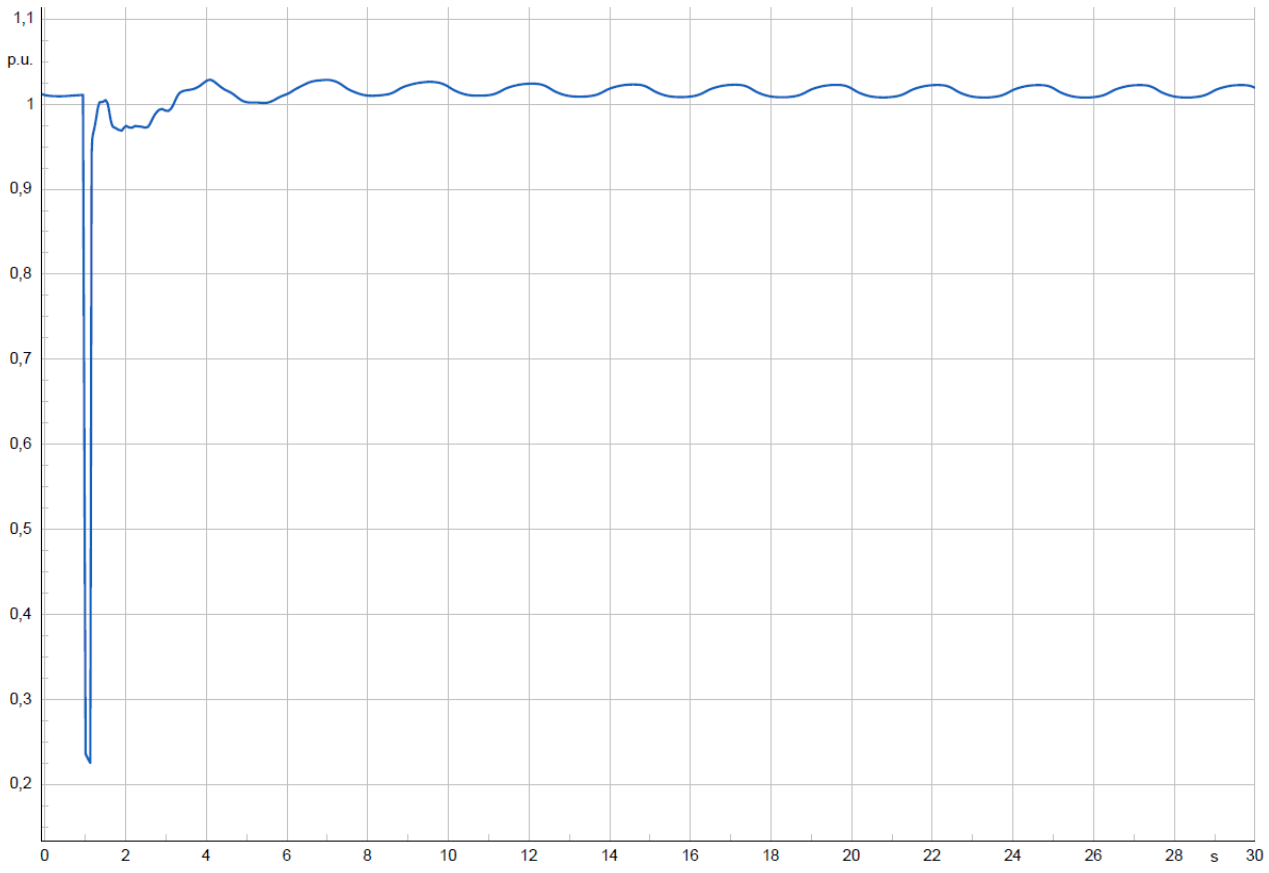

Fig5.11 Short circuit in 1.1 seconds with battery

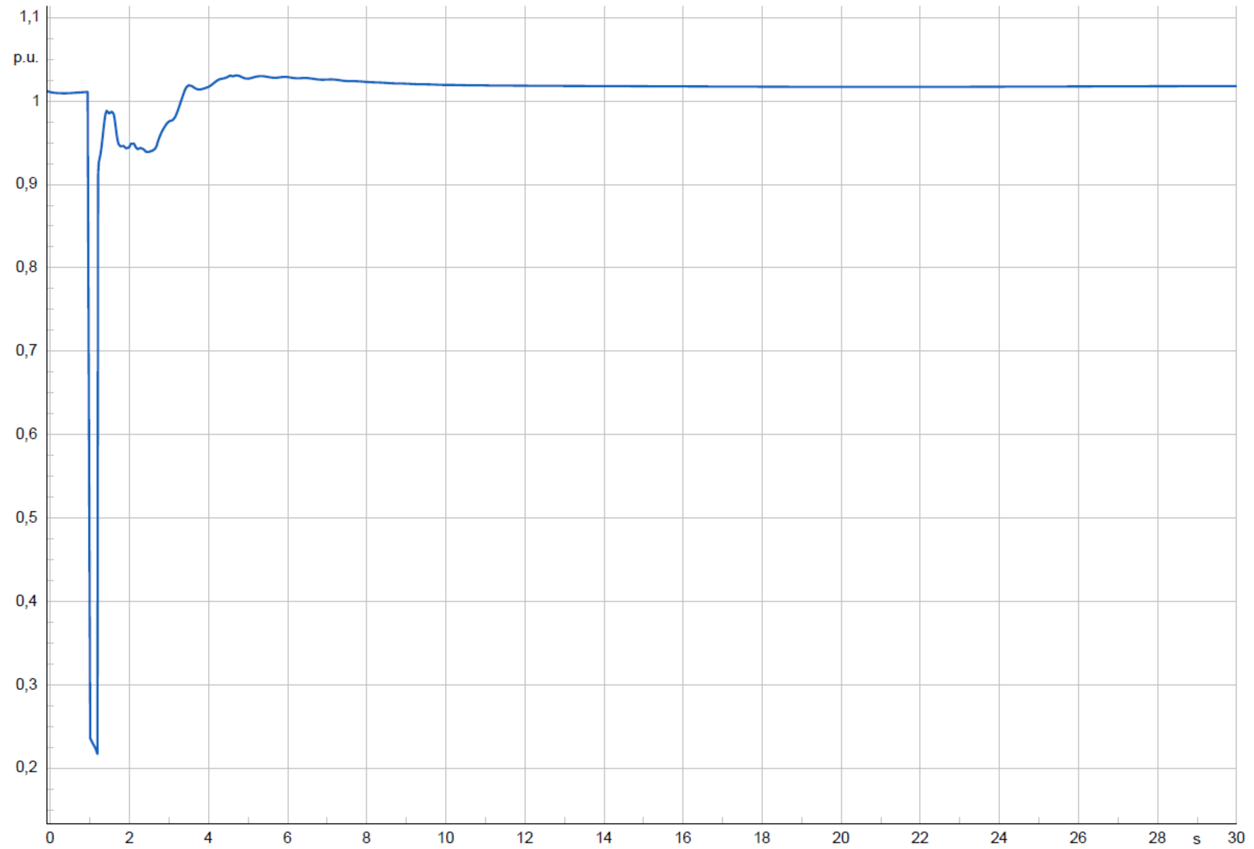

Fig5.12 Short circuit in 1.15 seconds with battery

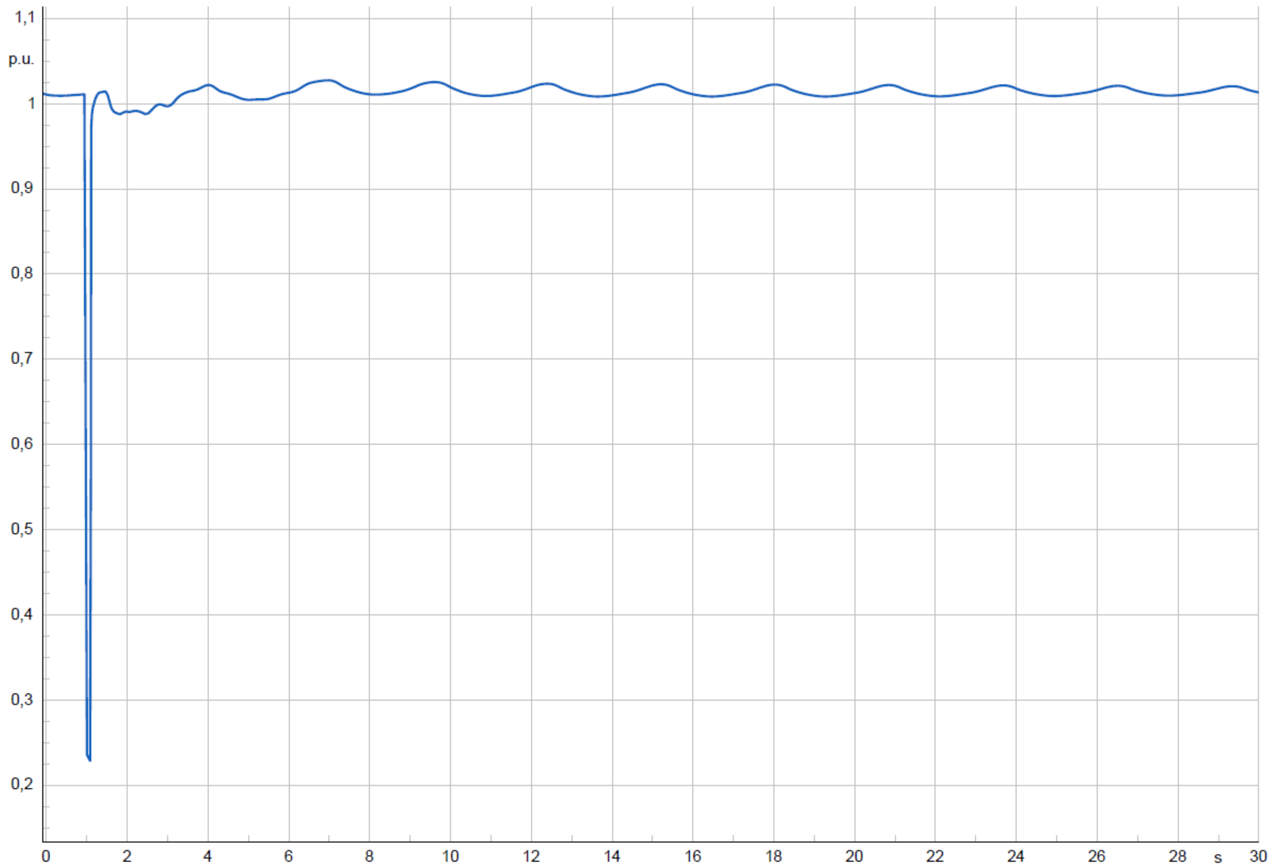

Fig5.13 Short circuit in 1.2 seconds with battery

According to the results of the analysis conducted with the DigSilent Power Factory software, batteries are important for maintaining voltage stability in the power system during short circuits.

During short circuits of 1.1 and 1.15 seconds, batteries achieved faster voltage recovery. During short circuits, the voltage decreased to a certain level and returned to its previous value faster after the batteries were used.

During a short circuit of 1.2 seconds, batteries were able to maintain their effects again. The faster voltage recovery reduced losses in the power system and had a positive economic impact. Batteries are important for reducing the effects of long-term short circuits.

CHAPTER FIVE

DISCUSSION AND CONCLUSIONS

1. **Voltage Stability Improvement:** The voltage level at the largest substation of the system has been improved by the introduction of Lithium-ion batteries. Although the voltage is lower without the battery, there are minimal fluctuations with the battery.

2. **Reactive Power Reduction:** The reactive power requirement has been reduced by adding the battery. This means better use of the existing network capacity. This reduction means an increase in the efficiency of the system. .

3. **Energy Loss Reduction:** By integrating the battery, energy losses in the lines have been reduced. Efficiency in energy transmission has been increased. This has also led to greater economic benefits.

4. **Dynamic Stability:** After the integration of the batteries, the dynamics of the power system have been significantly improved. It has helped to increase the reliability and stability of the system, as it has enabled better and more stable operation under different load conditions.

5. **Economic efficiency:** When the batteries are charged by solar energy, their cost has been paid back in about 3 years and profits have been achieved in the following years.

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