KADİR HAS UNIVERSITY
SCHOOL OF GRADUATE STUDIES
PROGRAM OF MANAGEMENT INFORMATION SYSTEMS

BLOCKCHAIN APPLICATIONS ON SMART GRID:A REVIEW

ALI SINAN KOYUNOĞLU

MASTER'S THESIS

ISTANBUL, May, 2019

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Submitted to the School of Graduate Studies of Kadir Has University in partial fulfillment of the requirements for the degree of Master's in the Program of Management Information Systems

ISTANBUL, May, 2019

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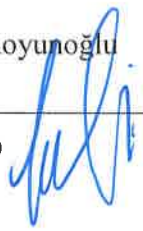

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ACCEPTANCE AND APPROVAL

This work entitled **BLOCKCHAIN APPLICATIONS ON SMART GRID:A REVIEW** prepared by **Ali Sinan Koyunoğlu** has been judged to be successful at the defense exam held on **7 May 2019** and accepted by our jury as **master's thesis.**

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BLOCKCHAIN APPLICATIONS ON SMART GRID:A REVIEW

ABSTRACT

In this study, energy transmission systems that are used from today's energy systems, ie non-renewable energy sources, transmission and distribution channels used in the process from the production of electric energy to consumption, the use of renewable energy sources and the use of smart network applications, in addition to these, the use of blockchain technology in these networks are mentioned. Along with the blockchain subarea, changes in the electricity market are described.

In the energy market with Blockchain; consumers will be able to exchange energy between themselves and there will be no need for a third party, centralized structure. Therefore, the cost of energy distribution and transmission will be reduced. Blockchain technology will provide security in this market which will be formed by cheaper energy. In this study, these security measures based on criterion and hash system are mentioned.

Furthermore, it is examined how the producers and consumers coming out of the market would affect the market price, when the Blockchain and smart grid systems are installed. Harmony search algorithm is used for to find optimal prices in the market when producers and consumers came out of the market.

In addition, smart home and smart network applications are combined with other technologies in the near future, and new innovations are likely to arise.

Keywords: Renewable Energy, Wind Energy, Solar Energy, Smartgrids, Peer-to-Peer Markets, Blockchain, Blockchain in Peer-to-Peer Markets, Harmony Search Algorithm

AKILLI ŞEBEKELERDE BLOCKCHAIN UYGULAMALARI:İNCELEME

ÖZET

Bu çalışmada, günümüzde kullanılan enerji sistemlerinden, yani yenilenemeyen enerji kaynaklarından üretilen enerji sistemlerinden, elektrik enerjisinin üretiminden tüketimine kadar olan süreçte kullanılan iletim ve dağıtım kanallarından, yenilebilir enerji kaynaklarının kullanımı ile gelişen akıllı şebeke uygulamalarından, bunlara ek olarak bu şebekelerde blockchain teknolojisinin kullanım alanlarından bahsedilmiştir. blockchain alt yapısıyla beraber, elektrik enerjisi pazarında meydana gelecek olan değişiklikler anlatılmıştır.

Blockchain ile enerji pazarında; tüketicilerin kendi aralarında enerji alışverişi yapabilecek ve üçüncü parti, merkezi bir yapıya ihtiyaç kalmayacaktır. Bu sebeple enerji dağıtımının ve iletiminin maliyeti azalacaktır. Blockchain teknolojisi, daha ucuz enerji ile oluşacak olan bu markette güvenliği de sağlayacaktır. Bu çalışmada, kritografi ve hash sistemine dayalı bu güvenlik önlemlerinden de bahsedilmiştir.

Ayrıca, Blockchain ve akıllı şebeke sistemi kurulduğunda, marketten çıkan üretici ve tüketicilerin, market fiyatını nasıl etkileyeceği incelenmiştir. Üretici ve tüketicilerin marketten çıktığında, markette oluşacak optimum fiyatı bulmak için Armoni Arama Algoritması kullanılmıştır.

Bunlara ek olarak, akıllı ev ve akıllı şebeke uygulamalarının, yakın gelecekte başka teknolojilerle birleşmesi ile beraber, ortaya çıkma ihtimali yükselen yeni inovasyonlardan bahsedilmiştir.

Anahtar Sözcükler: Yenilenebilir Enerji, Rüzgar Enerjisi, Güneş Enerjisi, Akıllı Şebekeler, Eşler Arası Piyasa, Blok Zinciri, Eşler Arası Markette Blok Zinciri, Armoni Arama Algoritması

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In addition, I must express my very profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

To my family, and especially my nephews Ali Yağız Koyunoğlu, Ömer İsbir and Yağmur Denizer.

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LIST OF SYMBOLS/ABBREVIATIONS

AC	Alternating Current
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
DAM	Day Ahead Market
DC	Direct Current
DES	Data Encryption Standard
DSM	Demand Side Management
HMCR	Harmony Memory Consideration Rate
HMS	Harmony Memory Size
HS	Harmony Search
HSA	Harmony Search Algorithm
IREA	International Renewable Energy Agency
EMRA	Energy Market Regulatory Authority
ESR	Electricity Supply Regulations
EWF	Electricity Supply Regulations
HAN	Energy Web Foundation
IOT	Internet of Things
KWh	Kilowatt Hour
MWh	Megawatt Hour
NAN	Neighborhood Area Network
OSI	Open System Interconnection
PAR	Pitch Adjustment Rate
PV	Photovoltaic
P2P	Peer-to-Peer
RES	Renewable Energy Sources
SHA	Secure Hash Algorithm
QoS	Quality of Supply
WAN	Wide Area Network

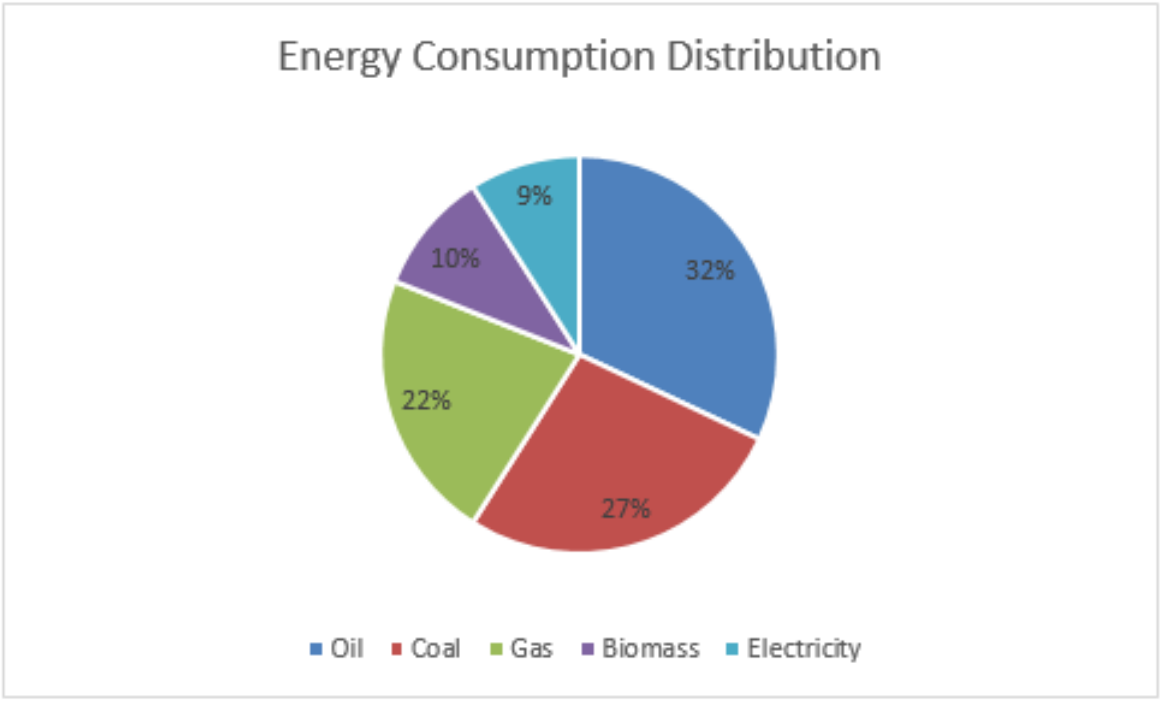
1. INTRODUCTION

The global energy consumption of the world is growing day by day especially because of strong industrialization. In China, the growth rate of energy consumption in 2017 (2, 3%) was doubled the growth rate in 2016 (1, 1%). The Asian countries such as India, Indonesia, Malaysia and South Korea also increased their energy consumption ratio. In addition to Industrialization, economic growth was a cause of the increased demand for some countries like Germany, France, Turkey etc. (Breakdown by country,2017).

Today, the global primary energy consumption of the World is based on non-renewable energy sources, which come from sources that will run out or will not be replenished for thousands or even millions of years, such as coal, natural gas and oil. In 2017 the distribution of global consumption was as 32% Oil, 27% Coal, 22% Gas, 10% Biomass and 9%electricity. In other words 81% of the global consumption obtained from non-renewable sources. Figure 1.1 Energy Consumption Distribution shows the usage ratio of resources (Breakdown by energy, 2017). Although non-renewable energy sources are widely used, it causes environmental and economic disadvantages. Firstly, using non-renewable energy sources increases environmental pollution, in other words, burning fossil fuels cause the carbon dioxide. In addition to these, public health problems may occur. Non renewable energy sources are not environmentally friendly and this will cause air pollution in long run which can have consequences for human health. Moreover, usage of it may not be managed.Huge tankers transport oil and sometimes they spill their contents into the sea because of crashes. Fourthly, health risk of the workers who work for coal companies also can be an environmental disadvantage. Diseases, injuries and deaths because of this disadvantage will increase every day. Furthermore, because just a few countries hold

a large amount of fossil fuels, rising fuel prices for the other countries can be thought as an economic disadvantage. Lastly, all of these resource will be run out so people will not be able to use them for their needs (Non-renewable energy, a sinking supply, n.d.).

Figure 1.1: Energy Consumption Distribution



Increasing energy consumption and the disadvantages of traditional energy production will make using renewable energy sources popular. In this study, varieties of renewable energy sources, especially the types of renewable energy from solar panels, will be evaluated. Due to the disadvantages which mentioned above, production is expected to increase from solar panels and other renewable energy sources. Increased production, will increase investments for renewable energy sources.

- In the introduction part of this study, the definition of renewable energy and non-renewable energy, sorts of renewable energy, and wind turbine system's and solar panel system's working logic with Photovoltaic will be given.

- In the Power System, Smartgrids and P2P Market chapter, power transmission and distribution system, microgrid systems and distributed generation, benefits of using microgird systems will be given. Furthermore, examples which make microgrid system compatible with Peer-to-Peer market, controls of production, and structure of Peer-to-Peer markets the will be explained.
- In the Blockchain Applications on Smartgrids chapter, the structure of blockchain, security measures which used in blockchain, protocol types for secure communication, transaction operation on blockchain, smart contracts structure, features of blockchain, usage areas of blockchain in electricity market and effects of using blockchain platform on energy markets will be explained.
- In the Case studies chapter, Harmony search algorithm is defined and case studies about the possible effects of Blockchain applications on the Turkish energy market prices will be shown. Optimal prices for different cases will be calculated by Harmony Search Algorithm.
- In Conclusion part, benefits of usage blockchain platform on smartgrid system, and expectations of future energy systems will be given.

1.1 Related works

In this study, it is mentioned that energy production and consumption can be monitored instantaneously with smart meters, and applications using blockchain infrastructure, can be used to make energy trade between prosumers and consumers using microgrids. Because this issue is not a very common topic, it is hard to find too many examples about it. In this section, some example studies about this issue are shown.

- Mihaylov et al. propose a trade paradigm to buy and sell locally generated energy in the smart grid. In the proposed technique, prosumers are invoiced by the distribution system operator according to their actual usage. at the same time, they are rewarded according to actual energy inputs. NGRcoin is used for all rewards and payments. Prosumers can replace NRGcoins in

currency market for a profit or to pay energy bills. Their study discussed the advantages of using NGRcoin on exchange market and benefits of smart grids (NRGcoin — Smart Contract for Green Energy, 2017).

- Dimitriou and Karame have explored how to increase the privacy of users in fast bitcoin operations. It is possible to protect the privacy of users in the proposed new system (Karame et al, 2012). In the light of this information, the use of bitcoin in smart grid systems, fast bitcoin transactions in the energy market with smart contracts, and the protection of user privacy when doing so seems possible. One of the reasons why 3rd parties are needed is that people are concerned about privacy.
- N. Aitzhan and D. Svetinovic discussed the issue of providing secure transaction without relying on reliable third party in decentralized Smart Grid energy trade. A decentralized energy trading system was implemented, where energy prices could be negotiated anonymously, and transactions could be performed safely. Blockchain technology was recommended to increase privacy and security levels. According to them, because data is replicated between all active nodes in the system, it can be said that operations are protected against failure. The countermeasures were taken against the attacks using the peer-to-peer community-based data replication method. In addition, the Byzantine failures protocol has been used to combat double spending attacks. Finally, energy trading case scenarios, performance analyzes, and attack simulations have been made among the peers in the smart grid. As a result, it has been mentioned that blockchain technology provides a reliable way to trade decentralized smart grid energy with higher privacy and security compared to traditional centralized trading solutions (Aitzhan and Svetinovic, 2018).
- According to M. Mylrea and S. Gourisetti, smart grids and other devices connected to networks are not very resistant to cyber-attacks. Cyber security vulnerabilities are breaking down the network and the building's control systems. Implementing Blockchain applications can help to increase the security of buildings and networks. In addition, nodes in blockchain can generate confidence environment by using cryptographic validation techniques. They also

discussed about blockchain technology can overcome optimization and security challenges in grid management. They have argued that Blockchain can manage real-time data and better manage sales processes, as it is compatible with smart contracts. Real-time data and power flow is a problem that today's grids which produce electricity from renewable energy sources. Blockchain help to optimize network data and save residual energy at transformer level. Increasing the quality and control of useful data will help negotiate future contracts as well as negotiate with collective systems (Mylrea and Gourisetti, 2017).

- K. Tanaka and R. Abe discussed about blockchain based electricity trading by a digital grid router. In their study, a power exchange system based on blockchain technology was developed. Microgrids using blockchain applications and microgrids not using blockchain applications were compared. It was concluded that energy efficiency increased in micro grids using Blockchain applications. The future expectation from this study will be to create a true smart meter and controller with blockchain. It will first be tested in laboratory conditions and, if successful, the system will be placed in a decentralized environment. In a system that provides bi-directional electricity transmission for the processors, a decentralized digital currency, which provides transparent rewards and is independent of the Feed-In Tariffs, will be generated. There will be a system in which smart contracts are actively used. It will contribute to subsystems to reduce the highest demands and provide effective incentives to adapt to changing conditions that will contribute to the problem of demand-response matching (Tanaka et al, 2017).
- M.Peck and D. Wagman discussed about the behaviour of people will improve the open market in decentralized energy production sector and using of renewable energy production. According to a study was done by Research and Markets, the global market size of rooftop photo voltaic panels was nearly 30 billion dollar in 2016 and is expected to grow almost 11 percent until 2022. They claim that these additional sources will help to manage demand more efficiently. Blockchain applications will work in the process of managing these demand. In practice, Transactive grid project which is a blockchain application

project is done by LO3 Energy, installed 200 smart meters in five neighborhoods in Brooklyn area. Renewable energy is produced in houses, and meters record the amount of supply to custom-built blockchain. Smart meters act as nodes and information flow is obtained. These process can be monitored by a smartphone application. Transactive Grid blockchain produced to record transactions among neighbors (Peck and Wagman, 2017).

- E. Kang et al. proposed an automatic decentralized and safe renewable energy trading platform in microgrid system using block chain technology. In the case of a smart home based Blockchain, the data of all security-sensitive and privacy-sensitive devices can be managed, controlled and monitored. Firstly, the data, is included in the block in the block chain, and secure access to IoT devices and their data is provided. In the case of energy trading platform, the smart contract system was tested in the blockchain infrastructure established with 2 nodes and no data change or falsify was experienced. Therefore it can be considered as a starting point for energy trading between microgrid system based on blockchain (Kang et al, 2018).
- P. Xie et al. analyzed a system that allows neighbors to trade energy autonomously with blockchain framework. Their study introduce basic principles of blockchain technology, communication network architecture and core technologies. In addition to these, they also analyzed the technical characteristics of blockchain and distributed energy transactions. In conclusion, they proposed a method to trade renewable energy between neighbors based on blockchain (Xie et al, 2018).

1.2 Renewable energy and non-renewable energy

From the sustainability perspective, energy sources has been classified into two categories. One of them is renewable energy sources; Renewable energy is the energy obtained from renewed sources continuously during the life of humanity. Hence it is sustainable. Most renewable energy sources are clean energy sources because they do not release pollutant gases. The resources of Bio energy, Geothermal energy,

Hydroelectricity energy, Hydrogen energy, Ocean energy, Wind energy and Solar energy can be shown as examples to renewable energy sources. The other one, Non-renewable energy which is produced from limited energy sources. This means it is not sustainable. The energy generated from Oil, Natural Gas, Coal, and Nuclear sources are the examples of Non-renewable energy sources. These can cause severe problems such as climate change, air pollution which are threat for human, plants and animals (Daniel, 2009).

Although renewable energy resources have some disadvantages, using them provide both environmental and economic advantages. First advantage of using these resources is its sustainability. As mentioned above, they are obtained from natural sources, so they are sustainable. At the same time, renewable energy sources produce little or no waste chemical pollutants. They are non-pollutant and they also do not contribute global warming. Hence, using of renewable resources have minimal impact on the environment. They also bring economic benefits to regional areas. They create new opportunities for people who live regional areas. On the other hand there are some disadvantages of using renewable resources. As an example, it can be hard to generate the quantities of electricity that are as large as those harvested by fuel fossil generators. Building new energy fields and managing these fields help to reach optimal level. In addition to this, they are dependent on weather conditions but weather temperature or wind velocity are unpredictable and inconsistent. Sometimes the capacity to make energy from them will be unavailable (Advantages and Disadvantages The Good, the Band and the Ugly, n.d.)

Types of renewable energy can be given as follows;

- **Bio energy:** Bio energy is the generic name given to energy that can be derived from plants or from any biological waste. Fuel production or electricity production can be shown as example of usage areas of bio energy. Biomass, is the plant which mentioned in definition, is comprised of materials of recently living plants or animal origin. Despite the fact that bio energy generates

almost the identical amount of carbon dioxide as fossil fuels, the carbon dioxide produced during generation, emerged as a result of the burning of the produced organic materials taken from the atmosphere before the formation of these substances. Therefore, the environment will be protected in terms of CO2 emissions during the generation of energy from biomass. There are a lot of system used to develop this type of electricity (Bioenergy, n.d.).

- **Geothermal:** It can be defined as hot water or steam which obtained by heat of ground of the earth (Arslan et al, 2001). The difference of this type of hot water or steam, is that it contains more molten mineral, salts and gases than the surface waters. There are geothermal sources in the World, where steam or hot water which coming out of the ground is directly fit for electricity generation in steam turbine (Blodgett, 2014).
- **Hydroelectric:** Electric energy obtained by water power is called as an hydroelectric energy. Turbines help to convert water flow to mechanical energy and generators convert this mechanical energy to electrical energy. This all process is called as Hydroelectric energy (Hidrolik Enerji Nedir, 2018).
- **Hydrogen:** Hydrogen can be found in organic compounds like hydrocarbons which are fuels like gasoline, natural gas, methanol and propane, can also be found in water (H2O). It has high energy but produces low pollution when burned. Basically, Hydrogen fuel cells convert the chemical energy of hydrogen into electricity energy (Hydrogen Energy, n.d.).
- **Ocean:** Thermal energy from heat of sun and mechanical energy from the motion of tides and waves are the inputs of the ocean energy. Thermal energy and wind-driven waves can be converted to electricity by using different systems (Ocean Energy, n.d.).
- **Wind:** Wind energy can be obtained by physical differences of ground of the earth or It also can be gained from diverse temperature of atmosphere caused by Sun. In other words, wind energy is acquired through atmospheric pressure differences. Basically the kinetic energy of the wind is converted to electricity by turbines (Uyar, 2016).
- **Solar:** Solar energy technology is used to transform the Sun's energy and

light into heat, electricity, hot water, illumination, and cooling systems for businesses and industry. Photovoltaic systems use solar cells to convert sunlight into electricity. Solar hot water systems are used to heat buildings by circulating water through solar collectors. The Sun's heat is concentrated by mirror-covered dishes whose goal is to boil water in a conventional steam generator to produce electricity. Commercial and industrial buildings can leverage the sun's power for large-scale needs which includes ventilation, heating and cooling (Solar Energy, n.d.).

1.3 Wind energy production

Wind turbines are used to generate energy from the wind (Uyar, 2016). In Figure 1.2 working logic of wind tribunes to produce electricity is presented.

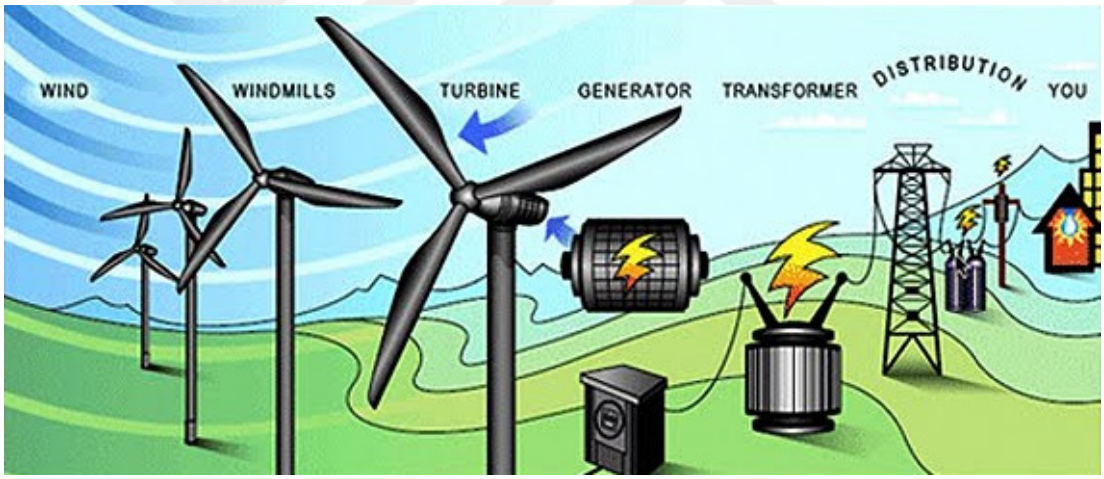


Figure 1.2 Working Logic of Wind Tribunes (Uyar, 2016)

When wind is emerged, it blows to tribunes and, rotor will turns with the power of the wind. Rotor is connected to a generator which is a machine contains magnets and coils of wire. When coils are spun quickly, the electricity is produced. Transformers increase the voltage and send electricity to distribution lines, and electricity is ready to use at home. In shortly, the energy of wind is converted to electricity energy (Uyar, 2016).

1.4 Solar energy production with panels

Sun is a natural nuclear reactor, which produce and controls the release of energy from dividing atoms. It can release the photons, which can travel from sun to earth in almost 9 minutes. In other words, every minutes, photons effects to Earth to generate solar energy. In 2017, a report of International Energy Agency, indicate that solar energy has become to fastest growing source of power (Solar Energy is Fastest Growing Source of Power, 2017).

Basically, logic of the production with solar panels is as follows; firstly, the photons hit to solar cell, they separate their electrons from their atoms. If conductors are connected positive and negative sides of a cell, they form an electric circuit. Thus, electrons generate electricity when they pass through such a circuit. Multiple cells form a solar panel and multiple panels can be linked together to form a solar array. Deployed more panels mean generated more energy (Debono, 2016).

Photovoltaic (PV) solar panels, generate electric power by converting sun light, are composed of many solar cells, which are made of silicon, constructed with a positive layer and a negative layer. Constructed negative and positive layer create an electric field, like a battery. PV solar panels generate direct current (DC) electricity which is the current where electrons flow in one direction around a circuit. This process can be explained through a battery. The electrons move from negative side of battery to positive side of the battery. However, with alternating current (AC) electricity, electrons are pushed and pulled in the opposite direction like a cylinder car's engine. In this point, Solar Inventers appear A solar inverter takes DC power from the solar array and uses it to generate AC power. In addition to this, they provide earth fault protection and system statistic. System statistic is the database of voltage, energy production and maximum power point tacking etc. The upgrade version of the solar inverter is micro-inverter which can optimize all individual solar panel and maximize potential. Micro inverters are also different from central inverters in case of troubles. When there is a problem in one solar panel, central inverters drag down

all entire solar array but this is not a case for micro-inverters, in other words the rest of the solar array continue to perform efficiently (Debono, 2016).

Figure 1.3 is an example of how a home solar panel system works. It begins when sunlight comes to a solar panel roof. The panel converts the energy to DC current, which flows to an inverter. Then inverter takes DC power and generates AC power which can be used at home. Panel produces more energy at peak sunny hours and gets credit for producer from grid. In night hours and in cloudy days producer consume from conventional grid. There is a system whose name is Net-meter which records energy sent to grid and received from the grid (Debono, 2016).

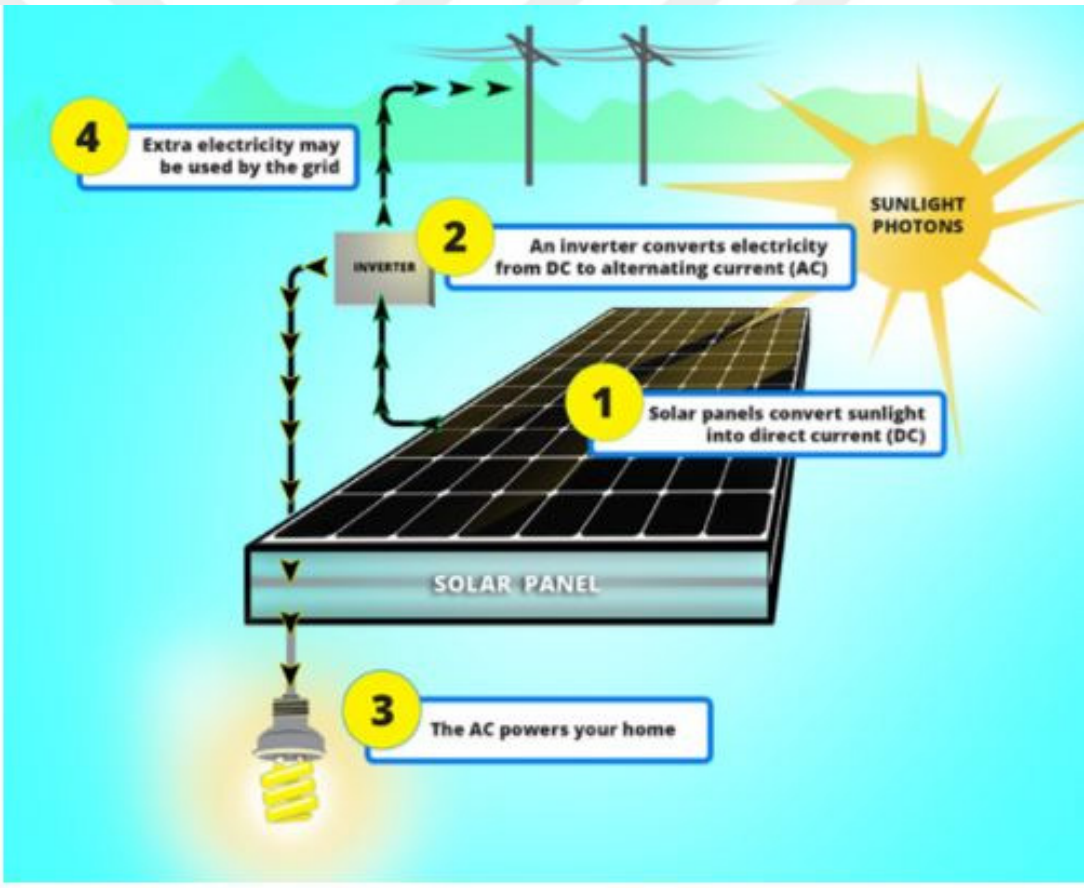


Figure 1.3 How a Home Solar Panel System Works (Debono, 2016)

2. POWER SYSTEM, SMART GRIDS AND P2P MARKET

In this chapter, transmission and distribution systems, and microgrid systems in distributed generation will be given. In addition these, benefit of decentralization with microgrids and examples which try to use P2P trading in energy market by blockchain infrastructure will be shown. Moreover, some technical necessities to set up market and structures of P2P market will be explained.

2.1 Transmission and distribution systems

Most of the plants established to generate electricity are away from consumption areas. Since electrical energy is a type of energy that cannot be stored, electrical energy should be transmitted to the consumption areas as soon as possible. Transmission of electricity, generated by the power plants to the user is carried out by transformers, poles, power transmission lines, insulators, breakers, dis connectors, coils, capacitors, surge arr esters and other switch gear installation elements. Generally, the connection between the power stations and the consumption centers, which are far from each other, is provided by the interconnected system using transmission networks (Wang et al, 2017). Figure 2.1 shows the simplest power transmission and distribution system used to deliver the electricity generated by the power plants to the subscribers (Wang et al, 2017).

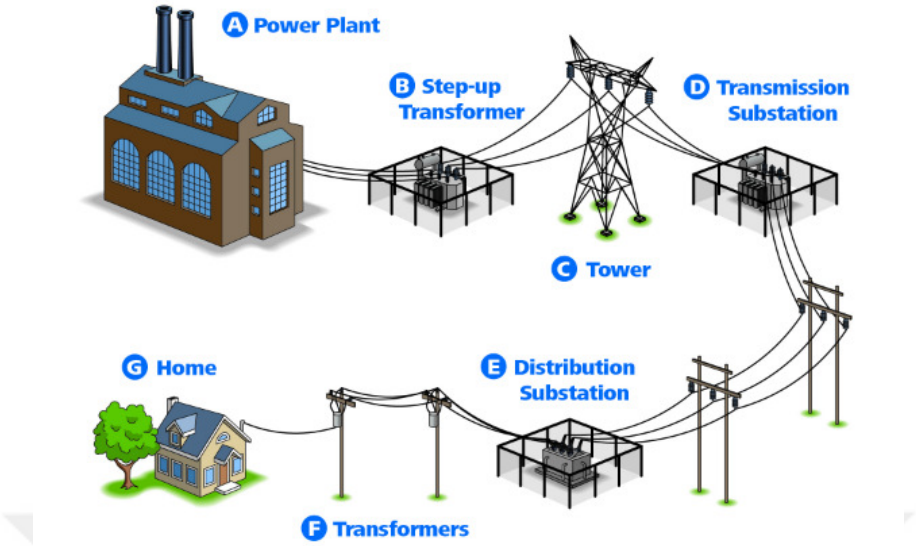


Figure 2.1 A Power Transmission and Distribution System (Wang et al, 2017).

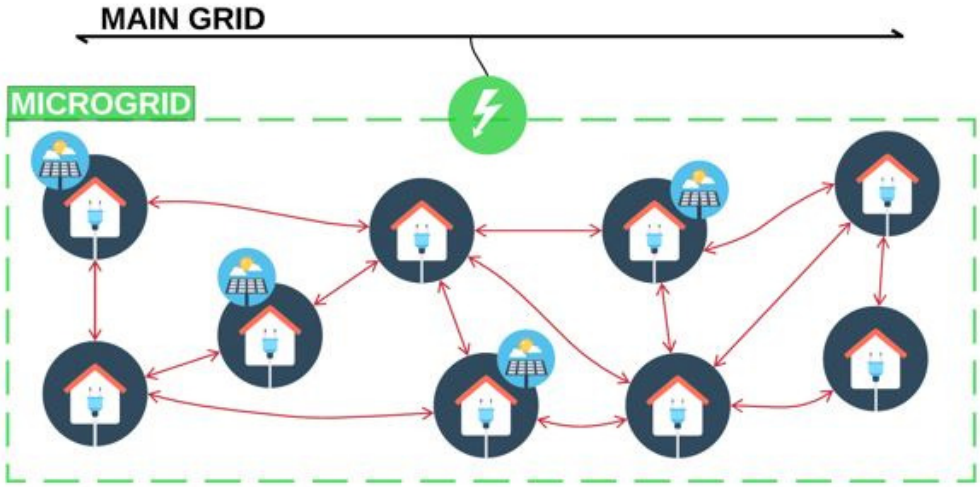
In power plants, the energy of a source such as water, wind and coal is first converted into mechanical energy. Generators (alternators) are used to convert this raw energy into electrical energy. The voltage generated by the generators is increased with the help of power transformers and then it is delivered to the distribution centers near the work and settlement centers or industrial zones by the transmission network. It consists of transmission network, poles, conductors, transformer centers and similar units (Abu-Shark et al, 2006) . The high voltage electrical energy reaching the distribution centers is reduced to the medium voltage values and given to the factories, urban transportation systems such as trams, urban distribution, lighting and signaling network. The voltage of the electrical energy which is close to our house or workplace is still high. For this reason, the voltage of electrical energy is reduced to 220 V by means of small transformers mounted on poles or placed in special cabinets (Abu-Shark et al, 2006) .

2.2 Microgrid

Microgrids, defined as small power distribution systems and energy storage devices consisting of loads, are considered an effective way of using renewable energy sources (Wang et al, 2017). These energy sources are located close to each other, a schematic

representation of Microgrids shown in Figure 2.2. Microgrids are owned by local prosumers , which is a person who consumes and produces a product. To supply a local area by power, small businesses or small power companies can be prosumers. The difference from a conventional power source is that the power generators are the same size as the loads in the micro groups and are positioned close to the end users (Abu-Shark et al, 2006) .

Figure 2.2 Schematic Representation of a Microgrid (Abu-Shark et al, 2006)



Benefits of Microgrids. Microgrids provide a range of advantages to the local level as well as to the inclusive grid in terms of increased efficiency, reliability, environmental and economic benefits. Some benefits of micgrogrid system as follows:

- Microgrid system improves local energy delivery. Most microgrids are developed using a design or plan that determines how local energy is delivered to society. The plan will define a set of objectives and determine which positions are most appropriate to achieve this objective. This means that, there is more opportunity to increase the energy efficiency of buildings.
- Microgrids can increase reliability. Microgrids help the community take action against power failures by providing a backup power supply in case a community drops in the home network. The details of how microgrid can be achieved

reliably should be cited in a reliability plan detailing how the microgrid will be built for related technologies, energy storage, system management and other components. For example, the management system plan will usually include management system software and smart energy devices such as smart switches and sensors. These will help the system to operate independently of the national grid when necessary.

- Microgrids are environmentally friendly. Considering that microgrids generally use renewable energy generation technologies, energy storage, energy efficiency and smart grid technology, these help to reduce carbon emissions of a community or business and thus counteract climate change.
- Microgrid provide economic benefits to prosumers. An example of economic advantage is that the microgrids create new business opportunities, especially helping to create jobs at the local level. Promoting more investment in the community and developing microgrids, encouraging innovation to reach more efficient renewable energy technologies and intelligent power systems will increase business opportunities. In addition to this it will decrease the cost by limiting the amount of energy consumed by net-meters system that makes energy consumption much more efficient. It will also make the system more reliable and thus prevent power outages. This means consumer can reduce the cost of power outages (Whitlock, 2015).
- Smart grids and smart meters allow increased device connectivity which allows real time monitoring of energy production and energy usage.

"Microgrids can be smart and put power in the hands of the consumer. Connecting up local resources and operating them through metering systems is the basic form of the modern microgrid. The next step is [..] the smart, transactive microgrid" (All About Microgrids, 2018).

Today, a number of communication mechanisms and communication techniques are used in the conventional power system for economic and technical reasons. As an example, Smart Meter which have advanced communication network, is implementing

in houses to collect meter readings. It designed to upgrade the billing process for energy usage and then expands into other areas such as Outage Management System, is a system used by electric distribution system to power recovery, Voltage Controller etc. Implementation of this communication infrastructure and related Smart Grid applications contributes to growth of data transmission volume in distribution networks. With this increasing communication and connection of renewable energy sources, consumers in traditional energy market will be prosumer (Zhang, 2017). In light of some popular applications like Airbnb or Uber, it can be said that traditional trading market in electricity, will leave its position to Peer-to-peer energy trading market.

Trails on Peer to Peer Energy Trading Markets. The power systems used are designed to meet uncontrollable and inflexible demands, and adapt to large-scale production facilities. However, with the evolving integration of Distributed Energy Resources (DERs), traditional consumers will be prosumers (Luo et al, 2014). Producers with excess energy can either store them with energy storage devices or provide energy-deficit ones. This energy trade between the prosumers is called the Peer-to-Peer energy trade (Zhang et al, 2017). In recent years, a number of experiments and projects have been done on Peer to Peer energy trading. This part summarizes the detail of Peer to Peer experiments which especially use Blockchain technology.

- **Transactive Grid:** *"Transactive Grid is combination of software and hardware that enables members to buy and sell energy from each other securely and automatically, using smart contracts and the blockchain"* (Zhang, 2017). Because transactions in blockchain are auditable, non-repudiable and cryptographically secure, it uses the Etherium blockchain technology to reach business models which have distributed grids such as projects of peer-to-peer trading (Goranoviç et al, 2017).
- **Electron:** Electron is a new platform for gas and electrical metering and billing systems in the UK, currently under development. It is a completely

secure, transparent, decentralized platform that runs on a blockchain and provides cost-effective honest metering, billing, and switching services using Smart Contracts and Distributed Consensus Power. The platform, which will probably be open source, will be beneficial to all users (Electron, 2018).

- **PWR. Company:** PWR.Company is interested in the Peer-to-peer market in microgrids. It works on the technology of storage of renewable energy with the help of batteries. PWR uses the Etherium infrastructure (Pwr company, n.d.).
- **PowerLedger:** Powerledger offers a market, using blockchain technology, where renewable energy producers, in other words, prosumers, can sell the excess energy they produce over a certain price. Transaction can be made via Microgrids and distributed network. Distribution System Operator (DSO), who distributes the low voltage energy in Peer-to-peer markets earns money, because Powerledger uses to distribution networks when transport electricity to customers (Power Ledger, n.d.).
- **Key2Energy:** This concept interested in apartment houses which produce electricity with solar panels. There are two key factors in this concept, one of them is the agent whose goal is maximizing revenue by selling excess energy on local market with best price, and the goal of other agent is minimizing cost in apartment by using electricity energy more efficient (Multi apartment PV accounting, n.d.).
- **NRGcoin:** This is a coin which uses the concepts of cryptocurrency and smart contracts. NRGcoin uses Etherium infrastructure and the conditions of this coin; value of electricity in market does not matter, every kWh is equivalent to one NRGcoin. In addition, energy must be consumed locally and produced from RESs. During the validation process this coin check for these conditions. It uses smart contracts in validation process (Energi, 2017).
- **SolarCoin:** The goal of this coin is to increase energy producing of solar energy. To reduce long payment process, one MWh producing is equivalent to one SolarCoin. An electricity meter controls producing for verifying. SolarChange, ElectriCChain and SolCrpto which are facilitators can be used to

register SolarCoin (Solarcoin, 2014).

All of these products use blockchain technology into energy trading market. And the focus of almost all is facilitating the billing and metering systems, and providing secure transaction in market. Most of products which aim to do using blockchain in energy trading market are in development process (Goranoviç et al, 2017).

2.3 Controls in distributed generation on P2P markets

As mentioned in transmission and distribution system of power plants section, in other words, centralized system, to use electricity at home, transmission lines should be structured and voltage of electricity should be in compatible mode. In this section, controls in distributed generation will be handled for using electricity energy at home.

Network Controls. Centralized generation means large-scale electricity production in centralized large power stations. In general, these generation areas are far from end users and connected to a network of high-voltage transmission lines. Some examples of centralized generation are nuclear power plants, fossil-fuel-fired power plants, wind farms, and hydroelectric dams etc. (Centralized Generation of Electricity and its Impacts on the Environment, 2018). However, distributed generation means various technologies that produce or use electricity in the vicinity. Products such as solar panels, combined heat and power are examples of this technology. It can serve as a small structure like home or microgrid etc. If it is connected to the low voltage distribution lines of the electric utility, distributed generation can ensure a clean and reliable power transmission to additional customers. It can also help reduce electrical losses along the transmission and distribution lines (Distributed Generation of Electricity and its Environmental Impacts, 2018). Electrical machines such as synchronous or asynchronous generators are used as the main equipment in the distributed generation. Their connection to distribution network can be directly or can be through an power electronic interface technique whose converters provide

the necessary adaptation functions to integrate all different microgrid components into a common system (Gao, 2013). Distribution networks accept power from the transmission network and distribute them to customers. In this way, both the real power and the reactive power flow from high voltage to low voltage levels. In Figure 2.3 Basic Grid-Connected solar system, Maximum Power Tracker convert a higher voltage DC output from solar panels down to the lower voltage which needed to charge batteries (All About Maximum Power Point Tracking (MPPT) Solar Charge Controllers, n.d.).

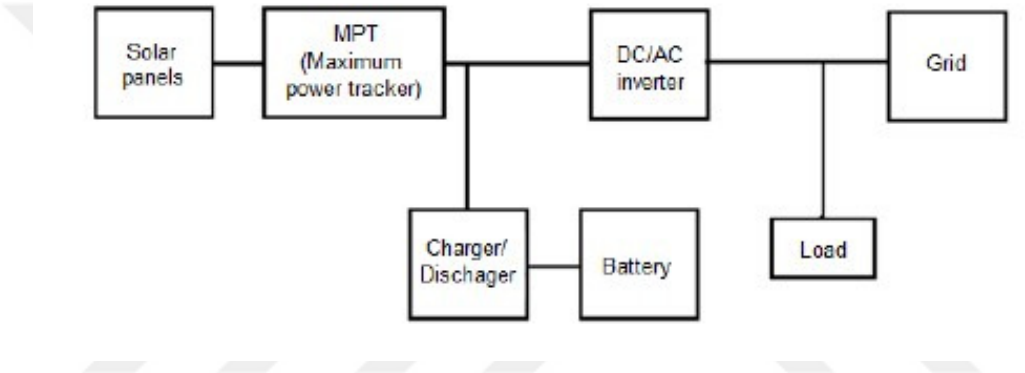


Figure 2.3 Basic Grid-Connected Solar System (All About Maximum Power Point Tracking (MPPT) Solar Charge Controllers, n.d.)

The diversity in actual and reactive power currents caused by distributed production has significant technical effects for the power system (Recommendations for the Connection of Embedded Generation Plant to the Public Electrical Suppliers Distribution Systems, 2016). In some countries, rules have been developed to standardize technical issues related to connection and operation generation in distribution systems (Sen et al, 2003). The approach was to prevent the distributed generation from reducing the quality of supply voltage to other customers and accepted the generators as negative loads (Jenkins et al, 2010). Stability, power quality and protection of distributed generators can be shown another positive technical impacts of distributed generation to distributed networks (Zhang, 2017).

Voltage Controls. For power distribution networks, the primary factors in the Quality of Supply (QoS) are voltage and frequency. According to Electricity Supply Regulations (ESR) for voltage levels between 1kV and 132kV voltage magnitudes of power system should be kept within $+-6\%$ of nominal voltage, and it should be kept between $+10\%/-6\%$ of nominal voltage for the voltage levels between 50V and 1kV (Gao, 2013). Distribution Network Operator controls the voltage limits. To regulate voltage, regulation methods which are the methods can be derived from Formula 1, are used (Zhang, 2017).

$$\mathbf{V_2 - V_1 \approx PR + QX} \text{ (Zhang, 2017)}$$

The value of can V2 be regulated by P, Q or V1

- **Active Power can be curtailed:** Because X/R ratio is low, active power flow which is actually consumed or utilized in an AC Circuit , P, has large effect on voltage level of distribution generation (Awad, 2010). *"If the generation is much higher than the load, voltage may exceed its limit. In this case, generation must be curtailed"* (Zhang, 2017).
- **Reactive power can be controlled:** By using reactive power compensators, reactive power flow, which flows back and forth that mean it moves in both the direction in the circuit or react upon itself, Q, can be controlled (Liew and Strbac, 2002). Because X/R ratio is low, reactive power control effect on voltage less than P effect (Jenkins et al, 2000). However, in general reactive power control is also used to control voltage and reduce production curtailment.
- **Tap Changers:** It is desired that the transformer voltage on the load side be close to the constant or design value. Based on the below equation, the function of tap changers can be explained mathematically. To maintain SV/Load Voltage constant or close to ratio which desired, tap changers of transformer help to change turn's ratio (What is a transformer tap changer?, n.d.).

Secondary Voltage = Supply(or Primary) Voltage / Turns Ratio(What

is a transformer tap changer?, n.d.)(Formula 2)

These controls provide a healthy communication of electricity from smart grids to house. This communication will make distributed energy production possible. Distributed energy production will make peer-to-peer trading between smart grids possible by a reliable infrastructure such as Blockchain.

2.4 Infrastructures of smart grids on P2P energy markets

In distributed generation, connection infrastructures and database infrastructures should be standardized to set up a reliable system. In addition to these, smart grids and smart meters implementation to these systems should be done compatible. In this section structures of smart grids and smart meters, communication infrastructures and database infrastructures will be explained.

Structure of Smart Grid and Smart Meter. *"A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both—in order to efficiently deliver sustainable, economic and secure electricity supplies"* (Jenkins et al, 2015). Communication, monitoring, control, and innovative services are some proposals of the smart grids. Better connection of generators, optimizing the efficiency of electricity market, lower environmental effect when generating and distributing electricity, increasing system reliability, increasing and maintaining efficiency, providing real time data monitoring and customer friendly approach are some of the goals of smart grids (Zhang, 2017). To reach these goals communication technology of smart grid plays a critical role.

Smart meter basically helps to consumer by providing consistent, integrated and available data. Consumer can follow the prices and volume information with it, and they can consume more energy at a lower price. In other words, they can save their

money on their energy bills, even they consume more energy. Because using smart meters and smart grids help to reduce annual energy consumption of a household and emission in the European Union up to 9%, until 2020 the goal of EU about this topic, replaces minimum 80% of electricity meters with smart meters where it is reasonable to do this process (Smart Grids and Meter, n.d.).

Communication Infrastructure of Smart Meters. An example of communication architecture for smart systems is shown in Figure 2.4 Communication Architecture for Smart Meter. The interfaces which used in this architecture is Home Area Network (HAN), Neighborhood Area Network (NAN) and Wide Area Network (WAN).

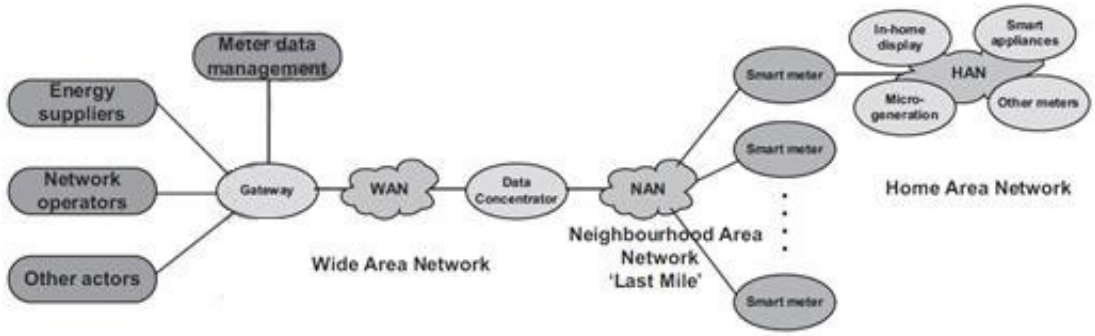


Figure 2.4 Communication Architecture for Smart Meter (Zhang, 2017)
In this typical example;

- Home area networks are used for integration of centralized energy management in houses. It aims to communicate houses between smart meters. And like all networks, it has some tools which used wired like sockets, plug in vehicles etc. and wireless protocols to communicate (Zhang, 2017).
- Neighborhood networks are used for consumption reading from meters. In other word for data transfer (Zhang, 2017).
- Wide area networks are used to communicate with outside, like energy suppliers, network operators. In addition it is used for data management and optimizing (Zhang, 2017). Most probably, it is used for monitoring all these

networks.

To communicate accurately between networks and applications, Open System Interconnection (OSI) model which standardize the functions of communication systems, can be used. In shortly OSI model which is a project of International Organization for Standardization (ISO) examine communication system by dividing layers. Physical layer, data link layer, network layer, transport layer, session layer, presentation layer and application layer are respectively the parts of Open System Interconnection model. The logic of OSI model is that each layer performs some operation to data like encrypting etc. then prepare for the next layer. In addition to standardization, preventing changes on data, using network communication easier by dividing allowing multiple vendor development are the some popular advantages, and data segmentation, flow control, error detection and correction, data encryption and lastly data compression are the some popular services of Open System Interconnection model (OSI Model Advantages and Basic Purpose Explained, 2018).

Database Infrastructure of Smart Meters. A database management system basically collect the information to be managed. It is used for storage, validation, verification, adjustment, delivery, integration of data by ensuring its security. For reliability, it should be setup securely.

There are two infrastructure which used for data transfer between consumers and utility companies, Automatic Meter Reading (AMR) and Advanced Metering Infrastructure (AMI). Automatic Meter Reading is an old meter technology which just collect the energy consumption information and energy transfer information from electric meter to utility. It uses one-way communication. However, Advanced Metering Infrastructure meter is basically updated version of Automatic Meter Reading. It is placed out of the house and measure both the quantity of electricity consumption and analyze of consumption times in a day. These are also used for transferring price and energy consumption information from the utility to consumer. It uses

two-way communication. This communication type help to obtain information to utility companies for analyzing customer generation, increasing effectiveness etc. (Dai, 2015).

As mentioned before, controls on distributed energy production, communication and database infrastructure of smart systems make peer-to-peer trading attainable. Blockchain applications can make this market more reliable.

3. BLOCKCHAIN APPLICATIONS ON SMART GRID

Blockchain which is a recorded, transparent and decentralized technology, means a distributed electronic database. This distributed electronic databases are known as ledger in society. This technology which was cloned over a peer-to-peer network and help to transactions between peers (Buth, 2018). The logic of this technology has emerged from opposition to current transaction system. Today, transactions are made by third parties which provide trustable relationship between transaction parties. However, basically blockchain provide a reliable platform for these parties and allows them to do their operations. *"Cryptographic proof instead of trust, allowing any two willing parties to transact directly with each other without the need for a trusted third party"* (Nakamoto, 2008).

It also can be defined as a tool of information management which manages the registration of any type of transaction. Blockchain can be thought as an online and interactive spreadsheet which can be shared, can be updated and monitored continuously by all members in the network. In Blockchain, this spreadsheet can be thought as ledger which store a copy of transactions details, and this ledger can work with any type of assets which is not necessarily to be any kind, in other words it can be intangible asset like idea, records, data etc. or can be a physical asset like a property. In addition to these, this ledger is used like an account for transaction assets on global between all members who connected to the ledger (Swan, 2018). One of the confusing aspects of Blockchain technology is that the processes are stored in a computer network and not in a central database. And these processes are reachable and visible to everyone on the network. However, basically a computational proof by time stamp is generated for each transaction in the network which provide assurance for that processes cannot be altered after the transaction is completed and hence

it is a trustable platform. Blockchain is a part of decentralization on transaction market (Swan, 2018).

In shortly, even blockchain seems to be unreliable because of its distributed structure, it is a platform which provide its own security. Every nodes in the network store data and control it in distributed structures. The advantages of blockchain as follows:

- Partners who make transaction, do not have to reach a third party which just function as an intermediary and do not have to obey the third parties rules (Dütsch and Steinecke, 2017).
- There is not key mechanism for storing and verifying the transactions, in other words, network is distributed and not a single entity so it is resistant to attacks (Dütsch and Steinecke, 2017).
- Because there is no intermediaries, there is also no charge fees. It is cost effective (Dütsch and Steinecke, 2017).

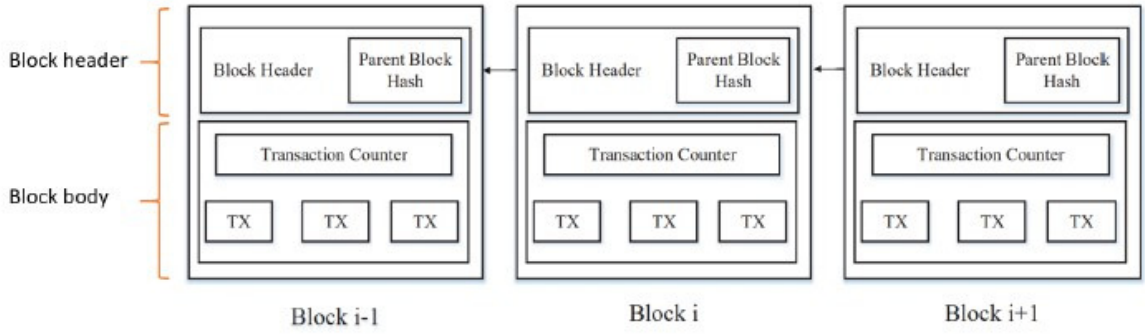
3.1 The architecture of blockchain

After Bitcoin implementation, all currently available blockchain types are not designed in the same way. However, despite the different designs, basic logic of almost all of the products that use blockchain technology are as follows. As mentioned blockchain can be defined as a distributed ledger, which consists of a chain of blocks that containing all the transaction data recorded in chronological order, where all data is stored in "blocks" that are interconnected by a unique cryptographic code. Blocks contain log of data activities that are permanently stored in the ledger and, the data which is written in the block, cannot be removed or changed. When a new transaction is performed, different block is added to the chain. If the cryptographic signatures in the previous block have been changed, a new block cannot be added, thus the validity of the block chain is confirmed when a new transaction is performed. It is very hard to change the blockchain because of this validation technique. Before the new block is added to its existing chain, changing all the data

which stored in the network blocks is almost impossible (Tapscott, n.d.).

Blocks. There are two elements in blocks, which are block header and block body. Block header include information such as reference number, time stamp and hash code etc. The hash code, which mentioned above as a cryptographic code helps the block to communicate with the previous block. The body part of block stored transaction counter and transaction data (Zheng, 2016). Figure 3.1 Continuous Sequence of Blocks shows the component of blocks.

Figure 3.1 Continuous Sequence of Blocks (Zheng, 2016)



3.2 How blockchain works?

In basically, Blockchain is an infrastructure that provides the security of transfer in a distributed architecture. Bitcoin has been using the blockchain infrastructure for more than 10 years, so it can be called an example that demonstrates the safe working of the blockchain. When a computer downloads the Bitcoin application, it actually downloads the records of all transfers. And when that computer enters the network, it becomes a node to keep those records. Blockchain is trying to prevent the change in data by keeping all processes in all over the world and using cryptographic encryption systems. Hash method is one of the encryption methods which is an unpredictable encryption method that encodes and splits data. Working

logic of hash cryptography is that, It must produce a different hash value for each data and produce the same hash value when the same data is written. The aim is to prove that the data in the distributed structure has not changed. Because when the data is changed, the hash value produced will change. When the blockchain system is setting up, a logic for the hash value is set by founder, and when a new block is added to the system, all computers do the mining to find a hash value in this specified hash logic. Such as, if founder decides that every hash function in the network will start with '0000', every nodes in the network try to find this specific hash value which starts with '0000'. This process is called 'mining' in blockchain world. The key feature of hash cryptography which ensure data integrity and security, is that, the hash value which produced also contains data from the previous block. This is done to ensure security. Because even if the data in the last block is changed, the hash value produced in the previous block and the hash value generated in the last block will be different from each other. This means that the newly added block will be ignored. Also, even if the data in the previous blocks are changed, the hash values which produced in that chain will be different from the hash values which produced in other chains. So the chain will be ignored. In this way, the blockchain will be secured.

Blockchain use different technologies when securing transactions. Each of these are technical necessities are fundamental issues for blockchain technology. These different necessities are respectively;

- **Peer-to-peer network:** *'A peer to peer network is a decentralized and interconnected network that shares tasks or workloads (such as processing power or data storage) between all participants equally. What they create, store or transfer is made available to everyone on the network'* (Peer to Peer Network, n.d.). The Peer to Peer network is a part of the blockchain technology that significantly affects the way it works. This network helps blockchain technology to be solid and secure (Peer to Peer Network, n.d.).

  In peer to peer technology all users are voluntary resources at the same time,

and they provide to foundation of network. Each peer which is a computer system on network are equal and referred as nodes which stores the information of transactions. A peer presents technical components to all network such as network bandwidth or disk storage etc. This contribution means that there is no need for coordination from center by hosts or servers.

In blockchain all the nodes are equal but tasks of nodes can be different. In other words some nodes are used for mining, but some of them are full node. Full nodes provide reliability to blockchain by copying blockchain information on a single device. This means that if something goes wrong and every full nodes can provide to rebuild network and the information on blockchain cannot be lost or destroyed (Peer to Peer Network, n.d.).

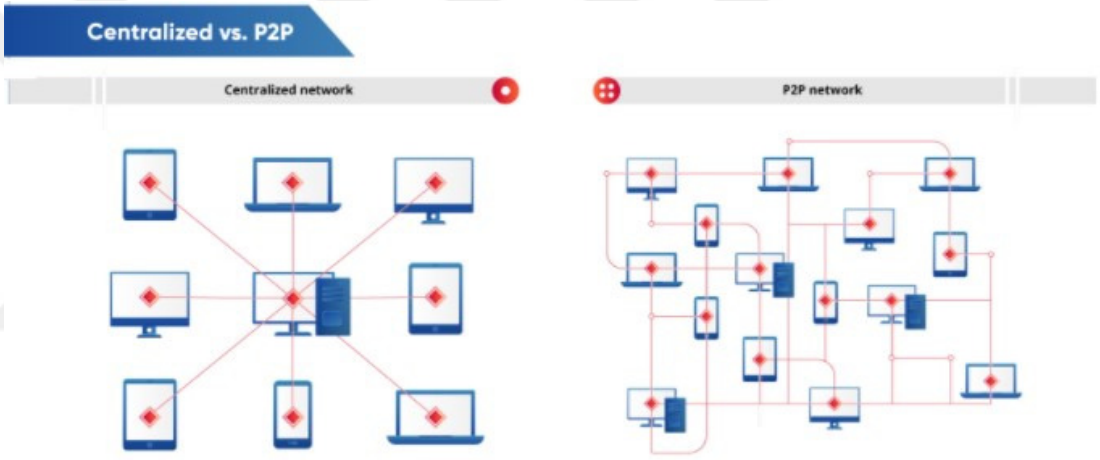


Figure 3.2 Centralized Network vs Peer-to-Peer Network

As showed in Figure 3.2 Centralized Network vs Peer-to-Peer Network, P2P network is totally different from centralized network, there is no central server or storage. The information is always stored, copied and relocated between peers in network. It also improve network power with more devices and more nodes. Lack of any central storage point means there is no need for an authority. Users are the true owner of their personal data, securing it properly is the responsibility and obligation of them (Peer to Peer Network, n.d.). These features of the peer to peer network plays role the emergency of blockchain technology.

- **Cryptography:** Cryptography is a way of encrypting and decrypting information by using complex mathematics. In other words, the information can

be only seen by the expected receiver. Cryptography takes a data, it can be a text, and encrypt it by mathematical algorithms to create a cipher text. Cipher text is unusable till it is decrypted. In blockchain, cryptography is used for securing the identity of sender of transaction and ensuring the past records cannot be changed (Cryptography, n.d.).

In Cryptography there two ways of encrypting and decrypting data. One of them is *symmetric cryptography;* there is only public key, and both sender and receiver know the public key before transaction. Sender encrypts the message, and sends it to receiver on a non-trustable platform like internet. When receiver takes the message, she also decrypts the message by public key (Cryptography, n.d.). Because this method is faster than asymmetric cryptography, it is used in some sector by very complicated mathematical algorithms. DES algorithm and 3DES algorithm are the popular public keys in nowadays. Because Symmetric cryptography provides confidentiality, but does not provide authentication and non-repudiation, it is not used in blockchain technology (Cryptographic Tools, n.d.).

Asymmetric cryptography: which is also known as Public key cryptography is the improved version of symmetric cryptography. There are two kind keys in this technique one of them is public key which can be known by everyone and the other one is private key which is only known by owner. Sender and receiver have their own public and private keys. Sender sends the message by encrypting public key of receiver. And decryption only can be done receivers private key. In addition to these there is a digital signature process in this technique. Sender send message by encrypt it her private key, and this message can only be decrypted by public key of sender. In this way non repudiation can be achieved. In other words, everyone who decrypt the message know that the message comes from the sender (Şeker, 2008).

In here the actual data is a part of digital signature and network cannot recognize it when any part of it changed. By this way blockchain can guarantee the message is original (Cryptographic Tools, n.d.).

- **Digital Signature:** Digital signatures which are used in asymmetric cryp-

tography, help to provide security and integrity of information which recorded in blockchain. They are stated in blockchain protocols which stated the rules to explain details of communication and transferring of information between nodes, the rules should be define before data transaction for example how data will be sent or which machine will receive it etc. Digital signatures mainly used for securing transaction of sensitive information like contracts to detect and prevent any change (Paul, 2017).

Mainly three key advantage can be obtained by digital signatures. Firstly, they provide integrity of information. As mentioned before, If the encrypted data is changed, the digital signature also change and it will be invalid. Secondly, it is like an identity card. The ownership of it is clear so the partners who communicate can be sure that they communicate with who they intended to. Lastly, digital signature provide non-repudiation. The owner of them are legally bound and using of legally binding. In shorty, it provides integrity, authentication and non-repudiation process which is best practice in data transferring (Paul, 2017).

- **Nodes:** A node which is a point of connection within a blockchain network. One of the essential part of foundation of blockchain technology. It can be any device on network such as computer, phone even it can be a printer. The objective of node in a network is to maintain a copy of blockchain. These are the individual parts of the data that structured as a blockchain. Nodes contributes their resources to record and verify transactions, and the owners of them can earn cryptocurrency, which is also known as tokens or digital assets, from transaction fees, which is a fee paid by senders of transaction. Because there should be a processing power to maintain blockchain network, nodes take fee from transactions. This action is also known as a mining which means recording and validation of transactions on to blockchain (Nodes, 2013).

  Because large amount of transaction is occurring in the blockchain network, the maintaining is require large computing power. In other words, capability of an ordinary computer is not adequate to this process. To earn reward, miners should have computers with improved CPUs or GPUs (Nodes, 2013).

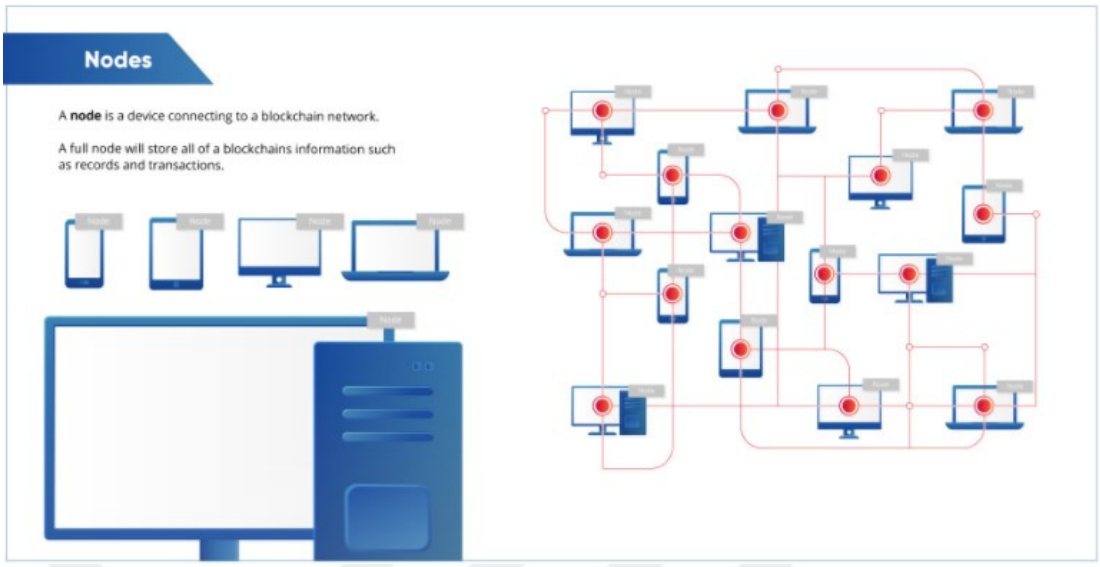


Figure 3.3 Structure of Nodes (Nodes, 2013)

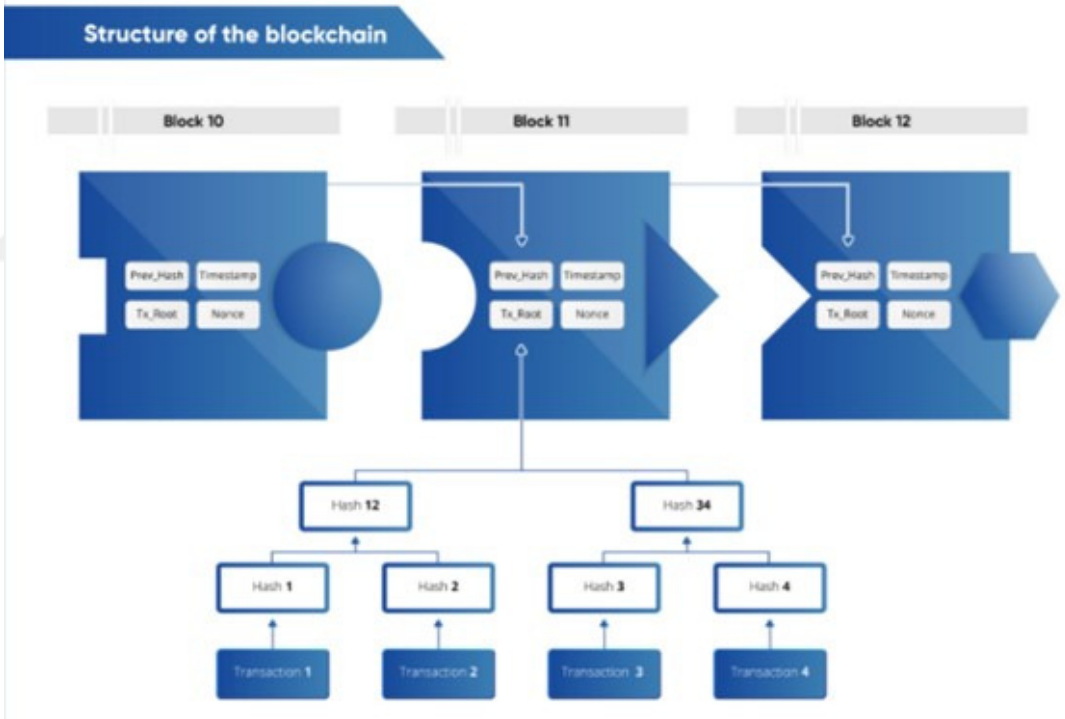
- **Hashing:** Hashing process is the reliability component of the blockchain technology. This process in basically, take the input and turn it into cryptographic output by mathematical algorithms. For example: Bitcoin cryptocurrency uses Secure Hash Algorithm-256 (SHA-256) which is an example of algorithms which provides confidentiality. Hashing process is help to increase the security of data. But to be successful in this process, it should have some critical qualities. The first one is that, same hash value cannot be reachable with different inputs to provide authenticity. Secondly, same message should always create same has value by algorithm. In addition to these, algorithm should work quickly, to be useful. Moreover, the inputs cannot be determined by hash value. Lastly, any change in input should effect the hash value. All of these provide security of the data in blockchain (Hashing, 2013).

  As mentioned before changing any stored information in block which newly added would change all the hashes and make all blocks unusable. But this is technically impossible because of transparent structure of blockchain. Because it is a chain and all hashes are created from hashes the first block, which is known as genesis block. Changing a hash process is going until the hash of genesis (Hashing, 2013). Figure 3.4 Structure of Blocks show us the relationship

between blocks.

There is special way of storing data which obtained from pointers and linked lists. Pointers stores cryptocurrency addresses which are used for sending and receiving transactions and other variables. Linked list are blocks which connected to other sequences with pointers. Logic is that when new block added in the sequence, data which stored in newly added block's pointer, also stored in previous pointer as hash format of data. It means that when last block experienced an attack and the data in block changed, because the hash of it was stored other block's pointers, this attack cannot change the information on them. This is the secure nature of data structure of blockchain (Hashing, 2013).

Figure 3.4 Structure of Blocks (Hashing, 2013)



- **Consensus Protocols:** These are the indisputable protocols which created in distributed networks. These protocols prevent the system down crashes. Because blockchain is a public system and anyone can record information on it, consensus about what is added as an information and what the form of it is important. In shortly, this process is like an audit. In acceptance information period, the goal is to obtain acceptance of every nodes in network even some

of nodes are failed or unsuccessful (Consensus Protocols, 2013). Some most used ways which is used to obtain consensus is like that;

- **Byzantine Fault Tolerance:** Byzantine Fault Tolerance approach in Blockchain world is as follows. The machine, which has a validator role in the network structure, has the public key information of other machines. Each machine checks the transaction information that is received by itself using the data structure held on it and shares it with the network by signing an approved transaction. If a transaction has been approved by a certain number of machines (for example, more than half), it is considered reconciled. And this transaction is defined by the network as a valid transaction (Özer, 2018).
- **Proof of Stake:** The block generation and validation approval mechanism is associated with the share of the block producing machine on this approach of consensus. In such systems, the members of the system receive the cryptocurrency which are in their shares according to their investments and no new additions are made. The share value within the scope of the system is calculated mainly based on the amount of the cryptocurrency. Different behaviors can be seen in trading by share amount: as an example: the machine that will produce the next block can be determined by a random function associated with its share. In other words the higher the share means the higher the chance of being chosen for producing block. If the relevant machine does not share a suitable block within a certain time, the next machine will be moved, or a machine identification is not done. The share information changes the difficulty of the problem that the machine should solve. For example, an easier problem solution range is provided for the machine with more shares. Since the use of share value creates a continuous advantage for high shareholder machines. An 'age' concept has been introduced for use in calculations. With this concept, the age values of the cryptocurrency within the share used for the production of blocks are reset, these cryptocurrency only begin to gain age value after a certain period of time and

the age value is advantageous in prioritizing/validating transactions. Although this structure may appear to be a more complex application, the process of verification and block creation of processes will be made faster and easier with this transition (Teknik Detayları ile Blockchain, 2017).

- **Proof of Work:** In this structure, a block structure of the system is prepared for the management of the blockchain network. The process of solving a problem in this system is difficult, but it is easy to check the accuracy of the solution. The most commonly used type of problem is that the hash value of the prepared block conforms to a specific structure such as being within a defined range of values, starting with a specific character sequence. Since the hash functions are unidirectional and their outputs are unpredictable, a large number of trials are required to produce an appropriate value. For example, in Bitcoin technology, a block suitable for the Proof of Work structure can be produced on average in 10 minutes. However, in order to check the shared hash value, it is sufficient to calculate the hash value only once in the corresponding block (Teknik Detayları ile Blockchain, 2017).
- **Proof of Authority:** With the PoA consensus protocol, one or more members must be authorized to modify Blockchain. For example: if the private key is a member, that member can be the person responsible for the addition of all new blocks. In the process of accepting a block, a new block is accepted when a plurality is provided between the authorized network nodes (Eurelectric, 2017). Even though this method seems to be more appropriate for a centralized approach, it is used among companies in the energy sector. This protocol can be used where security and integrity are not risky. Energy Web Blockchain can be shown as an example (Andonia et al, 2018).

In shorty, to prevent system crashes and provide healthy communication between nodes, consensus protocols are used. To read different consensus protocols see Appendix B.

3.3 How blockchain transaction occurs?

Transaction process in blockchain include authentication verifying and transaction verifying steps to be reliable process. This process begins with the sender who sends the transaction to the network. Sender specifies the public address of the recipient, the data content of the transaction, and the digital cryptographic signature which prove the authenticity of the transaction in the transmitted message. Then, devices in the network receive the message and decrypt the digital signature. If the validity of signature is verified, the transaction is authenticated. After authentication, one of the device in the network include this transaction to the last version of transaction in ledger which can be thought as 'a block'. Now the 'block' is updated for validation. Block validation should be done by all devices in the network. There is different types of mechanism for validating. When transaction is validated by hash function which process ensure that the altering block is not possible, the new block is chained the previous block [54,71].

Key Features Of Blokchain. As mentioned earlier, Blockchain is a recorded, means information is time-stamped, transparent, anyone in the network can reach the ledger of transaction and decentralized, details of ledger stored in multiple computers which is known as nodes, technology. To reach this peer to peer distributed ledger technology reliably, blockchain includes cryptography, smart contracts and consensus protocols (Froystad and Holm, 2015).

- **Smart Contracts:** With the algorithm embedded in the blockchain technology, it have ability to run smart contracts by its algorithms. Smart Contract, which is concept which introduced in 1994, *a computerized transaction protocol that executes the terms of a contract* (Morris and David, 2014). In other words, it is a protocol which enable to do automatic transactions in digital assets (Buterin, 2015). In shortly, the use of smart contracts with blockchain automates the transactions of participants. Etherium is the firstly developed blockchain type which was based on smart contracts. With Etherium, rules

for ownership, formation of transactions and functions of transactions were stated and smart contracts were built on blockchain. Traditional contracts are based on mutual agreement between the two parties and mutual trust. Smart contracts eliminate the element of trust between the parties necessary for the successful implementation of contracts; because contracts are automatically defined and implemented in code at their discretion (Swan, 2018).

Autonomy, decentralization and self-sufficiency are the elements that differentiate the smart contracts. Autonomy means that there is no need for further contact between the parties in the contract, provided that a contract comes into force and becomes operational. Decentralization means that the contract is not stored on a single central server, distributed among network nodes. Self-sufficiency means, smart contracts can allege resources and they can spend these resources according to system needs, in shortly, they are self-sufficient (Swan, 2018).

- **Types of Blockchain:** The first and original blockchain product was introduced by Nakomoto in 2008. It is a blockchain fully controlled by public. Now, there are more than one type blockchain with have different security measures or application opportunities. To classify these different types of blockchain, Bit Fury Group divide these types in two axes which indicates access of data, which divided into public and private, and transaction processes, which divided into permissioned and permissionless (Goranoviç et al, 2017).

  In shortly, A public blockchain is open. Any node on the network is allowed to process and check information about transactions. It is a fully distributed blockchain and allows everyone to add new transactions to the blockchain or can participate in process of consensus. Because this type is openness and trustable formatting of this, usage of this higher than others (Goranoviç et al, 2017). Conversely, a private blockchain is not open to anyone, and authorized participants can only access data on the blockchain or perform transactions. When blockchain becomes more private, they could be useful for small scale applications or optimization of business flow.

  In addition to these, in transaction process, permissioned blockchains have

strict rules. It can be defined as a consensus between a narrower team. Because only a selected group of participants or only one participant is allowed to update the ledger and join in the verification process. However in Permission less blockchains, anyone can allow join the mining process or can lead to mining pools.

Moreover, there is also a hybrid called the 'consortium block chain' between the public and private blockchain. This type can be called 'semi-special' or 'partial decentralized'. It allows a group of nodes determined by a small selection, or anyone in the network without selection, to implement the consensus protocol and allow an permissioned blockchain. It has the same benefits as a private blockchain. However, it provides more privacy because it is a permissioned blockchain (Zhang et al, 2017). This type is mostly used in financial transactions (Goranoviç et al, 2017).

3.4 Blockchain in the P2P energy trading

Useful blockchain feature and the main areas of using blockchain in peer-to-peer systems will be examined in this section.

Advantages of Blockchain for Energy Trading System. Some features of blockchain which listed below, can be also beneficial for energy trading market (Kounelis et al, 2017).

- **Decentralization:** In the traditional system, transactions must be approved by a central trusted third party. Bank can be shown as an example as a central node. This causes high cost in transaction systems. Because consensus protocols maintain data consistency on a distributed network, this central node is no longer necessary in the Blockchain transaction system. The lack of a third-party central structure in the energy market makes the system more flexible. In other words, it actually means the absence of a central point of failure. In addition, transaction costs are lower due to the elimination of

intermediary costs (Kounelis et al, 2017).

- **Immutability:** Modifying or deleting data is almost impossible after a transaction has been approved and authorized to a block. Hash code operation process defines blocks containing invalid operations. In all markets where a third party guarantee is needed to enter the market, participants can enter the market believing that they will no longer be defrauded (Kounelis et al, 2017).
- **Anonymity:** During the transactions, the identity of the participant is hidden and the transaction takes place via anonymous addresses and codes. However, the operations of each general key are clearly visible. Therefore, it can be said that transaction confidentiality is not fully guaranteed. In the energy market, the anonymity of the block chain improves the control of user communities over transaction and data. This creates a safer environment for users (Kounelis et al, 2017).
- **Auditability:** The transactions in Blockchain can be easily monitored and verified in real time. Controllability provides transparency in processing systems. This configuration allows auditors to make the processes verifiable and evaluate the reliability of the system. In the energy market, ease of inspection eliminates disputes and accelerates reconciliation processes (Kounelis et al, 2017).

Blockchain in the Electricity System. The first type of blockchain was originally designed to operate in the financial sector. Despite the fact that most blockchain initiatives are directed towards financing, blockchain technology has become more popular in recent years and other sectors also recognized the potential of the block chain. One of these sectors is energy sector. In this sector, especially in recent years, various pilot projects and start-ups have emerged in different parts of the world trying blockchain technology. However, almost all of these practices are in development, and these pilot projects have not yet been implemented on a large scale (Guide to Companies involved in Blockchain Energy Table of Contents, 2018). In shortly, the blockchain technology can be applied to the energy sector and the use cases for the blockchain may vary depending on the business requirements

(Buth, 2018).

The Energy Web Foundation (EWF), a global and non-profit-seeking organization, was created in 2017 for the purposes of ensuring the utilization of the blockchain technology, capturing the potential of the block chain, determining global standards for block chain applications in the energy sector and monitoring compliance with these standards. Shell, Engie, Eneco, Tepco and Statoil are some of the EMF members. EWF aims to increase the use of distributed and renewable energy sources. To achieve this goal, EWF attempts to build a blockchain infrastructure that supports a large number of applications. EMF has listed about 200 energy-themed blockchains currently explored by different organizations around the world. From the list EMF have prioritized and categorized four blockchain application domains with its affiliated companies (Buchanan, 2017).

- **Utility billing:** a blockchain application that can manage operational tasks such as customer measurement and deployment, and perform cryptographic identity management by itself or with a third party application.
- **Certificates of origin:** a blockchain application that will be able to manage the certificate of the energy manufacturer related to the use of renewable energy sources, manage this certification management process through smart contracts, and accelerate the whole process to the automation.
- **Demand response:** a blockchain application for third parties or public institutions which produce energy that will be able to perform operational operations of the demand management process through smart contracts, and to calculate energy efficiency while collecting these requests.
- **Transactive energy:** a blockchain application that can manage contracts, consumer needs and price reconciliation process in two ways and in real time. In shortly, application will manage peer-to-peer process between local consumers and prosumers.

Effects of Blockchain in Peer-to-Peer Market. Leading players in energy sectors such as utility companies and decision-makers, claim that blockchain tech-

nology can help to energy sector to deal with challenges in the industry. Blockchain can provide efficiency, and some practical solutions for peer-to-peer trading, and can improve practices of service, and cost etc.

Energy systems are undergoing a structural reform due to emerging technologies and distributed energy sources. One of the biggest challenges is to integrate the emerging digital energy sector with this distributed sources. Blockchain, because of its infrastructure, can provide practical solution to these challenges in management of these distributed energy systems and microgrids (Andonia et al, 2018). Providing trading platforms where prosumers and consumers can make transactions of money and energy surplus on a peer-to-peer basis, securing consumers by transparent, non-changeable and immutable smart contracts, and providing integrity, consistency and availability of data by algorithms are some key features of blockchain. In shortly, the solutions of blockchain can be used for smart systems which include charging and storage, and for cybersecurity. In addition to these, according to a report by Research Institute of the Finnish Economy, blockchain technology could offer open and transparent solution to assure to work of smart grids with Internet of Things (IOT) applications. Thus, the transactions in energy market will become more efficient (Mattilda, 2016). Some potential operational improvements which come with blockchain are like that:

- **Billing:** In distributed production, blockchain work with smart contracts and smart metering and automated billing process can be reachable (Sawtooth Introduction, 2017).
- **Sales and marketing:** Artificial intelligence and machine learning techniques work with blockchain and marketing techniques in energy trading market will develop. Thus, market for consumers and prosumer will reach to optimization point (Sawtooth Introduction, 2017).
- **Automation:** Control, peer-to-peer trading operations such as billing etc. and effectiveness can improve with blockchain technology (Burger et al, 2016).
- **Smart grid applications and data management:** Communication be-

tween smart devices for data transfer or storage is feasible with blockchain. This feature is, not only beneficial for distributed energy trading market but also useful for future innovations which will be done with smart systems such as smart energy management system for buildings.

- **Grid management:** Blockchain can help network integration and flexibility in trade platforms. Thus, optimizing can be achieved (Blockchain in energy and utilities use cases, vendor activity, market analysis, 2017).
- **Security and management of identity:** Security in blockchain is done by cryptographic techniques. Thus, privacy, confidentiality and identity management can be achieved with blockchain technology (Dal Canto, 2017).
- **Improvement in resource using:** Resource distribution to service effectively in multiple users environment can be achieved by blockchain (Dal Canto, 2017).
- **Competition:** Improvement efficiency and mobility in energy trading markets will increase competition (Electron reveals blockchain energy platform, 2017). Increasing competition will increase effectiveness of market.
- **Transparency:** Using blockchain in market will improve audit capability and compliance of regulatory, because of non-changeable records and clear transactions (Dal Canto, 2017).

In addition to these, because delays, reconciliation process, confirmations and volume actualization's imbalances are occurred. Blockchain can decrease the costs, delays and minimize the processes such as confirmation, it also increase the speed of payment process for services. Because the infrastructure of blockchain supports the billing process by smart contracts and support transparency for auditing in real time, the imbalances in energy trading market can decrease.

Moreover, Blockchain enable machine to machine communication which means data transfers between smart devices by internet, and this communication facilitates peer-to-peer transaction. For energy trading markets, this digitalization also helps to analytic of collected data, helps to increase network efficiency, facilitates billing pro-

cesses, helps to explore new sources for innovation etc. (Burger et al, 2016). In addition to these, for renewable energy sources, digitalization also helps to decrease management cost of renewable energy sources by remote control, enable to integration of software, hardware , sensors for physical security, and analytic tools etc. (Mattilda et al, 2016)

4. CASE STUDIES

In this section, Harmony Search Algorithm is defined and an optimization is done to predict the optimum electricity prices when renewable energy sources, microgrids and Blockchain applications are implemented. In addition to this, a case study which include 10000 times trials to predict electricity prices in market is shown. The directions of demand and supply lines of market with different shift ratios are analyzed. Furthermore, a different case study, trying to predict new prices with fewer offers in the market with the assumption that some producers and consumers are coming out of the market is implemented.

4.1 Harmony search algorithm

The Harmony Search algorithm proposed by Geem in 2001 is an intuitive algorithm that simulates the notes played by musicians (Geem et al, 2001). It is based on the principle that the musicians in an orchestra play the best melody harmonically from the notes they play. Since it does not require a special starting solution for the decision variables, it is the optimization of the regional optimum solutions by looking at the global optimum in many different directions due to the optimization process with more than one solution. The best solution in the optimization process is achieved as the objective function approaches the global solution (Xiang et al, 2014). The process steps of the Harmony Search Algorithm are as follows:

Step 1: Setting up the problem and solution parameters forming
The problem should be defined as an optimization problem.

$$z = \min\{f(x)\} \quad x_i \in X_i = 1, 2, 3, \ldots N$$

In this function;

$f(x)$: shows the objective function to be minimized

x_i: shows decision variables

X_i: shows the solution space used for each decision variable

N: the total number of decision variables

Solution parameters of Harmony Algorithm technique are like that;

HMS: Harmony Memory Size

HMCR : Harmony Memory Consideration Rate

PAR: Pitch Adjustment Rate

Step 2. Establishment of Harmony Memory

A random initial population is generated, such as:

$$x_{i,j}^{0} = x_j^{min} + r_j \left(x_j^{\max} - x_j^{\min}\right)$$

where i=1,2,...,HMS, j=1,2,.....,N and $r_j \in [0, 1]$ is a uniformly distributed random number generated new for each value of j. Solution vectors in Harmony Memory(HM) are analyzed, and their objective function results are then calculated.

Step 3. Development of new harmony

HMCR shows the probability that the value of a decision variable can be selected from the current harmony memory. (1-HMCR) represents the random selection of the new decision variable generated from the existing solution space. Selection procedure formula is shown in below:

$$x_i = \begin{cases} x_i \in \left\{x_i^1, x_i^2, x_i^3, \ldots, x_i^{HMS}\right\}(HMCR) \\ x_i \in X_i(1 - HMCR) \end{cases}$$

The value of a decision variable can be selected from the values in Harmony Memory with a probability HMCR. Decision variable can be further adjusted by moving to a neighbor value of a selected value from the Harmony Memory with a probability of pitch adjusting rate (PAR). In addition to these, it can be selected randomly from the set of all candidate values without considering the stored values in HM, with the probability of (1 - HMCR).

Step 4. Updating Harmony Memory

The result of the newly created harmony vector is compared to the result of the worst harmony vector in memory. If the newly created harmony vector is better than the worst harmony, the worst harmony vector is removed from memory and the new harmony vector is assigned in its place.

Step 5: Termination criterion check

In this step, the given stop condition is checked. If the condition is not satisfied, steps 3 to 5 are repeated until the desired condition is met.

Optimization Test Problems

In this part, three of well known optimization test problems will be solved with the Harmony Search Algorithm which works in visual basic, and the results of them will be shown graphically.

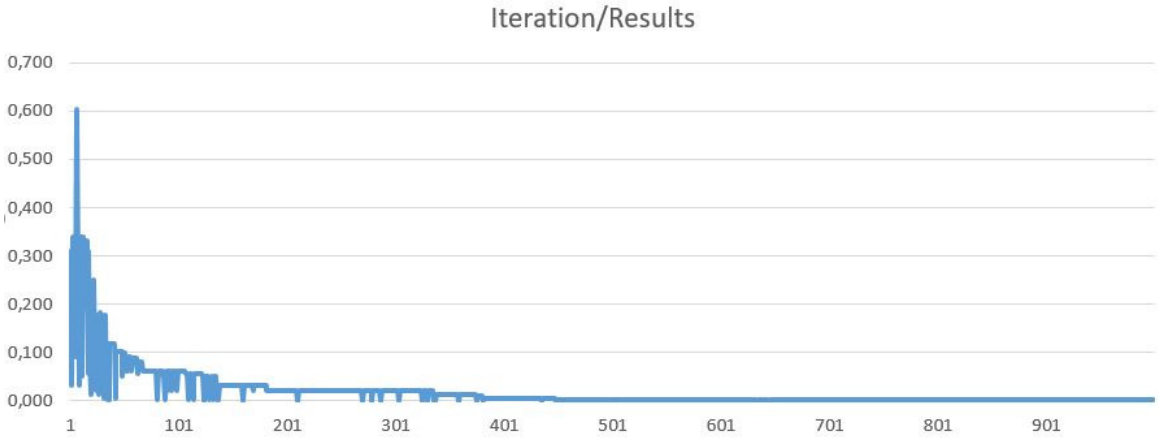
Sphere Function

Sphere Function has a convex graph, and reach its global minimum value when derivation of it is equal to 0.

$$\begin{aligned} &\text{minimize} \quad F(x) \\ &\text{subject to} \quad \sum_{i=1}^{n} F_(x) = \qquad [x_1^2 + x_2^2 +, , , +x_i^2] \\ &\text{where} \\ &\qquad\qquad x_i \in [-5, 12, 5.12] \quad (Xiangetal, 2014) \end{aligned}$$

In the Harmony Search Optimization Algorithm, HMS is chosen as 30, Upper Limit is chosen as 1, Lower limit is chosen as -1 and HMCR is chosen as 0.5 with 1000 iteration.Emerging prices can be shown in Figure 4.1.

Figure 4.1 Sphere Function



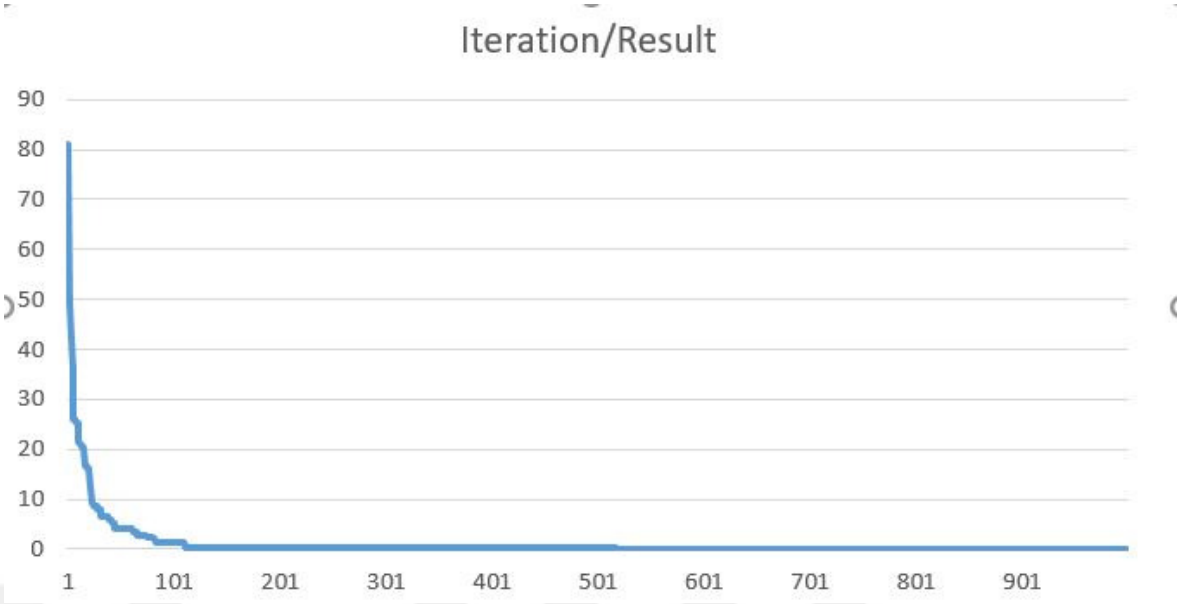
Matyas Function

The equation of Matyas Function and the graph of it are shown in below. It is tested with Harmony Search Algorithm in visual basic algorithm is shown Figure 4.2.

$$\begin{aligned} &\text{minimize} && F(x,y) \\ &\text{subject to} && \sum_{i=1}^{n} F_(x,y) = \quad [0.26(x_i^2 + y_i^2) - 0.48(x_i * y_i)] \\ &\text{where} \\ & && x_i \in [-10, 10] \qquad\qquad (Xiangetal, 2014) \end{aligned}$$

In the Harmony Search Optimization Algorithm, HMS is chosen as 30, Upper Limit is chosen as 10, Lower limit is chosen as -10 and HMCR is chosen as 0.5 with 1000 iteration. Emerging prices can be shown in Figure 4.2.

Figure 4.2 Matyas Function



Three-Hump Camel Function

Three-Hump Camel Function is another optimization function. The equation of this function and the test result graph with Harmony Search Algorithm are shown in below.

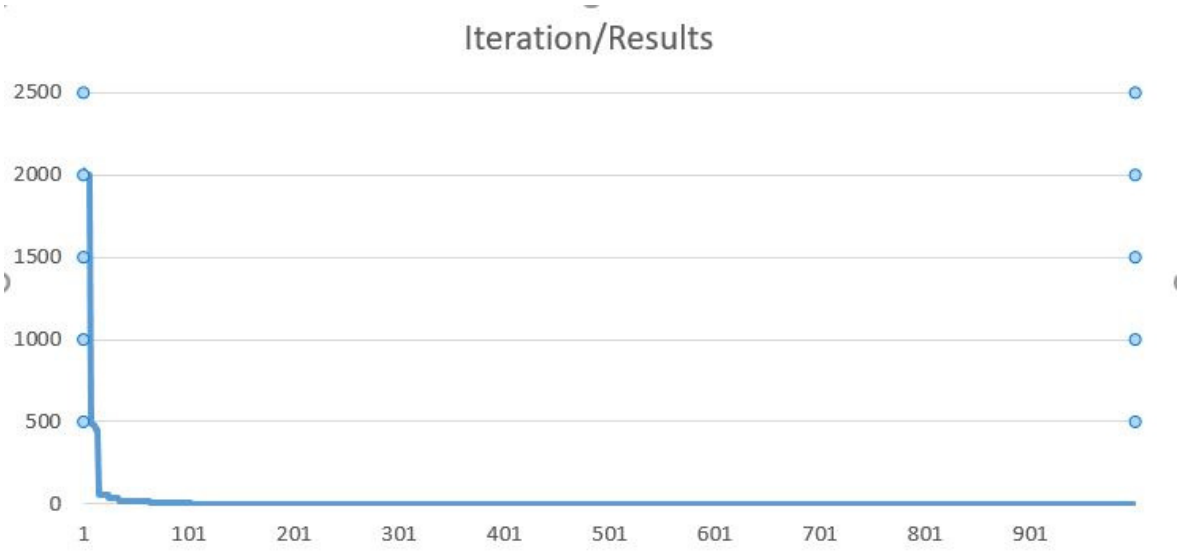
$$\text{minimize} \quad F(x,y)$$

$$\text{subject to} \quad \sum_{i=1}^{n} F_(x,y) = \quad [2(x_i^2) - 1.05 * (x_i^4) + ((x_i^6)/6) + (x_i * y_i) + (y_i^2)]$$

where

$$x_i \in [-5,5] \qquad (Xiangetal, 2014)$$

In the Harmony Search Optimization Algorithm, HMS is chosen as 30, Upper Limit is chosen as 5, Lower limit is chosen as -5 and HMCR is chosen as 0.5 with 1000 iteration. Emerging prices can be shown in Figure 4.3. Figure 4.3 Three-Hump Camel Function



According to results of optimization functions, Harmony Search Algorithm which works in visual basic can arrive to optimal solutions. Cases can be tested with this visual basic scripts.

In following parts, 3 case studies including EPİAŞ equilibrium prices and orders of Day Ahead Market for the date 05.03.2019 are shown. EPİAŞ institution works as a energy markets in Turkey, in other words it is Turkish Energy Exchange market. Day Ahead Market (DAM) is an emerging market one day before the delivery day of electricity, organized and operated by the market operator. It is used for electricity trade and balancing activities. In the first case, it will be given the optimal prices for one hour when demand and supply shifting with random values by using Harmony Search Algorithm. These random values presents the effect of Blockchain usage in energy market. In other words, when Blockchain will start to be used, some of consumers will be prosumers. So the demand lines and supply lines will be shifted with assumed bandwidths. The goal of this case is to predicts new minimum prices with optimal shifting rates when these lines move. In the second case, it will be given the direction of prices when demand and supply shifting with random values. Random values also present the effect of Blockchain usage. This process is done 10000 times to support first case results. In last case, the random chosen supply and demand offers will be discarded for all day, and the new equilibrium prices of

the day 05.03.2019 will be shown.

4.2 Case 1

In this part, 3 optimization cases for following formula will be solved by Harmony Search Algorithm.

$$\begin{aligned} &\text{minimize} && P(i) \\ &\text{subject to} && \sum_{i=1}^{n} P_i = [Dt(n) - (\alpha_j * Dt(n))] - [St(n) + (\beta_j * St(n))] \end{aligned}$$

where

$$0 < \alpha_j < 0.01$$

$$0 < \beta < 0.01$$

$$\forall i, j \in N$$

$$P(i) > FC(i)$$

n: number of nth bid

$Dt(n)$: Demand total of nth bid

$St(n)$: Supply total of nth bid

α_j: Demand coefficient

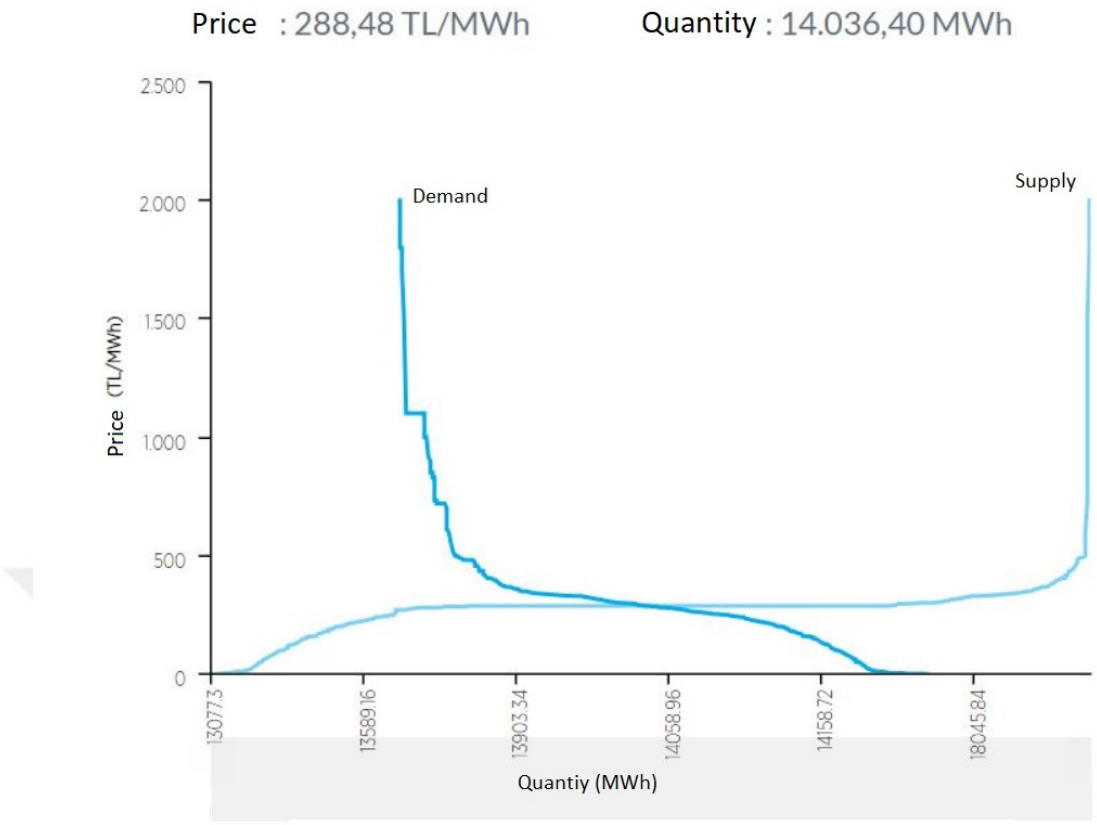
β_j: Supply coefficient

j: Number of trial

$FC(i)$: Fixed cost of producing one MWh

In this part, the demand quantities and prices, with supply quantities and prices for 00:00 on 05.03.2019 are taken from EPİAŞ (Epiaş, 2019). The real prices, quantities and equilibrium on 05.03.2019 at 00:00 are shown in Figure 4.4 (Epiaş, 2019).

Figure 4.4 Real Equilibrium of 00:00 on 05.03.2019



According to data, demand and supply lines reached to equilibrium with 288.48 TL/MWh price and 14.036,40 MWh quantity on 05.03.2019 at 00:00 (Epiaş, 2019). When blockchain applications are started to use demand line and supply line will be shifted. According to Logenthiran T., Srinivason D. and Shun T., Demand-side management (DSM) is one of the most important functions in a smartgrid network that enables customers to make informed decisions about energy consumption and help energy providers reduce the highest load demand and reshape the load profile (Logenthiran et al, 2012). In other words, demand optimization will be obtained by smartgrid infrastructure, supply of electricity will be used efficiently and demand line will be shifted to left side. In addition to this, prosumers will produce their electricity and their demand will be decrease. This also means that demand line will be shifted to left side, and because of increasing supply, supply line will be shifted to right. As a result, new demand line and new supply line will be reached a new equilibrium.

When determining new equilibrium point, the fixed costs of electricity production of power plants should be examined. Since no business will sell a property at a

price below its cost, the minimum selling price of electricity will be equal to its cost. National electricity prices are updated quarterly by Energy Market Regulatory Authority (EMRA). EMRA is responsible for determining energy and non-energy costs. Energy cost is the cost of production and, non-energy cost is the cost of distribution of electricity. In Turkey, there are different prices for houses and businesses in different time period of the day. The minimum unit price of electricity was determined as 0.3404 TL/kWh on 01.01.2019 for the first quarter. 51.9% of this price is separated for production cost, 28.8% of this price is separated for distribution and transmission, and the other share is separated for taxes, shares and funds (Gazelektrik, 2019). According to this information, production cost, and distribution and transmission cost are the fixed costs of power plants.

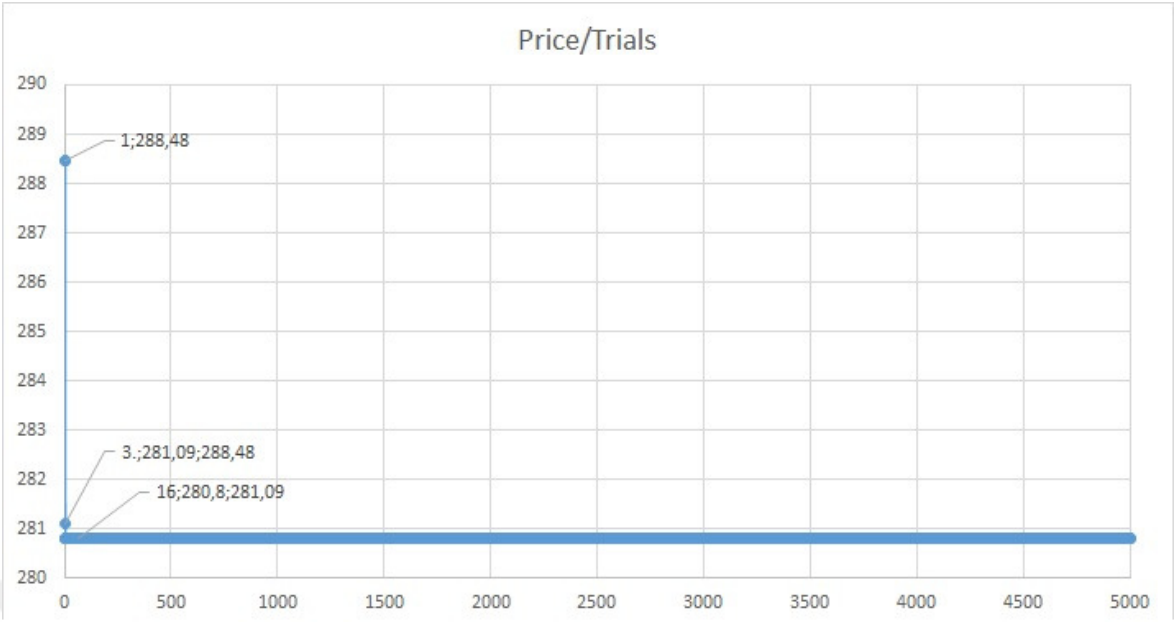
$$\mathbf{51.9 + 28.8 = 80.7} \text{ (The percentage of fixed costs of power plants)}$$
$$\mathbf{80.7/100 * 0.3404 = 0.2747TL/kWh} \text{ (The fixed costs in minimum price)}$$
$$\mathbf{0.2747 * 1000 = 274.7TL/MWh} \text{ (The fixed costs for one MWh)}$$

According to this calculation, new equilibrium price of electricity can not be below from the 274.7 TL/MWh. Different examples will be shown to guess new equilibrium price and quantity.

Example 1: If the demand values shifts to the left with a demand coefficient, a random number of between 0 and 1 percent, and the supply values shifts to the right with a supply coefficient, random number of between 0 and 1 percent, what will be the optimum value of demand and supply coefficients and minimum price by using Harmony Search Algorithm?

In the Harmony Search Optimization Algorithm, HMS is chosen as 30, Upper Limit is chosen as 0.01, Lower limit is chosen as 0.01 and HMCR is chosen as 0.5 with 5000 iteration. Emerging prices can be shown in Figure 4.5.

Figure 4.5 Optimized Prices of Example 1



According to results, new price of optimization algorithm is 280.8 TL/MWh with demand random coefficient is 0.0081 and supply coefficient 0.0095.

Example 2: If the demand values shifts to the left with a demand coefficient, a random number of between 0 and 1.5 percent, and the supply values shifts to the right with a supply coefficient, random number of between 0 and 1 percent, what will be the optimum value of demand and supply coefficients and minimum price by using Harmony Search Algorithm?

As mentioned above, Logenthiran T., Srinivason D. and Shun T. referred to Demand management systems. This will decrease the demand of electricity. In addition to this, prosumers will start to produce electricity. This will also be cause to decrease the demand of electricity and increase the supply of electricity. At this point, the left shift coefficient of demand may be higher than the right shift coefficient of supply. The result of the studies for demand optimization can shift the demand curve further to the left. In this example Upper Limit is chosen as 0.015 for demand, Upper Limit is chosen as 0.01 for supply , Lower limit is chosen as 0.01 for both with 5000 iteration. Emerging prices can be shown in Figure 4.6.

Figure 4.6 Optimized Prices of Example 2

According to results, new price of optimization algorithm is 275.75 TL/MWh with demand random coefficient is 0.01475 and supply coefficient 0.009845.

4.3 Case 2

In this part, like Case 1 the demand quantities and prices, with supply quantities and prices for 00:00 on 05.03.2019 are taken from EPİAŞ (Epiaş, 2019). Different coefficients cause the different demand line shifts and supply line shifts. As a result of 10000 trials, new demand curve, new supply curve and new prices and quantities are shown.

Example 1: If the demand shifts to the left with a random number of between 0 and 1 percent, and the supply shifts to the right with a random number of between 0 and 1 percent, what will be the result?
When the demand line shifts from 0 to 1 percent to the left by a randomly determined coefficient, and the supply line shifts to the right by a randomly determined coefficient between 0 and 1 percent, the new match price and quantity will decrease. As a result of 10000 trials, the best equilibrium price, in other words the lowest equilibrium price, is 280.8 TL / MWh and, the equilibrium amount of this price is

13.974,9 MWh with demand coefficient is 0.0095 and supply coefficient is 0.0085. End points of coefficients give also these results. These shifts can be seen in Figure 4.7.

Figure 4.7 New Equilibrium For Example 1

New Demand= Demand - (Demand * d)

d= Randomly determined coefficient

New Supply= Supply - (Supply * s)

s= Randomly determined coefficient

The price movement in the trials can be seen in Figure 4.8.

Figure 4.8 Price Movement For Example 1

According to the results, when Blockchain applications enter the energy sector in Turkey, the prices of EPİAŞ market may go down. As a result of the shifts in the demand and supply curves, between 0 and 1 percent, the new price will be 280.8 TL/ MWh which is higher than 274.7 TL / MWh , the fixed cost of the power plants.

Example 2: Provided that the new price will remain above the fixed cost, how many percent of supply and demand line can shift?

According to the price and quantity orders on 05.03.2019 at 00:00 (Epiaş, 2019), the minimum price above the fixed cost is 275 TL / MWh. At 275 TL / MWh price, quantity of demand is equal to 14.062,16 MWh and quantity of supply is equal to 13.709,37 MWh. To determine the percentage:

New Demand= Demand - (Demand * d)

d= Maximum coefficient

New Supply= Supply - (Supply * s)

s= Maximum coefficient

To find maximum coefficient ;

New Demand - New Supply value should be equal to 0

where s=d

Maximum coefficient will be equal to **0,0127**.

According the these result the new equilibrium price and quantity can be seen in Figure 4.9.

Figure 4.9 New Equilibrium For Example 2

The price movement in the trials can be seen in Figure 4.10.

Figure 4.10 Price Movement For Example 2

According to these results, it can be said that, a randomly coefficient for demand and supply can be determined between 0 and 1.27 percent. The equilibrium prices which obtained in these range, will be higher than the fixed cost of power plants. **Example 3:**If the demand shifts to the left with a random number of between 0 and 1.5 percent, and the supply shifts to the right with a random number of between 0 and 1 percent, what will be the result?

In this case, the demand line shifts from 0 to 1.5 percent to the left as a randomly determined coefficient, and the supply line shifts to the right as a randomly determined coefficient between 0 and 1 percent, the new match price and quantity will also decrease. As a result of 10000 trials, the best equilibrium price, in other words the lowest equilibrium price, is 276.75 TL / MWh and, the equilibrium amount of this price is 13.852,9 MWh with demand coefficient is 0.01475 and supply coefficient is 0.009845. End points of coefficients give also these results. These shifts can be seen in Figure 4.11.

Figure 4.11 New Equilibrium For Example 3

The price movement in the trials can be seen in Figure 4.12.

Figure 4.12 Price Movement For Example 3

As a result of the shifts in the demand and supply curves the new price will be 276.75 TL which is higher than 274.7 TL / MWh , the fixed cost of the power plants. In addition to this, when supply multiplier ranges from 0 to 1 percent, the demand multiplier can be up to 1.5 percent. If the demand multiplier rises to a value greater than 1.5 percent, the new equilibrium price occurs below the cost of power plant. In this case, the power plants may prefer not to produce.

4.4 Case 3

In this section, the supply and demand offers for all hours on 05.03.2019 are taken from EPİAŞ (Epiaş, 2019). Among these proposals, the sample was selected with a confidence level of 95%and a confidence interval of 1.96. The bids removed from the population can be assumed to be the offers to be withdrawn from the market with the implementation of the Blockchain applications. For the date 05.03.2019, 00:00, the calculations will be explained. Then, all results for that day will be shown in the table and graph.

05.03.2019 00:00

For 00:00, the equilibrium price and quantity was shown in Figure 4.4. Equilibrium price was 288.48 TL/MWh and equilibrium quantity was 14.036,40 MWh. According to data in EPİAŞ, there were 482 demand and supply bids at this hour. To choose sample with a confidence level of 95%and a confidence interval of 1.96

$\mathbf{ss} = ((\mathbf{zVal} * \mathbf{zVal}) * \mathbf{0.25})/((\mathbf{conInt}/\mathbf{100}) * (\mathbf{conInt}/\mathbf{100}))$(Sample Size Calculator, n.d.)

$\mathbf{ss} = \mathbf{ss}/(\mathbf{1} + (\mathbf{ss} - \mathbf{1})/\mathbf{pop})$ (Sample Size Calculator, n.d.)

$\mathbf{ss} = ((\mathbf{1.96} * \mathbf{1.96}) * \mathbf{0.25})/((\mathbf{1.96}/\mathbf{100}) * (\mathbf{1.96}/\mathbf{100}))$=2500

$\mathbf{ss} = \mathbf{2500}/(\mathbf{1} + (\mathbf{2500} - \mathbf{1})/\mathbf{482}) = 404$

where;

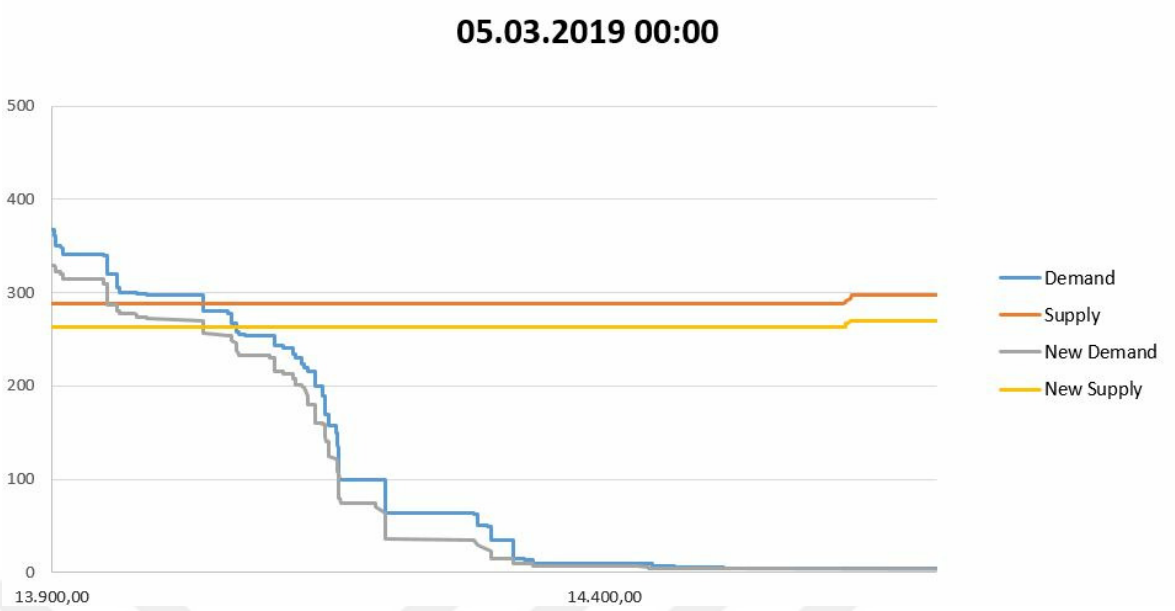
zVAl:Standard score of confidence interval

ConInt:Confidence level

ss:Sample size

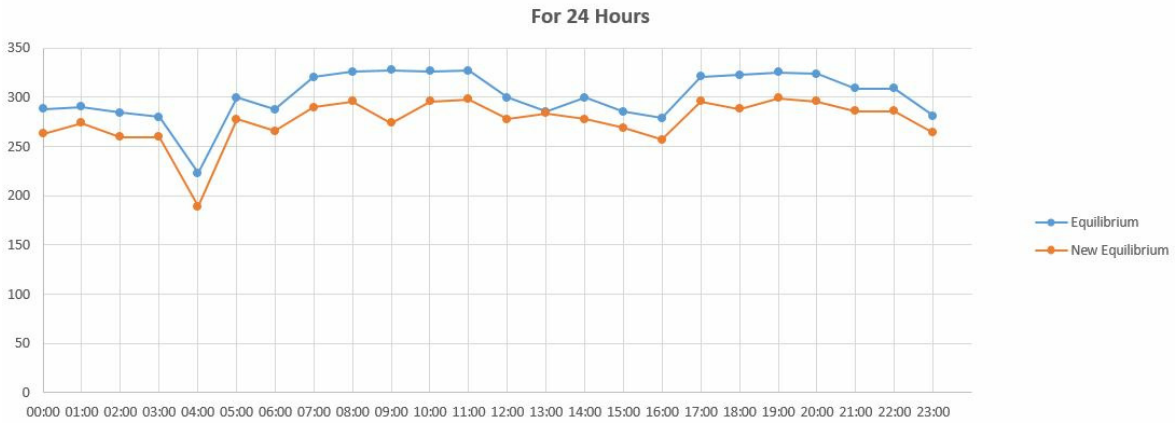
Among 482 different bids, 404 bids were chosen randomly with the assumption that 78 bids owner withdrawn from market. New demand line, new supply line, new equilibrium price and quantity can be seen from Figure 4.13.

Figure 4.13 New Equilibrium



As seen from the graph, new equilibrium price and quantity decreased. When this study implemented for all hours on 05.03.2019, the result will be like Figure 4.14.

Figure 4.14 All day



In this section, the supply and demand offers for all hours on 05.03.2019 were taken and, among these proposals, the sample was selected. According to graph, almost all of the equilibrium prices and quantities were decreased with 95% percent probability.

5. CONCLUSIONS

Energy consumption rates are increasing every year because of especially industrialization. Thus, renewable energy sources is increasing its importance day by day. Storage of excess energy which provided from these resources brings higher cost to producer, producers sell their excess supply to national grid on base of intermediaries technology. Then, smart grids which allow the energy trading between local areas are developed. Because of this, the new market, peer-to-peer trading market, is occurred for energy producers. Peer-to-peer market and smart grids decrease the energy losses which caused by costly storage, and provide an additional revenue to prosumers. Then, price is obtained from the market, in other words, not from national grids or intermediaries.

Location of renewable energy producers and smart grids are increase the importance of management of distribution areas. In other words, there is not a central mechanism, because of distributed energy producers. Thus, management of decentralization gains importance. In today's technology, blockchain technology is one of the practice method which manage this decentralization and distribution with its secure nature. In addition to secure structure, transparency, and auditable structure of blockchain give assurance to participants. This assurance makes the intermediaries unneeded. In shortly, peer-to-peer trading market on the basis of blockchain technology is occurred.

In the case of energy transfer in local areas with Blockchain, a new energy market will be added to the market formed between consumers and wholesale traders, and between wholesale traders and wholesale traders. Blockchain will optimize the energy market and create a new energy market between local consumers and pro-

sumers. In this new market, consumers and prosumers will be able to see real-time prices, supply and demand balance will be provided over the price formed in local markets, not on the price determined by wholesale traders. Consumers will be offered more options to buy electricity, and the need for centralized management will be reduced. Increased investments will strengthen this market. The microgrids to be established will connect consumers and prosumers within these markets. In the following years, removal of feed tariffs in many countries is one of the current research topics. It will be a profitable way for households to sell their electricity to each other instead of to a national grid.

A platform based on Blockchain technology allows these processes to be performed automatically. In this scenario, each household will have a battery, and will store the energy it generates in that battery. Households will be able to monitor their production, consumption and energy stored by smart meter. Since the local households are connected to the microgrids, the excess electrical energy exchange can be made via the microgrids via a platform based on blockchain technology. Thus, within the microgrids, production and distribution processes can be done independently and automatically. In addition to this process, the addition of intelligent contracts to this technology will accelerate the shopping process and, with the algorithms included in the contracts, the operational tasks of consumers and manufacturers will be reduced. With these contracts, consumers will be able to quickly select the type and source of the electricity energy they will receive.

In addition to these, according to case studies which is done in Turkey energy market, in this study, blockchain platform implementation to market may cause to decrease energy prices in energy market. In the light of the Demand-side management techniques and prosumers, the demand quantities in the market may decrease, at the same time, because prosumers produce their electricity in microgrids, supply quantities may increase. According to supply and demand graph, and Harmony Search Algorithm results, the equilibrium price between demand and supply quantities can decrease.

At the same time, along with other developing technologies, machines will also

communicate with each other. For example: the machines that consumers and prosumers use at home will begin to operate at times period when electricity is cheaper, or charge-powered devices will communicate with microgrid systems, and they will be charged on time period when electricity is cheap in the market. The devices will be connected to the network via smart meters or smart plugs. Together with these technologies, electricity usage and production will be optimized. Smart meters will make automatic use and automatic billing by means of smart contracts which using blockchain technology (Buth, 2018).

The formation of the new market will have a share in the whole market. When sufficient production cannot be achieved in local areas, consumers will likely continue to meet their energy needs from traditional producers. Moreover, although local production is a nice alternative to use in homes, it will probably be insufficient for large facilities. In other words, large plants, which consume a lot of energy, continue to meet their electrical energy needs from large producers. This will change the role of traditional producers in the market (Buth, 2018).

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APPENDIX A: SYSTEMATIC STUDIES

In this section, a general overview will be provided for current use of blockchain in energy trading industry as pilot projects and business models. Use cases of blockchain projects classified (Andonia et al, 2018).

- **Security, Metering and Billing Processes:** Blockchain technology, when integrated with the measurement infrastructure, offers automated billing for distributed production and consumption. In addition, it gives consumers information about the energy source and cost, the integration of the energy pricing process becomes more transparent, and finally the integration of the blockchain offers the ability to monitor the energy produced and consumed, which allows to customer and producer monitoring behavioral change, and making analyses about data. Moreover, integration with blockchain also can be used for identity management, and cyber security because of its cryptographic structure (Andonia et al, 2018).

  Bankymoon which is start-up company, tries to collaborate blockchain and its applications with banks and a provider of blockchain, is working on a system that integrates smart meters with Bitcoin, using blockchain technology. Smart contracts, which is an application of blockchain, allows automatic real time monitoring, payment and trading in electrical systems (Reserve Bank to begin testing Bitcoin and cryptocurrency regulations, 2018).

  Prosume, is a company that works to create blockchain platforms that can be used by energy producers, energy consumers and energy companies. It created a platform that can produce solutions to different needs, comply with regulatory rules, be suitable for intelligent measurement structure, can be used

for billing process, and uses blockchain technology (Prosume decentralising power White paper, 2017).

M-PAYG is a company that installs PV panels in apartment buildings in rural areas and explores blockchain technologies especially in developing countries. M-PAYG uses mobile payment channels, and works to provide pay-as-you-go services. M-PAYG works on blockchain-based solution applications that offer transparency, real-time monitoring and control of solar assets (Join us in democratizing access to energy, 2017).

In the cybersecurity field, technologies using the blockchain platform are being developed. Electron, an English start-up, is working on an intelligent meter recording platform for customers of electronic and gas, using cryptographic encryption techniques (Electron reveals blockchain energy platform, 2017).

Guardtime, which is a project financed by US Energy Department, has developed a blockchain product called the Keyless Signature Infrastructure (KSI). This product, which is validated by Hash algorithms instead of asymmetric cryptography, is used in verification processes. Guardtime is working on combining blockchain and cloud technologies for energy trading (Mylrea and Gourisetti, 2017).

When looked at these all system, a key point of them is smart meters. The availability of smart meters is key point for energy trading which using blockchain platform. In UK, some standards were published, SMETS2, for authorizing process of users who want to collect and distribute smart meters (Only 80 second generation smart meters have been installed- as rollout stalls again, 2018). However, integration smart meter with distributed ledgers will be an expensive process for countries, and at the development process of this integration, new standards will probably be published (Andonia et al, 2018).

- **Cryptocurrencies an Investments:** Cryptocurrencies are the popular products which uses blockchain platform. New cryptocurrencies which issued specifically for energy trading markets with some services, such as producing by renewable energy sources is rewarded with tokens, or more token will be given if least carbon intensive energy is produced to support green energy production

etc.

Businesses are now also using cryptocurrencies to attract investment and finance. For example: people who have a good idea, but no capital, are trading digital coins, such as Etherium, with their own digital coins. In this way they can find capital. This process is named Initial Coin Offer (ICO).

ImpactPPA can be shown as an example for this process. The goal of ImpactPPA is to develop a decentralized platform based on smart contracts and Etherium. ImpactPPA tries to collect funding for Renewable Energy Sources project. There are two energy token of this company, one of them is MPAQ, whose goal is to raise capital, and the other one is NGR which is used in energy transaction processes of consumers (The world's decentralized energy platform White paper, 2017).

Green energy wallet, is an another example which based on Etherium and smart contracts. Its goal is to find capital by using leasing processes of residential storage devices, such as EV batteries, to provide storage for overproduced energy from renewable energy sources (Commoditising forward purchase contracts in ultra-capacitor intellectual property rights on Ethereum blockchain, 2017).

There are also some companies which reward green energy and low carbon production such as SolarChange. SolarChange produced a cryptocurrency whose name is SolarCoin and, It gives one SolarCoin for every MWh solar energy. International Renewable Energy Agency (IREA) officially recognize this cryptocurrency (Solar Change, 2017).

- **Energy Trading in Decentralized Systems:** Decentralized energy trading is an attractive topic for blockchain technologies. Applications for energy trading, peer-to-peer energy trading, and wholesale energy market have been developed. Peer-to-peer energy trading can provide optimization in decentralized systems. In addition to these, Renewable Energy Sources (RES) , another benefit of decentralization process, not only provide additional revenue but also help to decrease cost of energy.

  Drift, which is company whose goal is to present cheaper electricity to its cus-

tomer by using smart algorithms like artificial intelligence or machine learning with blockchain technology in retail market. Customers can buy electricity from peer-to-peer providers or local conventional electricity providers (Drid clean energy without the premium price, 2018).

The Alva project which is a project for active network management system, works for link smart meters with Etherium blockchain. Metering data is used for smart contracts and transaction between participants included in distributed ledger. In addition to these, the operations of system can be monitored by mobile applications (Alliander, 2018).

Solar Bankers is a company that works to connect solar energy generators to the energy market. Established in Singapore, the company created the P2P energy trading platform. In addition to the protocols used, Solar Bankers developed a consensus protocol algorithm of its own. They claim that this protocol is more efficient and scalable than other protocols. This protocol, called Obelisk, works with SkyCoin running on the blockchain (Solar Bankers, 2018).

- **Peer-to-Peer Trading In MicroGrids:** There are some projects focused on making Peer-to-peer energy trade with Microgrids. LO3 Energy and TransActive Grid partnership is one of them. This partnership, created in New York City made the first transaction with Blockchain, which is among the neighbors who are producing electricity with PV (Peer to peer energy platform, 2018).

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  Power Ledger is a startup that uses blockchain technology in energy systems. It makes developments in the peer-to-peer market among consumers and prosumers in Australia. Power Ledger managed to take steps to generate additional income to the prosumers that produce energy with PV. In addition to these, the partnership between Power Ledger and Vector Energy, which is one

of the largest energy distribution company In New Zealand, implemented a peer-to-peer energy trading market which use blockchain technology in Auckland (Andonia et al, 2018).

The partnership of Alliander and Spectral Energy companies in Amsterdam, developed a peer- to-peer energy platform on the base of permissioned and private blockchain technology. An energy token which name is Spectral is used for peer-to-peer energy transactions. Energy is produced by Photovoltaic (PV) panels and exchanged within smart grids. Moreover, platform can be monitored real time and artificial intelligent algorithms is using for predicting consumption and production (Spectral Energy, 2018).

Bouygues Immobilier is a project which developed in France, also tries to develop energy trading between solar producers and consumers who stay in different flats of a building, on the basis of Blockchain technology. In this project, blockchain is used in authentication and verification processes of produced energy. In addition, Smart contracts are used for derivation of geolocation nodes to make calculation about energy losses in transaction process (Bouygues Immobilier , 2018).

APPENDIX B: CONSENSUS PROTOCOL TYPES

In consensus protocols part the most used protocols in blockchain are shown. The other protocols which are used also in blockchain technology like that:

- **Proof of Elapsed Time (PoET):** PoET concensus mechanism is used on a permissioned blockchian, which means every node must be accepted into the network and they must be identifiable. In this mechnasim, there is 'timer' boundary for each node. A random waiting time period is assigned for every node in network and the first node gets to commit new block which is next, to finish waiting. It is believed that PoET is more energy efficient than the others (9 Types of Consensus Mechanisms That You Didn't Know About, 2018).
- • **Proof of Capacity (PoC):** There is two different step in Proof of Concept, plotting and mining. In plotting step, all possible solutions to hashing algorithm are determined, and then mining process is starts. The goal is to provide shortest solution to mining algorithm. It is believed that, PoC use less energy than bitcoin transactions (9 Types of Consensus Mechanisms That You Didn't Know About, 2018).
- **Delegated Proof-of-Stake (DPoS):** Delegated proof of stake is an alternative to proof of stake protocol. In the Delegated Proof-of-Stake (DPoS) protocol, money holders vote and the delegates are appointed as a result of this voting. Delegates are responsible for approval of transactions and protection of the block chain (Asolo, 2018).
- **Proof of Importance (PoI):** Proof of importance is also a blockchain consensus algorithm. The Proof of importance is the mechanism used to determine which nodes are suitable for adding a block to the blockchain. This process is called harvest in this protocol. Harvesting blocks take a share from the oper-

ation. Accounts of high importance are more likely to be selected to harvest a block (Asolo, 2018).