REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF INDUSTRIAL ENGINEERING

DYNAMIC ENERGY PRICE DETERMINATION FOR BLOCKCHAIN BASED SMART MICROGRIDS WITH RENEWABLE SOURCES

ATİLLA MAMİŞ
MASTER OF SCIENCE

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ADANA, 2022

I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

Atilla MAMİŞ

ABSTRACT

DYNAMIC ENERGY PRICE DETERMINATION FOR BLOCKCHAIN BASED SMART MICROGRIDS WITH RENEWABLE SOURCES

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Since the use of electrical energy at beginning, energy prices have been specified by simple traditional methods. With the use of renewable energy sources widely, the variety of energy sources has increased, and smart grid concepts have started to be implemented. Due to developments in technology, energy pricing is becoming more complex, and more secure methods without intervention are needed.

In this thesis, a dynamic energy price platform for blockchain based smart microgrids with integrated renewable sources is proposed. Since intervention of any user or a host is not allowed in blockchain process, the reliability is very high. Real-time energy production of various sources in the microgrid and consumption rates are evaluated, and a dynamic price is determined simultaneously. The developed strategy is tested using different scenarios for a microgrid involving renewable sources such as solar power stations and wind farms. In the scenarios, several conditions were considered for both supply and demand side management. Use of the dynamic pricing strategy with the blockchain is explained. For blockchain connection and communication, smart metering is considered for energy meters and the connection and communication is done by Internet of Things (IOT). As a result, a novel, self-controlling and secure energy pricing scheme is generated.

Keywords: Dynamic energy pricing, Blockchain, microgrids, renewable energy sources

ÖZET

YENİLENEBİLİR KAYNAKLAR İÇEREN AKILLI MİKRO ŞEBEKELER İÇİN BLOK ZİNCİR TABANLI DİNAMİK ENERJİ FİYAT BELİRLENMESİ

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Elektrik enerjisinin kullanılmaya başlanmasından bu yana, enerji fiyatları basit geleneksel yöntemlerle belirlenmektedir. Yenilenebilir enerji kaynaklarının yaygın olarak kullanılmasıyla birlikte, enerji kaynaklarının çeşitliliği artmış ve akıllı şebeke konseptleri uygulanmaya başlanmıştır. Teknolojideki gelişmeler nedeniyle, enerji fiyatlandırması daha karmaşık hale gelerek, daha güvenli ve müdahalesiz yöntemlere olan ihtiyaç artmıştır.

Bu tezde, yenilenebilir kaynakların entegrasyonunda blokzincir tabanlı akıllı mikro şebekeler için dinamik bir enerji fiyat platformu önerilmiştir. Blokzincir işleminde herhangi bir kullanıcının veya sorumlunun (hostun) müdahalesine izin verilmediği için güvenilirlik çok yüksektir. Mikro şebekedeki çeşitli kaynakların gerçek zamanlı enerji üretimi ve tüketim oranları değerlendirilerek, eş zamanlı olarak dinamik bir fiyat belirlenmiştir. Geliştirilen strateji, güneş enerjisi santralleri ve rüzgâr çiftlikleri gibi yenilenebilir kaynakları içeren bir mikro şebeke için farklı senaryolar kullanılarak test edilmiştir. Senaryolarda hem arz hem de talep tarafı yönetimi için çeşitli koşullar dikkate alınmıştır. Önerilen dinamik fiyatlandırma elektrik enerjisinde blokzincir kullanımı açıklanmaktadır. Blokzincir bağlantısı ve iletişimi için, enerji sayaçları için akıllı ölçüm dikkate alınarak, bağlantı ve iletişimin Nesnelerin İnterneti (Internet of Things-IoT) ile yapılmaktadır. Sonuç olarak, tezde yapılan çalışma ile, yeni, kendi kendini kontrol eden ve güvenli bir enerji fiyatlandırma planı oluşturulmuştur.

Anahtar Kelimeler: Dinamik enerji fiyatlandırma, Blokzincir, mikro şebekeler, yenilenebilir enerji kaynakları

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NOMENCLATURE

P	: Power
V	: Voltage
W	: Watt
Hz	: Hertz
k	: Kilo
M	: Mega
h	: Hour
q	: Average flow
v	: Velocity
A	: Cross-sectional area
ρ	: Density 1000 kg/m^3
q	: Discharge through turbine (m^3/s)
h	: Height (m)
g	: Gravitational acceleration 9.81 m/s^2
e	: Efficiency
t	: time
Z	: annual working time
K	: cost of kW power
M_f	: Fixed expenses
M_v	: Variable expenses
M	: Total cost
m_t	: cost of kw energy
K_f	: Efficiency of power station
¢	: Cent
$	: US Dollar

ABBREVIATIONS

DAM	: Day-Ahead Market
ECM	: Intraday Market
P2P	: Pear to pear

1. INTRODUCTION

When the development of electrical energy in Turkey is examined, the first power plant was established in Tarsus in 1902, and the electricity has been used in İstanbul and İzmir since 1908. After 1935, some power plants were nationalized and transferred to the Ministry of Public Works. The first coal-fired thermal power plant was established in 1948 on the western side of the Zonguldak coal deposits.

In 1970, the power plants and transmission lines built by İller Bank and DSI were transferred to TEK (Turkish Electricity Authority). After 1984, TEK transferred management and coordination the power generation plants, power transmission and distribution to municipalities with suitable infrastructure. All these organizations are affiliated to the Ministry of Energy and Natural Resources. TEK has recently been divided as TEAŞ electricity generation and TEDAŞ electricity distribution.

Then, the transition to a free-market economy was started to be talked in the 1980s. In many countries a rapid progress was made in area and a rapid transition to a free-market economy was achieved. The goal is to eliminate the effective and decisive role of the state in the economy, and to make the private sector's dynamic and efficient working order effective instead of the cumbersome and bureaucratic working system. With the developments on this subject in recent years, the subject has started to gain importance again and new privatizations have been made in many areas. The most important of these is the electrical energy sector.

When the development in the energy market in Turkey is examined, the increasing demand in the last 20-30 years and the growth forecasts for the future reveal new investments and capital requirements. Long-term electrical energy production planning studies are carried out continuously by the Ministry of Energy and following natural gas agreements with Russia and Iran many new natural gas power plants were put into operation. According to the investigations, it has been revealed that in order to meet the future demand, in addition to the existing and under construction facilities, a huge level new power plant investment is necessary. It has been predicted that domestic resources will be primarily evaluated with the contracting of nuclear power plants with a capacity of 4500 MW as of 2025. It is also considered that Turkey will meet 60 to 70 percent of its electricity generation from renewable energy sources by 2030. With the increase in the renewable energy sources in production, the installed power of 20 GW of coal plants today will decrease by 5 GW in 2030.

The most important problem in the privatization of the energy sector is the security of supply. From the consumer's point of view, as mentioned before, the quality, continuity and price of energy are more of concern, not who the operator is. From this point of view, the most important problem in the atomization of the energy sector is to what extent the consumer will be protected after the free market conditions in the energy sector. This can be achieved with a good legal infrastructure.

The quality of electrical energy in an electrical system; quality of electricity is defined by variation of voltage and frequency within limits and waveform smoothness. For the electrical power system to work reliably, a number of factors must be considered during the design and operation phase.

The main purpose of the establishments responsible for the generation, transmission and distribution of electrical energy is to ensure that the energy produced is presented to consumers in a quality, continuous, sufficient, reliable, and economical way. Since electrical energy cannot be stored unlike other industrial products, it must be produced and consumed in the required amount, where and when it is needed. To ensure the continuity of energy supply, the relations between four main elements, which can be listed as generation, transmission, distribution and consumption, at different levels, make planning, organization, coordination and control much more important than other sectors.

The increasing energy consumption and decreasing energy resources necessitate efficient operation of existing energy resources on the one hand, and on the other hand, it is of great importance to provide energy transfer to consumers at the most cost-effective and reliable way. While trying to ensure efficiency and appropriate energy costs, the diversity of energy sources is increasing, the system is becoming more and more complex, and the control of network is becoming more difficult. There is a control mechanism related to the entire network however, the complex structure formed by energy diversity causes a separate control mechanism to be formed at regional scales as a microgrid. Along with all these developments, studies on energy automation and the creation of an independent working system are gaining importance. Blockchain is a suitable tool for providing this automation and independent working platform. Since the blockchain has made its name in the financial sector and is a reliable tool, there has been a rapid study trend on its applicability in all other fields.

In this thesis, dynamic energy price strategy for blockchain based smart microgrids with integrated renewable sources is studied. As the intervention of any user or a host is not allowed in blockchain process, the reliability is very high. Real-time production of several energy sources in the microgrid and consumption rates are evaluated simultaneously and resulting energy price is determined. The developed strategy is tested using different scenarios for a microgrid involving renewable sources such as solar power stations and wind power stations. In the first scenario, the effect of renewable energy sources on energy costs is investigated, considering a thermal station as a base power plant and wind and solar power plants as renewable energy sources. In the second scenario, a microgrid thermal and natural gas power plants as base power plants each having 100 MW power capacity, as well as wind and solar power plants as renewable energy sources with specifications given in the first scenario are considered. Additional energy need during peak hours is accomplished by hydroelectric power, which has 50 MW power capacity. In the third scenario, a microgrid with base load power plants, thermal and hydroelectric power plants, as well as wind and solar power plants as renewable energy sources is considered. In case of need, additional energy need will be met by an energy storage system with a capacity of 50 MWh hour. In the scenarios the effect of several energy sources is investigated by changing the priority of power sources. Energy prices are specified dynamically to manage in automated blockchain energy trading.

2. LITERATURE REVIEW

In last decades, increasing population and rising economic opportunities has increased the energy consumption and energy pricing is becoming more important. On the other hand, the diversity of energy sources is increased in parallel with these developments, which results energy pricing determination more complex. This situation, which concerns a very large audience, brings along security problems and the importance of an affordable and secure energy trading is increasing day by day.

Power trading problem had been in concern since the beginning of the use of electrical energy. In the early stages, the specification of electrical price was simple as the sources for electrical power generation are not complex. In last decades, power consumption has been increased and due to the limitation in the source of fossil fuels the use of renewable sources has been considered widely. Therefore, many publications have been devoted to energy pricing, power trading, efficiency, and security problems in last years.

With the increasing of diversity of power resources and requirements in the demand side, the system has been incredibly complicated and power trading problem has been very complex. Therefore, many publications have been devoted to this issue in last years. Oh et al. (2017) were studied the power trading problem by considering the interaction between nodes of admin, producer, and consumer. A power trading scenario for this model was developed using a blockchain platform called Multichain. They implemented a trading system to validate the generated scenario using Savoir, a Python-based JsonRPC module.

Due to the need for renewable energy integration, microgrid is becoming essential and renewable energy trading platforms has been an innovative solution for efficient system control and maintenance. With the development in the technologies such as smart-home applications and interconnected networks, microgrids are being developed and established. With the development of technologies such as Internet of Things (IoT), interconnected networks becomes easy and recently Kang et al. demonstrated a blockchain-based smart home application (Kang et al., 2018).

As the renewable energy sources are distributed, a new energy trading system becomes necessary. The emergence of blockchain makes the distributed multi-energy system possible. From this point of view, a kind of energy trading system based on blockchain was proposed by Dong et al. (2018). The trust problem of the traditional energy trading mode was solved by providing technical support for the new energy trading system.

The energy demand and supply during peak hours of a day is another challenging expectation which is needed to be managed. To eliminate the energy shortage especially in the areas where the energy demand grows rapidly many renewable energy sources (RES) are being integrated into the main grid. However, primary renewable energy sources such as solar and wind energy are weather dependent and intermittency of energy generation in renewable energy sources and the irregularity may lead to unpredicted demand peaks. This issue was addressed by Moniruzzaman et al. (2019) by considering a balanced demand and supply in a decentralized approach. To trade energy securely two blockchain-based Local Energy Market (LEM) mechanisms that assist prosumers (i.e., users with RESs that can either produce or absorb energy) and consumers were proposed. Excess energy is sold to the main grid. The concept of Proof of Energy Consumption (PoEC) was propped to incentivize a user to reduce energy consumption at peak hours. A transaction system that consists of five nodes, a wallet, and real price and consumption data from the Ontario Electric Board was implemented to validate the blockchain-based mechanisms they proposed, they.

Smart parking lots are smart places capable of supporting both parking and charging services for electric vehicles. An application of blockchain-based energy trading platform for electric vehicles in smart campus parking lots were proposed by Hou, Guo and Ning (2019). Another blockchain-based secure energy trading scheme for electric vehicles (EVs) was also proposed (Chaudhary et al., 2019).

In last years, the peer-to-peer energy trading among nodes in the industrial Internet of Things has been achieved (Silva et al, 2019).

In the last decade, with increasing number of electric vehicles (EV), a transformation is activated in the power distribution and electricity market, which generate suitable platforms for the blockchain technology. This development states the bases of the next generation grid. Liu et al. proposed a scheme in order to obtain a fully decentralized grid system and to adapt the high volume of EV integration (Liu et al., 2018).

To take trading decisions securely for managing the overall load of residential, commercial, and industrial sectors, a secure demand response management scheme based on blockchain was proposed by Jindal et al (2020). In the proposed scheme where the communication and computation costs were reduced and the effectiveness of the scheme and the results obtained demonstrated for secure demand response management in the smart grid.

To hide the trading distribution trends, Gai et al. (2019) proposed a blockchain-enabled neighboring energy trading system using noise-based privacy-preserving approach. The authors have improved a privacy-preserving mechanism without reducing other performances, such as accuracy.

The cost by scheduling the appliances of an individual home in a smart community is another problem and Afzal et al. used a game theoretic mathematical model to reduce this cost (Afzal et al., 2020). The main principle of the approach is that and the domestic users are the part of the smart community market transactions are executed on blockchain without the need of a central control entity. The blockchain approach was used to exchange the energy. Domestic user’s behavior towards community goals (cost minimization) is managed by game theory. By this way, lower cost of electricity can be achieved to the users and the flexibility in the local community market is increased. As a result of this study, a mathematical model is suggested to schedule the appliances in a smart community on basis of electricity price.

The growing volume of renewable energy supply is needed to be accumulated and to provide peer-to-peer energy transacting network. Kodali et al. proposed a permissioned blockchain that uses hyperledger fabric (Kodali et al., 2018). Hayes, Thakur and Breslin (2020) developed a blockchain-based peer-to-peer (P2P) energy trading platforms in order to facilitate P2P trading between individual users of the LV network. A co-simulation framework designed to investigate the potential network impacts from various alternative trading mechanisms. The proposed approach was demonstrated on a typical European suburban distribution network configuration using the IEEE European Low Voltage Test.

Blockchain-enabled P2P energy trading was also found as a useful attempt to trade energy produced from local and distributed renewable energy resources. Thompson, Sun and Jiang (2021) proposed an algorithm that is builds upon a system of scoring an energy transaction, based on the preference of factors like price, locality, and the type of energy generation, in addition to the quantity of energy being traded.

In last years with the application of IOT, the peer-to-peer energy trading has been achieved among nodes in the industrial Internet of Things (Silva et al, 2019).

The traditional grid systems use centralized architecture, which results in large transmission losses and mismatch between supply and demand. Moreover, owing to the presence of intruders or attackers there may be unsecure data, which may cause system instability. Thus, an automated energy exchange to provide secure and reliable energy trading between users and suppliers is necessary. In the existing literature it is found that that blockchain can be an effective solution to handle the aforementioned issues (Tanwar et al., 2020). In regard of these facts, they propose a blockchain-based smart energy trading scheme called ElectroBlocks, which is able to provide a secure energy exchange between users and service providers.

For managing the overall load of residential, commercial, and industrial sectors, a blockchain-based secure demand response management scheme is presented by Jindal et al., (2020) to take energy trading decisions securely. The proposed scheme by the authors is lightweight in terms of communication and computation costs and the effectiveness of the scheme for secure demand response management in the smart grid was also demonstrated.

Tao et al. (2021) introduced a scheduling architecture on the blockchain platform for multi microgrids. They analyzed the security and economy of the combination of blockchain and a dynamic electricity price model was generated. The price is set depending on the amount of the total power supply and the level of demand in the multi microgrid system. They set a load optimization model, which satisfies an optimal system economy in one hand and minimum environmental pollution as the objective function in the other.

Tomin at al. (2022) proposed a unified approach to building and optimally managing the community microgrids with an internal market, given the social, environmental, and economic benefits of a particular location of such a community.

Regarding that the traditional energy trading requires the storage, verification, and sharing of data related to the trade while keeping records tamper-proof and traditional database solutions are centralized and susceptible to data tempering, Khan, Dovla and Niloy (2022) proposed a scheme, and they aim to solve those problems with the help of blockchain technology by storing data on blockchain and verifying transactions with the PoA consensus algorithm for faster processing.

With the gradual opening of the electricity sales market, distributed energy trading is becoming an important research topic. These developments encourage researchers for new studies. Lei et al. (2022) proposed an automated trading management platform for renewable energy trading of microgrids. The energy transaction processing mechanism is based on permissioned blockchain and IoT. In one of the recent studies an energy trading scheme based on consortium blockchain and game theory is proposed (Chen, Chen, Wang and Tan, 2023). In another study, the energy trading problems such as insecure energy trading and inefficient charging mechanisms for electric vehicles (EVs) in a vehicular energy network are considered and a secure energy trading mechanism deals with based on blockchain technology is proposed (Asfhaq et al., 2022).

Considering these developments in the energy sector, a dynamic electric energy pricing method based on the chain blockchain is proposed in this thesis, which is secure, self-operating and compatible with the recent technologies. Application of the developed system is simulated on MATLAB for a microgrid containing renewable resources such as solar and wind. In the first stage of the study, traditional and presently used energy pricing methods are explored in detail and the structure of a microgrid and its components are examined separately. A special attention is paid on the renewable sources. Smart metering using IoT and interfacing with a microgrid is explained next. In the applications, several scenarios with different conditions for both supply and demand side management are considered. After specifying a novel and suitable energy pricing methods for microgrids, finally a scheme for integration of the blockchain to the energy pricing problem is given. As a result, a novel self-controlling and secure energy pricing scheme is developed. The proposed energy pricing scheme considers the priorities and limitations of energy sources to achieve an optimum energy price.

3. OVERVIEW OF POWER GENERATION SYSTEMS AND MICROGRIDS

In this section, types and basic structures of power systems that provide energy to the networks are described briefly. For the analysis of energy costs in power systems, it is necessary to know the structure of the system components that constitute a source. In last years, the energy sources have gained diversity with the addition of renewable energy sources such as solar power stations and wind farms. In addition to traditional thermal and hydroelectric power plants, natural gas plants have started to be used widely, and wind, solar, biomass and geothermal power plants have also become common as renewable energy sources.

3.1. Hydroelectric Power Stations

The cheapest and the oldest method for generating electrical energy from water is hydropower. The running cost in a hydroelectric power station is almost free and air pollution is completely avoided. However, the capital cost is high, and it requires a long gestation period which is about five to eight years as compared to four to six years for steam power plants. Beside energy generation, hydroelectric stations are also used for different purposes such as river flood control, irrigation and drinking water, fishery, and navigation. A simple block diagram of a hydro plant is shown in Fig. 3.1. Hydro power plants can be classified as 1) run-of-river (use of water as it comes), 2) pondage (medium head) type, and 3) reservoir (high head) type. The reservoir type hydroelectric power stations are employed to supply energy during peak demand. Depending on the geographic conditions (water flow rate, height etc.) different types of turbines are used, namely Pelton, Francis and Kaplan turbines.

Currently, there are 325 hydroelectric power plants on a large scale in Turkey. It is planned to increase the number of dams for energy, irrigation, drinking water and flood protection purposes to 454 by 2023. There are also many micro, mini, and small power plants built on small water resources in Turkey. On a day when hydroelectric power plants do not produce enough energy, peak load can be balanced with pumped storage. The system, defined as pump-hydro, is used to store energy by pumping water from a lower reservoir to an upper reservoir with an electric motor. At normal load, water from the lower chamber is pumped into the upper chamber to be ready for use on the next cycle of the peak load period. In this period, the generators start the synchronous motor movement and drive the turbines, which are working as pumps in this case. In this operating mode the turbines are driven in the usual way by water from the upper reservoir. Electrical power is supplied from the connected power grid or from the adjacent thermal power plant. When additional electrical energy is needed, the engine-pump set works as a turbine-generator set reversibly and produces energy. Such a facility contributes to energy production by operating like a conventional hydro power plant during peak load periods when production is insufficient to feed the peak load. The overall efficiency of such storage systems is normally about 60-70 percent.

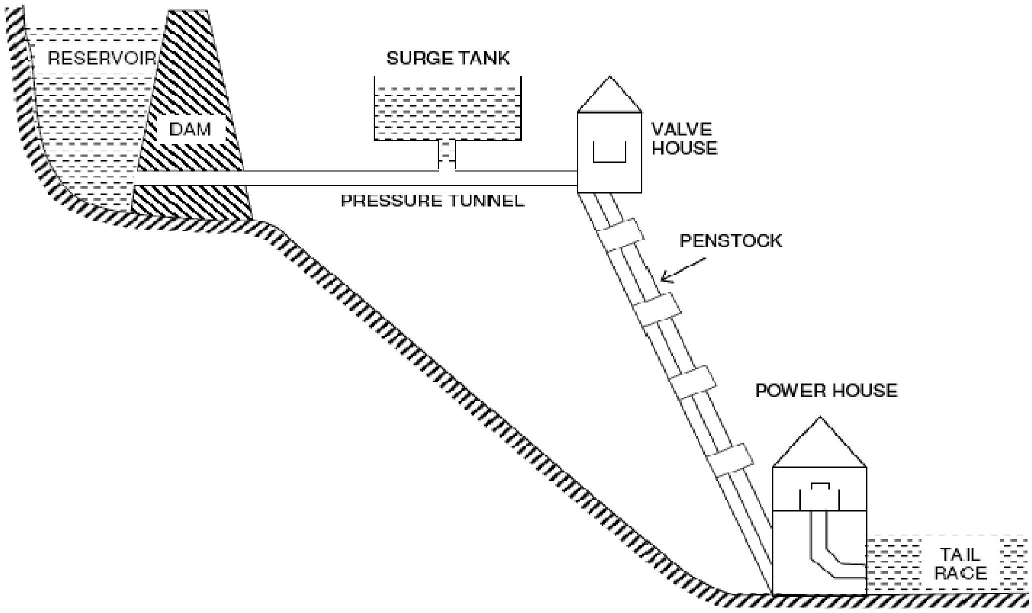


Figure 3.1. Typical layout for a storage type hydroelectric power plant.

Hydroelectric power plants are classified according to the energy they produce as:

1. P <100 MW Large hydroelectric power plants
2. 20 MW<100 MW< P Medium-sized power plants
3. 1 MW< P<20 MW Small power plants
4. 20 kW< P< 1000 kW Mini power plants
5. P< 20 kW P Microplants

The amount of water that a stream passes per unit time is called the flow of that water. The amount of flow of water is calculated with the formula

$$q = v * A \tag{3.1}$$

where q is the average flow (m^3/s), v is the average velocity of the stream (m/s) and A is average cross-sectional area of the stream (m^2).

The amount of power in a hydroelectric plant is expressed as:

$$P = eg\rho qh \quad \text{(W)} \tag{3.2}$$

where;

ρ: density 1000 kg/m^3

q: discharge through turbine (m^3/s)

h: height (m)

g: gravitational acceleration 9.81 m/s^2

e: efficiency range (0.75 - 0.88) or (75% - 88%)

3.2. Thermal Power Stations

The reciprocating steam engine has been used to produce mechanical power since the 18th century and the first commercially developed central electrical power stations were established in 1882. Energy conversion in a steam turbine is illustrated in Fig. 3.2. Schematic diagram of an ideal coal-fired thermal power plant is shown in Fig. 3.3. The most important units of steam power plants are:

a) Steam boiler and fuel system,

b) Water treatment and pumping units,

c) Steam engine (piston steam engine and steam turbine),

d) Condenser,

e) Electrical equipment.

The fuel burned in steam boilers transforms the water in the boiler into steam. Various grids are used in the combustion chambers of steam boilers. The type of these grids depends on the type of fuel used, the size of the boiler and the desired characteristics of the boiler. For efficient working of the boilers, it is necessary to contact the water or steam more with the gases formed by the fuel and to prevent heat loss. The use of good quality coals is preferred in industry and heating. Therefore, burning of low-quality coals is common in thermal power plants. After this type of coal is crushed and transformed into powder in mills, it is sprayed with compressed air into the combustion chamber of the boiler through the spray nozzles and burned there. Ash traps are placed in the chimneys to prevent the fly ashes from polluting the environment in dusty coal burning power plants.

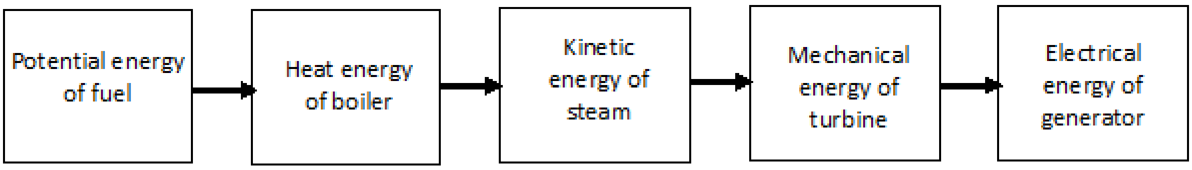


Figure 3.2. Energy conversion in a coal-fired steam turbine.

The construction of the boilers may also vary according to the type of fuel used. Liquid and gas fuels can also be used for heating the water in the boiler. Liquid fuels are sprayed into the boiler with the help of an injector. The fuel sent with a photocell system is adjusted automatically. Fuel oil is an example of the liquid fuel used.

To store the fuel used in thermal power plants, warehouses are required that can take enough fuel for the power plant for a long time. The necessary protection of these warehouses against fire is also an important issue.

The boilers in use today are divided into two as flame tube and water tube. In fire tube boilers, the pipes through which hot gases pass through a water tank. As the gases, heated by the energy of the fuel burned under the boiler, pass through the boiler water with pipes, they radiate their heat to the water and enable the water to change its form into steam.

To increase the boiler efficiency, it is necessary to ensure that many pipes circulate through the boiler water. These boilers are used in small power plants. Water tube boilers are used more than flame tube boilers. Hot gases, heated by the heat generated by the fuel burned under the boiler, circulate around the water pipes through which water circulates, give the heat to the water, and evaporate the water. However, the pressure of this steam is low. If it is sent to turbines as it is, it immediately turns into water. Low pressure also affects turbine speed. To obtain high cycles, the wet steam taken from the boiler is extra heated up to 300-400 °C and then sent to the turbines. For this purpose, steam superheater units, for example, pre-heater (Economizer) or superheater are used. To gain from the heat contained in the gases discharged from the boiler, the boiler feed water pipes are mounted on the path of these gases and the feed water comes to the boiler a little warmer. Each 6 °C increase in the feed water temperature of the preheater increases the boiler efficiency by 1%. Thus, fuel consumption is also reduced. When the hot gases formed by the burning of coal in the boilers are used as much as necessary, the boiler efficiency can increase up to 80-90%. The efficiency rate varies according to the heat given by the lignite and coal used in the thermal power plant. Efficiency changes between 33% and 38% are seen in low-calorie thermal power plants. It works with 40% to 46% efficiency in power plants with medium calories. It varies between 60% and 70% in high-level calorific power plants. Even when a counter-pressure turbine is used, this efficiency goes up to 85%.

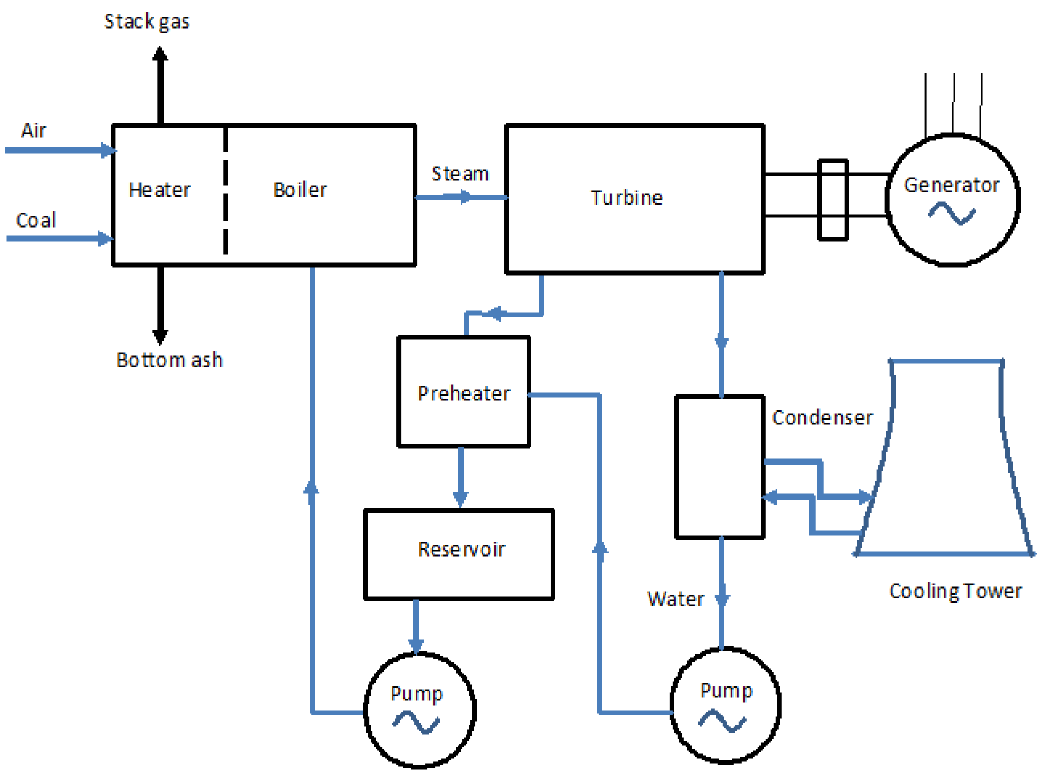


Figure 3.3. Schematic diagram of an ideal coal-fired thermal power plant.

3.3. Nuclear Power Stations

In last century, as the fossil fuel reserves are diminishing very quickly, therefore, electric energy generation from nuclear energy has been as an alternative source of largescale power generation. In the developed countries, the use of nuclear energy for power generation is very common. Nuclear energy is obtained either by splitting a heavy nucleus of an atom into smaller nucleus with low mass (fission) or combining the nucleus of two low mass atoms forming one nucleus (fusion) with heavy mass. Only atoms with atomic number greater than 90 can undergo nuclear fission and Uranium-235 is used for fission. When a neutron strikes the nucleus of an Uranium-235, fission reaction takes place releasing neutrons and heat energy. The realized neutrons then participate in the chain reaction of other atoms of U235. Nuclear fuel rods like made from neutron-absorbing material such as graphite, heavy water, etc. called moderators must be embedded in reactor for controlling neutron speed, which is needed to generate heat and for the reaction to be sustained.

The schemed, diagram of a nuclear power plant is shown in Fig. 3.4. The process of generating electricity is similar as a conventional steam power generator. The heat released by the nuclear reaction in the reactor is transmitted to a heat exchanger via primary coolant (CO_2, water, etc.). Steam is then generated in the heat exchanger, which is used to generate electric energy by means of a steam turbine. Various types of reactors are being used in practice for power plant:

- Pressurized water reactor (PWR)
- Boiling water reactor (BWR)
- Advanced gas-cooled reactor (AGR)
- Light water graphite-moderated reactor (LWGR)
- Fast neutron reactor (FNR)

Advantages of nuclear power plants are:

- A nuclear power plant has no undesirable effects on air pollution.
- It requires little fuel in terms of volume and weight, and therefore poses.
- Transportation problems do not exist.

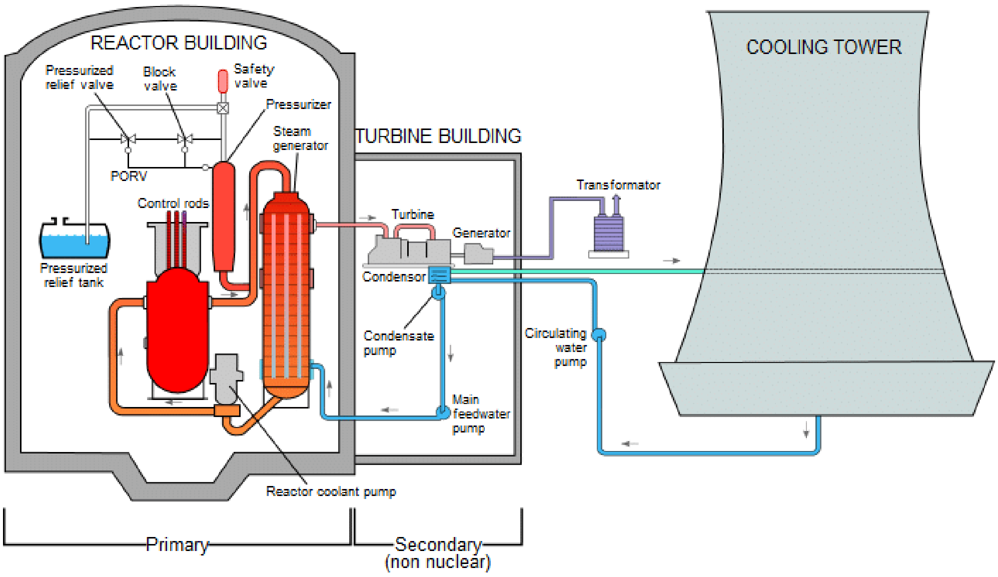


Figure 3.4. Schematics of Three Mile Island (TMI-2) Nuclear Power Station Reactor.

Nuclear power does not cause any effect on air pollution, but the radioactive fuel waste is a problem in a nuclear reactor when generating heat. The nuclear wastes are radioactive and need to be disposed of tethered thousands of years. It is possible to control the rate of reaction in a reactor by a small margin, so that the electric load on a nuclear power station can only be reduced below its full load value in a small margin. Therefore, nuclear power station needs to be connected a to a power network, as tripping of the lines connecting the station can be quite serious and may require shutting down of the reactor with all its consequences. The extensive power of the nuclear station can be stored by storage systems such as a pumped storage scheme. A nuclear power station has relatively high capital cost against running cost; therefore, a nuclear plant operates continuously as the base load power station. The loss of coolant is the greatest danger in a fission reactor which cause an accident.

Nuclear power plant is the power plant that produces energy with the most efficiency in electricity production. It is possible to produce electrical energy 24 hours of 365 day continuously. Initial installation cost of nuclear power plants is about $5530/kW. The efficiency of nuclear power plants varies between 80% and 93%. Most of the power plants operate at 92% efficiency.

3.4. Gas Turbines

Gas turbines are similar to those used in aircraft in working principle. In last century, the increase in natural gas resources allowed development of primemovers based on gas turbines. Gas combustion can produce high temperatures, which has the ability of generating high pressures needed to drive a turbine. The rotor is of the generator is driven by the turbine and electricity is generated as a result. The efficiency of the gas turbine is comparable to that of conventional steam turbine. The exhaust gas from the turbine has still heat content, which can be used to increase the steam temperature of a conventional steam turbine. Such a design construction is called combined-cycle gas-turbine plant (CCGT) and the schematic diagram of such a plant is illustrated in Fig. 3.5. The unit can take up to overload for short periods of time to take care of any emergency. CCGT unit environmentally friendly and produces 55% of CO2 produced by a coal/oil-fired plant. Designs for fully automated operation for 24h or to meet the peak demands are available. Total energy efficiency in natural gas combined cycle power plants is about 85%. The electrical efficiency is 61.5%. The cost of a natural gas installation varies between 750 $/kW and 1000 $/kW.

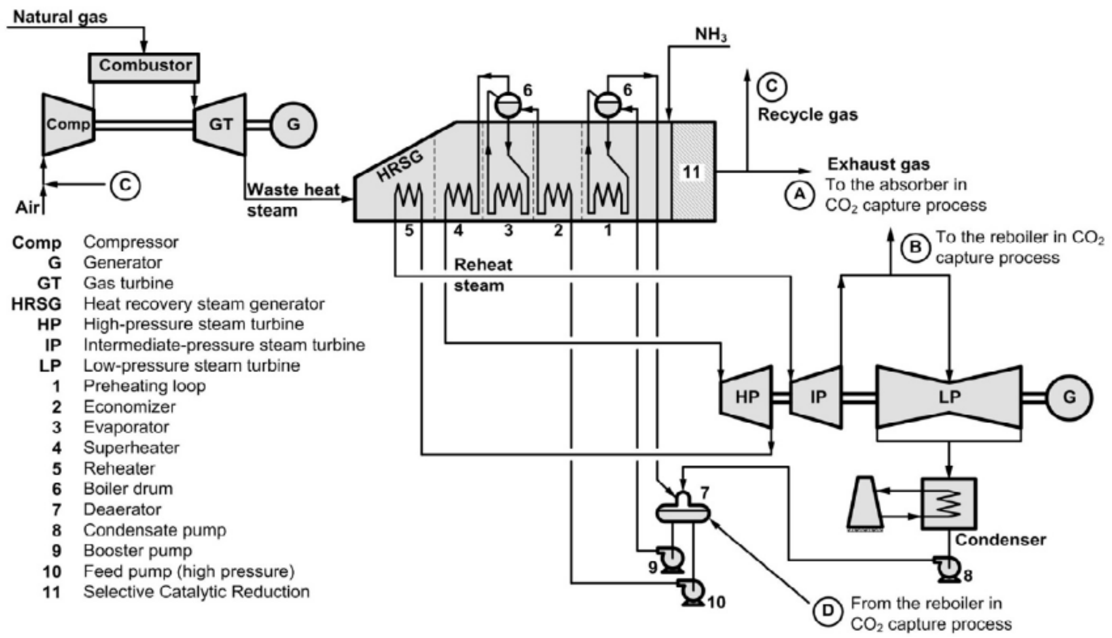


Figure 3.5. ITC's natural gas-fired combined-cycle gas turbine (CCGT) power plant (Sanpasertparnich, 2011).

3.5. Geothermal Power Plants

Geothermal power plants are similar to thermal power plants in many ways except instead of steam generator in thermal power plant geothermal steam power is used. A schematic diagram of a geothermal condensing power plant is shown in Fig. 3.6. Schematic of the regenerative Organic Geothermal Rankine (ORC) geothermal power plant is shown in Fig. 3.7. For a geothermal power plant operating at 85% capacity and producing 1 MW of energy the initial investment cost about 2500$/kW.

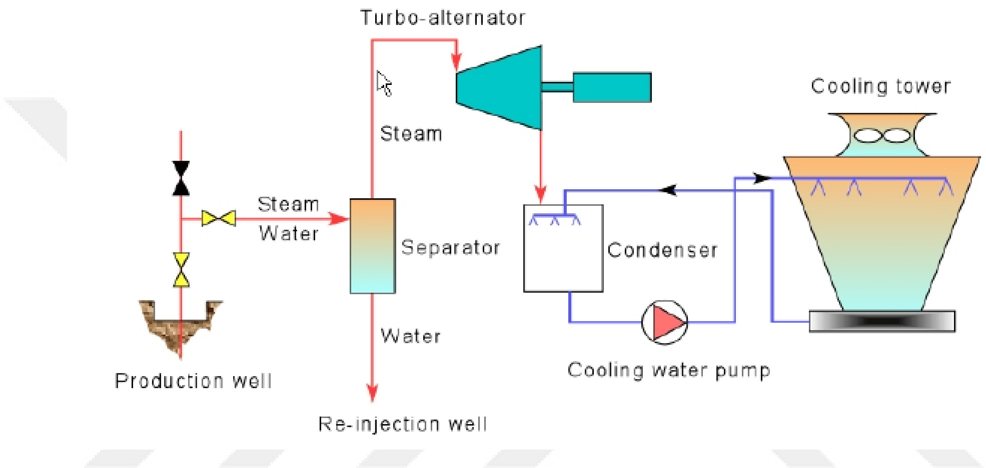


Figure 3.6. A schematic diagram of a geothermal condensing power plant (Fridleifsson, 2008).

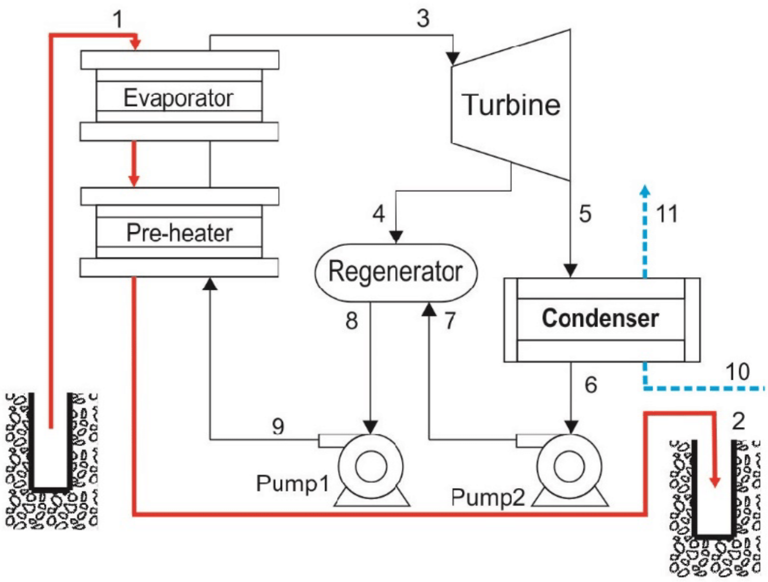


Figure 3.7. Schematic of the regenerative ORC geothermal power plant. A schematic diagram of a geothermal condensing power plant (Bina, 20017).

3.6. Diesel Power Stations

Diesel power plants are used especially in feeding residential areas such as small cities or towns, in factories, businesses, etc., in enterprises providing communication services, in establishments such as shopping malls, hospitals and schools, to meet the energy needs when required or to provide the continuation of services in case of power shortages. Due to their easy installation and compact structure diesel power plants can be installed anywhere. In addition, diesel used as fuel is easy to transport. In last years, these power plants are not used as base load due to the high fuel cost. However, they can be used to meet the peak loads when the energy consumption is high. The installation of diesel power plants is easy, and their costs are low. Also, they take up little space thanks to their compact structure. The most important disadvantages are the high cost of fuel, as mentioned before. There are 56 diesel power plants in Turkey. The annual electrical energy production from the installed power of 682 kW is 4470 GWh/year. A typical diesel power station is illustrated in Fig. 3.8. Main parts of the station are diesel motor, generator, cooling system, fuel system and lubrication system.

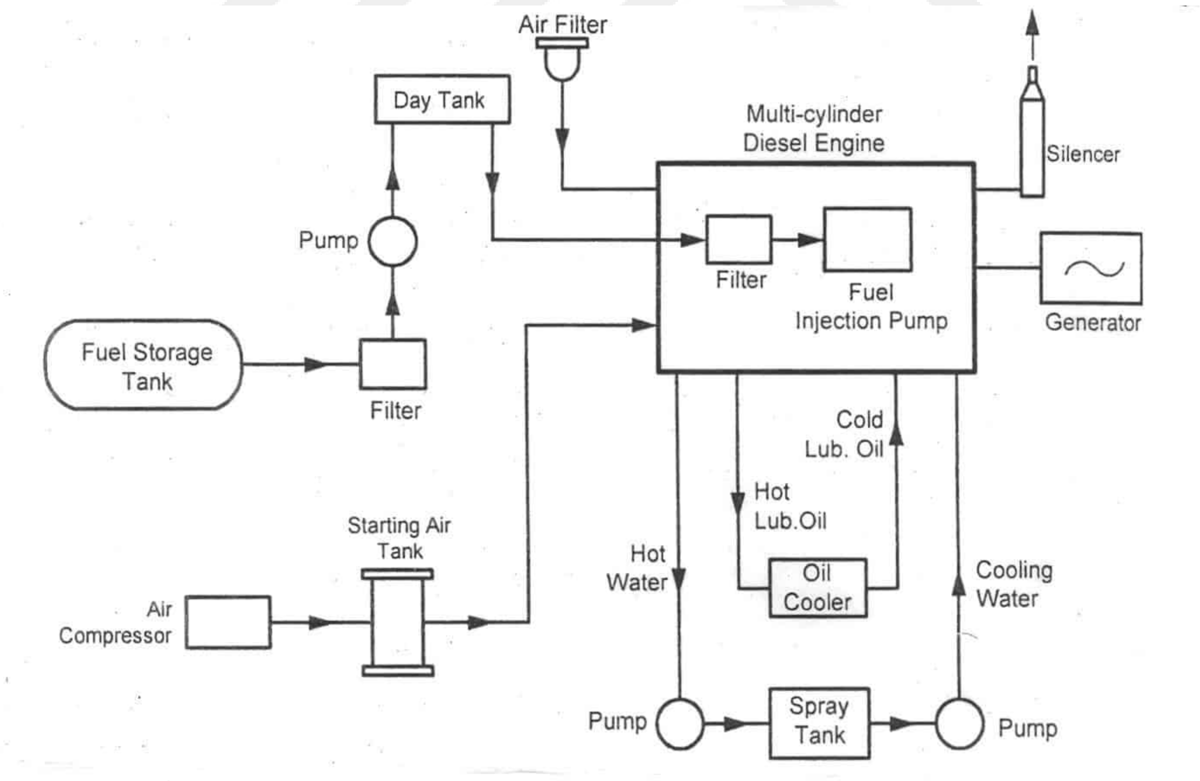


Figure 3.8. Schematic diagram of a diesel power station.

3.7. Solar Energy

Converting the energy from sunlight into electrical energy has been in concern many years and besides common usage of small-scale applications solar power plants have been built in last decades for electric generation. It is observed that the contribution rates of photovoltaic systems, which are an important alternative to fossil fuels in energy production, are increasing rapidly in the grid. When the developments in the world are examined, there has been a significant growth in photovoltaic energy production worldwide especially in recent years, and more is expected soon. For this reason, it has become important to design and develop the necessary hardware and software for solar power plants-SPPs to meet the network requirements in order to avoid potential problems related to network reliability, stability and security.

An overview of solar PV power plant is shown in Fig. 3.9. The basic building block in power plants is the solar cell. Solar cells are photovoltaic, which can convert incoming sunlight into electricity. A solar module is formed with the series or parallel interconnection of several cells having the same characteristics to obtain suitable ratings of voltage and current respectively. Partial shadowing cause nonhomogeneous sunlight distribution and as a result the module may be damaged. A group of several modules are connected in series parallel on a frame to form a solar panel that can be mounted on a structure. To obtain high level of power, such panels are combination on a land and this combination is called as a solar array. The main ingredients of the solar cells are crystalline silicon and gallium arsenide.

Advantages of solar energy are:

- Solar energy is a renewable, clean, and continuous source of energy.
- Systems working with solar energy can be easily transported and installed.
- They are systems that do not pollute the environment, are environmentally friendly, and can be easily changed depending on the energy need when necessary.
- Solar energy has advantages such as no fuel consumption, ease of operation, no mechanical wear, modular structure (changeable), reliable and working without any problems for many years.
- Solar Panels are durable and long-lasting.
- The use of solar cells may be more economical in rural areas where the electricity grid line is far or where taking the grid line is expensive.

- With solar cells installed on its roof, every house can meet its own energy. Thus, transmission and energy transmission costs and line losses are eliminated.

Disadvantages are:

- Energy gains are low in winter and none at night.
- In order to emit the sun's radiation continuously, the surroundings of the system should be open and shadow should not be formed.
- Storage possibilities of solar energy, which is an intermittent resource, are limited.
- In the most efficient times when the sun's rays are perpendicular, energy production is low because the heat density is high. There is a solar power plant in worldwide where solar energy is used in different ways.

Two types of panels are used in production: monocrystalline and polycrystalline panels. Taking incoming sunlight as the base, monocrystalline panels work with an efficiency of 26% and polycrystalline panels with an efficiency of 19%. The place where the panels are installed, the interval of day and night or the angle of the sun to the earth differ in energy production in the panels. 92% of the panels used in Turkey are polycrystalline panels.

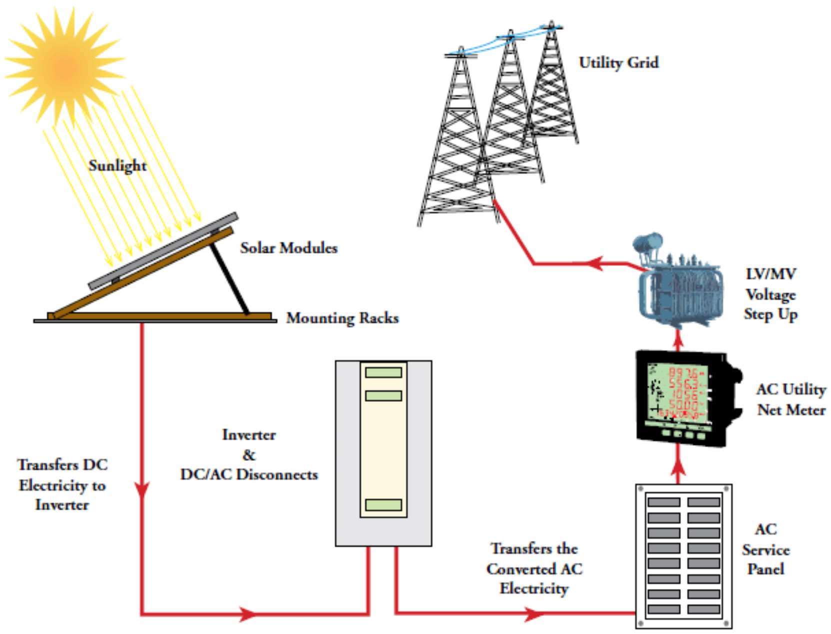


Figure 3.9. Overview of solar PV power plant (Lumby, 2012).

3.8. Wind Energy

In recent years, decrease in fossil energy resources and the rapidly increasing consumption have increase in the consideration on the interest in renewable energy sources. The first two renewable energy sources that have the highest level of utilization are solar and wind energy. A significant amount of energy has been produced using solar power stations in recent years, but it is not possible to obtain energy from solar energy when there is no sunlight. Wind energy therefore has gained an importance. The main problem of wind energy is that there is no guarantee of the wind in terms of continuity.

The main source of wind energy is the sun. All renewable energy (except tidal and geothermal energy) ultimately comes from the sun. Therefore, wind is a form of solar energy. Wind is caused by the uneven warming of the earth's surface and the rotational motion of the earth. Differential warming of the Earth's surface and atmosphere causes vertical and horizontal air currents. Wind energy is affected by the rotation of the earth and the contours of the terrain. Wind turbines are systems that convert kinetic energy in the wind into mechanical power. A wind turbine can convert the kinetic energy of the wind into mechanical energy and the generator connected to the turbine can convert this power into electricity. A schematic of a wind farm is shown in Fig. 3.10.

Earth receives $1.74x10^{17}$ watts (per hour) of power from sun. About one or two percent of this energy is converted into the wind energy. This rate is approximately 50-100 times higher than the energy converted into biomass by all plants in the world.

Despite being intermittent, both solar energy and wind energy have an advantage over fossil fuel sources because they do not have fuel costs and do not have a significant negative impact on the environment. Turkey currently has recently more than 1600 MW of installed capacity and produces about 3 billion kWh of electricity each year. This is enough to meet the annual residential needs of 1 million people.
Electricity generated from wind has increased from 0.1% in 1997 to 1.5% in 2008 and to 8% in 2020.

The amount of power a wind turbine can generate is expressed by the function:

$$Wind\ Power\ Density\ = ½\ \rho v^3 \tag{3.3}$$

where ρ is air density and v is the wind speed.

High costs for construction of large turbines may not be economical in some areas, as local electrical grids may not be able to handle the large electrical output from a large turbine. Smaller turbines may be more suitable for such conditions. Landscape concerns are main limitations for wind energy production.

Some specifications for a typical 600 kW wind turbine are as follows:

- The construction cost is about $450000.
- The installation costs are about $125000.
- The total costs are about $575000.
- Maintenance costs are about 1.5-2.0 percent of the total cost, per year.
- For modern wind farms the average price per kilowatt is around $1,000 per kilowatt electrical power installed.
- Modern wind turbines are capable of working for 120000 hours of operation throughout their design lifetime of 20 years, which corresponds 13.7 years of non-stop working.

Advantages of wind power are:

- Contrary to solar stations the wind blows day and night; therefore, it is possible to produce electricity throughout the day.
- Wind energy is a domestic.
- Wind energy is a renewable source of energy that generates no pollution and has little environmental impact.

Disadvantages of wind power are:

- Electrical energy output varies as wind speed varies.
- Noise generated form the turbine. But increasing tip speed causes less sound. The closest neighbor is usually 300 m experiences almost no noise.
- Some birds even nest on cages on wind towers.

Since 1940, several attempts have been made to generate electricity form wind and researches are still carried out to improve wind energy power stations. Wind energy is plentiful, inexhaustible and has no adverse effects on air pollution. Further, it does not impose extra heat burden on the environment. However, wind power stations cannot be used as base power station as it is intermittent. Control equipment are used for the wind turbine to work when the wind speed is above 15-20 km/h. For the wind speed above 60-80 km/h the turbine is stopped by the control system as the turbine may be damaged at high wind speed. Another problem in wind energy is the frequency. The frequency of generated electricity changes if the rotor speed is changing. Methods have also been found to generate the electricity at constant frequency besides wind turbine varying rotational speed. Wind power may be suitable especially for small power needs in isolated sites. But for maximum flexibility, hybrid usage should be preferred to ensure power generation continuity.

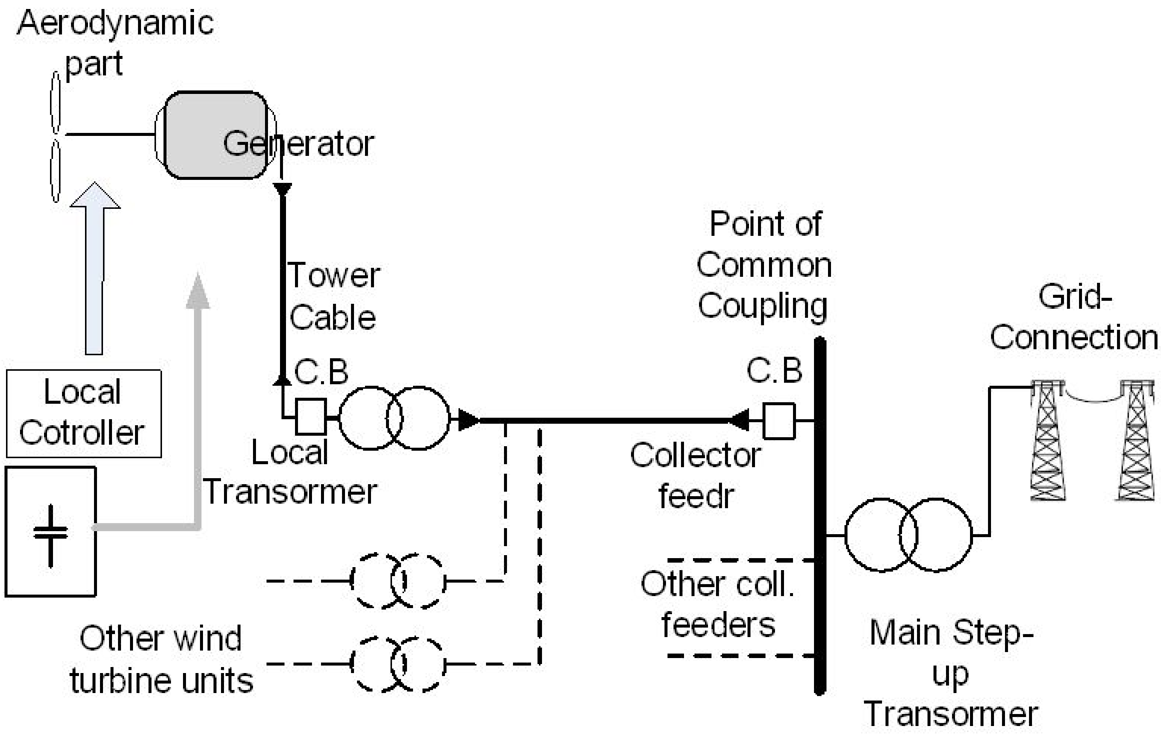


Figure 3.10. General schematic of a wind farm (Kawady, 2012).

For wind power generation, there are three types of operations:

1. Small, 0.5-10 kW for isolated residential.
2. Medium, 10-100 kW for communities.
3. Large, 1.5 MW for connection to the grid.

3.9. Biofuels

The residues and wastes from animals and plants are called biomass. It is possible to transform biomass by chemical and biological processes to produce methane gas, ethanol liquid or charcoal solid. These intermediate biofuels can be used with petroleum fuels for transportation or can be directly used in turbine to turn generator rotor and produce electricity. Biomass is also burnt to provide heat for cooking and space heat, crop drying. In biomass energy production, vegetable (sunflower, potato, wheat, pea, branch, stem, root, bark, etc.) and forest resources (trees in forests, non-woody bark and leaves, etc.), animal wastes (fertilizer) and urban-industrial wastes (scrap wood that cannot be used in industry, garbage, sawdust, etc.) are used. Principle of operation of a steam turbine biomass cogeneration plant illustrated in Fig. 3.11.

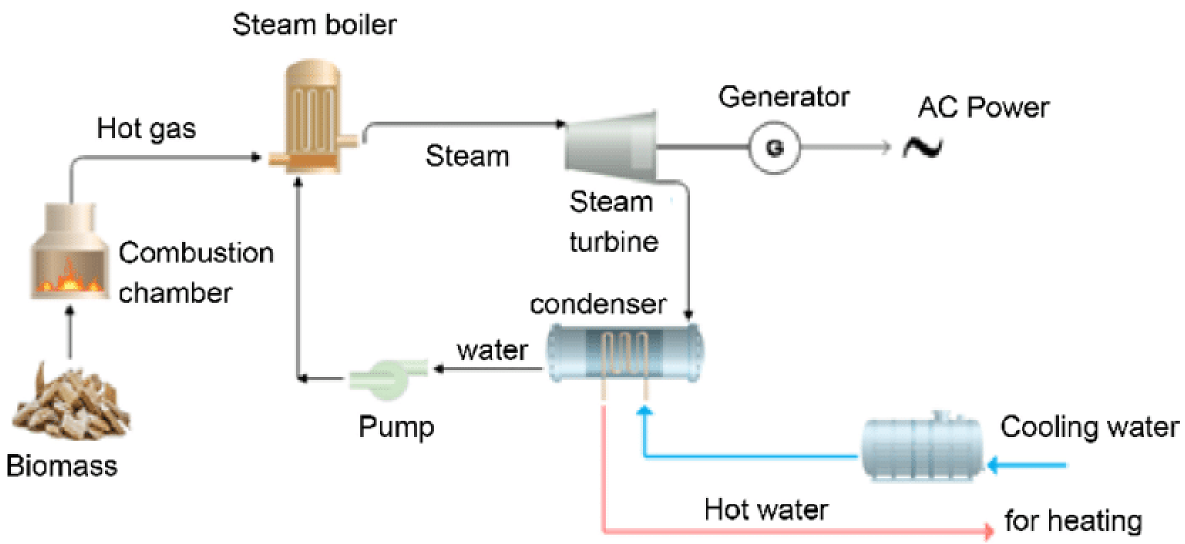


Figure 3.11. Principle of operation of a steam turbine biomass cogeneration plant (Abbas, 2020).

3.10. Energy Storage

Storing electricity in small quantities is easy; however, storing electricity in large quantities is expensive and there are some problems in achieving high efficiency. Electrical energy can be stored by compressed air, pumped storage, heat, hydrogen gas, flying wheels and super conducting coils. In electrical power systems, gas turbines are normally used for meeting peak demand but are very expensive. A significant amount of storage capable of instantaneous use would be battery for meetings peak loads. Scheme of diabatic Compressed Air Energy Storage (CAES) is shown in Fig. 3.12. Overview of heat storage system is shown in Fig. 3.13. Power grid with distributed energy storage systems is shown in Fig. 3.14. A bidirectional energy storage system for a Vanadium Redox Flow Battery (VRB) proposed by Gong and Lei (2017) is shown in Fig. 3.15.

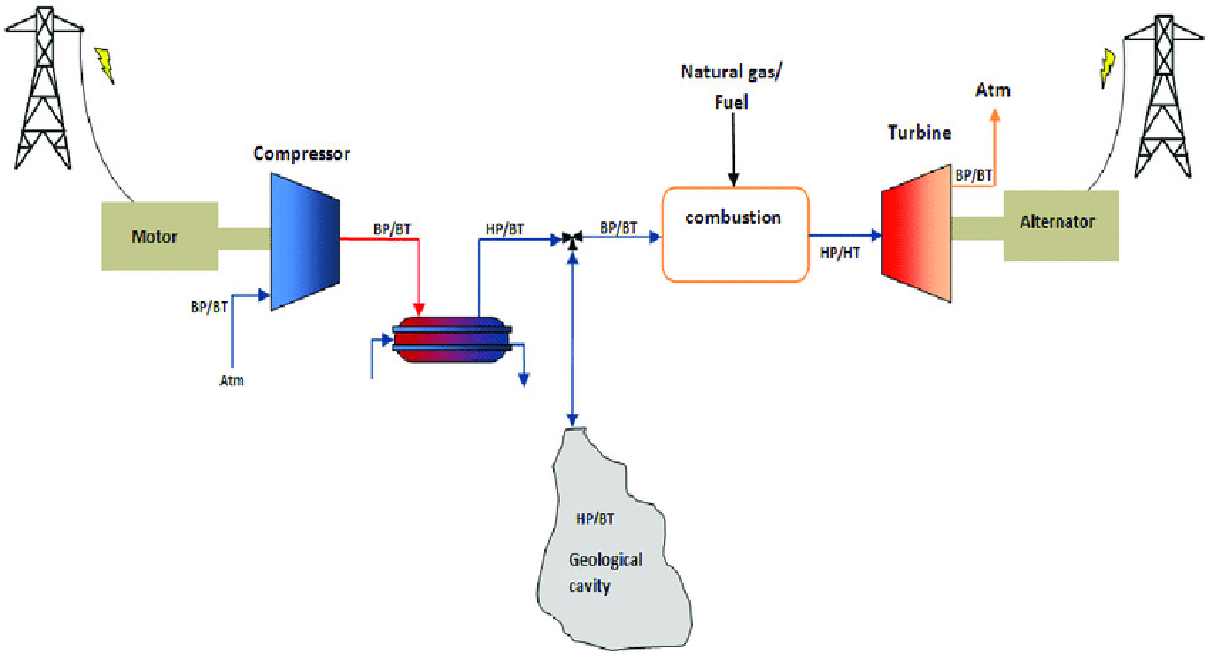


Figure 3.12. Scheme of diabatic compressed air energy storage (CAES) (Kere, 2014).

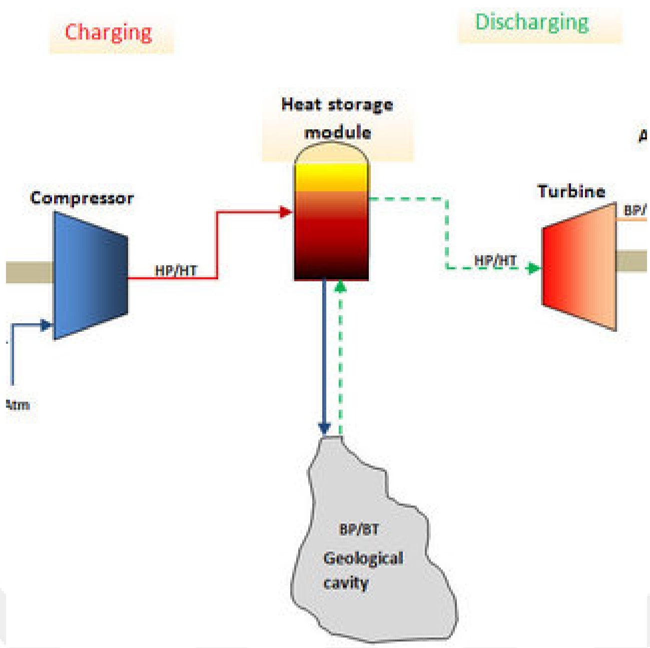


Figure 3.13. Overview of het storage system (Lumby, 2012).

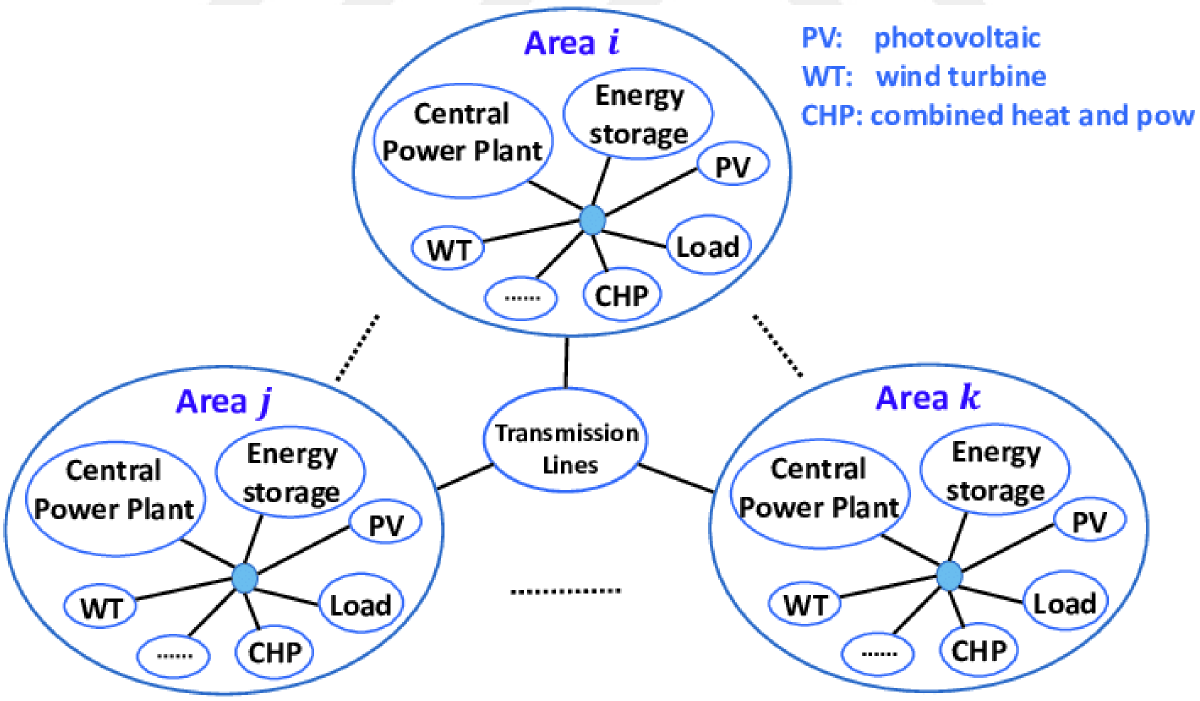


Figure 3.14. Power grid with distributed energy storage systems. (Xing, 2019).

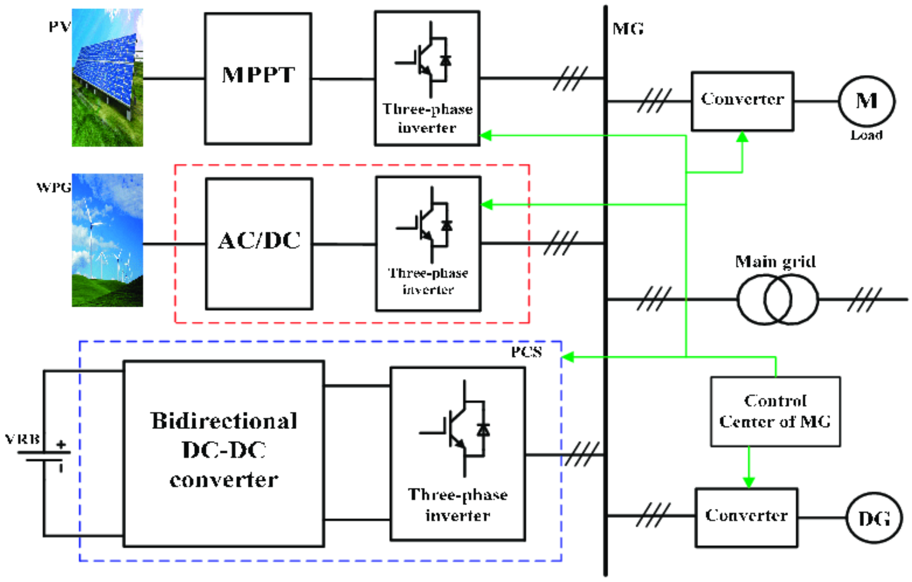


Figure 3.15. Topology of the VRB energy storage system in the microgrid (Gong, 2017).

3.11. Secondary Batteries

High level of energy requirement in a time may cause unstable and unsecure grid operation and this may lead to loss of critical loads. Weak distribution system and poor power quality may require purchase of additional electrical equipment. Insufficient response time is a problem for diesel generators to this load.

As an alternative, large scale battery use is almost ruled out and they will be used for battery powered vehicles and local fluctuating energy sources such as wind farms or solar power stations. The lead acid battery is the most widely used storage battery, which is invented by Plantei in 1860.

Battery storage systems has the following advantages:

- Very fast feed intervals: 5, 15, 30 min and 1, 2, or 4 h,
- Multi-storage architecture,
- Multiple enclosure options,
- High round trip efficiency,
- Accurate, real-time response in (< 3 cycles),
- Re-deployable.

3.12. Fuel Cells

Fuel cells convert chemical energy of a fuel into electricity directly, without using intermediate combustion cycle. Electrical energy is produced from the combination of hydrogen and oxygen and water is generated as a residue. In the fuel cell, hydrogen is supplied to the negative electrode and oxygen (or air) to the positive electrode. The porous electrodes allow hydrogen ions to pass. A wide use of fuel cells has not gained yet as their cost is still very high (>$2000/kW). US, Germany and Japan are leading countries for this technology.

3.13. Hydrogen Energy Systems

Hydrogen is a very suitable medium for energy transmission and storage. Pure hydrogen can be produced by electrolysis and can be stored in the form of fuel cells. Fuel cells can be used to generate electricity in requirement. The use of hydrogen as fuel for aircraft and automobiles could encourage its largescale production.

3.14. Microgrids

An electrical grid is the system from the producer or producers where energy is produced and converted (power plants and substations) and transmitted to the destination where electricity is consumed. Home, workplaces and various facilities are the consumers in general. In practice, it is a network in which substations, transmission lines and wiring, distribution lines, transformers and all similar system elements are interconnected, which can be described as macrogrid.

Today, with the increase in resource and load diversity, network structures and their operation have started to form different structures. Resource and load groups can be a part of a wide network structure as in the past, as well as some of these resource and load groups can have the opportunity to work independently among themselves. A microgrid is a decentralized group of electrical sources and loads connected to the grid (macrogrid). Microgrids are networks formed by load and resource groups that are connected to the main network, when necessary, but have the ability to operate independently when necessary. When a microgrid is disconnected to the grid it works in "island mode". By this way, it is possible to integrate various sources of distributed generation (DG), especially Renewable Energy Sources (RES) effectively. A microgrid can supply emergency power, changing between the island and connected modes.

Control and protection are challenges of microgrids. A very important feature is also to provide multiple end-user electricity needed for heating, cooling etc. Microgrids best serve for the electrical demand where power transmission and distribution are too far from a major centralized grid. Figure 3.16 shows illustrative description of a microgrid. As can be seen from the figure, a microgrid consists of resources, loads, storage areas and a central operating system, including renewable resources such as wind and solar energy, connected by a distribution network. This network can be connected to the main network with a circuit breaker, or it can operate independently when the circuit breaker is open.

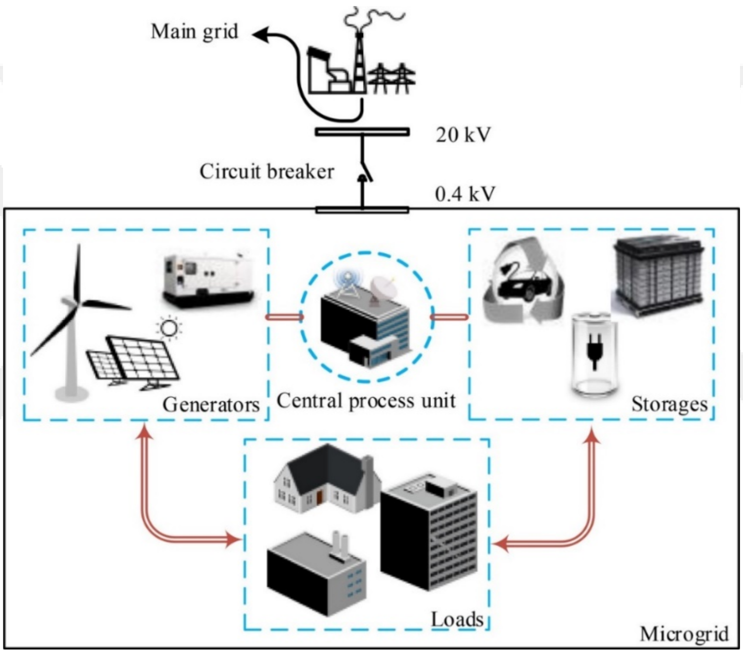


Figure 3.16. A sample model of microgrid structure considering main components (Jirdehi, 2020).

Microgrids have transformed into structures that contain different resources, especially renewable resources, in addition to traditional resources, and therefore the operation of these types of networks has become more and more complicated. The operation of a microgrid has to be easy, it should be efficient, close to loads, flexible and stable. Instead of a very large network, it is possible to operate the smaller networks independently as much as possible. Therefore, microgrids facilitates the operation of the networks that are getting more complicated day by day.

Microgrid studies can be divided into two main categories: energy management and control. Energy management includes optimum energy distribution taking into account various purpose functions subject to various constraints. In contrast, voltage, frequency, active and reactive powers are the main variables in a control problem (Meng, 2017).

4. ENERGY PRICING AND ENERGY TRADING BY BLOCKCHAIN

In this section the traditional energy pricing methods, and cost calculation of energy sources are described and tariffs for electrical energy, components of electrical rate are explained. Then smart contacts for energy trading, the structure of blockchain and IoT are described.

4.1. Traditional Energy Pricing

Subscribers pay certain fees according to the current tariffs for the electrical energy they purchase from energy distribution companies. Sales tariffs are prepared by the ministry of energy and natural resources. After calculating the unit cost of the energy produced to the power plants, this price includes operating costs, taxes, power loss on the lines, profit, etc. Sales tariffs are prepared by adding costs. The following features are considered in the preparation of the tariffs:

i-The tariffs should be in such a way that they do not cause injustice.

ii-Tariffs should help the development of the industry by providing cheap and continuous energy.

iii- The energy tariff should be of a quality that will enable electrical energy to compete with other energies.

iv-The tariffs should not exceed the service value offered by the enterprise.

While calculating the unit energy price in the tariffs, it is also important to use the energy produced in the most efficient way. Countries arrange appropriate tariffs, taking into account their own economic situation. Increasing fuel and personnel costs may require the tariffs to change from time to time. Tariffs prepared on the basis of charging a fee for the power to be drawn or for fixed service and additionally the amount of energy to be used are called double-term tariffs, and tariffs based on the determination of a fee based on the amount of electrical energy alone are called mononomial tariffs. Single-term tariffs are more suitable for customer groups that do not exceed a certain annual energy consumption. In the double term tariff, there are three different tariffs: power tariff, energy tariff and peak tariff. In order to prevent overloads during peak hours, a high tariff is applied to the energy consumed during these hours. At night, when the power plant load is low, energy is given at a cheap tariff.

The price of electrical energy is quoted in cents per kilowatt-hour (kWh) or dollars per megawatt-hour (MWh) worldwide. The following items are the components that comprise an electricity rate:

Capacity: The requirement of the electric system operators in several electricity markets is defined as the capacity. These charges help guarantee that there will be sufficient generation to meet the maximum energy demand of the market at all times.

Ancillary Services: Charges for the services needed to support and maintain reliable and continuous operation of the electric grid.

Losses: This charges cover the losses in transmission of electrical energy that occur between the generation units and consumers.

Transmission cots: Transmission of power is required from the generation substation to the local distribution company and the charges occurs due to transmission of energy are called transmission cots. These cots are billed by either the supplier or the local utility.

For a price quote for electricity or natural gas from an energy supplier, generally there are three core terms:

Price of energy supply: The price is quoted in cents or dollars per unit in international markets.

Amount to be supplied: The amount of energy to be expected to use is called supply. This is generally derived from historical consumption and estimates of future consumption.

Duration of the service: Indicates the period between the start and end date of the quoted price.

Buyers participating in the energy exchange apply to this market to supply the unmet part of their own production of the total amount of electrical energy they demand for the next day. For example, a company that may consume 100 MWh of electricity the next day applies to this market to supply 80 MWh of electricity on top of the 20 MWh of electricity it will produce. This estimated consumption expectation is determined by factors such as subscriber profile, consumption habits and meteorological conditions, and according to these, it specifies the amount of electrical energy that it thinks it will need hourly. Power plants and companies that are in the position of producers give their estimates of the amount of electrical energy they plan to produce the next day. This production status is calculated hourly depending on variables such as the condition of fuel resources in thermal power plants, the occupancy rates of dams in hydroelectric power plants, seasonal conditions, and how much consumption they expect at what hour, and these values, which are determined in line with the forecasts, are entered into the system. The electricity market regulator takes this determined total demand and supply, performs the necessary analyzes and determines the next day's price per unit kW of electrical energy. As in every market, prices are formed in the balance of demand and supply, and low demand lowers prices, otherwise prices rise as demand rise.

Figure 4.1 shows the price change curves according to the production and consumption. The point where the two curves meet is the resulting actual price. In case the supply and demand curves do not intersect, the purchase offer amounts are reduced in a way that affects all participants equally and the intersection is achieved. If the curves intersect at more than one point, the average value forms the Market Clearing Price (MCP). According to how much the prices are below or above the expectations of the companies that will buy, how much they will buy depends on the intraday market.

Real-time markets include a) Balancing Power Market and b) Ancillary Services Market. These two markets are operated by Turkey Electricity Transmission A.Ş. (TEİAŞ) in Turkey. Services aimed at ensuring the security and quality of supply in the electrical system, such as frequency and power control, are carried out within the scope of these markets. Spot electricity trading in Turkey, on the other hand, is carried out through two main organized markets: a) Day-Ahead Market (DAM) and b) Intraday Market (IM). Day Ahead Market is an organized wholesale electricity market established for hourly electricity purchase and sale transactions, with delivery one day later. In this market, participants bid or sell one day in advance. At the intersections of these offers, an electricity price is formed for each hour and the purchases in the market are made at this price.

Among the main purposes of the Day Ahead Market are:

1. To establish a reference price for electrical energy.
2. To create a platform for market participants that provides electricity trading and balancing in addition to bilateral agreements.
3. Facilitate the operation of the electrical system by providing a system that is balanced one day in advance.

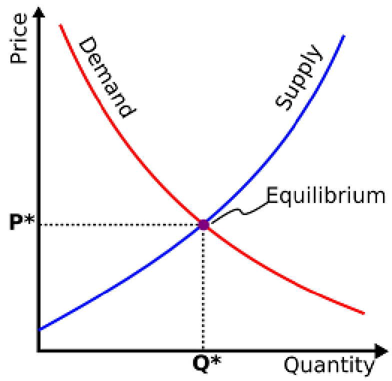


Figure 4.1. Change of energy price and setting an equilibrium point depending on supply and demand.

Stages of day ahead market is illustrated in Fig. 4.2. In the day ahead market, the hourly electricity price is called the Market Clearing Price (MCP). This price is an indicator in terms of the cost of generation in the electricity market. Price estimation studies in the electricity market are based on the price formed in this market. Another important criterion of the scenarios regarding the development of Turkey's electricity generation capacity in the upcoming period is the course of prices in the market (Mazman and Yılmaz, 2019). In the cost calculations of the energy storage investment, the "Day-Ahead Market", which determines the prices of electricity during the day, and the 24-hour electricity price of the next day, and the "Energy Balancing Market", where the electricity property components in the electricity exchange between the relevant power plant and the system are controlled in 15-minute periods. Considering the change range of prices, an optimum investment plan and energy storage system design will be possible (Taşçıkaraoğlu and Erdinç, 2018). Many physical based technologies such as kinetic, potential, mechanical, electrical, heat, magnetic, radiation, nuclear, elastic, thermal, gravity have been developed for energy storage. Existing EDS technologies are listed in (Turan and Yönetimken, 2016).

4.2. Balancing in Demand and Supply

Supply and demand balancing is very important to set an appropriate energy price. Change of energy prices depending on demand and supply is shown in Fig. 4.3. According to the Electricity Market Network Regulation, network frequency is 50 Hz. If the frequency is below 50 Hz, it means production is smaller than the consumption. To correct this situation, it is necessary to increase the production rates or reduce the consumption as described in Fig. 4.4 (a). If the frequency is greater than 50 Hz, it means production is greater than consumption. To correct this situation, it is necessary to reduce the production rates as illustrated in Fig. 4.4 (b). Change energy prices with respect to supply and demand is illustrated in Fig. 4.5.

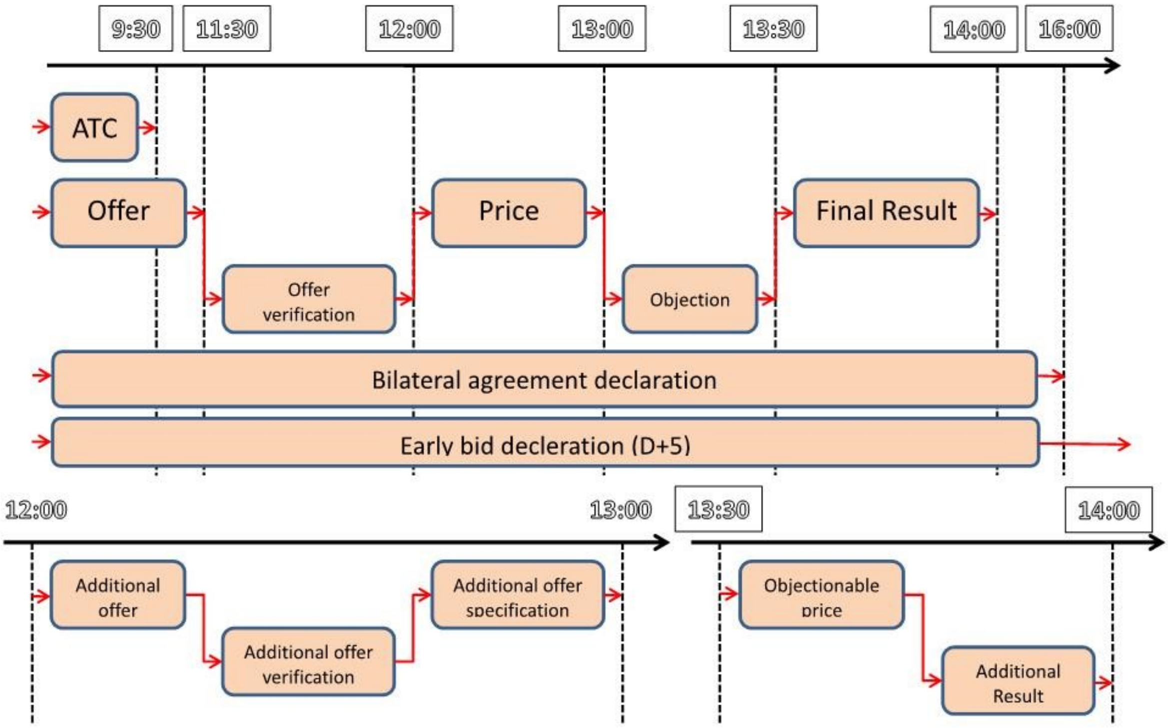


Figure 4.2. Stages of energy pricing.

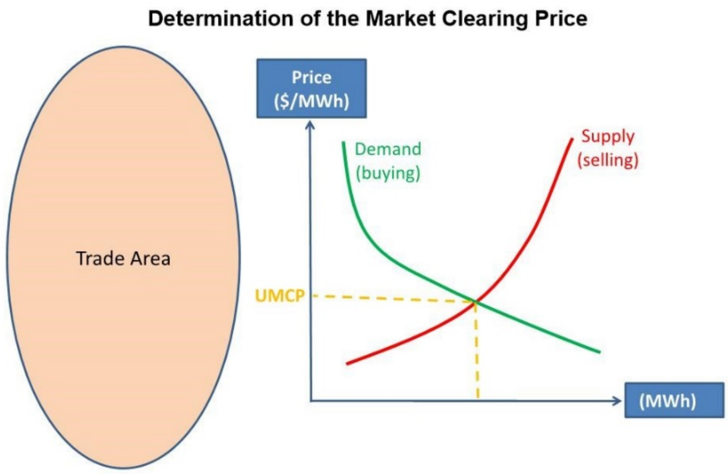
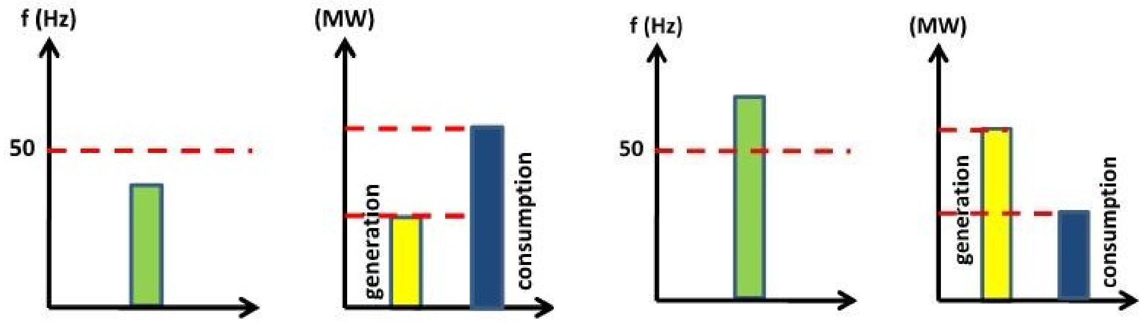


Figure 4.3. Change of energy prices depending on demand and supply (UMCP: Undetermined Market Clearing Price).



(a) (b)

Figure 4.4. a) Frequency when consumption is greater than generation and b) Frequency when generation is greater than consumption.

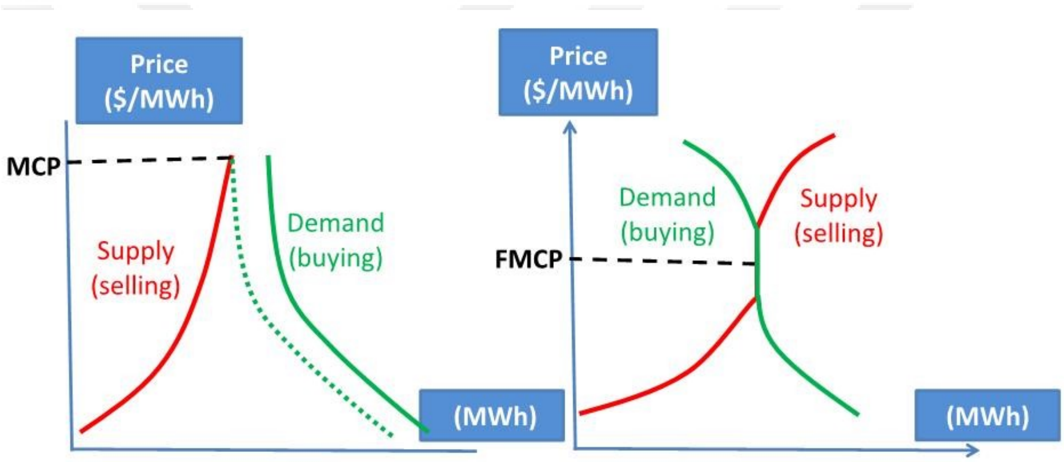


Figure 4.5. Change energy prices with respect to supply and demand (MCP: Market Clearing Price, FMCP: Final Market Clearing Price).

4.3. Determination of Energy Costs

Before the power plant is installed, the maximum energy or power that can be drawn from the power plant should be determined by considering the energy need and the future energy situation. This power is called peak power. If the cost for each kW of power is (k) \$, the installation cost of the plant $(k * P_{max})$ will be equal to determine the point. This includes interest, depreciation, repairs, maintenance, and any remaining costs. If the 1-year sum of all these expenses is determined by (a) in proportion to the founding capital, the total fixed expenses are formulated as $M_f = k * Pmax * a$.

Since (b) $ fuel is required for 1 kW of energy and the annual operating time of the plant is (Z) hours, the variable costs are determined as $Mv = b * Z * Pmax$. The total costs for 1 year are found by adding the previously found fixed costs and variable costs by:

$$M = M_f + M_v \; or \; M = a * k * P_{max} + b * Z.*= P_{max}(a * k + b * Z) \quad (4.1)$$

When reduced to a total installed power of 1 kW, the following expression is achieved:

$$\frac{M}{P_{max}} = a.k + b.Z \quad (4.2)$$

This equation gives the mandatory cost amount paid for 1 kWh of energy in 1 year. If it is known that the power plant works for Z hours in 1 year, it produces $(Z * P_{max})$ kWh energy per year. Cost of each kW of energy is:

$$m_t = \frac{M}{Z.P_{max}} = \frac{a.k}{Z} + b \quad (4.3)$$

As can be understood from the formula, the longer the 1-year working period, the less the unit cost of energy. The low annual total costs can also be expressed as one of the factors that reduce the unit cost. Since there is no expense for fuel in water, solar and wind power plants, the formula for these power plants is:

$$m_t = \frac{a.k}{Z} \quad (4.4)$$

It can be taken as Another factor that reduces the unit cost in the formula is that the plant is operated at full load or close to full load.

The formula for calculating the efficiency of a power plant is:

*K_f=Annual Electricity Generation/(Installation Power*365*24)* (4.5)

Each power plant shows a different efficiency rate due to annual electricity production and installed power. Construction costs of power plants on average are given in Table 4.1.

A power station operates for at least 30 years. A thermal power plant with an installed capacity of 1000 MW produces an average of 7 billion kWh of energy per year. A water (hydraulic) power plant of the same size also produces an average of 4 billion kWh of energy per year.

To find the share of establishment expenses in the generation cost for the thermal power plant: 7 billion kWh/year *30 years=210 billion kWh. From the point of view of construction costs only, excluding operating costs to produce this energy is 700 million$/ 210 billion kWh = 0,003 $/kWh. Since dollar cents are generally used, 0,3 cent/kWh for thermal power plants, the cost of construction and financing resources is added, this value will be 0,4 cent/kWh at most. If this calculation is repeated for hydroelectric power stations, 0,8 cent/kWh is obtained.

Considering that almost all of the energy produced in our country is provided by thermal and hydraulic sources, the above data can be used. Considering the ratios of thermal and hydraulic resources in electricity generation (20% hydraulic 80% thermal), an average value of 0,5 cents/kWh is achieved. Considering the 30-year production of the installation costs of the power plants, its contribution to the total energy costs is 0,5 cent/kWh.

The operating costs of power plants are very variable according to the primary sources of the power plants. Namely.

- The biggest ratio in the operating costs of thermal power plants is the fuel cost.
- For natural gas and fuel oil power plants, this rate is around 90%.
- For coal-fired power plants, the fuel cost is around 60-70%.

This is not the case for hydraulic power plants. Personnel expenses and other operating expenses determine the cost for hydraulic power plants. The fuel and labor cost of power plants is given in Table 4.2.

Table 4.1. Construction costs of several power plants.

Primary source	Percentage cost (dolar/kW)	1000 MW plant cost (million dolar)
Coal	750	750
Petrolium	650	650
Natural gas	650	650
Hydro	1000	1000
Wind and others	1000	1000

Table 4.2. Fuel and labor costs of several power plants.

Primary source of plant	Fuel costs (%)	Labor and other costs (%)	Total (%)
Coal	60-70	30-40	100
Liquid fuel	85-90	15-10	100
Natural gas	90-95	10 -5	100
Hydro	……	100	100

4.4. Coal-fired Power Plant Energy Costs

Expense items of core-fired power plants in energy production are expressed in Fig. 4.6. Let a maximum of 1500 people will work in the coal enterprises that provide fuel to this power plant. The coal produced by the work of 1500 people meets the fuel need of a power plant with a power of 1300 MW. In this case, it will be necessary to look at the total cost of the coal plant.
The share of labor in the total expenditure of the coal mill, which operates as an open pit, is around 70%. The annual cost of 1500 people is; at a monthly cost of $2000 per person, 1500 *2000*12=36 million$. The annual total expenses of the coal plant are 36 million$*100/70 =51.4 million$ is the total expenses of the coal power plant.

The annual expenses of the power plant are 51.4 million$ *100/70 =73.4 million$ is the total expenses of the plant. The coal-fired thermal power plant spent $73.4 million annually and 7.5 billion kWh of energy is supplied to the grid. The, the unit cost can be found as: $73.4 million/7.5billion/kWh=$0,009/kWh=0,9cents/kWh*0,5+0,9=1,45 cents/kWh with investment costs included, which is the total production cost for coal-fired power plants.

4.5. Hydroelectric Power Plant Energy Costs

Average investment cost per kW of hydro power plants is varying with their size. For large hydropower plants with storage investment cost per kW typically range from $1050/kW to $7650/kW. The cost is between $1300/kW and $8000/kW for small hydropower plants. For existing hydropower or existing dams that don’t have a hydropower plant Adding additional capacity is cheaper and is about $500/kW. Annual operations and maintenance costs (O&M) are typical values range from 1% to 4%, which are quoted as a percentage of the investment cost per kW and 2% to 2.5% in the case of large hydropower plants 1% and 6%, in the case of small hydropower plants (IRENA, 2012).

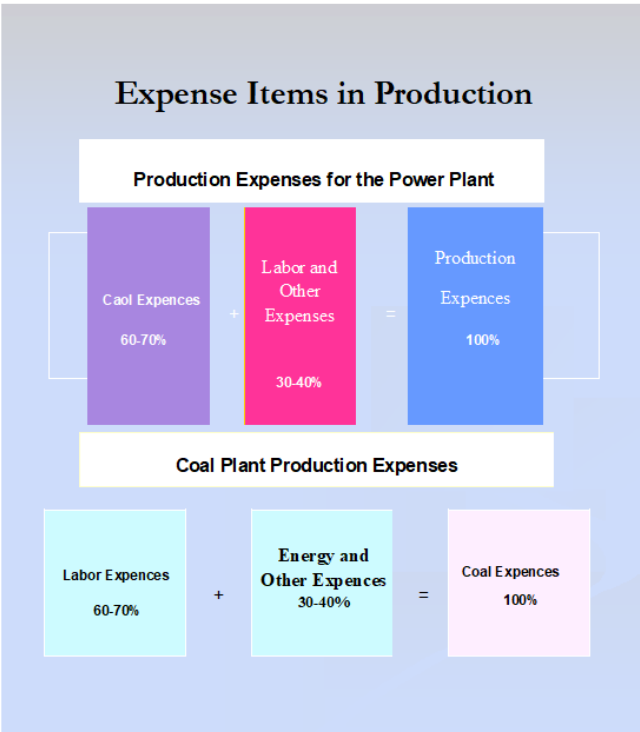


Figure 4.6. Expense items of power plants in energy production.

The cost of electricity generated by hydropower is generally low although the costs are very site-specific. The cost of energy for large hydropower projects typically ranges from $0,02 to $0,19/kWh assuming a 10% cost of capital. The cost of electricity for hydropower refurbishments and upgrades ranges from as low as $0,01/kWh for additional capacity at an existing hydropower project to around $0,05/kWh. For small hydropower plants the cost of energy range is between $ 0,02 and $0,10/kWh, making small hydro a very cost competitive option to supply electricity to the grid, or to supply off-grid rural electrification schemes. Very small hydropower projects can have higher costs than this and can have a cost of $0,27/kWh or more for pico-hydro systems (IRENA, 2012).

4.6. Wind Power Energy Costs

Let us consider a wind turbine operating at %30 mean capacity and 10 MW power. For a wind turbine, the average turbine price including the investment cost and license fee is about 1400 $/kW per 1 MW power. Installation cost and other costs (wind analysis, project design, etc.) are approximately 25% of the average turbine price, which is calculated as 350 $/kW. The total installation cost is then 1750 $/kW. The total initial investment cost for 10 MW power 1750 $/kW*10000 kW=17.5 million$. The annual electricity generation with %30 mean capacity is 1000kW*8760h*0.30=2628000 kWh. Current sales price of the electrical energy produced by the wind turbine is 0,055 $/kWh and the operating costs are approximately 0,010 $/kWh. As a result, the annual profit of the wind station becomes 2628000 kWh*(0,055-0,010) $/kWh= 118260 $.

4.7. Energy Costs of Geothermal Power Plants

A cost analysis is carried out considering to a geothermal power plant operating at %85 capacity and producing 1 MW of energy. The initial investment cost of such a plant is approximately 2500 $/kW. The total initial investment cost will be 2500 $/kW*1000 kW= 2500000 $. Annual electricity generation will be 1000 kW*8760h*0.85= 7446000 kWh. The sales price of the electricity produced is 0,055 $/kWh currently. The operating cost is approximately 0,011 $/kWh. As a resultant, the annual electricity profit is determined as 7446000 kWh*(0,055-0,011) $/kWh = 327624 $.

4.8. Energy Costs Solar Power Stations

A solar power station with 1 MW of mean power is considered assuming that the solar panel works with the highest efficiency per day. The total energy produced in a year will be 1000 kW*365*10h=3650000 kWh. Energy selling price is 0,055$/kWh for solar power. The operating costs are about 0,010 $/kWh. Then the annual income is calculated as: 3650000kWh*(0,055-0,010)$/kWh =164250 $. It should be noted that to obtain a 1 MW mean power with 20% mean efficiency, the power of solar panels should be 5 MW.

4.9. Comparison of Efficiency in Base Power Plants

Both steam and hydropower plants are base power stations. They are constructed to match the base power. In this section production efficiency and cost comparison of steam and hydro power plants is investigated by examples.

Let a=5000 $ and k=0.1 in a hydro power plant. Accordingly, the annual amount of money spent for each kW is founds as (Peşint, 1996):

$$\frac{M}{P_{max}} = 5000 * 0.1 + b * Z = 1000 + b * Z \quad (4.1)$$

As $b = 0$ for the hydro power plant from the above formula it is found that $\frac{M}{P_{max}} = 500$. That is $\frac{M}{ZP_{max}} = \frac{500}{Z}$ for each kWh of energy according to the annual Z-hour working time.

For a steam power plant let b=0.11 $/kWh; k=0.16; If a=500 $, and annual working time Z hours

$$\frac{M}{P_{max}} = a.k + b.Z \text{ and } \frac{M}{P_{max}} = 500 * 0.6 + 0.22.Z = 300 + 0.22 * Z \quad (4.2)$$

is obtained.

Two different change characteristics of these two power plants can be seen in Fig. 4.7. As can be seen here, steam power plants are more economical than hydro power plants in cases where the annual operating time is less. In our example, it is seen that this period is 909 hours. With more than 909 hours of operation per year, hydro power plants produce cheaper electricity and are more economical. Since 909/24=38 days is very little for a year's working period, we can say that cheaper energy is produced in hydro power plants compared to steam power plants. In Fig. 4.8, we see the change in the unit price of energy according to the annual working time.

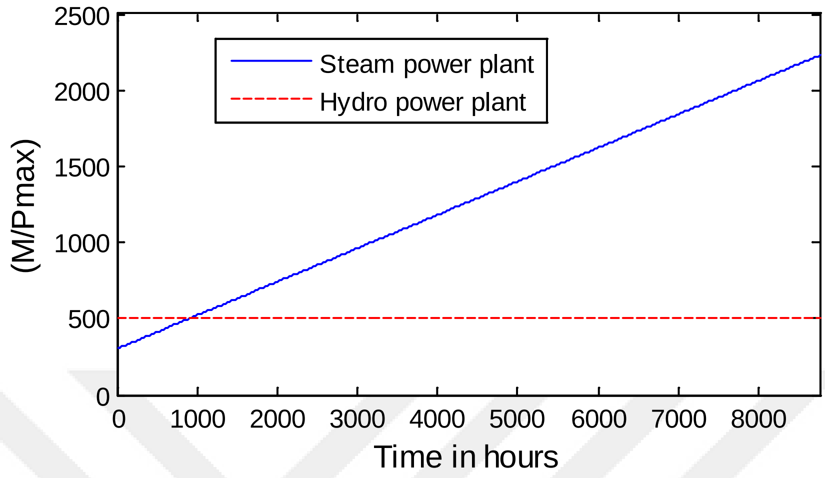


Figure 4.7. Energy cost comparison of thermal and hydro power.

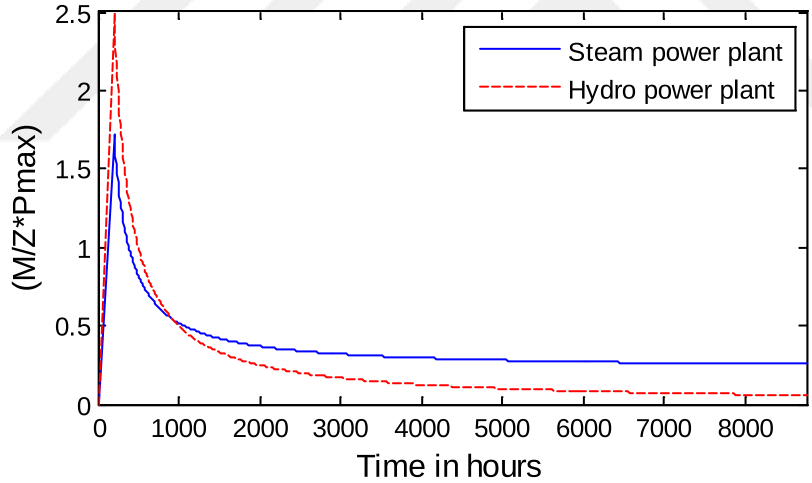


Figure 4.8. Change in the unit price of energy according to the annual working.

In order a power plant to pay off the installation costs, the power plants must be operated at an efficient point in terms of harmony of input costs and output values. Fuel costs are constantly changing in thermal and natural gas power plants. On the other hand, there are no fuel expenses in hydro, wind, solar and biomass power plants. Therefore, wind, solar and biomass power plants that do not have fuel costs should be the priority to ensure an efficient operation. In hydro and geothermal power plants, on the other hand, since the reserve status and storage status are available, their output values should be determined by taking into account their needs and also the annual planning status. Another situation that should be taken into consideration regarding this issue may be the instantaneous high need (peak power). Today, when the level of renewable energy generation has not yet met the need, thermal power plants that use lignite, coal and petroleum resources, which have high environmental adverse effects and cause the depletion of fossil fuels, have to be used as basic load power plants.

4.10. Pear to Pear (P2P) Energy Trading and Smart Contacts

Compared to traditional networks, a more efficient energy trade is possible in networks connected to each other by person-to-person (P2P). Consumers can also be producers in a P2P trading network and an example scheme of distributed ledger technology integrated with renewable energy resources is shown in Fig. 4.9 (Gai,2019). In (Afsal, 2020), reliably managing energy and financial flows between microgrids are aimed and it has been shown that energy efficiency can be achieved using a set of interoperable blockchains embedded with self-implementing smart contracts shown in Figure 4.10.

In a scenario developed by Musleh, Yao and Muyeen (2019) solutions have been developed for the challenges for future and the existing smart grids and the applications of blockchains in smart grids. A study evaluating real-time results was conducted by Andoni et al. (2019), demonstrated its commercial viability and showing the challenges and market barriers that the technology must overcome. In another study, the results were evaluated by van Leeuwen, AlSkaif, Gibescu and Wilfried van Sark (2020), using real data from a consumer community in Amsterdam, and the effects of various scenarios, physical restrictions and trade on social welfare. Studies have been conducted on simulations and scenarios that can be integrated with renewable energy that compare the network losses of P2P trading and traditional method (Azim, et al., 2020). In another simulation study, Zhao, Guo and Chan (2020) questioned the widespread use of blockchain distributed generation and its applicability as information communication technology (ICT).
A net interchange with neighboring areas, to determine the desired each plant in the area for economic dispatch, and to cause the area to do its share to maintain the desired frequency of the interconnected system.

The flow of information in a computer controlling a particular area. The numbers enclosed by circles adjacent to the diagram are used to express the processing of the control operation. The symbols × or E on the diagram enclosed in larger circles indicate points of multiplication or algebraic summation of incoming signals.

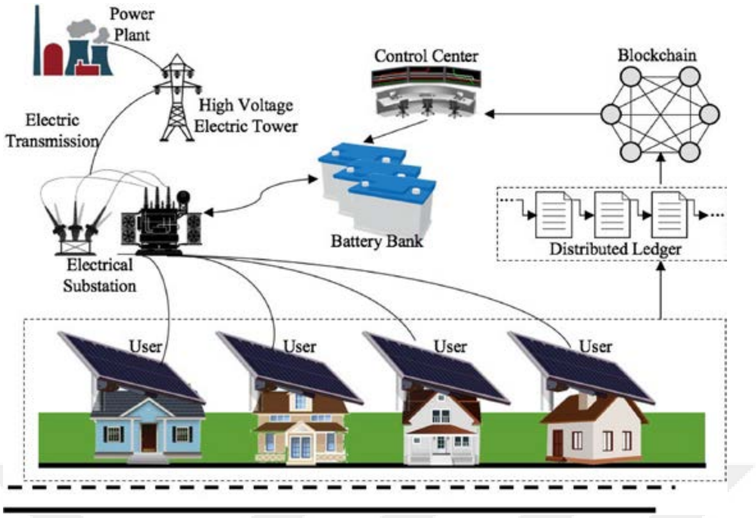


Figure 4.9. Energy trading with blockchain (Gai, 2019).

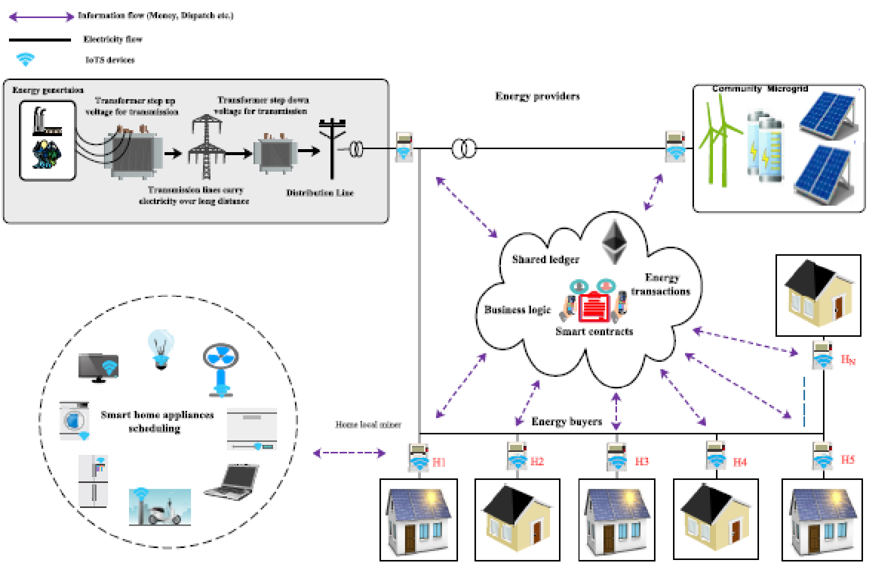


Figure 4.10. Self-implementing smart contracts (Afzal, 2020).

4.11. Blockchain Networks:

One of the main properties of peer-to-pear (P2P) blockchain networks is that these networks have no central vulnerability. These systems are decentralized therefore, hackers cannot exploit. Likewise, there is no central point of failure. Blockchain security is achieved by the use of public key encryption methods. A public key in the form of a long, random-looking string of numbers is used as an address in the blockchain. Value tokens sent over the network are saved as belonging for this address. A private key is like a password that gives its owner access to their digital assets.

Public blockchains make available the block-level data available and public transparent by decentralizing data in an accessible ledger. In traditional systems central data can be controlled more easily however in blockchain information and data manipulation is impossible and the data stored in the blockchain is almost indestructible. A blockchain is a decentralized, distributed, and public digital ledger used to record transactions on many computers. Thus, the record cannot be changed retrospectively except that all subsequent blocks are changed, and the network is understood.

Every node in a decentralized system has a copy of the blockchain. Data quality and computational trust is maintained with massive database replication. None of the user is more "trusted" than any other and there is no central "official" copy of the system. Transactions are transmitted to the network using software and messages are delivered on a best effort basis. Mining nodes verify each transaction, add them to the block they created, and broadcast the completed block to other nodes. This blockchain-based value exchange can be completed faster and more securely than traditional systems. However, the growth of a decentralized blockchain causes the computer resources required to process more data, which is expensive. The architecture of blockchain edge networks is shown in Fig. 4.11.

4.12. Blocks

A blockchain is a distributed database that stores information in digital format, which is shared among the nodes of a computer network. Blockchain and a typical database are similar, however the method of structuring the data is different. Data is usually accumulated into tables in a database, whereas in a blockchain, data is structured into distributed and interconnected blocks. By this way, a secure and decentralized record of data and information (transactions) is maintained and are best known for their crucial role in cryptocurrency systems. The renovation with a blockchain is that it ensures the security and fidelity of a record of data and generates trust without the need for a control of third party. In blockchain, the information is collected in groups, expressed as blocks that hold sets of information. Each block involves the cryptographic hash function of the previous block in the blockchain and combines these two.

Blocks hold stacks of valid transactions that have been hashed and encoded into a Merkle tree. Each block has a certain storage capacity and are closed when filled. They linked to the previously filled block and a chain of data is formed known as the blockchain. All new information is compiled into a newly formed block that will then also be added to the chain once filled.

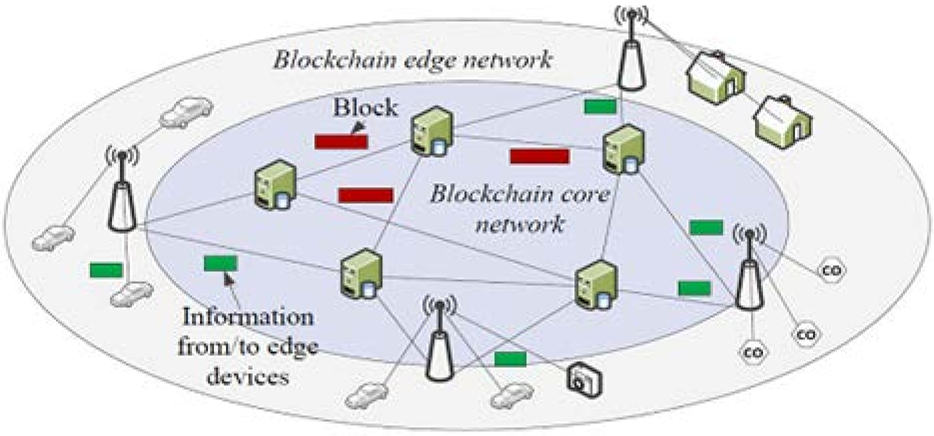


Figure 4.11. The architecture of blockchain edge networks.

Separate blocks can be generated simultaneously and each time a temporary fork is created. In addition, any blockchain has a specific algorithm for scoring different versions of the date so that one with a higher value can be selected over the others. This is needed to secure hash-based date. The blocks that are not involved in the chain are called orphan blocks. The peers that support the database have different versions of the history from time to time. They keep the highest rated version of the database known only to them. When a peer receives a higher rated version (usually the old version with a single new block added), it expands or overwrites their databases and retransmits the development to their peers. There is never an absolute guarantee that any entry will stay on the best version of history forever. Blockchains are typically built to add the score of new blocks to old blocks and there are incentives to work on extension with new blocks rather than simply overwriting old blocks. The probability of substituting an entry becomes very low as more blocks are created towards the top, as a result, decreases exponentially.

4.13. Interaction of IOT Devices with Blockchain Networks

One of the main blockchain-powered mechanisms that is likely to gain wide acceptance in the IoT space is smart contracts. Transactions related to smart contracts take place with two-way communication traffic. Dealing with this blockchain-sourced traffic, with which IoT devices are associated and connected, requires an appropriate architecture for the blockchain network structure.

4.14. Internet of Things IOT

IOT (Internet of Things: Internet of Things) is a system that connects smart objects to the internet. It enables the exchange of new data that was not previously available and can transmit users' information more securely. As the meters will be connected by IOT, the power consumption of each consumer can be taken in to account in real time. Therefore, with known energy supply in the supplier side and consumption on the consumer side, a real time dynamic pricing can be achieved. Fig. 4.12 shows an illustration of the internet of things.

The Internet of Things brings many benefits to organizations and businesses, having a great impact on our personal and professional lives. With IoT; the overall business processes can be overseen, the customer experience improves, saving in time and money is possible, the integration and coordination of business models is easy, better business decisions is allowed, employee productivity is increased, and life quality is improved.

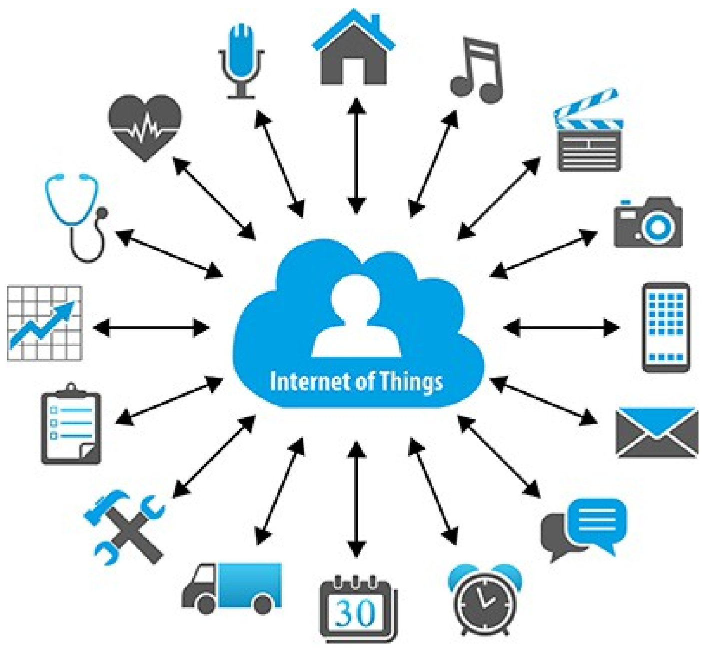


Figure 4.12. Internet of Things (IOT).

5. APPLICATION AND RESULTS

In this section, a dynamic pricing has been realized in case different energy sources provide energy to the microgrid according to different scenarios. Since the energy costs of each energy source are different, energy prices also change instantly according to the costs attained. The aim here is to ensure that the energy price is variable, thus enabling the most efficient use of energy resources. In the scenarios examined, priority has been given to base load power plants, which are difficult to off-line in practice and which must be constantly on, and renewable energy sources that do not have fuel costs. In the assigning the priorities, the feature of hydroelectric power plants to store water and to meet this need when the energy need during peak hours is also taken into consideration. The developed strategy allows to provide energy to the system at an optimum cost. At the end of the chapter, there is a proposal on how dynamic pricing can be adopted with blockchain.

5.1. Energy Pricing Strategy

A typical load duration curve is shown in Fig. 5.1. The load duration curve can be assumed to be a triangle. In terms of loading conditions, there are 3 types of power plants. 1) base load power plants, 2) intermediate load power plants and peak load power plants. Base load power plants are in operation continuously. These power plants must have high energy generation potential, and it should not have fuel or potential energy source considerations. Therefore, in a traditional power network generally hydro and thermal plants operate together to meet the base load in an integrated power system. Such a combined system allows maximum efficiency as well as optimum economic conditions. As a base load power plant, hydroelectric power plants and thermal power plants are planned to be in operation in a rotational manner by considering the level of water stored in the reservoir, the expected rain or snowfall condition, and the price and availability of the fuel. In periods with plenty of water hydroelectric power plants are considered to operate as base load plants in order to save fuel. In periods with low flow season thermal plants are used to produce the base load power.

Typical minimum load ratio in existing hard coal plants is in the range of 25% to 40% of nominal load. For a gas turbine combined cycle gas power plant (CCP), the typical minimum load is 40-50% of nominal load and 50-60% for lignite-fired power plants (Lens, 2013).

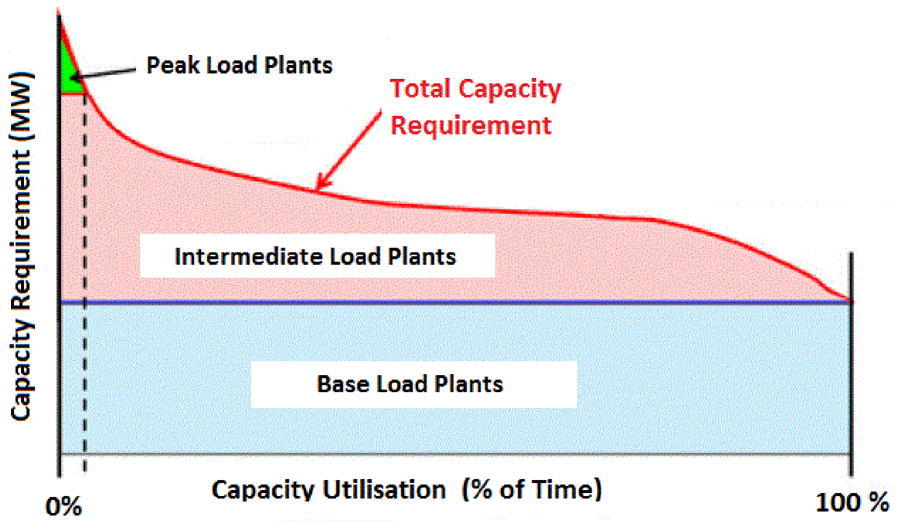


Figure 5.1. A typical load duration curve.

In the proposed dynamic pricing strategy, availability, energy production costs and energy storing capabilities are considered. The priority of the power plants with availability of Hydro power is described in Table 1. The priority of the power plants with unavailability of Hydro power is described in Table 2. The priority is given to solar and wind power as there is no fuel consumption for these sources and these power sources are renewable and not harmful for the environment. Biomass, geothermal and hydropower can also be considered and included as renewable power sources. It should be noted that unlike solar and wind energy these power sources have ability to reserve their energy in their natural form without need of any other storage equipment. Storage of solar and wind energy is not possible directly; storage is possible for the electrical energy produced. Therefore, when demand side needs energy, this energy should be provided first by solar and wind energy. If the energy supplied by the solar energy+wind energy is greater than the demand energy, the excess energy can be stored in battery storage systems. In the second stage the demand can be meet by thermal power as thermal power stations cannot be taken out of work and start up in short duration. Although biomass and geothermal energy sources are also renewables as solar and wind energy, these energy sources and be stored in their natural form, they have to be considered in the third stage, i.e., when solar energy+wind energy is not sufficient to meet demand. In the next stage hydro power is added if available. In the last stage the demand can be meet from natural gas as gas stations can be easily adopted to the net in short duration.

Table 5.1. The priority of the power plants when hydro power is available.

Plant	Priority
Solar power plant	1
Wind power plant	1
Biomass	2
Geothermal	2
Thermal	3
Hydro	4
Natural Gas	5

Table 5.2. The priority of the power plants when hydro power is unavailable.

Plant	Priority
Solar power plant	1
Wind power plant	1
Biomass	2
Geothermal	2
Thermal	3
Natural Gas	4

5.2. Scenario 1: Effect of Renewable Sources on the Cost

In the first scenario, the effect of renewable energy sources on energy costs is investigated. it is considered that a thermal station as a base power plant and wind and solar power plants as renewable energy sources feed network. In case of need, additional energy need will be met by natural gas power plant at peak hours. The priority of power stations is given in Table 5.3. The total consumption of consumers for the microgrid changes hourly in a 1-day period as in Table

5.4. This table is constructed considering 1/250 consumption of one day (24 March 2022) consumption of Turkey, which is approximately a daily consumption of a medium scale city (Table 5.5), which is illustrated as a chart shown in Fig. 5.2. Change of power demand in the microgrid per 15 minutes is as shown in Fig. 5.3. As there are no fuel costs, all the energy provided by solar power stations during the daytime and the energy provided by the wind power plants both during the day and at night are used.

The energy supplied by each of the solar and wind power stations are shown in Figures 5.4 and 5.5, respectively. For solar power stations, solar power data from Malatya Turgut Özal Medical Center 5.3 MW Solar Power Station on 24 March 2022 provided in Table A.1 is taken as reference. It is considered that the number of solar power plants in the microgrid is 10 each having 5.3 MW nominal power and the number of wind turbines in the wind farm is 5 each having 10 MW nominal power. The power output of each wind turbine is as given in Table A.2. The nominal power outputs of both steam power plant and natural gas power plants are 100 MW.

Power supplied from steam power plant and natural gas power station are as shown in Fig. 5.6. and Fig. 5.7, respectively.

Table 5.3. Priority of the power plants for Scenario-1.

Plant	Priority
Solar power plant	1
Wind power plant	1
Steam	1
Natural Gas	2

Table 5.4. Consumption rates for Scenario-1.

Hours	Consumption (kW)
0	134220,4
1	127366,8
2	122705,2
3	119916,6
4	119295,9
5	120262,2
6	122990,6
7	129685,4
8	155785,2
9	172313,1
10	178417,1
11	182536,4
12	178139,6
13	178790,6
14	180782,2
15	178132,5
16	175878,6
17	170228,9
18	163876
19	166415,8
20	162385,7
21	157378
22	153565,2
23	146675,1
24	134220,4

Table 5.5. Data of energy consumption of Turkey on 24 March 2022.

Hour	**Consumption (MWh)**
00	33555,09
01	31841,71
02	30676,23
03	29979,16
04	29823,97
05	30065,55
06	30747,64
07	32421,36
08	38946,31
09	43078,28
10	44604,27
11	45634,11
12	44534,91
13	44697,66
14	45195,56
15	44533,13
16	43969,66
17	42557,23
18	40968,99
19	41603,94
20	40596,43
21	39344,49
22	38391,29
23	36668,77
24	33555,09
Total	506192,46

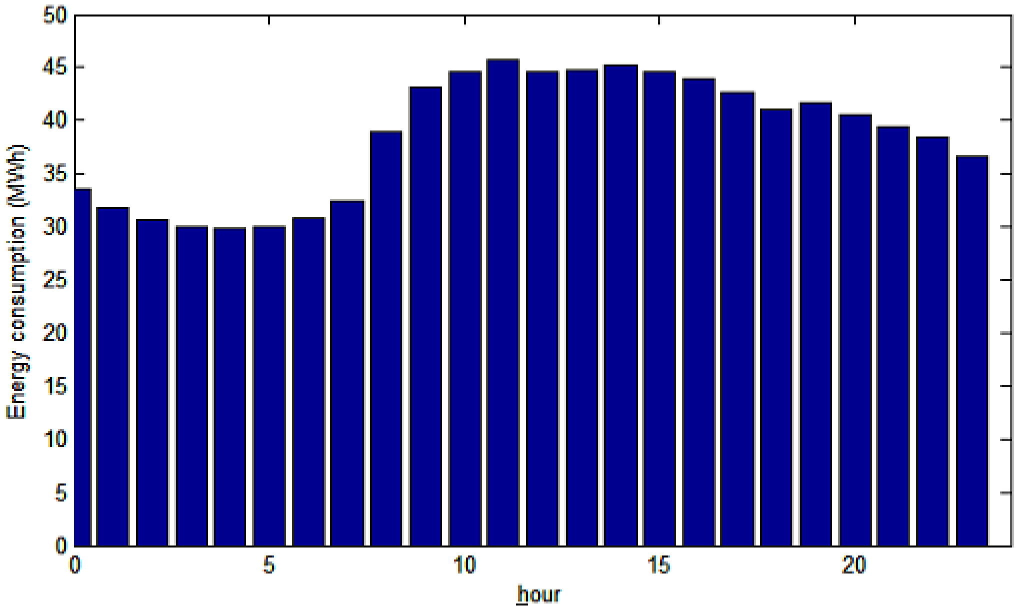


Figure 5.2. Energy consumption of Turkey on 24 March 2021.

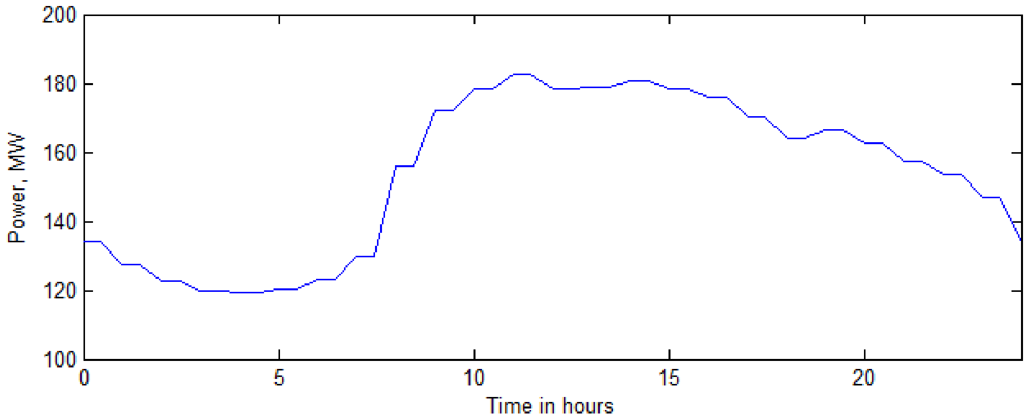


Figure 5.3. Power demand per hours for Scenario-1.

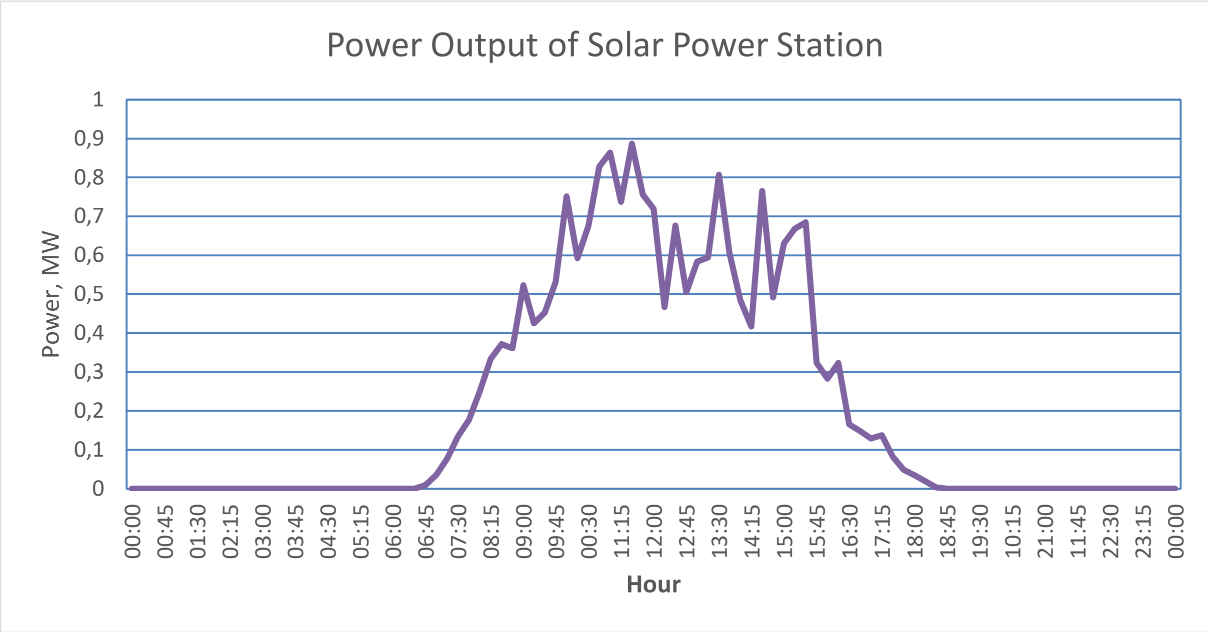


Figure 5.4. Energy produced by 5.3 MW Turgut Özal Medical Central Solar Power Plant on 24 March 2022.

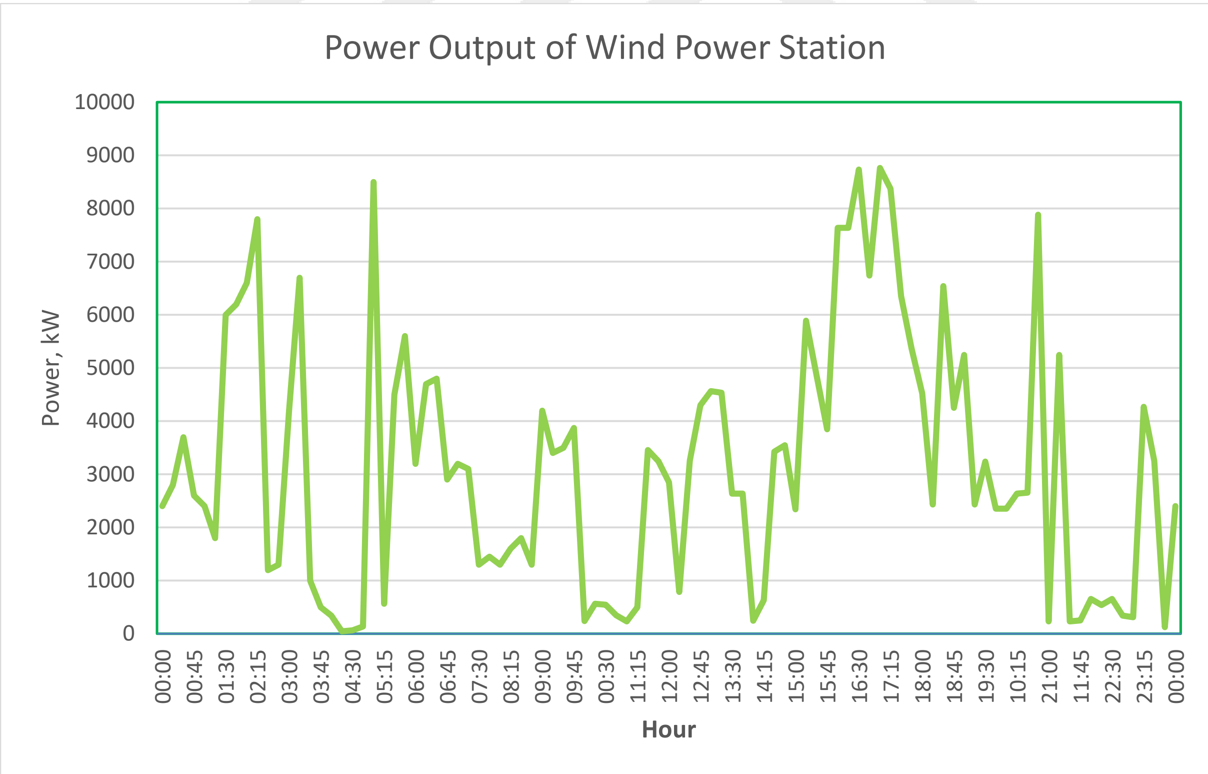


Figure 5.5. Energy produced by the wind power station.

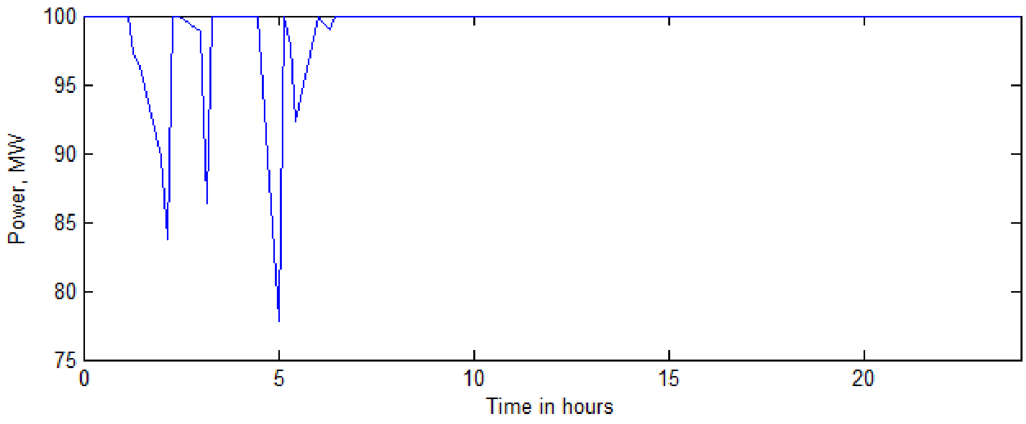


Figure 5.6. Power supplied by the steam power station

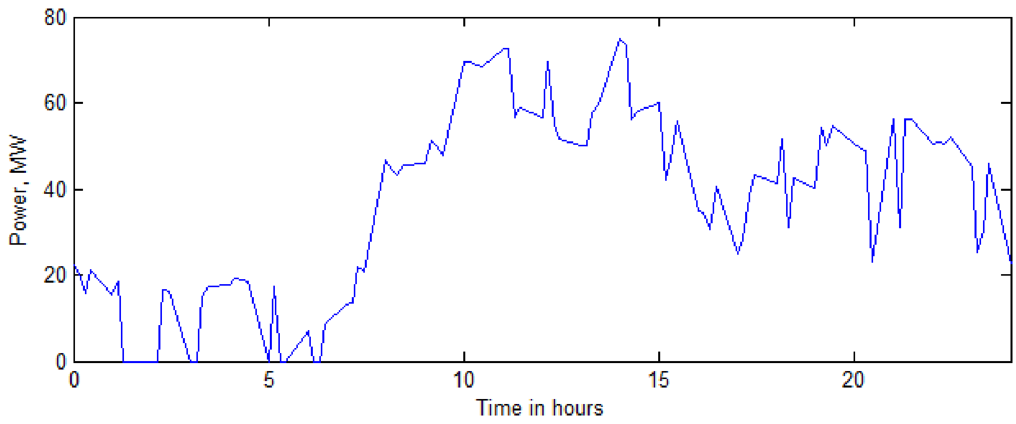


Figure 5.7. Power supplied by the natural gas power station.

The instantaneous change of the energy prices realized according to this production planning is calculated and the change of energy costs is given in Figure 5.8. Energy price at 15 minutes discrete time instant in is calculated from

$$Energy\ price = \frac{\sum_{i=1}^{i=n} P_i c_i}{P_{total}} \tag{5.1}$$

where P_i is the power output and c_i is the cost of energy of each individual power plant, respectively.

Mean values for the energy prices taken from (https://energyfreedomco.org/f3-LCOE.php) are used. The cost ranges are (3 - 6¢/kWh) for wind power, (4.6 - 5.3 ¢/kWh) for utility-scale solar power, (4.2 - 7.8¢/kWh) for natural gas and (6.0 - 14.3¢/kWh) for coal power plant. Mean values for costs are taken to be 4.5 ¢/kWh for wind power, 4.95 ¢/kWh for solar power, 6 ¢/kWh for natural gas and 10.15 ¢/kWh for coal power plant. Energy costs is taken to be 6 ¢/kWh for hydro power station based on mean values provided in (IRENA, 2012). Mean energy costs for 1 day period is calculated by

$$Mean\ energy\ price = \frac{\sum_{i=1}^{i=n} E_i c_i}{E_{total}} \tag{5.1}$$

where E_i is the energy provided from each individual power station and c_i is the cost of energy of each individual power plant, respectively.

Total energy consumption is determined as 3731300 kWh. Energy supplied from each source is calculated and it is found that 383370 kWh of this energy (%10.2744) is from wind turbines, 50621 kWh of this energy (%1.3567) is from solar power station, 2404700 kWh (%64.45) is from steam power plant and 892620 kWh (%23.92) is from natural gas power station. Daily mean energy cost is determined as 0.0851 $/kWh on the existence of solar and wind power stations. Daily mean energy cost is 0.0870 $/kWh when solar and wind power does not exist. As the solar power stations do not works at their full capacity due to weather conditions in march, the difference is not too much, since the solar stations work %16.7 of their full capacity. However, if it is considered that they work with their full capacity, the mean cost reduces to 0.0844 $/kWh. When the number of wind turbines is doubled a further reduction is accomplished and daily mean cost reduces to the value 0.0814 $/kWh.

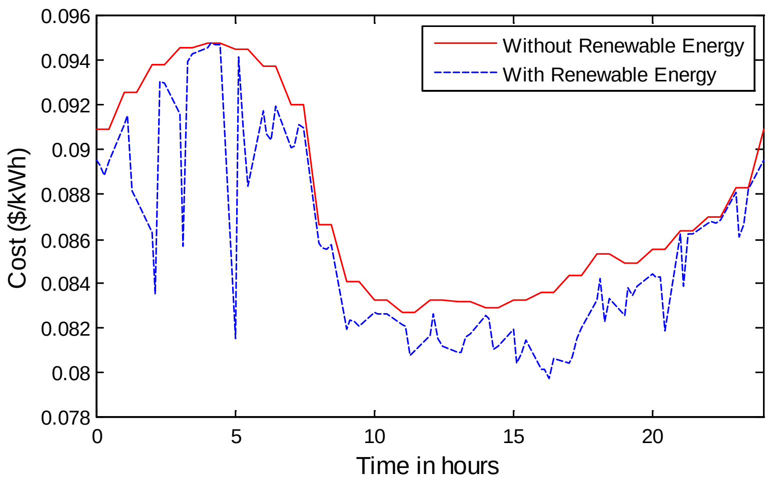


Figure 5.8. Energy cost variation i) with renewable sources exist and ii) renewable sources do not exist.

5.3. Scenario 2: Microgrid with Hydro Power Plant as a Storage

Since hydroelectric power plants have energy storage opportunities in the dam as potential energy of water, energy supply from hydro comes after solar and wind power plants. In the second scenario, a microgrid thermal and natural gas power plants as base power plants each having 100 MW power capacity, as well as wind and solar power plants as renewable energy sources with specifications given in scenario 1 are considered. In case of need, additional energy need during peak hours, hydro power supplies energy, which has 50 MW power power capacity. It is assumed that the total consumption of consumers for the microgrid changes hourly in a 1-day period, as in Table 5.6. Consumption of microgrid is extended by adding 50 MW to the power consumption rates used in Scenario 1. Excess energy need is met from hydro station during peak hours. The energy consumption is illustrated as shown in Figure 5.9. The energy that cannot be met by a thermal power plant is primarily provided by solar and wind power plants, where there are no fuel costs. All the energy provided by solar energy during the daytime and the energy provided by wind power plants both during the day and at night is used. As the hydroelectric power plants have energy storage features, energy supply from here comes after the solar and the wind power plants. However, due to the lack of fuel costs, the order of preference of these power plants may be before the power plants based on natural gas and petroleum products. Costs per kWh for the energy sources are as those provided in Scenario 1. The energy situation provided by the gas power plant and hydro power plant and natural is shown in Figures 5.10 and 5.11, respectively. The instantaneous change in energy costs realized according to this production planning is given in Figure 5.12.

Total energy consumption is determined as 4943800 kWh. Energy supplied from each source is calculated and it is found that 383370 kWh of this energy (%7.75) is from wind turbines, 50621 kWh of this energy (%1.02) is from solar power station, 2425000 kWh (%49.05) is from steam power plant 2009700 kWh of this energy (%40.65) is from hydro and 75091 kWh (%1.52) is from natural gas power station. Mean energy cost is calculated as 0.0791 $/kWh.

Table 5.6. Consumption rates for Scenario 2.

Hours	Consumption (MW)
0	184220,4
1	177366,8
2	172705,2
3	169916,6
4	169295,9
5	170262,2
6	172990,6
7	179685,4
8	205785,2
9	222313,1
10	228417,1
11	232536,4
12	228139,6
13	228790,6
14	230782,2
15	228132,5
16	225878,6
17	220228,9
18	213876
19	216415,8
20	212385,7
21	207378
22	203565,2
23	196675,1
24	184220,4

Table 5.7. Priority of the power plants for Scenario-2.

Plant	Priority
Solar power plant	1
Wind power plant	1
Steam	2
Hydro	3
Natural gas	4

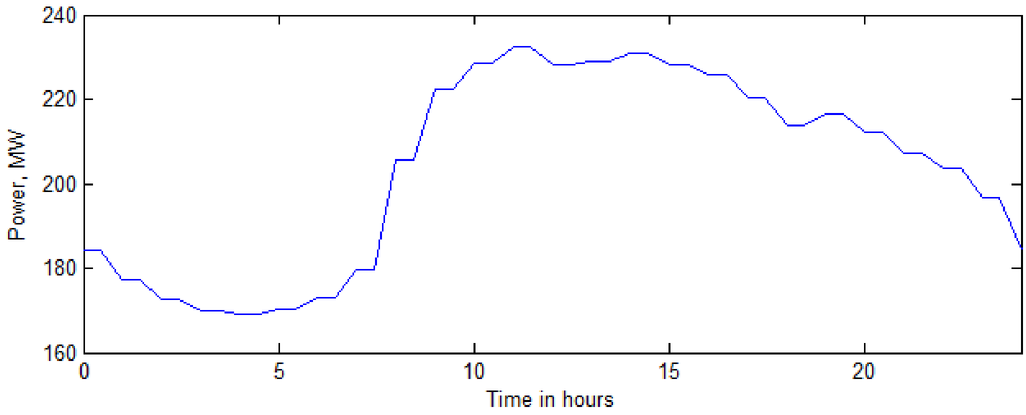


Figure 5.9. Power demand per hours for Scenario-2.

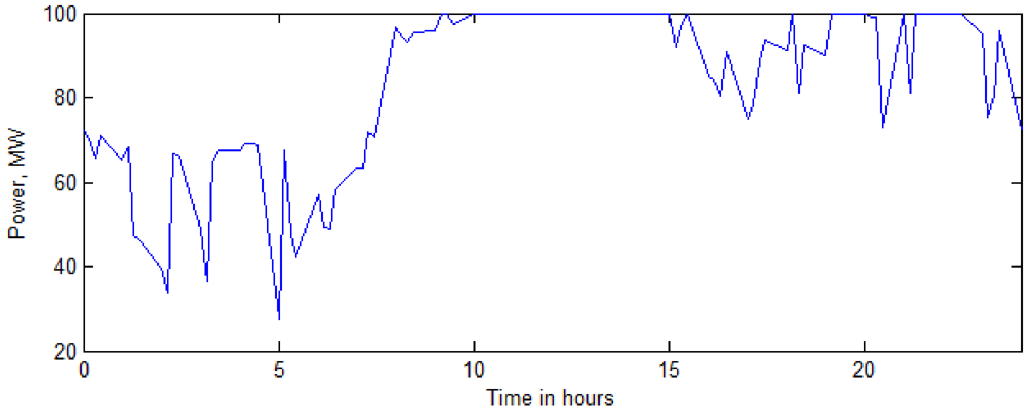


Figure 5.10. Power supplied by the natural gas power station.

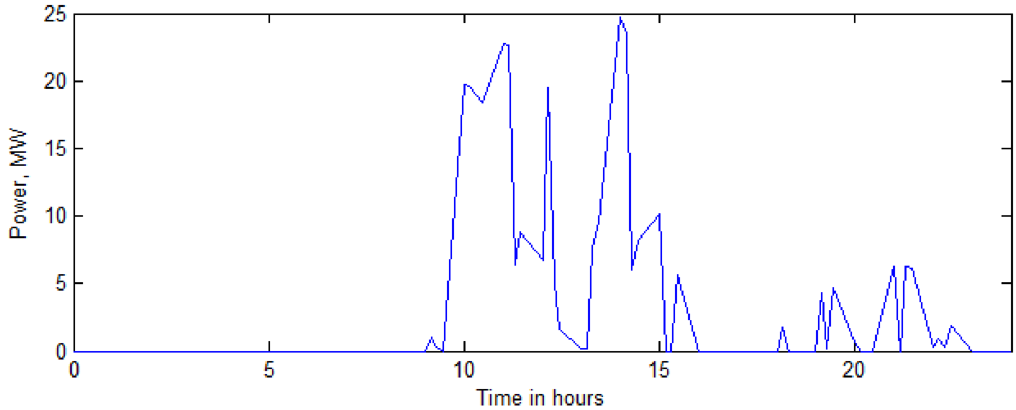


Figure 5.11. Power supplied by the hydro power plant.

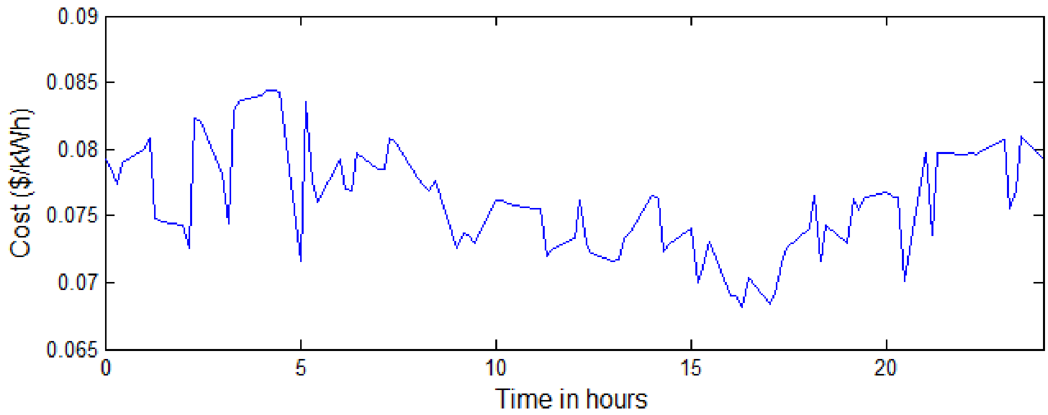


Figure 5.12. Change of energy costs for Scenario-2.

5.4. Scenario 3: Microgrid with Energy Battery Storage System

In the third scenario, a microgrid with base load power plants, thermal and hydroelectric power plants, as well as wind and solar power plants as renewable energy sources is considered. In case of need, additional energy need will be met by an energy storage system with a capacity of 50 MWh hour. The priority of power stations is as in Table 5.8. Energy price for battery storage system is taken to be as 12.484 ¢/kWh based on data provided in (U.S. Energy Information Administration, 2022). Energy costs per kWh for other sources is taken as in scenario 1. It is assumed that the total consumption of consumers for the microgrid changes hourly in a 1-day period as in Table 5.4 given in Scenario 1. The energy consumption change is shown graphically in Figure 5.15. The energy that cannot be met by a thermal power plant is primarily provided by solar and wind power plants, where there are no fuel costs. All of the energy provided by solar energy during the daytime and the energy provided by wind power plants both during the day and at night is used. In cases where this energy is insufficient, the energy provided from the energy storage system is used. In cases where the stored energy is insufficient, energy is provided by the hydroelectric power plant. The variation of the energy drawn from the battery storage system and the hydro power plant is given in Figures 5.16 and 5.17, respectively. As can be seen in Fig. 5.16, since the storage system is limited to 10 MW for the power output, it remains at this level and provides a total of 50 MWh energy, which is full power capacity.

The instantaneous change in energy costs per kWh, which is realized according to this production planning situation, is calculated and the change situation is given in Figure 5.16. Mean energy cost is determined as 0.084 $/kWh.

Total energy consumption for this scenario is determined as 3731300 kWh. Energy supplied from each source is calculated and it is found that 383370 kWh of this energy (%10.27) is from wind turbines, 50621 kWh of this energy (%1.36) is from solar power station, 2404700 kWh (%64.45) is from steam power plant, 843770 kWh (%22.61) is from natural gas power station and 44847 kWh (%1.31) is from battery storage system.

Table 5.8. The priority of the power plants for Scenario-3.

Plant	Priority
Solar power plant	1
Wind power plant	1
Steam power	2
Battery storage	3
Hydro power plant	4

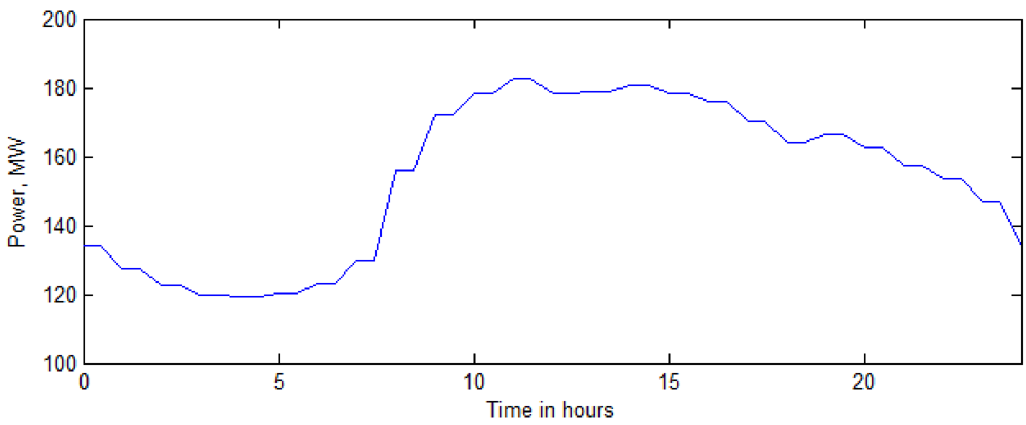


Figure 5.13. Power demand per hours for Scenario-3.

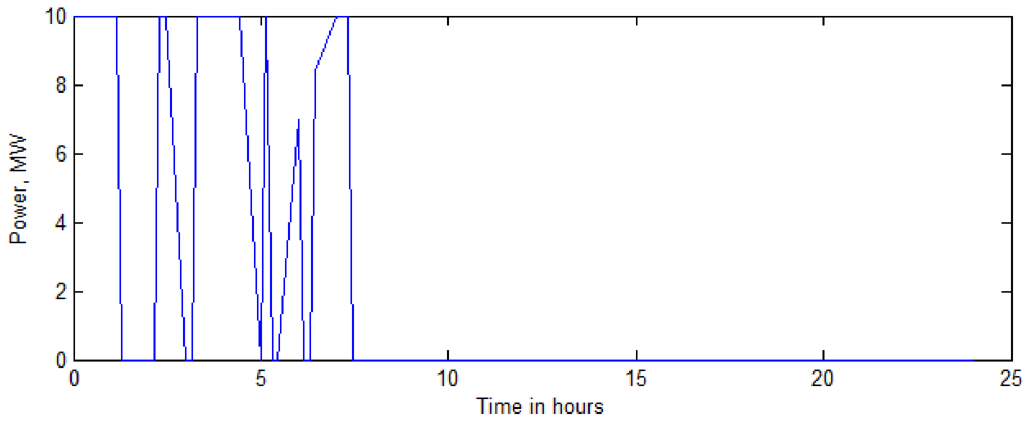


Figure 5.14. Energy supplied by the battery power storage.

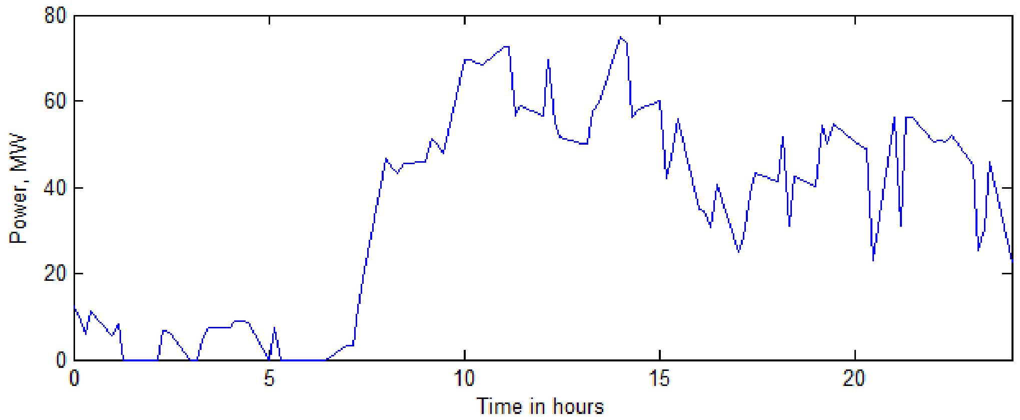


Figure 5.15. Energy supplied by the hydro power plant.

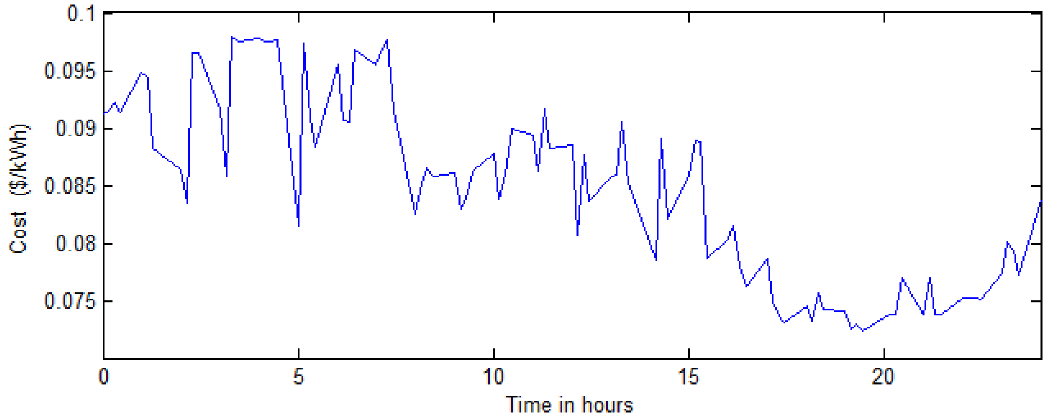


Figure 5.16. Cost variation per kWh for Scenario-3.

5.5. Energy Pricing Using Blockchain

The system proposed is composed of two subsection zone comprising a microgrid as shown in Fig. 5.17. Zone1 is the supply side and area 2 is the consumer side. This side has n power plants, containing renewables such as solar power plants, wind power plants, biomass, geothermal and hydropower and fossil thermal power plants and the storage systems. All power plants have a communication link with all other power plant together with Central Supply Node (CSN). The central supply node has the communication link with the Central Demand Node (CDN). CDN collects data received from all consumers at discrete times specified by the control mechanism. CSN receives the quantity of demanded energy from CDN. The output power for each plant is determined in blockchain without any user interruption.

Here, the required production value is determined according to the instantaneous consumption situation. In the current situation, considering the reaction times of the power plants, it has been evaluated that it would be appropriate to make this period in 15 minutes. However, it is possible to apply the developed algorithms for shorter time intervals as long as the central response times do not create a constraint. For the determined instantaneous production value, information is sent to each power plant with the blockchain algorithm, production is provided in line with the priority order that has emerged according to the energy pricing and resource status, and price determination is made in the previous sections. Thus, without any outside intervention, energy is produced directly at the most affordable price. While priority is given to renewable energy sources in energy production, fossil energy sources (it can be nuclear power plants for larger-scale energy networks, depending on the situation), which is an inevitable necessity, are used as base load power plants, while hydroelectricity is used to meet the energy need in case of insufficiency. , natural gas and battery storage systems are planned to be put into operation. Low cost must be taken into account for the order of priority, but another issue to be considered here is that thermal and nuclear power plants have to remain in operation continuously.

In line with the above planning, it is planned that the blockchain will operate in an integrated manner both in the energy production region and in the consumption region. Thus, while providing the best production and best price situation, the fact that the system is closed to outside interference is important both in terms of information security and in terms of efficiency. Information exchange on the part of the consumer can be carried out without any problems with hardware IoT. It is foreseen that the resulting information transfer and information storage will not pose a problem. The information transferred in the information exchange is generally instantaneous consumption values on the consumer side, and the production data of each power plant on the producer side. Each power plant will produce within the production limits in line with the priority given to it, and the remaining amount will be provided by other energy sources in order to meet the consumption value.

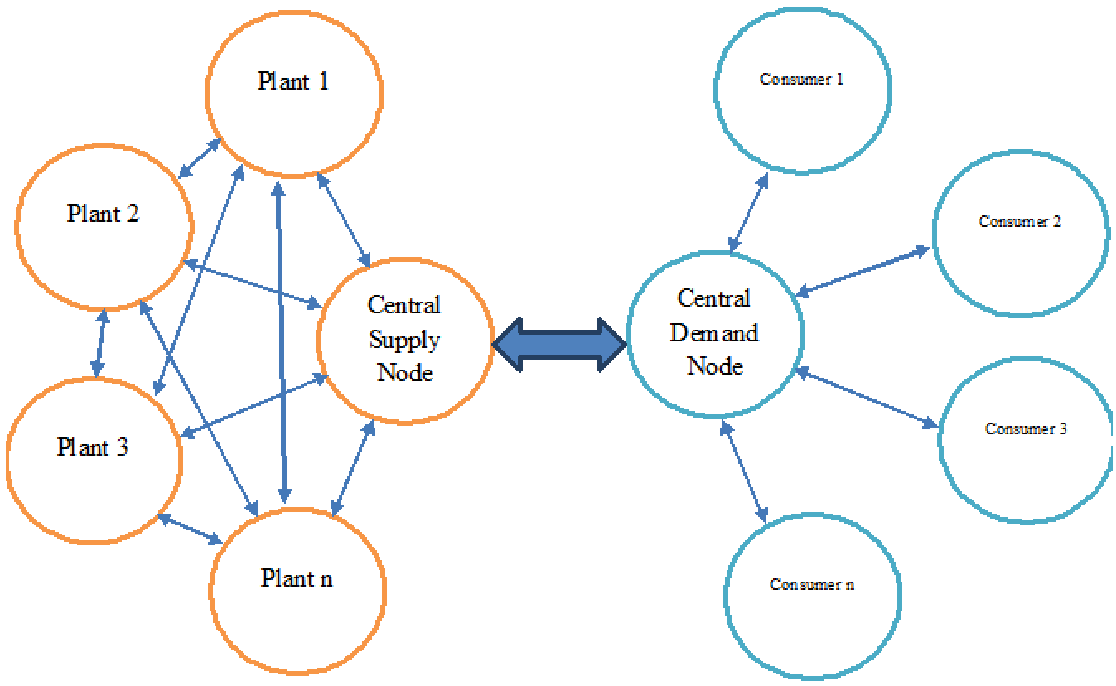


Figure 5.17. Proposed blockchain for energy pricing.

6. CONCLUSIONS

Due to the increase in energy consumption in proportion to the increasing population and the decrease in energy resources, the importance of efficient use of energy is increasing. Developing communication and computer technologies allow systems to operate more efficiently. One of these technologies that has been on the agenda in recent years is blockchain technology, and the use of this technology in many areas such as payment systems is becoming more and more widespread. In this thesis, a study has been made to use dynamic pricing methods instead of traditional energy pricing methods. Dynamic pricing is intended to be blockchain compatible and easily integrated in the future. Dynamic pricing also ranks the energy sources connected to the microgrid in terms of both cost and accessibility, allowing it to provide energy to the system in the most appropriate and cost-effective way.

In this thesis, a structure has been developed for microgrids including renewable energy sources to provide optimum energy pricing that does not require human control to the consumer by using blockchain. After giving the characteristics of energy resources and power plants, how traditional energy pricing is realized, and the basics of energy pricing are given. Needs have been determined as hardware, how energy pricing should be shaped using the current blockchain structure has been researched, and solutions that can be applied in this area have been given. The proposed blockchain-based pricing mechanism ensures the most efficient use of energy resources and at the same time provides the consumer with instant, dynamic energy supply at the lowest cost. In addition, since external intervention will be eliminated, a safe supply of energy is also ensured.

7. RECOMMENDATIONS

As a future work, In this thesis a microgrid has been considered however, a complete electrical grid can be taken into consideration.

It is also recommended to create this computer platform with the coordination of software engineering.

REFERENCES

Abbas, T., Issa, M., & Ilinca, A. (2020). Biomass cogeneration technologies: A review. *Journal of Sustainable Bioenergy Systems*, *10*(1), 1-15.

Afzal, M., Huang, Q., Amin, W., Umer, K., Raza, A., & Naeem, M. (2020). Blockchain enabled distributed demand side management in community energy system with smart homes. *IEEE Access*, *8*, 37428-37439.

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., ... & Peacock, A. (2019). Blockchain technology in the energy sector: A systematic review of challenges and opportunities. *Renewable and Sustainable Energy Reviews*, *100*, 143-174.

Ashfaq, T., Khalid, M. I., Ali, G., Affendi, M. E., Iqbal, J., Hussain, S., ... & Mateen, A. (2022). An Efficient and Secure Energy Trading Approach with Machine Learning Technique and Consortium Blockchain. *Sensors*, *22*(19), 7263.

Azim, M. I., Tushar, W., & Saha, T. K. (2020). Investigating the impact of P2P trading on power losses in grid-connected networks with prosumers. *Applied Energy*, *263*, 114687.

Bina, S. M., Jalilinasrabady, S., & Fujii, H. (2017). Thermo-economic evaluation and optimization of a regenerative ORC cycle utilizing geothermal energy. In *Conference Thermo-Economic Evaluation and Optimization of a Regenerative ORC Cycle Utilizing Geothermal Energy. Geothermal Resources Council*.

Chaudhary, R., Jindal, A., Aujla, G. S., Aggarwal, S., Kumar, N., & Choo, K. K. R. (2019). BEST: Blockchain-based secure energy trading in SDN-enabled intelligent transportation system. *Computers & Security*, *85*, 288-299.

Chen, Y., Li, Y., Chen, Q., Wang, X., Li, T., & Tan, C. (2023). Energy trading scheme based on consortium blockchain and game theory. *Computer Standards & Interfaces*, *84*, 103699.

Dong, X., Zaoyu, W., Hua, M., Jing, X., Debo, Y., Fanjin, W., & Wei, B. (2018, December). ETSB: energy trading system based on blockchain. In *International Conference on Security with Intelligent Computing and Big-data Services* (pp. 673-684). Springer, Cham.

Evren Deniz Erturan, Doğalgaz Kombine Çevrim Santrallerinde Enerji Verimliliği, Siemens Enerji Ankara, 24.02.2020

Fridleifsson, I. B., Bertani, R., Huenges, E., Lund, J. W., Ragnarsson, A., & Rybach, L. (2008, January). The possible role and contribution of geothermal energy to the mitigation of climate change. In *IPCC scoping meeting on renewable energy sources, proceedings, Luebeck, Germany* (Vol. 20, No. 25, pp. 59-80). State College, PA, USA: Pennsylvania State University.

Gai, K., Wu, Y., Zhu, L., Qiu, M., & Shen, M. (2019). Privacy-preserving energy trading using consortium blockchain in smart grid. *IEEE Transactions on Industrial Informatics*, *15*(6), 3548-3558.

Gong, Q., & Lei, J. (2017). Design of a bidirectional energy storage system for a vanadium redox flow battery in a microgrid with SOC estimation. *Sustainability*, *9*(3), 441.

Hayes, B. P., Thakur, S., & Breslin, J. G. (2020). Co-simulation of electricity distribution networks and peer to peer energy trading platforms. *International Journal of Electrical Power & Energy Systems*, *115*, 105419.

Hou, W., Guo, L., & Ning, Z. (2019). Local electricity storage for blockchain-based energy trading in industrial internet of things. *IEEE Transactions on Industrial Informatics*, *15*(6), 3610-3619.

IRENA, (2012). Hydropower RENEWABLE ENERGY TECHNOLOGIES: COST ANALYSIS SERIES Volume 1: Power Sector Issue 3/5.

Jindal, A., Aujla, G. S., Kumar, N., & Villari, M. (2019). GUARDIAN: Blockchain-based secure demand response management in smart grid system. *IEEE Trans. on Services Computing*, *13*(4), 613-624.

Jirdehi, M. A., Tabar, V. S., Ghassemzadeh, S., & Tohidi, S. (2020). Different aspects of microgrid management: A comprehensive review. *Journal of Energy Storage*, *30*, 101457.

Kang, E. S., Pee, S. J., Song, J. G., & Jang, J. W. (2018, April). A blockchain-based energy trading platform for smart homes in a microgrid. In *2018 3rd international conference on computer and communication systems (ICCCS)* (pp. 472-476). IEEE.

Kawady, T. A., & Nahhas, A. M. (2013). Modeling issues of grid-integrated wind farms for power system stability studies. *INTECH, Modelling and Control Aspects of Wind Power Systems*, 153.

Kere, A., Goetz, V., Py, X., Olives, R., Sadiki, N., & Mercier, E. (2014). Dynamic behavior of a sensible-heat based thermal energy storage. *Energy Procedia*, *49*, 830-839.

Khan, M. T., Dowla, M. N. U., & Niloy, F. A. (2022). A blockchain-based efficient data storage and sharing scheme for renewable energy trading in smart grid. *International Journal of Blockchains and Cryptocurrencies*, *3*(3), 222-234.

Kodali, R. K., Yerroju, S., & Yogi, B. Y. K. (2018, October). Blockchain based energy trading. In *TENCON 2018-2018 IEEE Region 10 Conference* (pp. 1778-1783). IEEE.

Lei, Y. T., Ma, C. Q., Mirza, N., Ren, Y. S., Narayan, S. W., & Chen, X. Q. (2022). A renewable energy microgrids trading management platform based on permissioned blockchain. *Energy Economics*, *115*, 106375.

Lens, H. (2013). Mid-load operation of large coal-fired power plants. *Proceedings of PowerGEN Europe, Cologne, Germany*.

Li, Z., Bahramirad, S., Paaso, A., Yan, M., & Shahidehpour, M. (2019). Blockchain for decentralized transactive energy management system in networked microgrids. *The Electricity Journal*, *32*(4), 58-72.

Liu, C., Chai, K. K., Lau, E. T., & Chen, Y. (2018, April). Blockchain based energy trading model for electric vehicle charging schemes. In *International Conference on Smart Grid Inspired Future Technologies* (pp. 64-72). Springer, Cham.

Lumby, A. M. (Feb 2012). Utility Scale Solar Power Plants (A guide for developers and investors). SgurrEnergy Limited.

Meng, L., Shafiee, Q., Trecate, G. F., Karimi, H., Fulwani, D., Lu, X., & Guerrero, J. M. (2017). Review on control of DC microgrids and multiple microgrid clusters. *IEEE journal of emerging and selected topics in power electronics*, *5*(3), 928-948.

Miller, A., & Lumby, B. (2012). Utility scale solar power plants: a guide for developers and investors. *Guidilines book written for IFC. World Bank Group, New Delhi, India*.

Moniruzzaman, M., Yassine, A., & Benlamri, R. (2019, October). Blockchain-based mechanisms for local energy trading in smart grids. In *2019 IEEE 16th International Conference on Smart Cities: Improving Quality of Life Using ICT & IoT and AI (HONET-ICT)* (pp. 110-114). IEEE.

Musleh, A. S., Yao, G., & Muyeen, S. M. (2019). Blockchain applications in smart grid–review and frameworks. *Ieee Access*, *7*, 86746-86757.

Oh, S. C., Kim, M. S., Park, Y., Roh, G. T., & Lee, C. W. (2017). Implementation of blockchain-based energy trading system. *Asia Pacific Journal of Innovation and Entrepreneurship*.

Ertuğrul, Ö. F., & Kurt, M. B. (2009). Yenilenebilir Enerji Kaynaklari Maliyet Analizi ve Sürdürülebilir YEK Uygulamaları. *V. Yenilenebilir Enerji Kaynaklari Sempozyumu Bildiriler Kitabı. Haziran*, *37*, 42.

Peng, S. L., Wang, S. J., Balas, V. E., & Zhao, M. (Eds.). (2018). Security with intelligent computing and big-data services (Vol. 733). Springer.

Peşint, M. A. (1996) Electric Power Plants, Power Transmission and Distribution (in Turkish), MEB Basımevi, İstanbul.

Sanpasertparnich, T., Idem, R., & Tontiwachwuthikumul, P. (2011). CO2 absorption in an absorber column with a series intercooler circuits. *Energy Procedia*, *4*, 1676-1682.

Silva, F. C., A Ahmed, M., Martínez, J. M., & Kim, Y. C. (2019). Design and implementation of a blockchain-based energy trading platform for electric vehicles in smart campus parking lots. *Energies*, *12*(24), 4814.

Tao, M., Wang, Z., & Qu, S. (2021). Research on Multi-Microgrids Scheduling Strategy Considering Dynamic Electricity Price Based on Blockchain. *IEEE Access*, *9*, 52825-52838.

Tanwar, S., Kaneriya, S., Kumar, N., & Zeadally, S. (2020). ElectroBlocks: A blockchain-based energy trading scheme for smart grid systems. *International Journal of Communication Systems*, *33*(15), e4547.

Thompson, M. J., Sun, H., & Jiang, J. (2021). Blockchain-based peer-to-peer energy trading method. *CSEE Journal of Power and Energy Systems*.

Tomin, N., Shakirov, V., Kozlov, A., Sidorov, D., Kurbatsky, V., Rehtanz, C., & Lora, E. E. (2022). Design and optimal energy management of community microgrids with flexible renewable energy sources. *Renewable Energy*, *183*, 903-921.

U.S. Nuclear Regulatory Commission, "Fact Sheet on the Three Mile Island Accident," 18 February 2008. [Online]. Available: http://en.wikipedia.org/wiki/Three_Mile_Island_accident#cite_note-FactSheet-14. [Accessed 24 September 2014].

U.S. Energy Information Administration, (2022). Levelized Costs of New Generation Resources in the Annual Energy Outlook

van Leeuwen, G., AlSkaif, T., Gibescu, M., & van Sark, W. (2020). An integrated blockchain-based energy management platform with bilateral trading for microgrid communities. *Applied Energy*, *263*, 114613.

Xing, L., Mishra, Y., Tian, Y. C., Ledwich, G., Su, H., Peng, C., & Fei, M. (2019). Dual-consensus-based distributed frequency control for multiple energy storage systems. *IEEE Transactions on Smart Grid*, *10*(6), 6396-6403.

Zhao, F., Guo, X., & Chan, W. K. V. (2020). Individual green certificates on blockchain: A simulation approach. *Sustainability*, *12*(9), 3942.

https://www.enerjiatlasi.com/cesitli/

https://energyfreedomco.org/f3-LCOE.php

APPENDIX-A POWER OUTPUT OF SOLAR ANS WIND STATIONS

Table A1. Power generated from Malatya Turgut Özal Medical Center on 24 March 2022.

Time	Power (kW)	Time	Power (kW)	Time	Power (kW)	Time	Power (kW)	Time	Power (kW)	Time	Power (kW)
00:00	0	03:00	0	07:00	35.864	11:00	864.072	15:00	630.595	19:00	0
00:15	0	03:15	0	07:15	77.865	11:15	736.949	15:15	668.350	19:15	0
00:30	0	03:30	0	07:30	135.251	11:30	886.544	15:30	684945	19:30	0
00:45	0	03:45	0	07:45	177.177	11:45	756.113	15:45	323.666	19:45	0
01:00	0	04:00	0	08:00	251.275	12:00	719.473	16:00	282.663	20:00	0
01:15	0	04:15	0	08:15	333.612	12:15	466.932	16:15	322.961	10:15	0
01:30	0	04:30	0	08:30	371.758	12:30	676.397	16:30	165.827	20:30	0
01:45	0	04:45	0	08:45	360.829	12:45	505.117	16:45	147.958	20:45	0
02:00	0	05:00	0	09:00	523.034	13:00	583.516	17:00	129.134	21:00	0
02:15	0	05:15	0	09:15	424.990	13:15	594.233	17:15	137.438	21:15	0
02:30	0	05:30	0	09:30	452.879	13:30	806.843	17:30	82.540	21:30	0
02:45	0	05:45	0	09:45	531.888	13:45	604.949	17:45	48.548	11:45	0
03:00	0	06:00	0	10:00	751.339	14:00	484.598	18:00	34.411	22:00	0
03:15	0	06:15	0	10:15	592.720	14:15	417.229	18:15	19.138	22:15	0
03:30	0	06:30	0	10:30	674.566	14:30	765.310	18:30	3.627	22:30	0
03:45	0	06:45	9.234	10:45	827.910	14:45	491.879	18:45	0.043	22:45	0

Table A2. Power output of 10 MW wind turbine.

Time	**Power (kW)**	Time	**Power (kW)**	Time	**Power (kW)**	Time	**Power (kW)**	Time	**Power (kW)**	Time	**Power (kW)**
00:00	2400	03:00	4200	07:00	3200	11:00	234	15:00	2341	19:00	5243
00:15	2800	03:15	6700	07:15	3100	11:15	498	15:15	5893	19:15	2431
00:30	3700	03:30	1000	07:30	1300	11:30	3456	15:30	4857	19:30	3241
00:45	2600	03:45	500	07:45	1450	11:45	3245	15:45	3846	19:45	2351
01:00	2400	04:00	340	08:00	1300	12:00	2847	16:00	7638	20:00	2351
01:15	1800	04:15	45	08:15	1600	12:15	789	16:15	7638	10:15	2635
01:30	6000	04:30	67	08:30	1800	12:30	3256	16:30	8735	20:30	2653
01:45	6200	04:45	134	08:45	1300	12:45	4300	16:45	6738	20:45	7882
02:00	6600	05:00	8500	09:00	4200	13:00	4562	17:00	8763	21:00	231
02:15	7800	05:15	567	09:15	3400	13:15	4536	17:15	8373	21:15	5243
02:30	1200	05:30	4500	09:30	3500	13:30	2635	17:30	6352	21:30	234
02:45	1300	05:45	5600	09:45	3870	13:45	2635	17:45	5362	11:45	254
03:00	4200	06:00	3200	10:00	239	14:00	243	18:00	4524	22:00	653
03:15	6700	06:15	4700	10:15	567	14:15	632	18:15	2435	22:15	543
03:30	1000	06:30	4800	10:30	546	14:30	3425	18:30	6541	22:30	652
03:45	500	06:45	2900	10:45	345	14:45	3546	18:45	4253	22:45	342