OPERATION AND CONTROL OF MICROGRID SYSTEMS BY USING HEURISTIC METHODS

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Master's Thesis

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Programme in Electrical Installations

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ABSTRACT

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Electrical energy is important to fulfill people's needs with developing technology. Electrical energy is reacquired to be uninterruptible and clean energy. Carbon gas emissions should be reduced since global warming increases. Instead of fossil fuels, renewable energy sources (RES) should be preferred to generate clean electrical energy. Solar energy, wind energy can be used. At this point, a grid-connected microgrid (MG) system with integrated RES is a useful choice for pollution.

This thesis includes three parts which are optimization, control, and comparison with different situations in the MG system. Firstly, optimization techniques are searched for the applied MG which are analytical, heuristic, and metaheuristic methods. These are separated from each other from the point of the approach. Metaheuristic optimization techniques Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) are preferred to find the optimal solutions since these methods are efficient methods to solve complex MG systems. Secondly, Control methods are investigated to apply in MG systems which are centralized, decentralized, and distributed control. A control strategy is applied for the designed MG system distributed control methodology which is a combination of centralized and decentralized control methodologies is used.

Finally, a grid-connected MG system is solved by using two different optimization techniques (PSO-GA) and results are compared with each other. Results were demonstrated PSO is better than GA. Uninterruptible and clean energy has been aimed at the integration of RES.

Keywords: Microgrid, Particle Swarm Optimization, Genetic Algorithm, Distributed Control, Renewable Energy Sources.

ÖZET

MİKRO ŞEBEKE SİSTEMLERİNİN SEZGİSEL YÖNTEMLER KULLANILARAK İŞLETİMİ VE KONTROLÜ

CANAN SAKALLI

Elektrik-Elektronik Mühendisliği Anabilim Dalı

Elektrik Tesisleri Bilim Dalı

Eskişehir Teknik Üniversitesi, Lisansüstü Eğitim Enstitüsü, Nisan 2021

Danışman: Doç. Dr. ÜMMÜHAN BAŞARAN FİLİK

Gelişen teknoloji ile insanların ihtiyaçlarını karşılamak için elektrik enerjisi önemlidir. Elektrik enerjisi kesintisiz ve temiz enerji olarak yeniden elde edilir. Küresel ısınma arttığı için karbon gazı emisyonları azaltılmalıdır. Temiz elektrik enerjisi üretmek için fosil yakıtlar yerine yenilenebilir enerji kaynakları (YEK) tercih edilmelidir. Güneş enerjisi, rüzgâr enerjisi kullanılabilir. Bu noktada, entegre YEK ile şebekeye bağlı bir mikro şebeke (MŞ) sistemi, kirlilik için yararlı bir seçimdir.

Bu tez, optimizasyon, kontrol ve MŞ sistemindeki farklı durumlarla karşılaştırma olmak üzere üç bölümden oluşmaktadır. İlk olarak, uygulanan MŞ için analitik, sezgisel ve meta-sezgisel yöntemler olan optimizasyon teknikleri araştırılmıştır. Bunlar yaklaşım açısından birbirinden ayrılmıştır. Meta-sezgisel optimizasyon teknikleri Parçacık Sürü Optimizasyonu (PSO) ve Genetik Algoritma (GA), bu yöntemler karmaşık MŞ sistemlerini çözmek için etkili yöntemler olduğundan, en uygun çözümleri bulmak için tercih edilir. İkinci olarak, kontrol yöntemleri merkezi, merkezi olmayan ve dağıtılmış kontrol olan MŞ sistemlerine uygulanmak üzere araştırılmıştır. Tasarlanan MŞ sistemi dağıtılmış kontrol metodolojisi için, merkezi ve merkezi olmayan kontrol metodolojilerinin bir kombinasyonu olan bir kontrol stratejisi uygulanır.

Son olarak şebekeye bağlı bir MŞ sistemi, iki farklı optimizasyon tekniği (PSO-GA) kullanılarak çözülmüş ve sonuçlar birbiriyle karşılaştırılmıştır. PSO'nun GA'dan daha iyi sonuç verdiği görüldü. YEK'in entegrasyonunda kesintisiz ve temiz enerji hedeflenmiştir.

Anahtar Sözcükler: Mikro Şebeke, Parçacık Sürü Optimizasyonu, Genetik Algoritma, Dağıtılmış Kontrol, Yenilenebilir Enerji Kaynakları.

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I would like to give thanks to my parents for their prayer, encouragement, and support at all times.

CANAN SAKALLI

19/04/2021

STATEMENT OF COMPLIANCE WITH ETHICAL PRINCIPLES AND RULES

I hereby truthfully declare that this thesis is an original work prepared by me; that I have behaved in accordance with the scientific ethical principles and rules throughout the stages of preparation, data collection, analysis and presentation of my work; that I have cited the sources of all the data and information that could be obtained within the scope of this study, and included these sources in the references section; and that this study has been scanned for plagiarism with “scientific plagiarism detection program” used by Eskişehir Technical University, and that “it does not have any plagiarism” whatsoever. I also declare that, if a case contrary to my declaration is detected in my work at any time, I hereby express my consent to all the ethical and legal consequences that are involved.

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GLOSSARY OF SYMBOLS AND ABBREVIATIONS

AC	:	Alternating Current
CHP	:	Combined Heat and Power
DC	:	Direct Current
DER	:	Distributed Energy Resources
DG	:	Distributed Generator
GA	:	Genetic Algorithm
IEEE	:	Institute of Electrical and Electronics Engineers
MG	:	Microgrid
MPPT	:	Maximum Power Point Tracking
MV	:	Medium Voltage
PLL	:	Phase Locked Loop
PSO	:	Particle Swarm Optimization
PQ	:	Active-Reactive Power
PV	:	Photo Voltaic
RES	:	Renewable Energy Sources
SCADA	:	Supervisory, Control and Data Acquisition
VCM	:	Voltage Control Mode

1. INTRODUCTION

Electrical energy is vital for people's life with developing technology. Using of electrical devices which are the mobile phone, computer, washing machine, refrigerator, and so on is increased in daily life. Electrical energy is needed to work electrical devices. There are some steps respectively to get and use this energy, which are generation, transmission, and distribution. Fossil fuels are commonly used in the generation step which are non-renewable energy sources with adverse effects on the environment (Springer, 2019) (Başaran Filik, Filik, & Gerek, 2015). RES can be preferred instead of non-renewable energy sources. Renewable energy types like solar energy, wind energy, and the main grid combination of MG systems have great importance at this point.

There have been a lot of research about MG systems recently (Guerrero, A survey on control of electric power distributed generation systems for microgrid applications, 2015). The main goal of the researches is to control and manage the energy systems systematically. In addition to this, to go towards using RES and to allow regenerating of the environment are the aims. MG systems have a lot of different energy types so these systems contribute to providing uninterruptible energy.

A big-scale of MG can be sometimes more complex and has a lot of parameters. So, control and optimization are important steps to design an MG. Centralized, decentralized, and distributed control are control types of MG. Communication of MGs can be needed in the future, so a centralized method is not effective (Cao, 2014). In addition to this, there are a lot of optimization techniques. Metaheuristic methods PSO and GA are used to perform the optimal analysis commonly in MG.

A MG system controlling and optimization are the main components to protect the environment and to provide uninterruptible energy.

1.1. Literature Review

There are a lot of studies and experiments to optimize and control of MG systems. Such as:

In Ref (Hakimi, 2019), the topic is about economy and PSO in MG systems. It is focused on demand calculations. MG components before and after situations are compared. In conclusion, PSO is an important method for DGs economic dimension.

In Ref (Zhu, 2019), a MG project is designed in a rural area that has a problem of unstable hydropower. As a result, MG is an important way of adding renewable energies, controllable and financial support.

In Ref (Demirtaş, 2019), using probabilistic programming method for Gazi Teknopark, energy production estimation is applied. The results show that using a probabilistic programming method increases the generation of solar energy.

In Ref (Lai, 2018), a control mechanism is developed in AC MGs to provide voltage regulation and reactive power-sharing. IEEE 34 bus system is used. As a result, overall control is the recommended data strategy.

In Ref (Romero, P., S´anchez-Braza, & Galyan, 2020), atmospheric CO_2 is increased by %70 by using fossil fuels which are used in the energy sector generally. Electricity is a form of energy, so using renewable energy was encouraged with Paris Agreement. The countries which were accepted Paris Agreement have followed the CO_2 ratio by increasing the use of renewable energy.

In Ref (Stürmer, Theuretzbacher, & Saracevic, 2020), in Austria which had the first electricity grid, around 300 biogas plants are installed to focus on green electricity production. As a result, the share of renewable electricity generation is increased and costs are reduced.

In Ref (Ajaz & Bernell, 2020), a pioneer of energy system innovations and clean energy in California. Clean energy can be provided from solar, geothermal, and biomass resources. MG systems are available for clean energy. MGs effect by landscape factors, climatic changes, economic, and cultural situations. In addition to this, disasters, extreme events, and cybersecurity threats can occur. As a result, a symbiotic relationship between the government and supporters of MGs is important.

In Ref (Hassan & Abido, 2010), an inverter-based MG which has optimal autonomous control is designed. Control parameters are get with the PSO technique which is very useful for controlling and providing system stability.

In Ref (Liang & Gooi, 2010), one of the complex optimization problems is the unit commitment problem in power systems. In this paper, conventional GAs and improved GAs are compared. As a result, the improved GA shows advantages. One of the advantages is time.

In Ref (Guerrero, A survey on control of electric power distributed generation systems for microgrid applications, 2015), electrical energy demand is increasing nowadays. So, RES is increased to use in electrical grids. In addition to this, RES reduces using of fossil fuels and do not damage the environment. Mainly, MGs consist of energy sources, power electronic converters, energy storage systems, and local loads. Converters are an interface between MG and the other devices. Control is important for MG systems. There are three control classes which are primary control (droop control), secondary control (synchronization, voltage-frequency control), tertiary control (PQ control). In the future, MG technology will be used advanced decentralized control techniques.

In Ref (Naderipour, 2020), generating greenhouse gases is increasing so global warming occurs. To solve this problem using distributed energy sources is a solution. In this study, to generate power is used combined heat and power (CHP) system. PSO is implemented to 84 and 32 bus standard MGs. Reducing losses and improving the voltage profile are the main issues. In addition to this, PSO is compared with GA to confirm the results.

1.2. The Purpose and Methodology of the Thesis

The purpose of this thesis is to operate and control of MG systems. To realize this purpose, the methodology is listed:

- Modeling and simulation of MG system

- Implementation of PSO and GA methods in MATLAB/Simulink to provide the optimal analysis.

- Control of MG system.

- Examination and comparison of the simulation results.

1.3. Thesis Structure

This thesis is constructed as 5 chapters.

In chapter 1, the purpose, methodology, and structure of the thesis are explained. Experts' reviews are included about the thesis theme.

In chapter 2, MG systems, components, types, and applications are given.

In chapter 3, MG optimization and control methods are explained.

In chapter 4, simulation results are shown.

In chapter 5, conclusions and contributions of the thesis are presented.

2. ABOUT MG SYSTEMS

MG is a system that allows a group of distributed RES connected to work synchronously by integrating into the basic grid. MG can be connected or islanded mode from the grid. MG structure is presented in Figure 2.1.

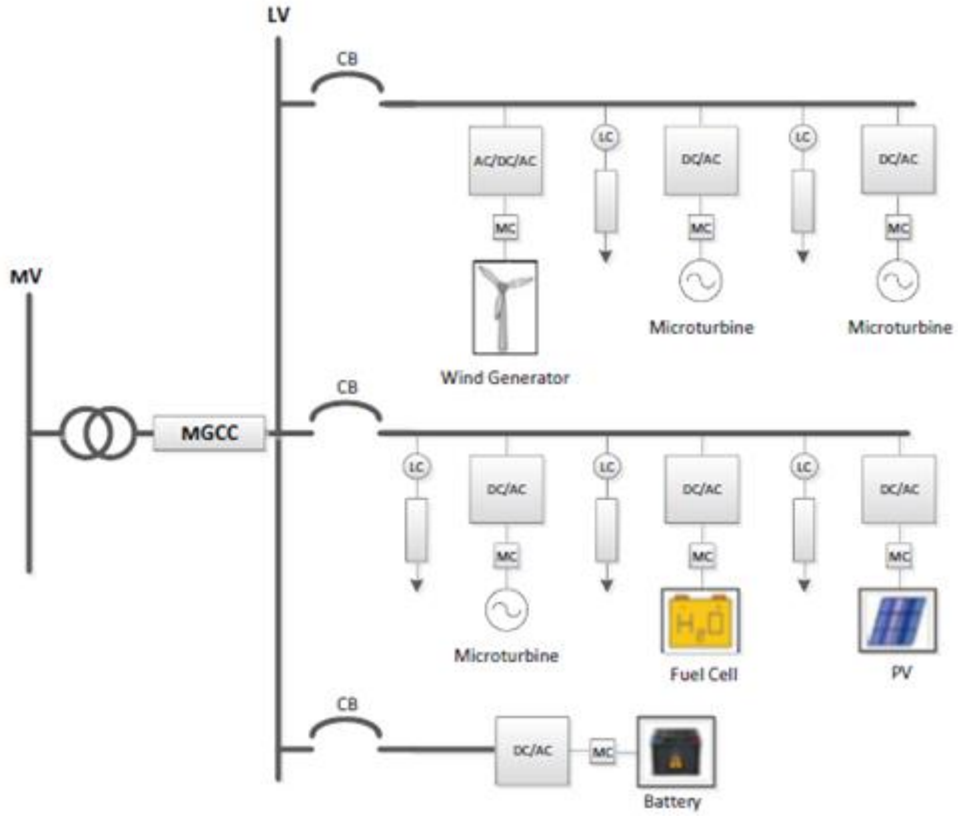


Figure 2.1. *MG structure (Springer, 2019)*

MG should be confirmed the below options:

- Energy efficiency provider

- If micro sources can be used in electrical requirements, using heat will be optimized

- MGs work compatible with utility

- Decrease losses of the system.

- Increase the distribution system and local comfortability

- Wind and solar systems can be used more effectively than the old systems

- Types of power can be transferred between MG and distribution systems.

- There is no problem in connection or disconnection.
- If system faults occur, MG can operate itself.

2.1. History of MG Systems

MG concept is very old. The first electrical utility was established by Thomas Edison in approximately 1880, in New York. This utility had a 27-ton steam generator and 82 local customers and had no connection to the main utility. The first and oldest version of the MG can be said Thomas Edison’s electrical utility (Schewe, 2007) which is shown in Figure 2.2.

Figure 2.2. *Thomas Edison’s electric utility (Pourbabak, Chen, Zhang, & Su)*

The first electrical grid operating with alternating current was established in 1886 by Great Barrington in Massachusetts. After, economic and efficient transmission of high voltage electricity over long distances became possible as a result of Tesla and Westinghouse's studies on alternating current (AC). The average age of power plants is 35 years. Local networks developed over time and interconnected and created interconnected networks in the 20th century. The electrical grid had grown in developed countries until the 1960s. Electrical demand increased considerably between 1970-1990. For this reason, the number of power plants has also increased. The electrical demand model was established to shape the electrical demand towards the end of the 20th century. Countries such as China, India and Brazil have been the pioneers of smart grids in the 21st century.

2.2. Advantages and Disadvantages of MG Systems

The advantages of MG systems are listed below:

- If there are disturbances in the grid, there will be no interruption in the system by using MGs which can be isolated itself from the system.

- Optimize all of the systems.

- If consumption increases, MGs can be balanced load with utility.

- There is no carbon emission in energy sources because of the using RES.

- Increase energy efficiency because of the closing between consumer and energy sources.

- MGs can be able to decrease consumer energy cost.

- Increase power quality of the critical loads.

The disadvantages of MGs are listed below.

- High cost

- Engineering needs

- Enhancing the connections between standards

- Challenge’s control and protection hardware of MGs

- Difficulty of the synchronization.

2.3. MG System Components

2.3.1. Distributed Energy Resources (DER) in MGs

One of the MG components is DER which include solar energy, wind energy, heat energy, fuel cell, combine heat and power, etc.

In MG, DER increases efficiency and reduces electricity cost and carbon footprint. In addition to this, DER improves power quality and reliability at load points.

2.3.1.1. Wind energy

Wind energy is a renewable energy type that converts mechanical energy to electricity by using wind. One of the components to get wind energy is a wind turbine. The wind turbine has blades that turn between 13-20 revolutions per minute. The velocity of the blades can be changed according to wind velocity and using technology. A wind turbine structure is presented in Figure 2.3.

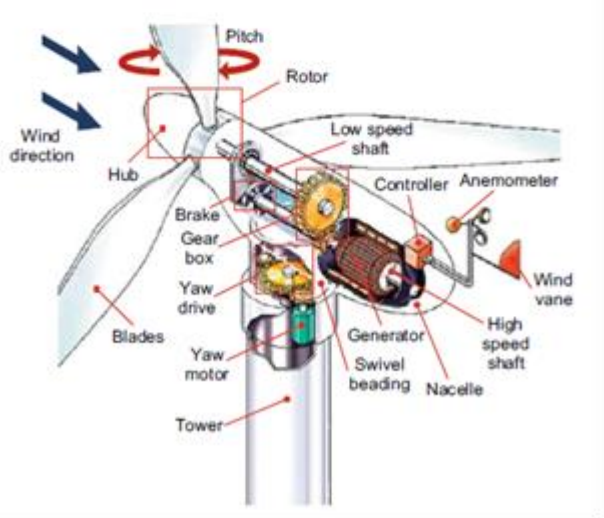


Figure 2.3. *Wind turbine structure (Molina & Alvarez, 2011)*

2.3.1.2. Solar energy

Solar energy is a renewable energy type that gets by converting sunlight into electricity. Solar energy is clean and reliable which can be using industry, livestock, etc. In addition to this, solar energy can be stored or used directly or connected to a utility.

Solar energy components are explained. Converting sunlight into DC electricity component is PV Module. The solar charge controller arranges the voltage and current from the PV panels to the battery, preventing the battery from overcharging and extending the battery life. The inverter is a type of converter that converts the DC output of PV panels or wind turbines to AC for AC devices. A battery is a type of storage device to supply electrical devices.

2.3.1.3. Fuel cell

Fuel Cells; It is an electrochemical mechanism that transforms the chemical energy of the fuel and oxidizer used into electrical energy through the unchanged electrode-electrolyte system without burning. They operate far below the emissions specified by the standards with high efficiency. They work like a battery, but they need a constant fuel supply. This fuel is hydrogen usually. Another name for fuel cells is cell. Fuel cells are silent and reliable since they do not contain moving parts (Çavuşoğlu).

2.3.1.4. Combine heat and power

Combine heat and power is an energy type that converts gases or bio-oil fuels to electrical and thermal energy at the same time. It can be used in space heating, cooling, domestic hot water, and industrial processes.

Heat is wasted in conventional electrical energy generation with the transmission. Instead of this method, combined heat and power can be used for needs electrical and thermal energy (https://www.epa.gov/chp/what-chp#:, tarih yok).

2.3.2. MG Storage

If a generation is not sufficient, demand fulfills from storage devices like batteries, capacitors. Storage can supply MGs in a short period, reduce network losses. An example of a battery is demonstrated in Figure 2.4.

Figure 2.4. *Battery (https://www.sanerticaret.com/urun/200-amper-aku-carbon)*

There are various storage types which are categorized especially electrochemical and battery storage, flywheel energy storage etc.

Batteries and capacitors are electrochemical energy storage devices. Natural energy storage devices are batteries which have high energy densities and high voltages. In addition to this, capacitors which are supercapacitors and ultra-capacitors, store and deliver energy. They have high storage efficiency (>95%).

Ultra-capacitors are energy storage devices like a battery but there is a difference between them that ultracapacitors can achieve higher power densities over a shorter time duration. In addition to this, they are used in electric vehicle charge stations recently.

High power demands and transients' control is efficient in ultra-capacitors (https://www.electronics-tutorials.ws/capacitor/ultracapacitors.html, tarih yok).

Cost, energy density, power density, cycle life, and safety are important factors for batteries. Capacitors can be self-discharge so it is a disadvantage. Battery and capacitor combination is very popular in researches. If batteries and supercapacitors are compared, batteries can store up to 30 times more charge per unit mass than supercapacitors.

Redox flow battery is a type of electrochemical energy storage device which is suitable for utility-scale renewable energy storage applications. Hybrid battery is a combination of conventional batteries and redox flow batteries.

Flywheel energy storage is a kinetic energy storage which converts mechanical energy to kinetic energy. Permanent magnet machines have high efficiencies, high power densities, and low rotor losses. So permanent magnet machines are used for flywheels. If flywheel energy storage system is compared with batteries and supercapacitors, flywheel energy storage system has some disadvantages such as cost, noise, and maintenance efforts (Rosen, 2019). Flywheel energy storage system structure is presented in Figure 2.5.

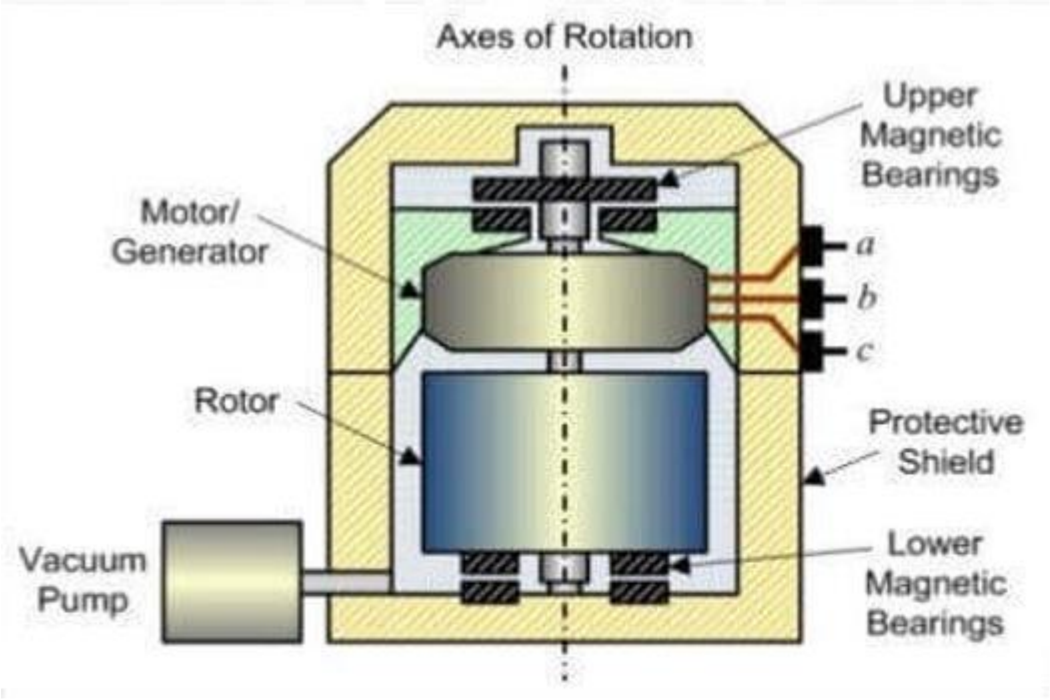


Figure 2.5. *Flywheel energy storage system structure (https://electricalfundablog.com/flywheel-energy-storage-calculations-rotor/)*

2.4. MG Types

There are three types of MGs which are AC, DC, and AC-DC hybrid MGs.

2.4.1. AC MGs

In an AC MG, there is an AC bus which has connected to distributed generators (DGs) and energy storage systems. This system can be expanded. In addition to this, inverters are needed.

- The advantage of AC MGs is that circuits are simple.
- The disadvantage of AC MGs is that inverters make the system less efficient.

An example of an AC MG is demonstrated in Figure 2.6.

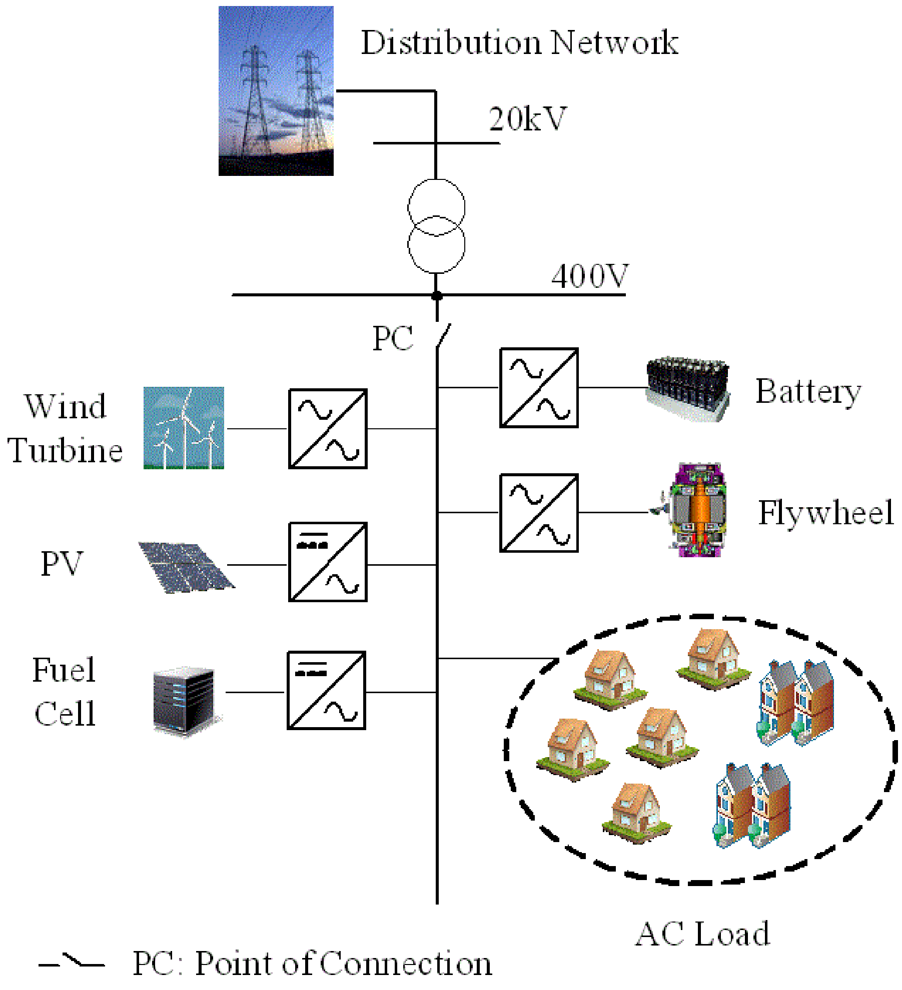


Figure 2.6. *Example of AC MG (https://electricala2z.com/electrical-power/microgrid-advantages-structure-applications/)*

2.4.2. DC MGs

There is a DC bus in DC MG. DC bus has used with low power consumption loads like mobile phones, computers generally.

- The advantage of DC MG is that this system doesn't need inverters. So cost is reduced. Line losses are less than AC MG. Control is simpler than AC MG.
- The disadvantage of DC MG is that system expanding is difficult. In addition to this, if there is a work accident, DC electric is more dangerous than AC electric.

DC MG example is demonstrated in Figure 2.7.

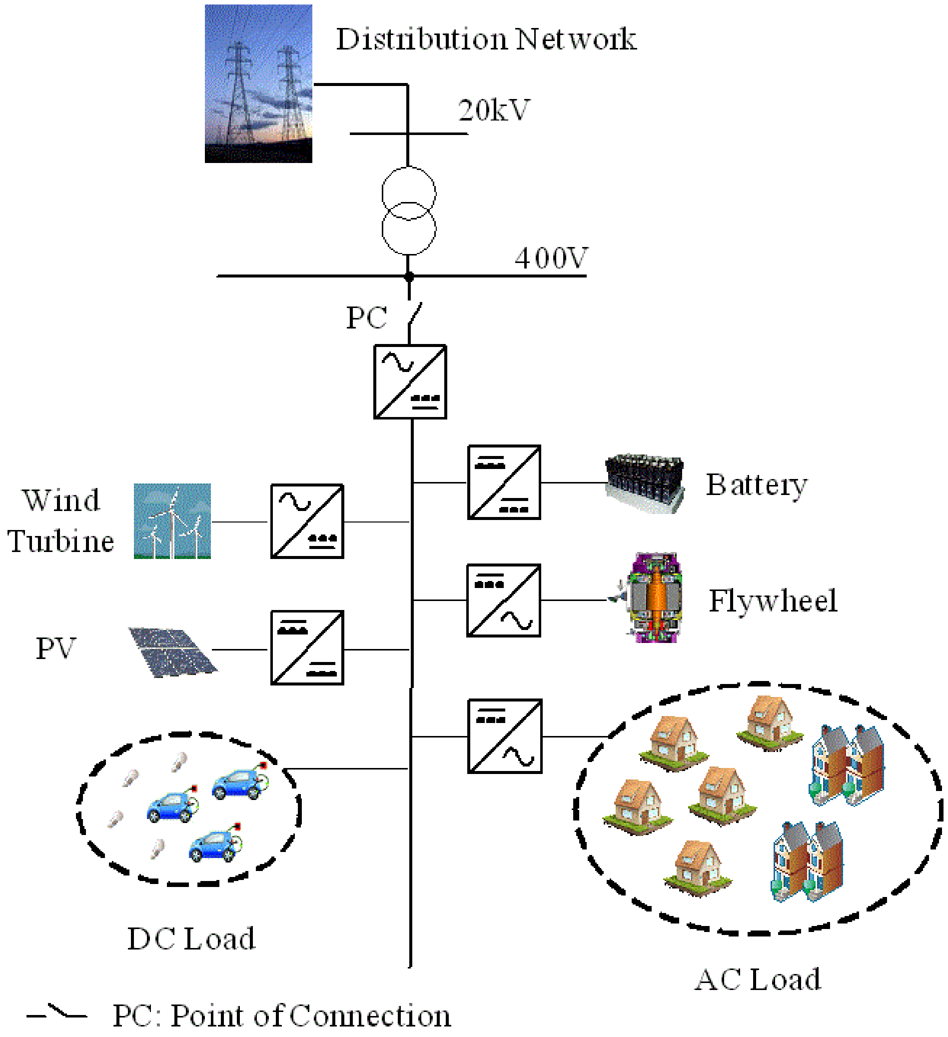


Figure 2.7. *Example of DC MG (https://electricala2z.com/electrical-power/microgrid-advantages-structure-applications/)*

2.4.3. Hybrid AC-DC MG

A combination of AC and DC MG is called a hybrid MG. AC DER and loads are linked to AC buses. DC DER and loads are attached to DC buses. A hybrid AC-DC MG example is demonstrated in Figure 2.8.

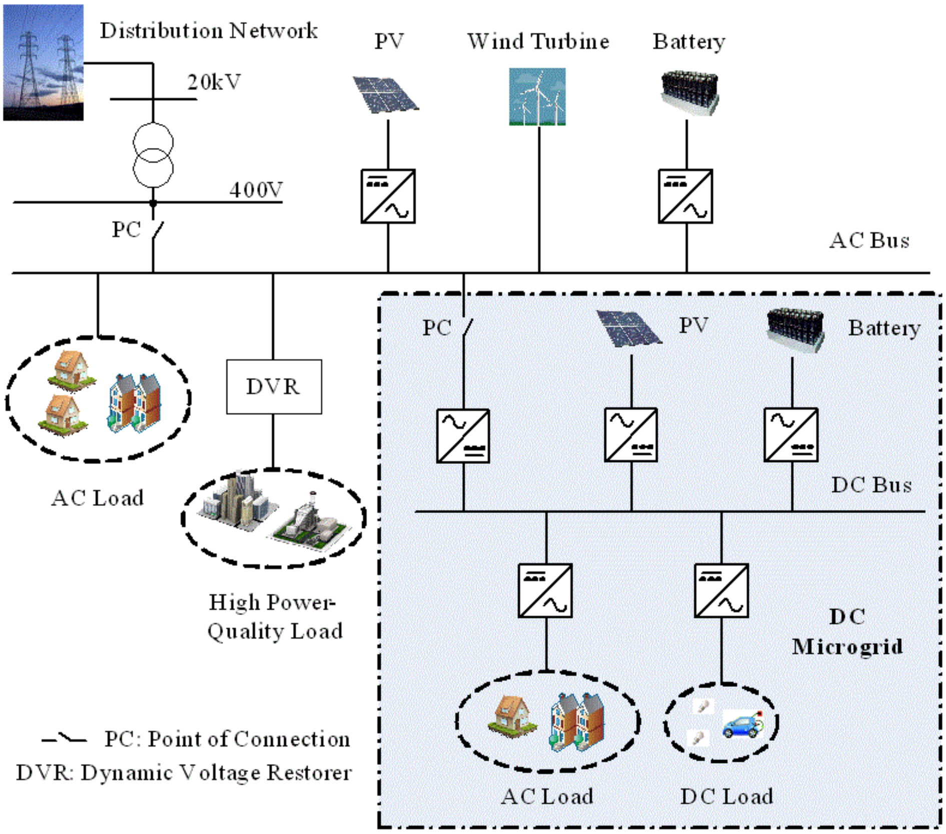


Figure 2.8. *Example of Hybrid AC-DC MG (https://electricala2z.com/electrical-power/microgrid-advantages-structure-applications/)*

2.5. MG Applications

MG can be applied with different components and structures. So, four groups can be obtained.

2.5.1. Independent MG

The independent MG is applied in far areas usually. So, this is difficult and expensive. MG components should be suitable for local environmental conditions. If wind and solar energy are sufficient, a combination of MG with wind turbines, PV arrays, diesel generators, and batteries can be used in isolated mode.

2.5.2. Renewable energy-dominated MG

This MG type is applied in areas with a high RES. Mainly composed of wind, solar energy, and batteries are used in grid-connected mode.

2.5.3. Integrated energy MGs

This MG type is applied in areas with diverse energy sources and demands. It is usually used in large public buildings, schools, and hospitals. Examples of different demands are cooling, heating, and electricity demands. Purposes of this MG type are to provide energy-saving technology and improve efficient energy using.

2.5.4. Highly integrated MGs

It is important for smart distribution networks. If DGs are connected to distribution network directly, DGs cannot supply loads independently. So, DGs have to close when there are faults in the distribution work. In addition to this, if there is a fault, the other generators can supply the system by using substation-type MGs. A highly integrated MG example is shown in Figure 2.9.

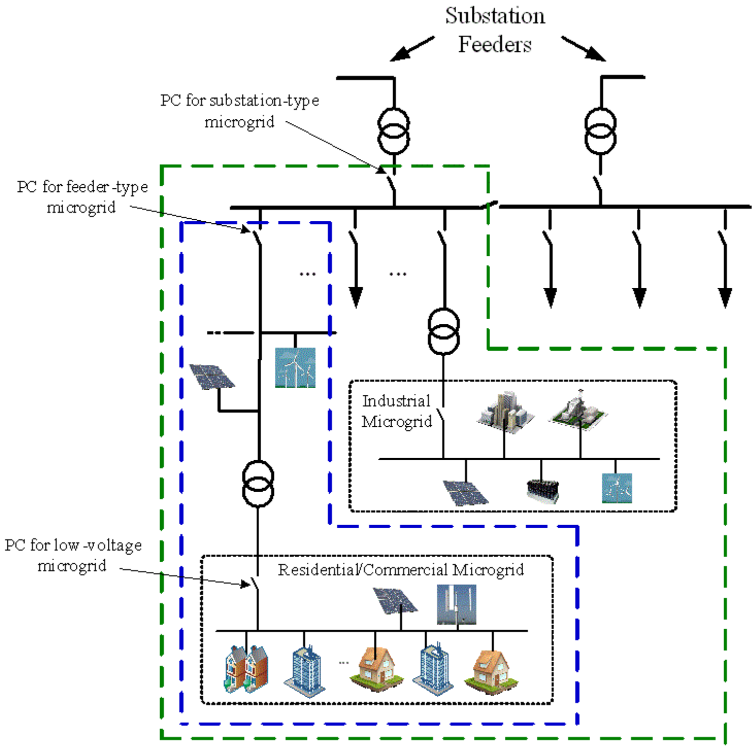


Figure 2.9. *Highly integrated MG example (https://electricala2z.com/electrical-power/microgrid-advantages-structure-applications/)*

3. MANAGEMENT OF MG SYSTEMS

3.1. Optimization Methods of MG

There are three types of optimization methods.

3.1.1. Analytical Methods (mathematical modeling, branch-bound algorithm ...)

Analytical methods give the optimum solution within tolerances but in large-scale problems, it takes too long to achieve results or cannot be achieved. The analytical method example is presented in Figure 3.1.

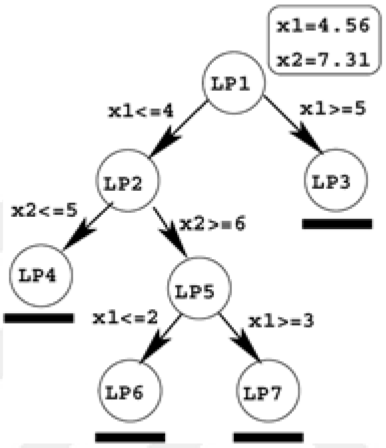


Figure 3.1. *Analytical method example (A-sketch-of-the-working-principle-of-the-branch-and-bound-method-for-a-twovariable_fig1_220742933)*

3.1.2. Heuristic Methods

Heuristic methods are solutions for specific problems. They follow a specific algorithm. Although they do not guarantee the optimum solution, they produce faster solutions than analytical methods. For example, Johnson algorithm for flow-type scheduling problems, Greedy Algorithm for travelling salesmen problem. The heuristic method example is shown in Figure 3.2.

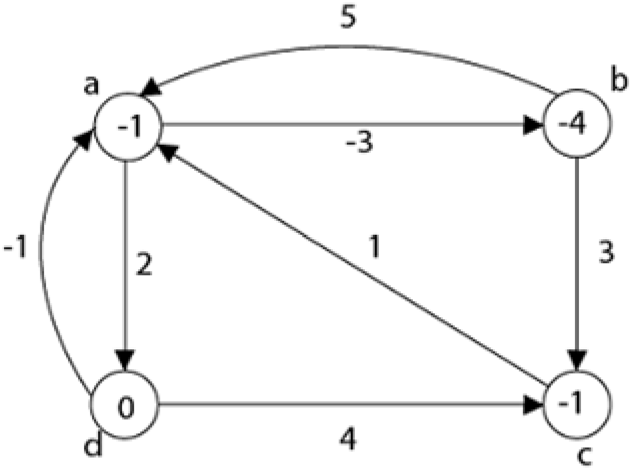


Figure 3.2. *Heuristic method example (javatpoint.com/johnsons-algorithm)*

3.1.3. Metaheuristic Methods

It is the solution method obtained by adapting certain algorithms to the problem structure that can be solved. For example, GA, ant colony algorithm, PSO technique. Metaheuristic method example is shown in Figure 3.3.

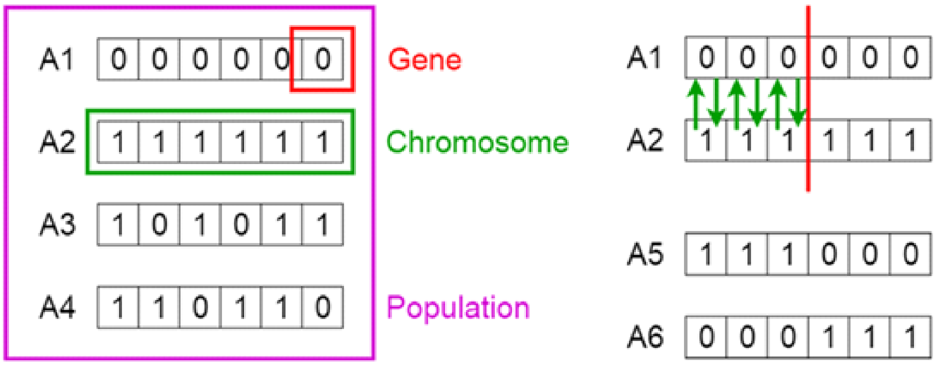


Figure 3.3. *Metaheuristic method example (towardsdatascience.com/introduction-to-genetic-algorithms-including-example-code-e396e98d8bf3)*

3.1.3.1. PSO technique

Bird or fish population behaviors are the basis of the PSO technique. By using this technique, optimal parameters are found for the system

On the basis of this algorithm, there are lots and particles that are each individual of the flock. Each particle adjusts its position to the best position in the flock, using its previous experience. Other particles update their movement according to the individual of the herd who has the best position at the moment. This approach speed is a randomly developing situation, and generally, the particles are in a better position in their new movements than the previous one. This process continues until it reaches the goal.

$$v_{k+1}^{i} = wv_{k}^{i} + c_1 rand \frac{\left(\rho^{i} - x_{k}^{i}\right)}{\Delta t} + c_2 rand \frac{(\rho_{k}^{g} - x_{k}^{i})}{\Delta t} \tag{1}$$

The velocity (V) formula of the particle i at time k + 1 is given above in Equation 1. W indicates the inertia factor which should be 0.4 to 1.4 range. C_1 is the own coefficient of the particle which should be 1.5 to 2 range. And C_2 is the flock dependent coefficient which should be 2 to 2.5 range. The best part of P_i particle P_{gk} is the best part of the flock. These values are multiplied by a random number and the next move is determined. With this movement, the new position of X_i (k + 1) is obtained.

These processes enter the process in order and complete the process as follows;

1- The starting position and the speed and direction of the randomly generated starting herd are created.

2- The suitability values of all particles are calculated.

3- The best approach is found for each particle.

4- It is chosen among the best globally.

5- Speed and position are calculated again.

6- If the result is sufficiently approached, it will be stopped, otherwise the procedures will be repeated from the second step.

Thus, in each movement of the particle, a certain amount reaches its new position by moving in the direction of the previous movement, a certain amount in the direction of its best approach, and some in the direction of the flock best approach, as given in the figure. And it keeps moving until it gets close enough to the right spot. In non-linear problems solved with PSO, the more the local minimum points in a problem, the harder it is to find the global minimum with PSO. In these cases, it is needed to increase the number of particles to prevent erroneous results. As can be seen in Figure 3.5, each particle has gathered its own and flock best points and approached the correct point after 75 iterations. A particle of motion is shown in Figure 3.4.

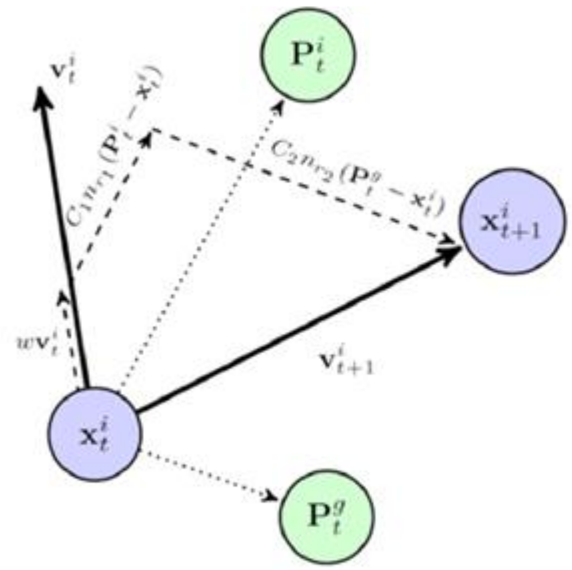


Figure 3.4. Particle of motion (medium.com/@hamzaerguder/parçacık-sürü-optimizasyonu-24e01beec438)

In the PSO algorithm, solutions are produced as much as the number of particles at the same time, and new solutions are produced as much as the number of particles in each iteration. Therefore, the proposed algorithm appears to be very fast in finding the lower limit or optimal result. When the complexity and size of the problem increase, the number of particles and iterations should also be increased. In this case, as expected, the solution times of the proposed algorithm increase. PSO iteration example is demonstrated in Figure 3.5.

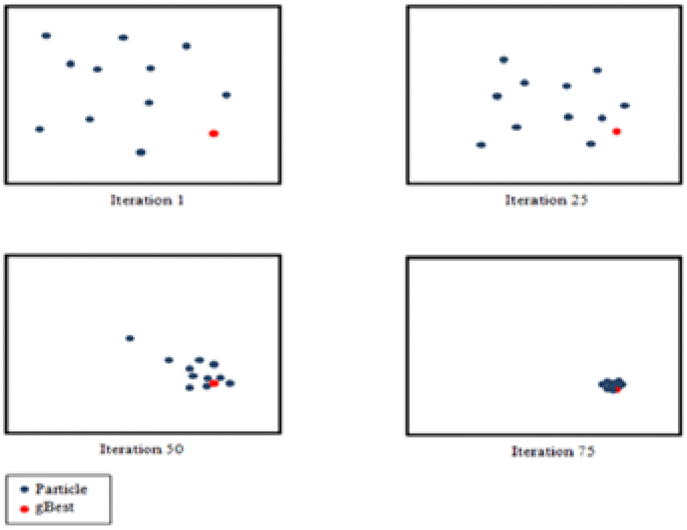


Figure 3.5. *PSO iteration example (medium.com/@hamzaerguder/parçacık-sürü-optimizasyonu-24e01beec438)*

3.1.3.2. GA

GA is a method that works by imitating natural life and is frequently used in optimization problems. The idea put forward by John Holland, developed by Holland, David Goldberg, and other students, other scientists have become popular with its development and implementation. (Holland, 1975) (Mitchell, 1995)

The first point at which GA imitates nature is that it is an iterative process. Each iteration represents a generation for GA. Until the graduation requirement is met, with searching GA will create new generations. GA operators are reapplied in each generation and thus, a new generation will be created.

Generations consist of a community. Community is made up of individuals. Each individual (chromosome) in the community refers to a candidate solution for GA.

The environment in which individuals must adapt is the goal function. Each individual that makes up the community gains the chance to take part in the next generations as long as they adapt to the environment, namely the purpose and function, and can create new individuals.

Objective functions take an individual as input and return the result obtained with this individual as a success, or penalty points according to the problem to be optimized. If the objective function returns achievement points, the addressed problem can be viewed as maximization, if it returns penalty points, it can be viewed as a minimization problem.

In each iteration, selection, crossing, and mutation operators are applied to the present population with determined probabilities and a new generation is obtained. GA search ends when the specified number of iterations or the expected optimum result comes, and the individual who achieves this result is obtained as the result of the search. GA works independently of the problem addressed. It may be sufficient to write an objective function that can generate a numerical value for each individual. The content of the problem is expected not to affect the working mechanics of GA. This situation significantly increases the applicability of GA.

3.2. Control of MG

Different MG control methods can be explained in three major groups which are centralized, decentralized, and distributed control methods. On the other hand, control methods are called MG central controller, micro source controller, and load controller. These controllers allow safe and flexible operation.

The centralized method is used to control generators and economic dispatch. In this method, there is a central controller which is called SCADA (supervisory, control, and data acquisition). For communication links, this method is not efficient.

In the decentralized method, each subsystem has its controller. It can be gathered voltage-frequency values. But this method is not global. It can be used for local areas.

The distributed control method shares information with its neighbors and gets local measurements. It can be a global optimization like a centralized method.

The advantages and disadvantages of the control methods are compared to each other in Table 5.1.

Table 3.1. *Comparison of control methods (A Control and Protection Model for the Distributed Generation and Energy Storage Systems in Microgrids, 2016)*

Control Method	Advantages	Disadvantages
Centralized	• Implementation is easy. • If there is a single point error, system maintenance is easy.	• Computational is difficult. • It is difficult to add new operands. For example: for smart grid system is not suitable. • It is unstable. • High-level connectivity is required.
Decentralized	• For local information, implementation is easy. • High-level communication is not necessary.	• There is no connection between agents, so system performance restricts. • There is moderate scalability.

	• Although there is no main control, the system still includes control in a specific area. • There is low computational cost.	
Distributed Control	• Expanding is easy. And it has scalability. • Cost is low. • It is not allowed a single point error. • It is appropriate for large-scale systems. • Not affected by the system altering's. • It provides a fast solution for smart grids.	• It needs to be synchronized. • It can be time-consuming for common ideas with local controllers. • Two-way communication infrastructure is needed. • The cost is high to develop communication.

3.2.1. Power Converter Classification in MGs

According to MG operating modes, there are three types of power converters which are grid-forming, grid-feeding, and grid-supporting converters which are shown in Figure 3.6.

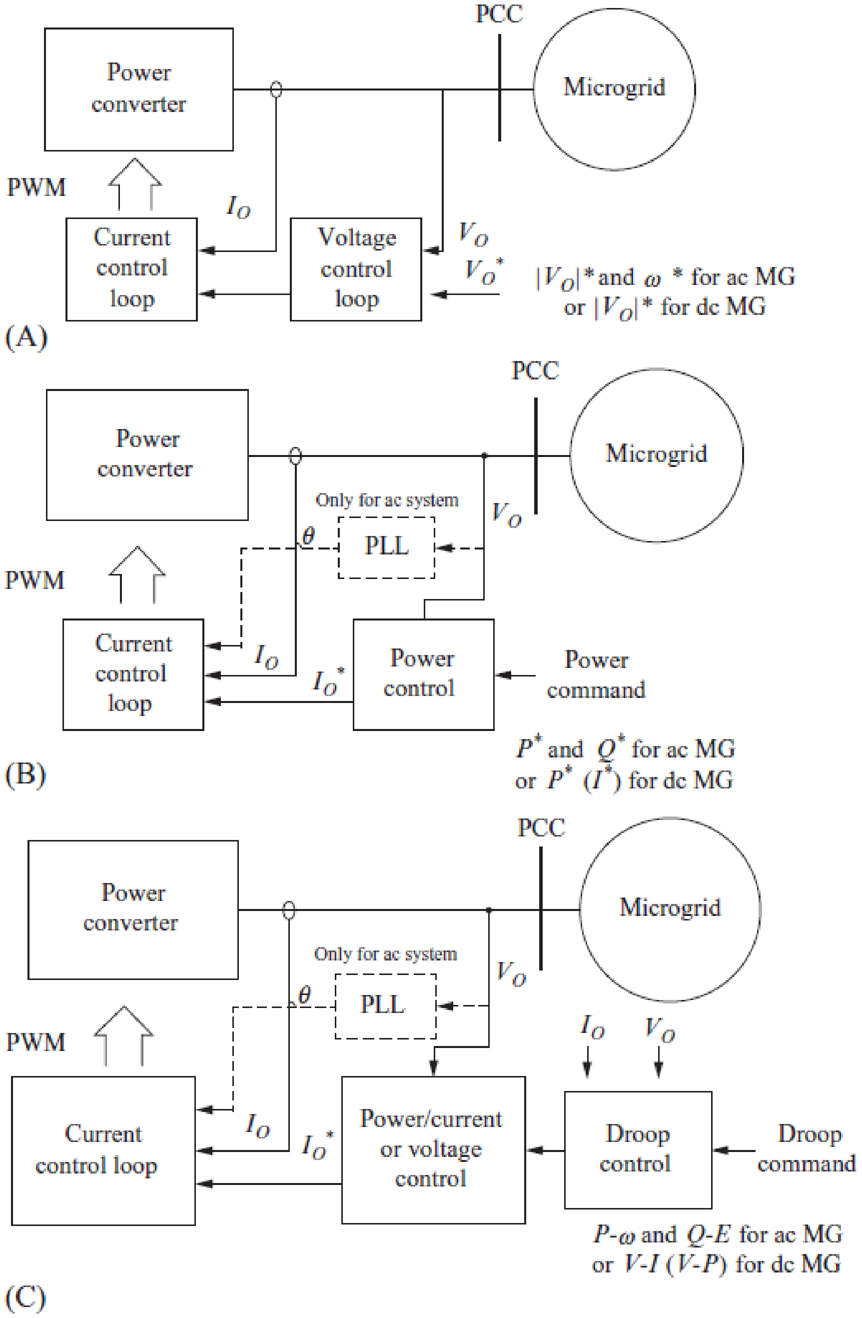


Figure 3.6. *System and control diagram for (A) grid-forming power converters, (B) grid-feeding power converters, and (C) grid-supporting power converters (Dragicˇevi & Yunwei Li)*

3.2.1.1. Grid-forming converters

If there is no main grid, grid-forming converters are used to provide the demand of voltage in MG. This type of converters is used as an ideal voltage source and grid-forming converters operate in voltage control mode (VCM). Voltage magnitude and frequency control are provided with VCM in an AC MG. If there are a lot of grid-forming converters they should be synchronized with each other in an AC MG. With droop control, synchronization is provided. In addition to this, synchronization is not a need in islanded DC MGs. Because, the only control parameter is voltage magnitude in these MGs. Regulating the respective voltage, one converter is a need.

3.2.1.2. Grid-feeding converters

Grid-feeding converters are used to add active and reactive power for AC coupling, or current for DC coupling. This type of converters is controlled directly with power reference. They have large equivalent output impedance so generally connected to the system parallel. They tract maximum power point tracking (MPPT) with power and current reference. Nowadays, most converters that are based on renewable energy, operate in the grid-tied mode. This type of converters is called grid-feeding converters.

3.2.1.3. Grid-supporting converters

Grid-supporting converters can be added to the AC MGs by regulating voltage amplitude and frequency. In the DC MGs, grid-supporting converters can be added with regulating only voltage amplitude. In both conditions, a droop control strategy is used.

3.2.2. MG Operating Modes

3.2.2.1. Grid-connected mode

Energy management of MGs must be considered energy storage system and energy flow control. There is a link between MG and main grid in grid-connected mode. In addition to this, the main grid and local DG units send all the power to the loads in grid-connected mode.

3.2.2.2. Islanded mode

The MG is isolated from the main grid. In islanded mode, the system dynamics are presented by DG units, which regulate the frequency and amplitude voltage of the MG.

3.2.2.3. Transition mode

If there is a problem in the main grid, the MG is disconnected from the main grid. So, MG has from grid-connected mode to islanded mode. This mode is called transition mode.

3.2.3. MG Hierarchical Control

There are three main hierarchical control levels which are primary control, secondary control, and tertiary control which are shown in Figure 5.8.

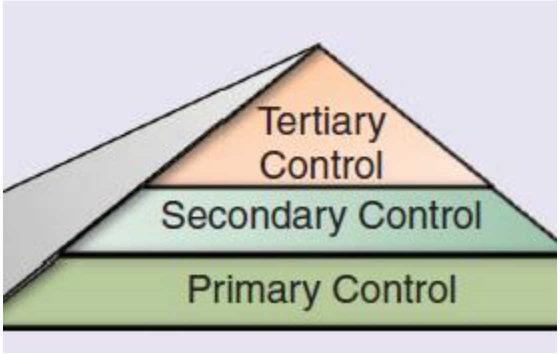


Figure 3.7. *Hierarchical control levels (Guerrero, Hierarchical Control of Intelligent Microgrids , 2010)*

3.2.3.1. Primary control: PQ droop control

There is an external power loop for each inverter to develop system performance and stability and to divide active and reactive power in DGs. It is called decentralized control. This control regulates the frequency and magnitude of the output voltage.

Frequency and magnitude output voltage can be adjusted to obtain good power-sharing with this control which is get from the classic high power system theory. If generator frequency decreases, grid power increases.

Generally, in transmission systems, grid impedance is inductive to obtain linear load changings in active and reactive power. If power electronic converters are used, the impedance is far away from the inductance.

3.2.3.2. Secondary control: synchronization and adjusting voltage-frequency

Signals are sent to fix the MG voltage in nominal values, using low-bandwidth communication. This control is provided MG synchronization in the main grid.

3.2.3.3. Tertiary Control: importing or exporting of PQ

MPPT control is the third control level. Block diagrams of control loops are shown in Figure 3.8.

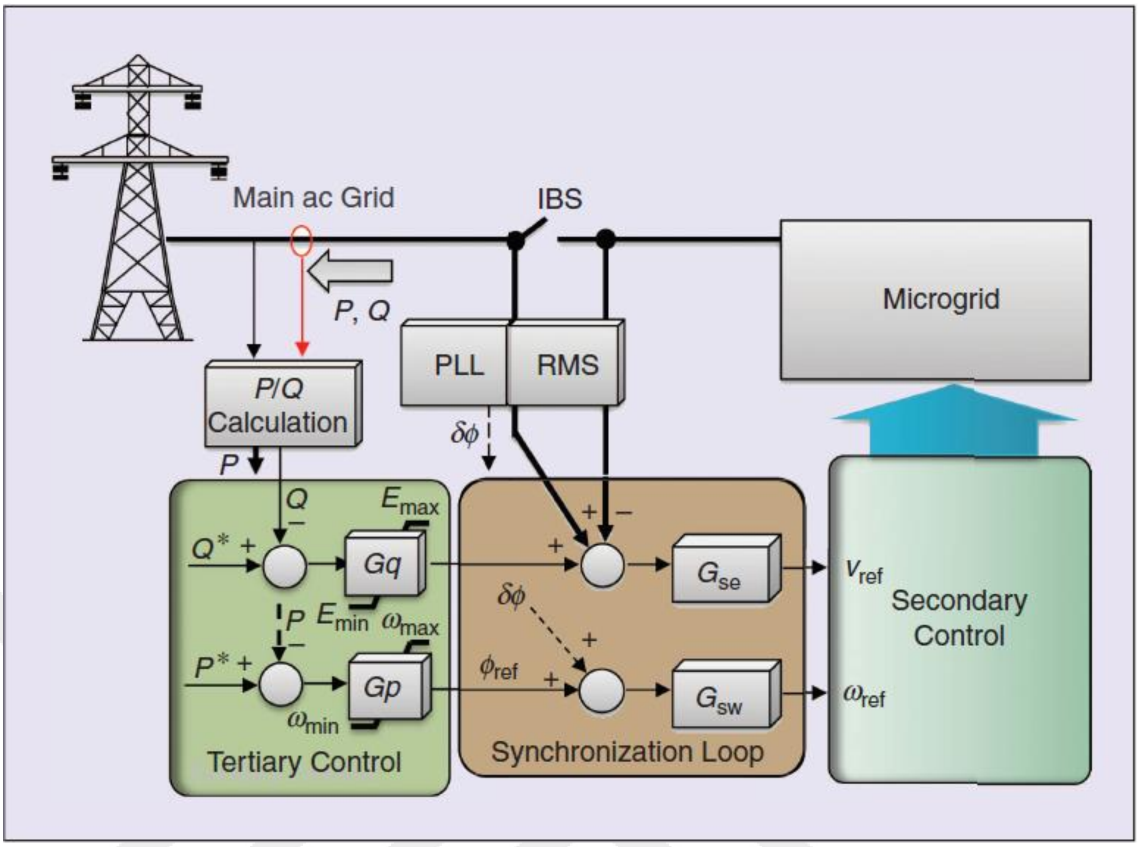


Figure 3.8. *Block diagram of control loops (Guerrero, Hierarchical Control of Intelligent Microgrids , 2010)*

4. SIMULATION AND RESULTS

Simulation and results are presented in two subparts which are optimization and control in MG. Firstly, a grid-connected MG system is designed. In the designed grid-connected MG system, 5 loads, solar and wind energy, and energy storage system are integrated. There are 3 buses which are grid bus, energy storage system bus, and renewable energy bus. In renewable energy buses, 6×1,5 MW wind turbines and 66 parallel and 5 series-connected solar panels (100 KW) are used. System schema is shown in Figure 4.1. In addition to this, load and line values are shown in Table 4.1.

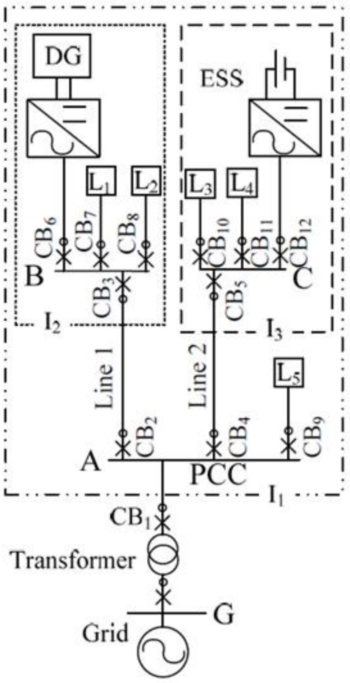


Figure 4.1. *System schema (Ballal, 2016)*

Table 4.1. *Load and line values (Ballal, 2016)*

Load 1 KVA	2+j0
Load 2 KVA	2+j1
Load 3 KVA	5+j2
Load 4 KVA	2+j0
Load 5 KVA	8+j4
Line 1 impedance in ohms	1/25+j 1/40
Line 2 impedance in ohms	1/60+j 1/80

In this thesis, objective function is demonstrated in Equation 2 for a MG minimizing total cost. And constraints of the objective function are shown in Equation 3.

T indicates the total time of the study (hours). Ng shows number of generators. N_S shows number of storages. $P_{Gi}(t)$ and $P_{Sj}(t)$ are the amounts of output power for the ith unit and jth storage at time t, $B_{Gi}(t)$, and B_{Sj} (t) represent the energy price offered for the ith unit and jth storage at the time t, and P_{Grid} (t) and B_{Grid} (t) indicate the amounts of power exchanged with the offered market at time t.

$$f(x) = \sum_{t=1}^{T} \left(\sum_{i=1}^{Ng} P_{G_i}(t) B_{G_i}(t) + \sum_{j=1}^{Ns} P_{s_j}(t) B_{s_j}(t) - P_{Grid}(t) B_{Grid}(t) \right) \quad (2)$$

$$P_{G_i,min}(t) \le P_{G_i}(t) \le P_{G_i,max}(t)$$

$$P_{S_j,min}(t) \le P_{S_j}(t) \le P_{S_j,max}(t)$$

$$P_{Grid,,min}(t) \le P \quad (t) \le P_{G_i,max}(t) \qquad (3)$$

4.1. Optimization in MG

Solar irradiation and wind speed data are given for Gölbaşı/ANKARA which are presented in Table 4.2, 4.3 for each season a month.

Table 4.2. *Solar irradiation and wind speed values in January and April.*

HOUR	Direct normal irradiation (Wh/m^2) in January	Wind speed value(kmh) in January	Direct normal irradiation (Wh/m^2) in April	Wind speed value(kmh) in April
1	0	1,11	0	0,93
2	0	1,09	0	0,91
3	0	1,1	0	0,91
4	0	1,08	0	0,91
5	0	1,07	0	0,87
6	0	1,11	18	0,8
7	0	1,11	212	0,84
8	56	1,07	356	0,96
9	206	1,1	442	1,07
10	268	1,19	483	1,15
11	299	1,27	470	1,26
12	311	1,28	449	1,35
13	300	1,28	430	1,38

14	289	1,3	418	1,38
15	269	1,35	391	1,36
16	204	1,43	344	1,38
17	28	1,44	284	1,39
18	0	1,39	144	1,39
19	0	1,32	1	1,33
20	0	1,25	0	1,26
21	0	1,24	0	1,19
22	0	1,23	0	1,14
23	0	1,22	0	1,12
24	0	1,22	0	1,05
SUM	2230	29,25	4442	27,33

Table 4.3. *Solar irradiation and wind speed values in July and October.*

HOUR	Direct normal irradiation (Wh/m^2) in July	Wind speed value(kmh) in July	Direct normal irradiation (Wh/m^2) in October	Wind speed value(kmh) in October
1	0	0,76	0	0,72
2	0	0,8	0	0,67
3	0	0,77	0	0,63
4	0	0,72	0	0,62
5	0	0,67	0	0,61
6	206	0,67	0	0,62
7	454	0,72	67	0,62
8	592	0,74	336	0,61
9	687	0,77	443	0,62
10	747	0,75	510	0,71
11	763	0,79	538	0,76
12	740	0,88	517	0,78
13	699	1	494	0,81
14	667	1,1	472	0,84
15	616	1,22	433	0,89
16	556	1,43	334	1
17	506	1,76	73	1,04
18	413	1,88	1	1,02
19	95	1,4	0	0,94
20	0	0,88	0	0,92
21	0	0,8	0	0,89
22	0	0,74	0	0,88
23	0	0,69	0	0,85
24	0	0,65	0	0,82
SUM	7741	22,59	4217	18,87

Solar irradiation and speed values are shown in Figure 4.2, 4.3 ,4.4, 4.5 for each season a month.

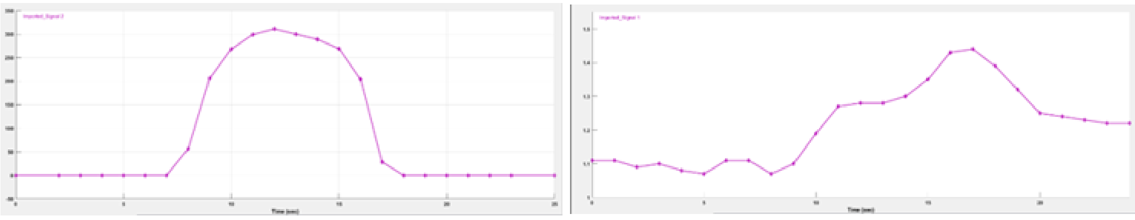


Figure 4.2. *Solar irradiation and wind speed values in January.*

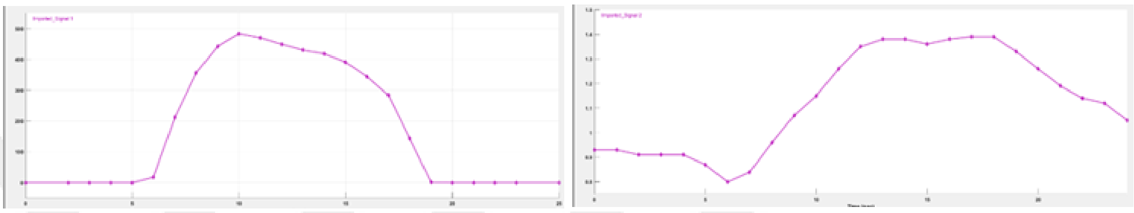


Figure 4.3. *Solar irradiation and wind speed values in April.*

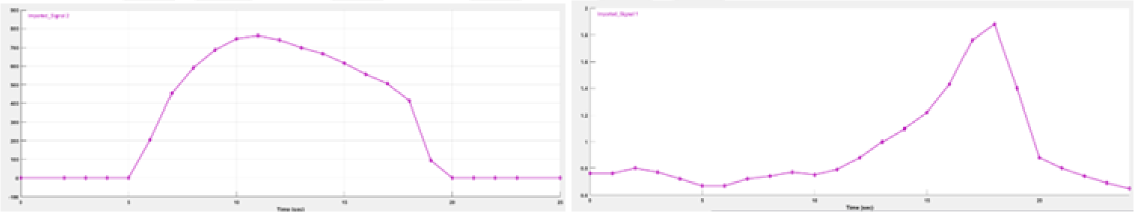


Figure 4.4. *Solar irradiation and wind speed values in July.*

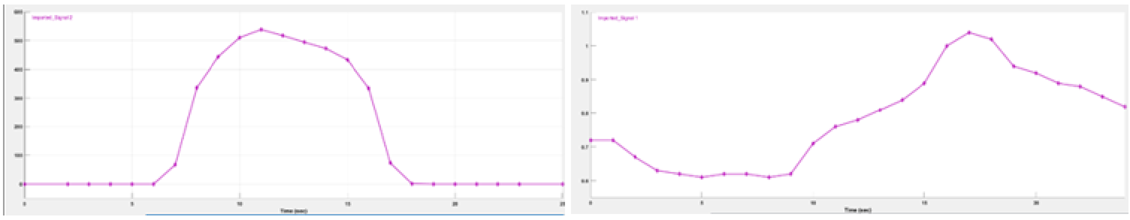


Figure 4.5. *Solar irradiation and wind speed values in October.*

4.1.1. PSO

Firstly, PSO technique is implemented in a MG system.

In the algorithm, initialization values are

popsize = 2;	swarm size
npar = 4;	problem dimention
max_{it} = 2;	iteration number (this value can be changed)

$c_1 = 1.5$;	cognitive parameter
$c_2 = 2.0$;	social parameter
C=1;	constriction factor
$w_{max}=0.95$;	inertia factor maximum
$w_{min}=0.15$;	inertia factor minimum

The size of the swarm (pop size) is 2 which are solar and wind energy systems. After that, $2K_p$ and $2K_i$ values are found which shows that the dimension of the problem (npar) is 4. A maximum number of iterations is chosen as 2 which can be more than 2 for the optimal solution. Cognitive and social parameters are assigned for the PSO algorithm. They are the preferred minimum values of the ranges. In addition to this, to calculate inertia factor(w), w_{max} and w_{min} values are assigned. The inertia factor formula is shown in Equation 4 (iter is between 0 and 2).

$$W = w_{max} - \left(\left(\frac{w_{\max}-w_{\min}}{max_{it}}\right).\mathrm{iter}\right) \tag{4}$$

As a result, code run and find optimal K_p, K_i values, and error.

For 50 iteration, the optimal solution is shown in Table 4.4.

Table 4.4. *Optimal solution with PSO.*

ITERATION	**K_p**	**K_{p1}**	**K_i**	**K_{i1}**	**J_{min}**
50	1.2000	1.2000	1.2000	1.2000	1.0416

Per unit voltage values are shown in Table 4.5.

Table 4.5. *Per unit voltage values*

Season/Month	V_A max value(pu)	V_A max time(s)	V_B max value(pu)	V_B max time(s)	V_C max value(pu)	V_C max time(s)
Winter/January	0,9970	0,775	0,001229	0,972	0,9950	0,966
Spring/April	0,9970	0,686	0,001231	0,802	0,9950	0,655
Summer/July	0,9970	0,545	0,001216	0,661	0,9950	0,064
Autumn/October	0,9970	0,666	0,001213	0,764	0,9950	0,075

Season/Month	V_A min value(pu)	V_A min time(s)	V_B min value(pu)	V_B min time(s)	V_C min value(pu)	V_C min time(s)
Winter/January	0,9970	0,664	0,0004862	0,752	0,9950	0,915

Spring/April	0,9970	0,503	0,0005204	0,662	0,9950	0,406
Summer/July	0,9970	0,266	0,0004728	0,452	0,9950	0,855
Autumn/October	0,9970	0,505	0,0004534	0,582	0,9950	0,495

Per unit voltage values are shown in Figure 4.6, 4.7, 4.8, 4.9.

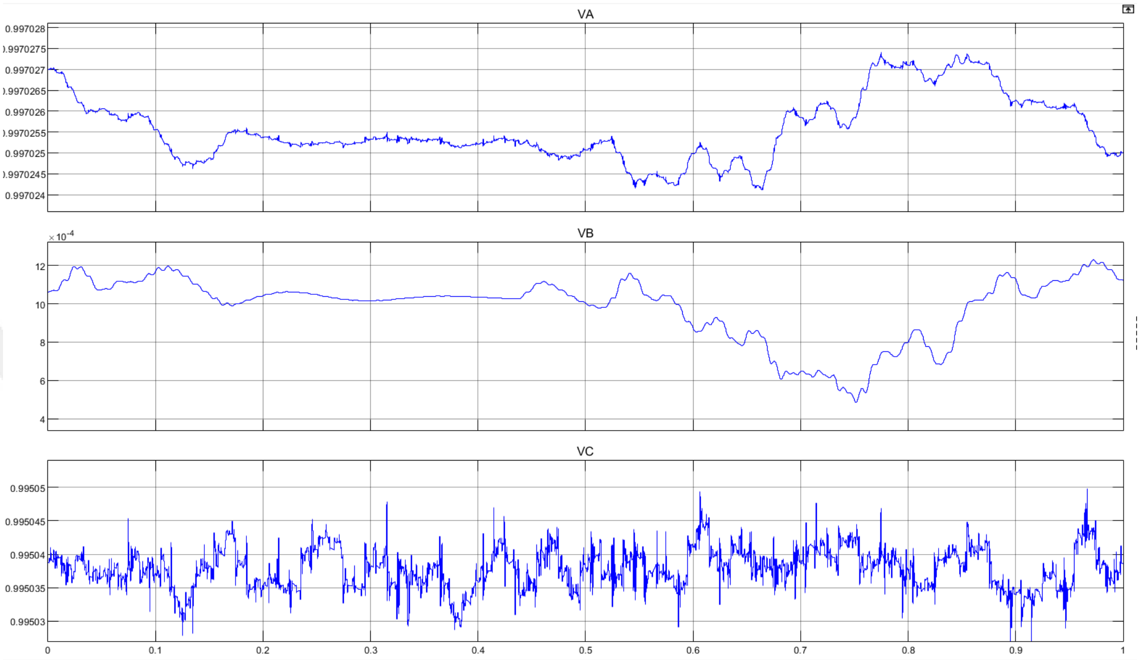


Figure 4.6. *Per unit voltage values in January*

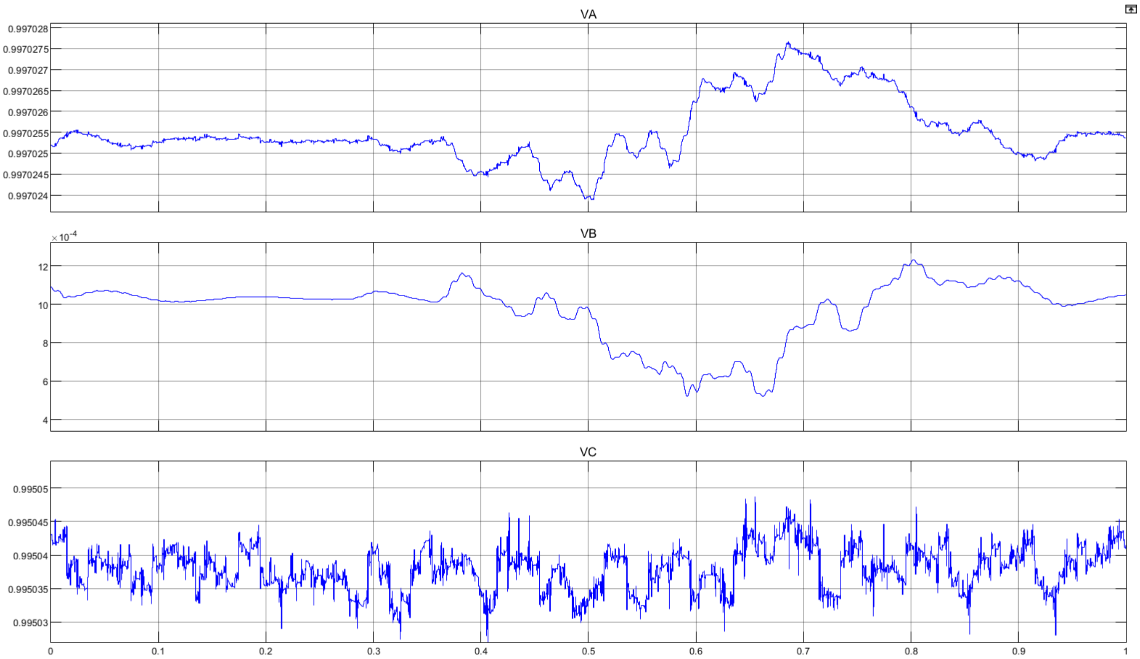


Figure 4.7. *Per unit voltage values in April*

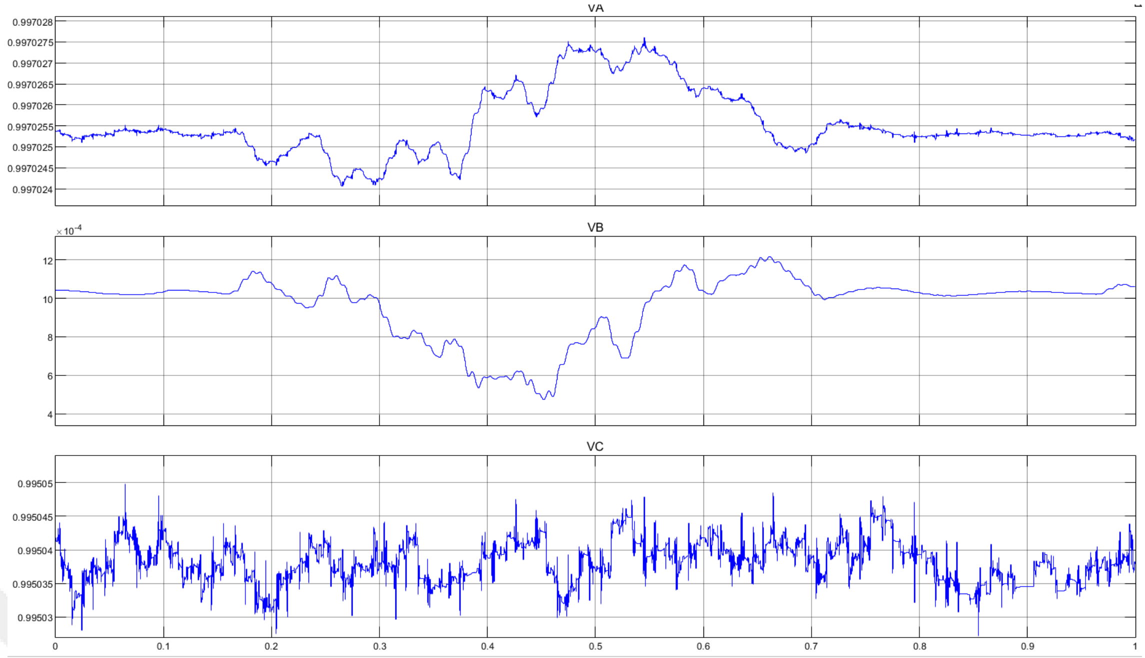


Figure 4.8. *Per unit voltage values in July*

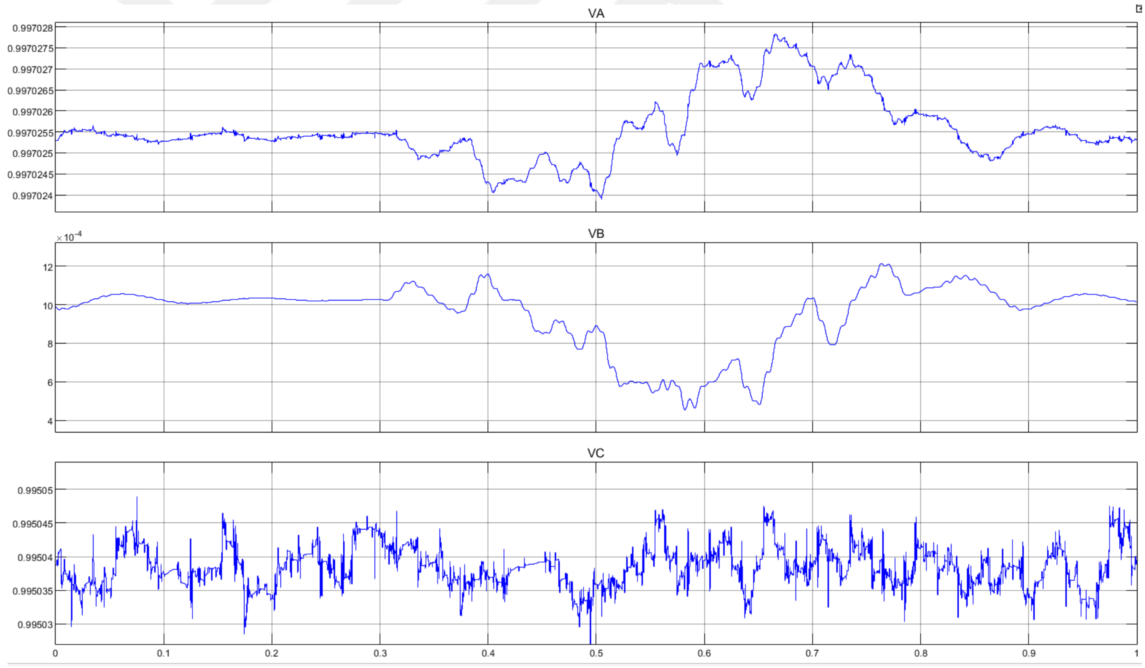


Figure 4.9. *Per unit voltage values in October*

PQ values are shown in Table 4.6 for DG.

Table 4.6. *PQ values for DG*

Season/Month	P_{DG} max value	P_{DG} max time	Q_{DG} max value	Q_{DG} max time
Winter/January	-0,001648	0,658	-0,004064	0,760
Spring/April	-0,0008371	0,575	-0,004020	0,668
Summer/July	-0,0009045	0,367	-0,003535	0,461
Autumn/October	-0,0002809	0,569	-0,002926	0,594

Season/Month	P_{DG} min value	P_{DG} min time	Q_{DG} min value	Q_{DG} min time
Winter/January	-0,01548	0,020	-0,01832	0,977
Spring/April	-0,01578	0,793	-0,01755	0,378
Summer/July	-0,01512	0,576	-0,01782	0,662
Autumn/October	-0,01513	0,761	-0,01833	0,392

PQ values are shown in Figure 4.10, 4.11, 4.12, 4.13 for DG.

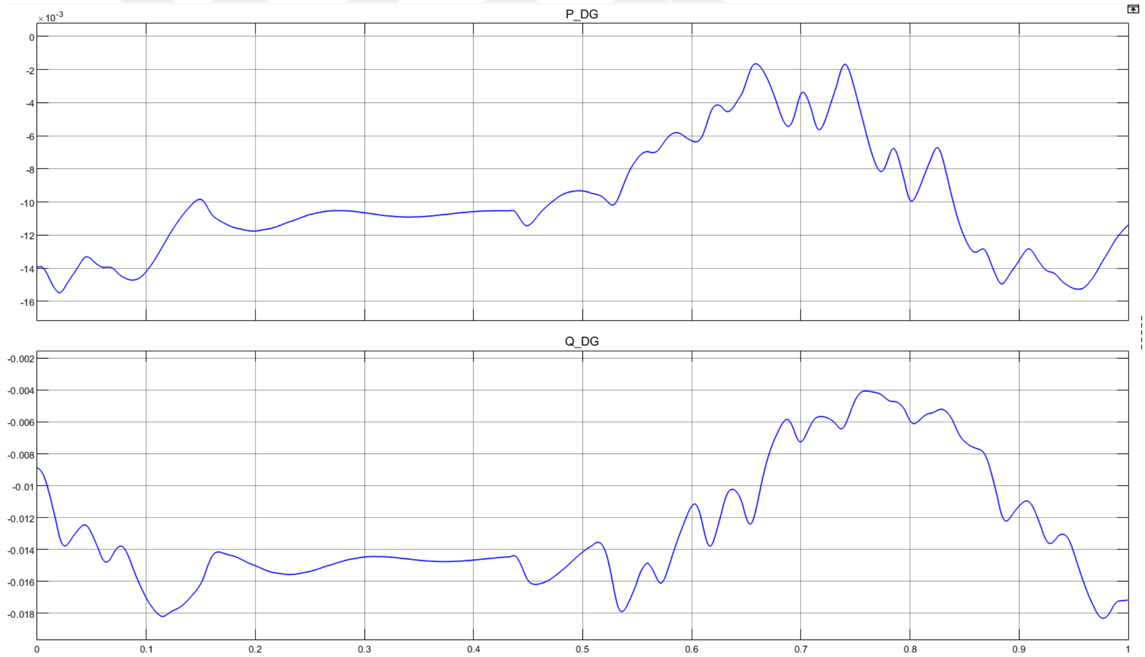


Figure 4.10. *PQ values in January for DG.*

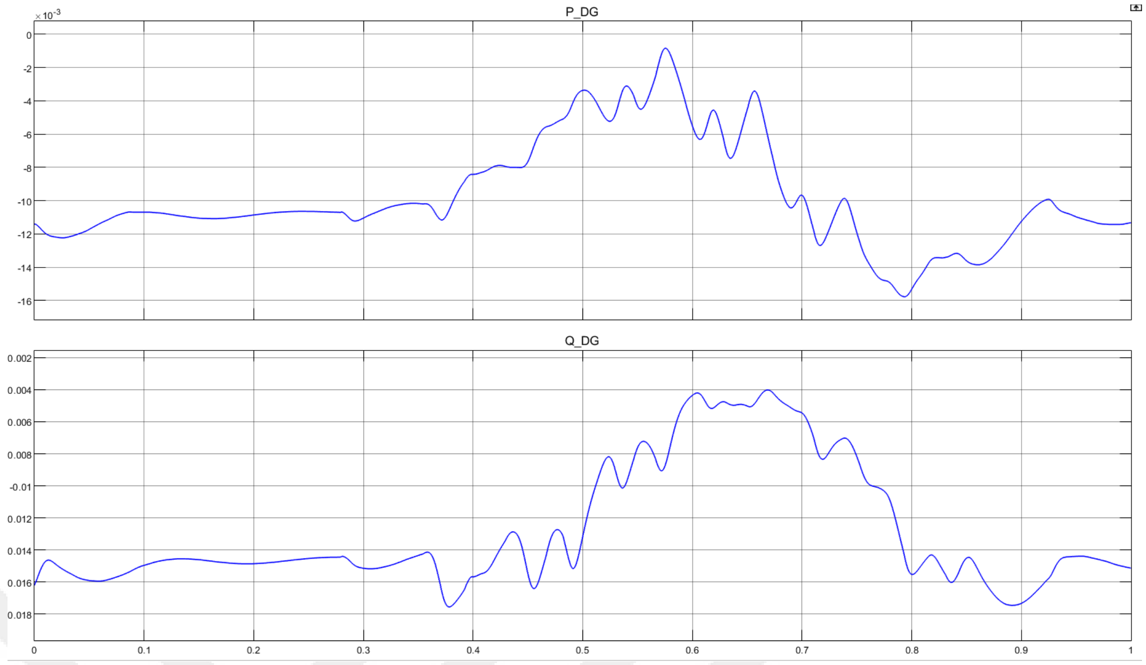


Figure 4.11. *PQ values in April for DG.*

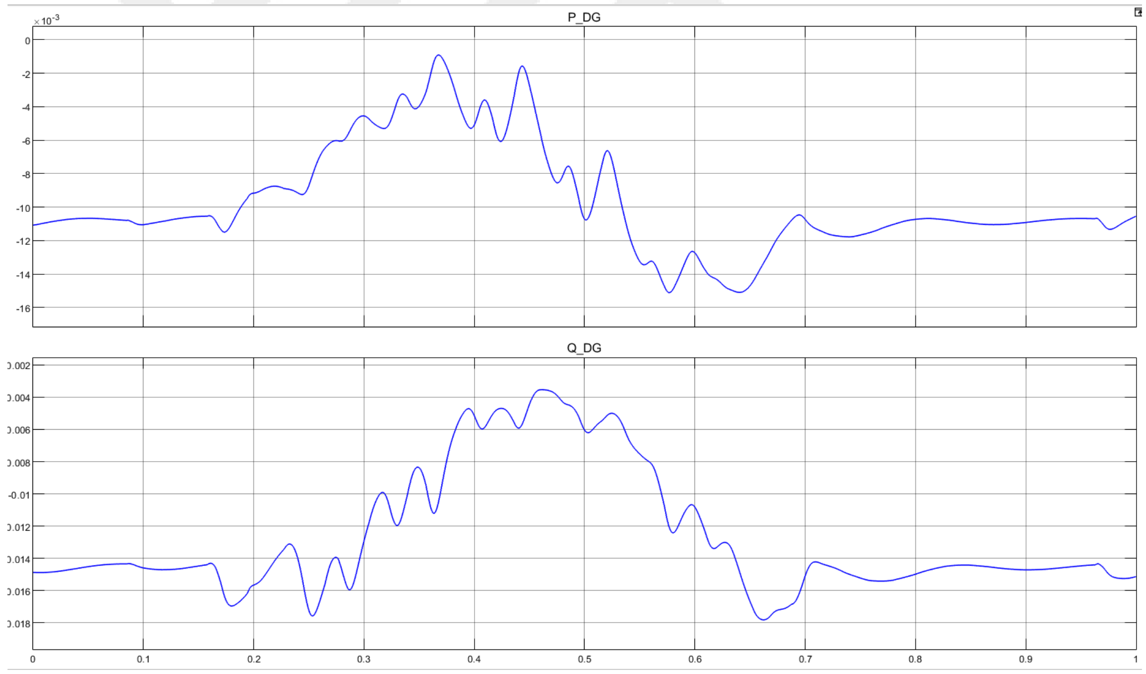


Figure 4.12. *PQ values in July for DG.*

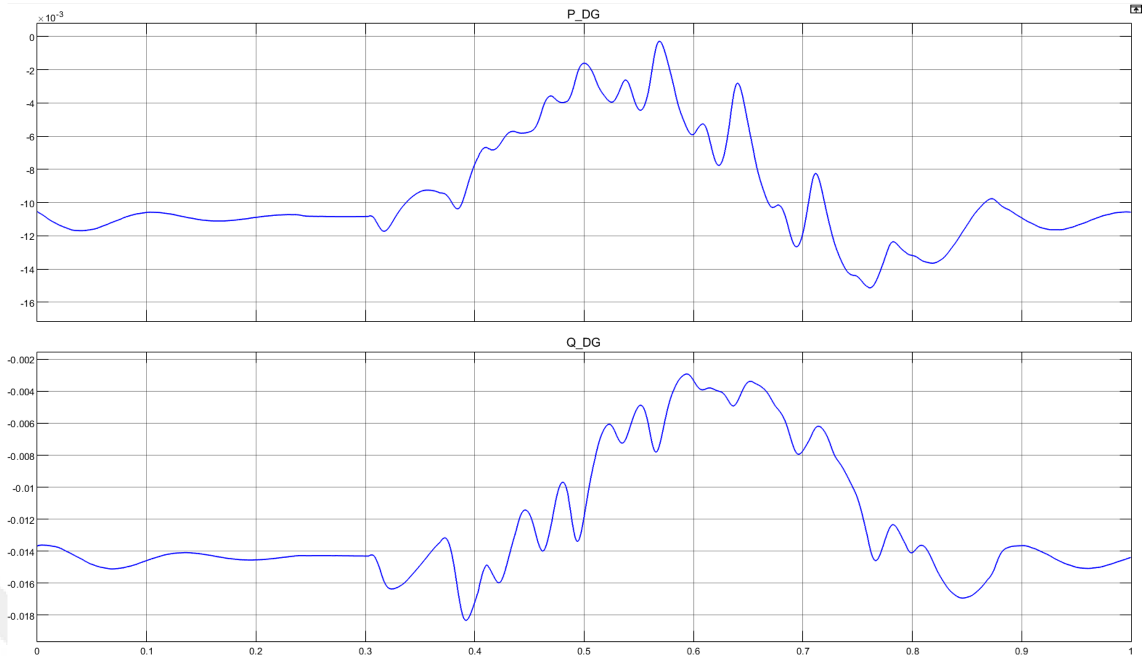


Figure 4.13. *PQ values in October for DG.*

Energy storage bus PQ values are shown in Figure 4.14, 4.15, 4.16, 4.17.

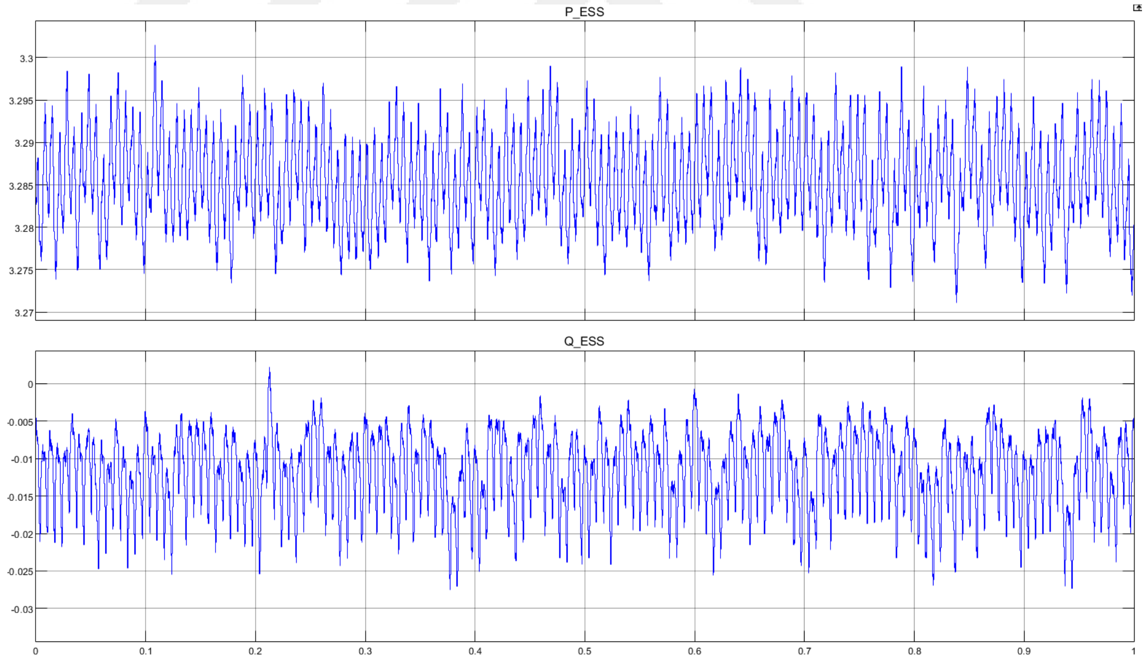


Figure 4.14. *Energy storage bus PQ values in January.*

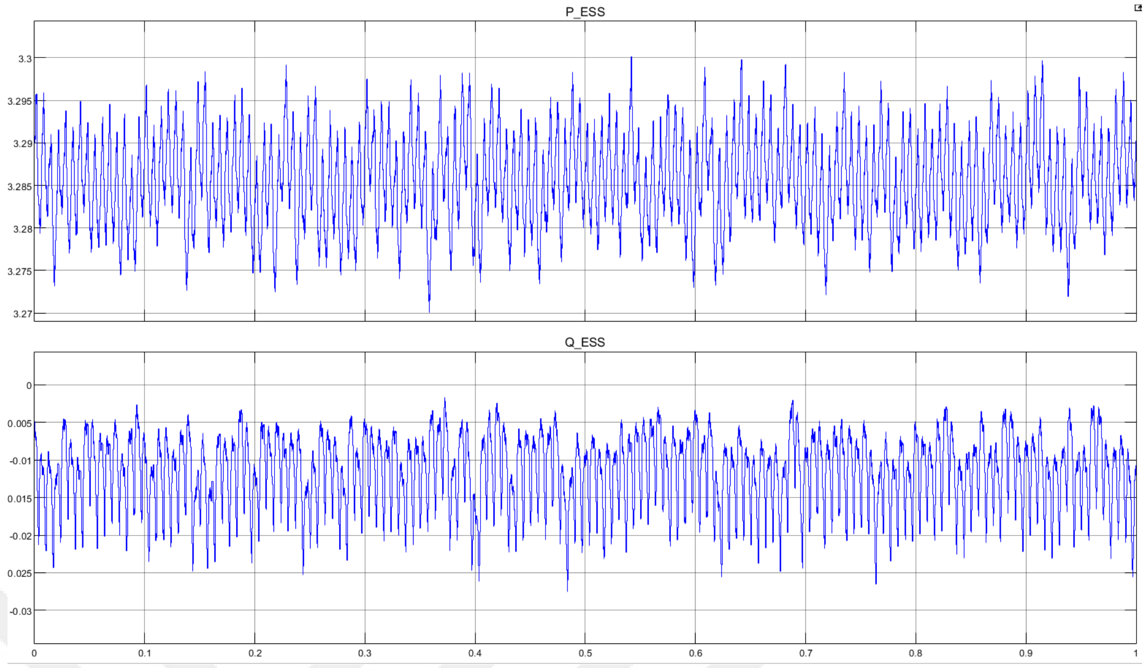


Figure 4.15. *Energy storage bus PQ values in April.*

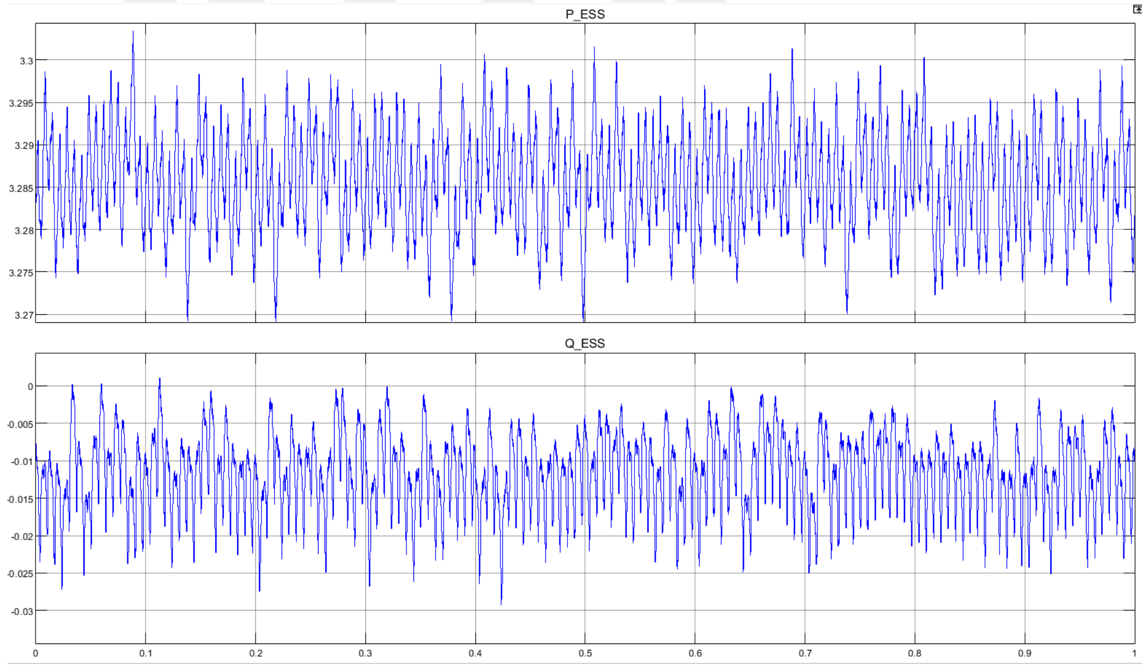


Figure 4.16. *Energy storage bus PQ values in July.*

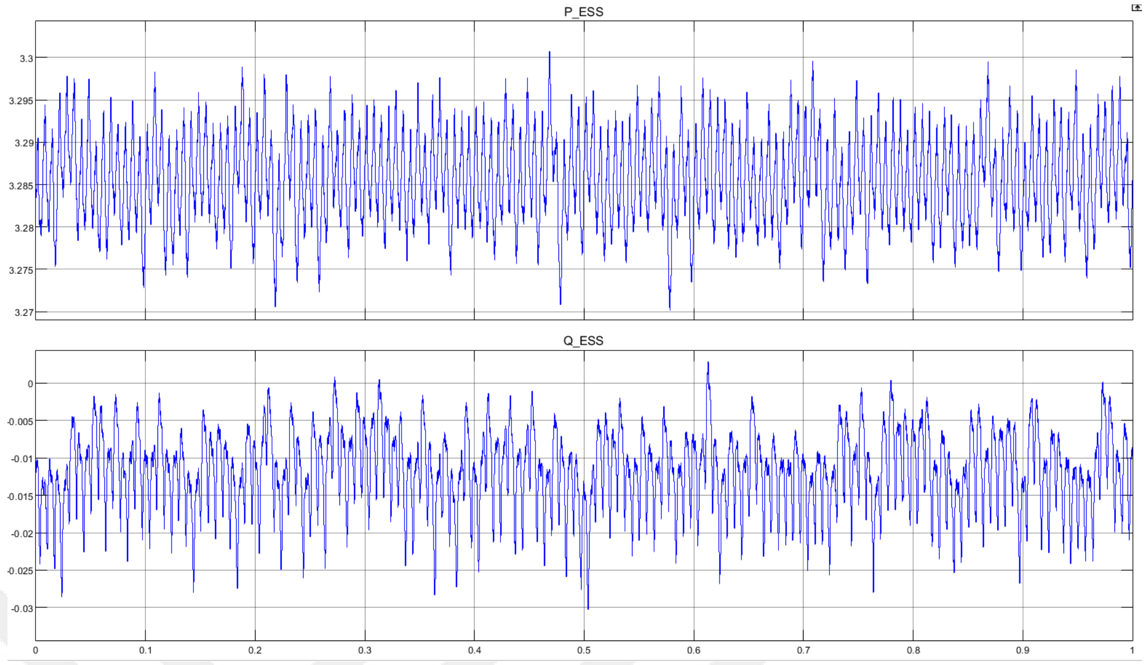


Figure 4.17. *Energy storage bus PQ values in October.*

Bus voltage values are shown in Figure 4.18, 4.19, 4.20, 4.21.

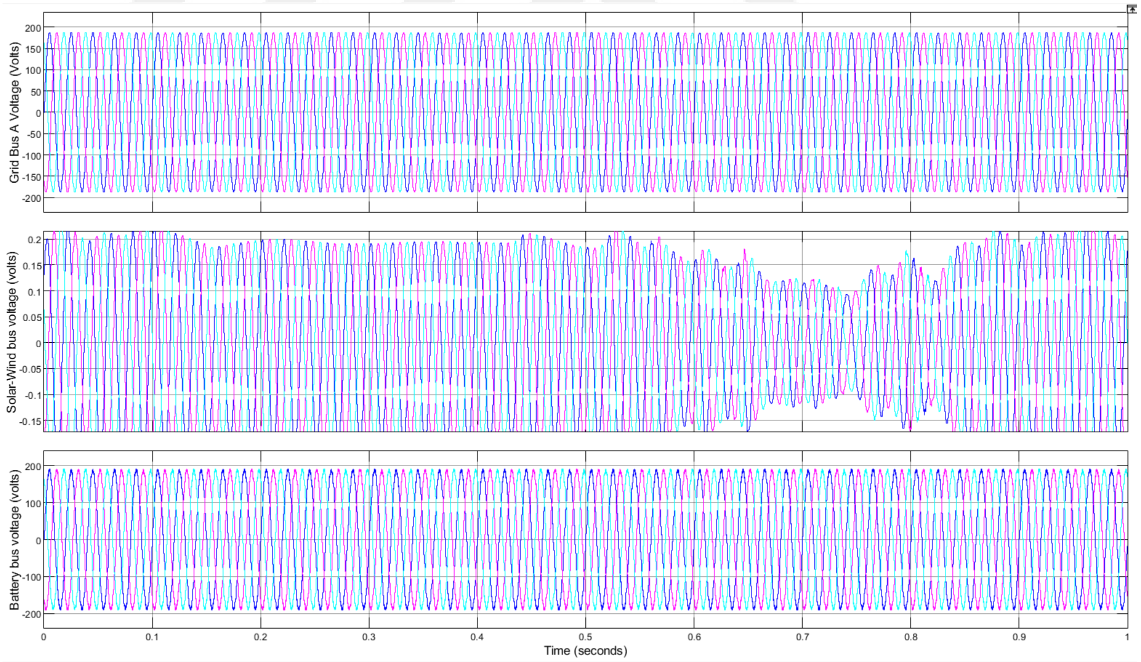


Figure 4.18. *Bus voltage values in January*

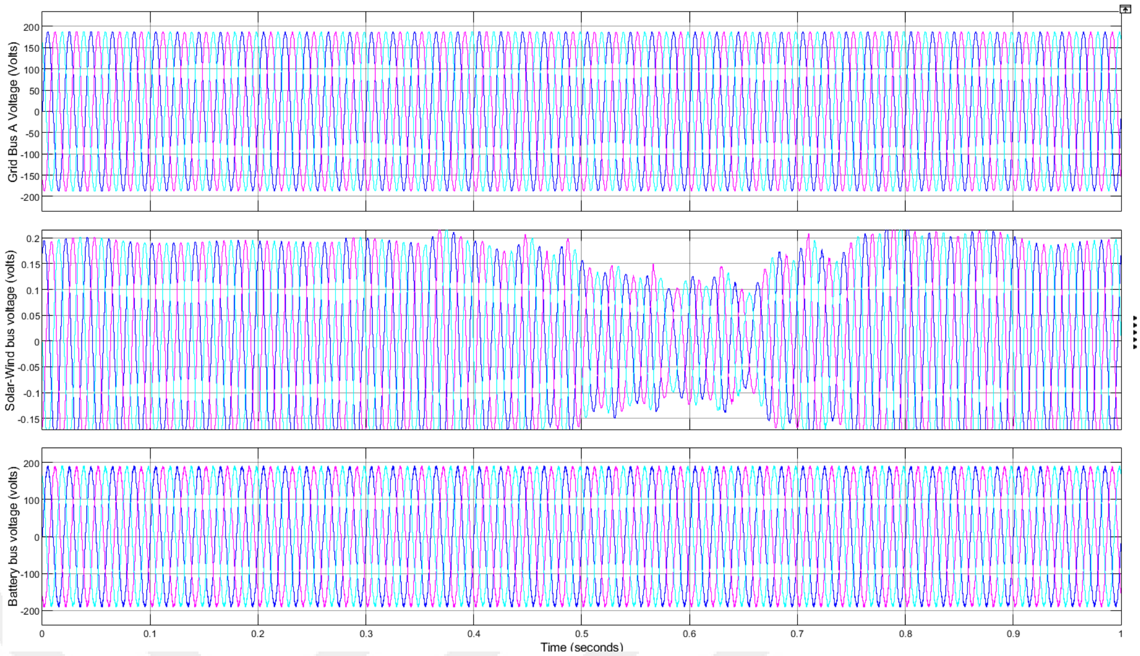


Figure 4.19. *Bus voltage values in April*

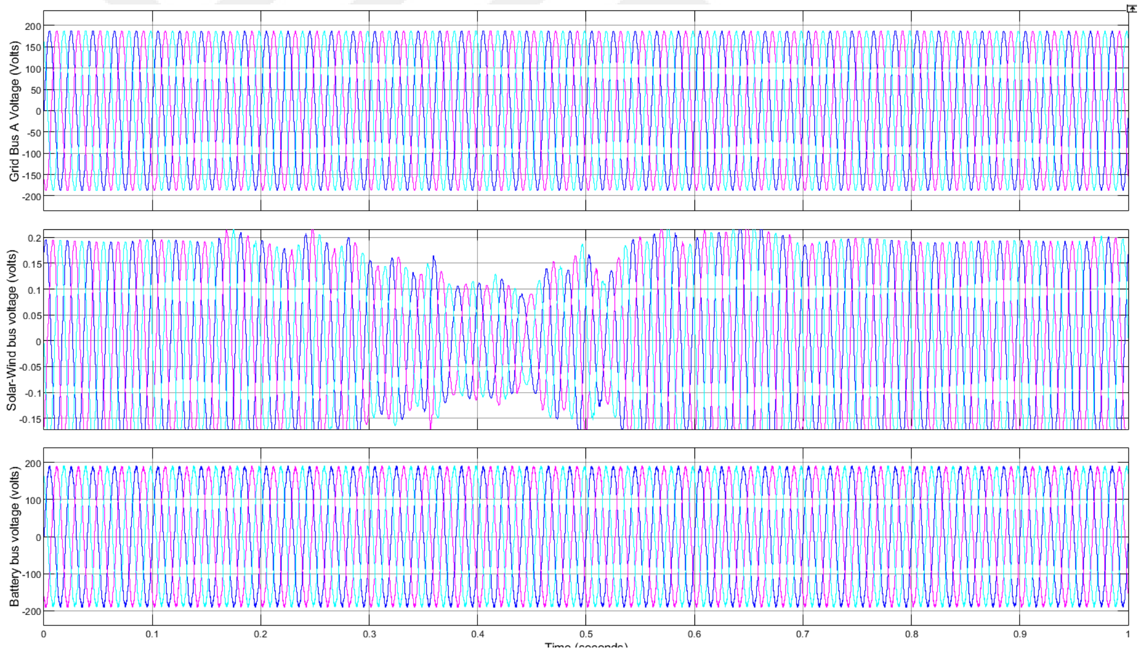


Figure 4.20. *Bus voltage values in July*

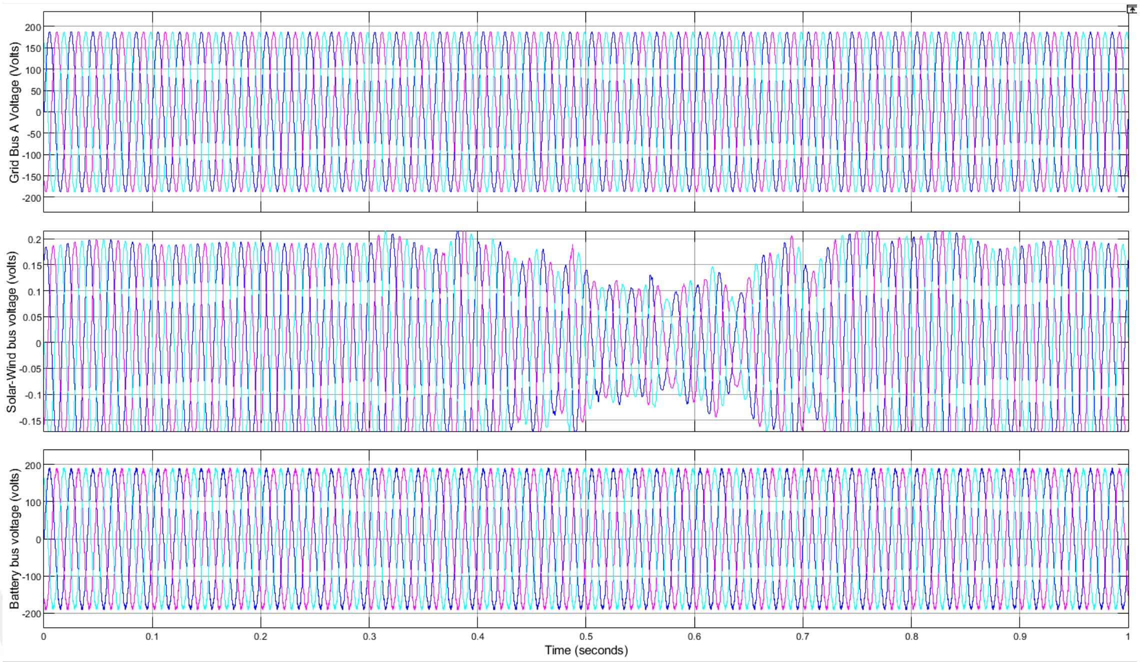
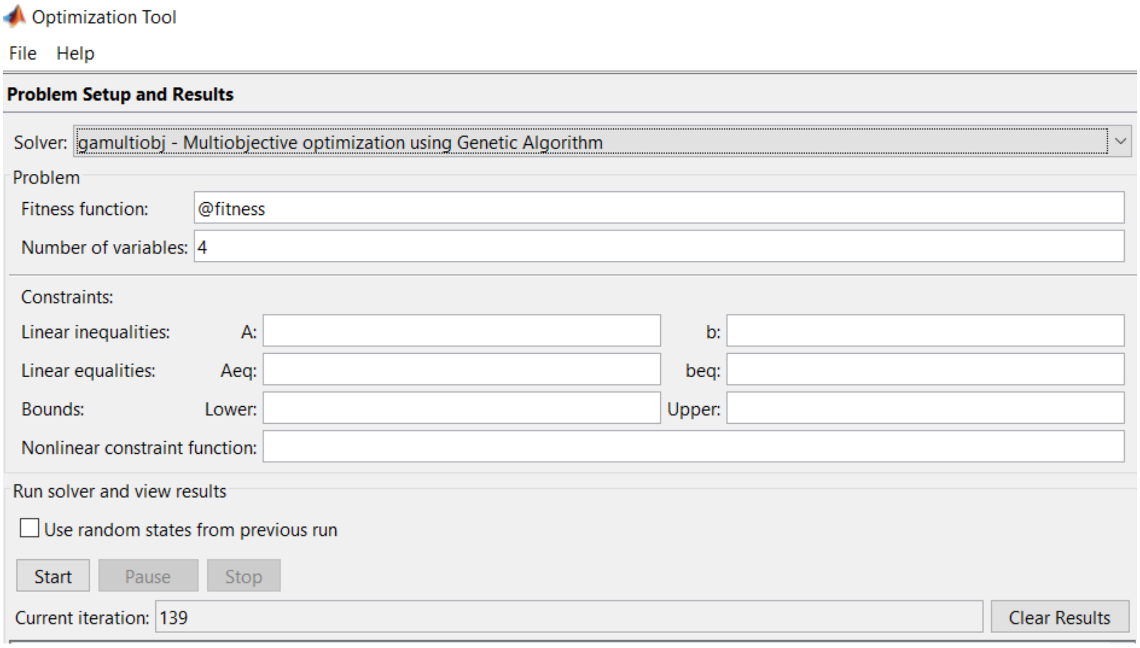


Figure 4.21. *Bus voltage values in October*

4.1.2. GA

Secondly, GA is implemented in an MG system. The objective function is assigned to generate individuals. MATLAB optimization toolbox is used (Figure 6.29). Several variables are chosen as 4 (2 K_p and 2K_i values).



Problem Setup and Results

Solver: gamultiobj - Multiobjective optimization using Genetic Algorithm

Problem

Fitness function: @fitness

Number of variables: 4

Constraints:

Linear inequalities: A: b:

Linear equalities: Aeq: beq:

Bounds: Lower: Upper:

Nonlinear constraint function:

Run solver and view results

☐ Use random states from previous run

Current iteration: 139

Figure 4.22. *GA optimization toolbox*

Optimal solution GA is shown in Table 4.7.

Table 4.7. *Optimal solution GA*

ITERATION	K_p	K_{p1}	K_i	K_{i1}
139	62.9732	1.9424	5.3449	41.4251

Generation or iteration numbers versus average spread of individuals are shown in Figure 4.23.

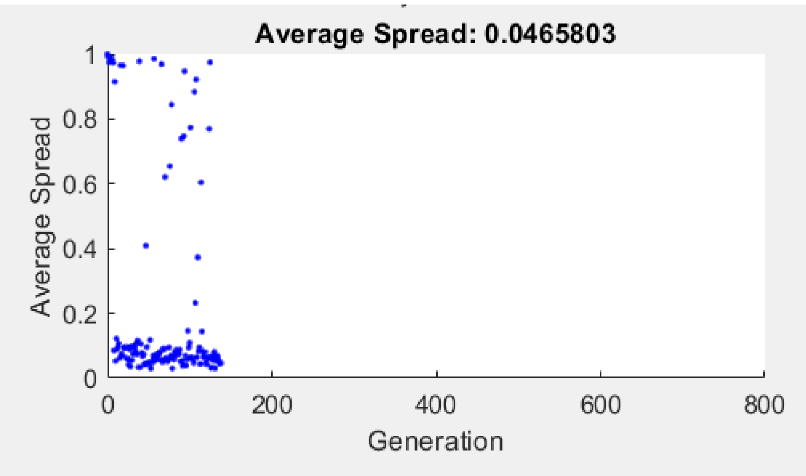


Figure 4.23. *Average spread individuals*

Per unit voltage values are shown in Table 4.8.

Table 4.8. *Per unit voltage values*

Season/Month	V_A max value(pu)	V_A max time(s)	V_B max value(pu)	V_B max time(s)	V_C max value(pu)	V_C max time(s)
Winter/January	0,9970	0,995	0,0009253	0,030	0,9951	0,646
Spring/April	0,9970	0,136	0,001018	0,939	0,9951	0,146
Summer/July	0,9970	0,016	0,001603	0,849	0,9950	0,166
Autumn/October	0,9970	0,054	0,001001	0,957	0,9951	0,175

Season/Month	V_A min value(pu)	V_A min time(s)	V_B min value(pu)	V_B min time(s)	V_C min value(pu)	V_C min time(s)
Winter/January	0,9970	0,965	0,0001584	0,981	0,9950	0,335
Spring/April	0,9970	0,944	0,00009322	0,893	0,9950	0,517
Summer/July	0,9970	0,985	0,0002050	0,016	0,9950	0,317
Autumn/October	0,9970	0,956	0,00001653	0,479	0,9950	0,704

Per unit voltage values are shown in Figure 4.24, 4.25, 4.26, 4.27.

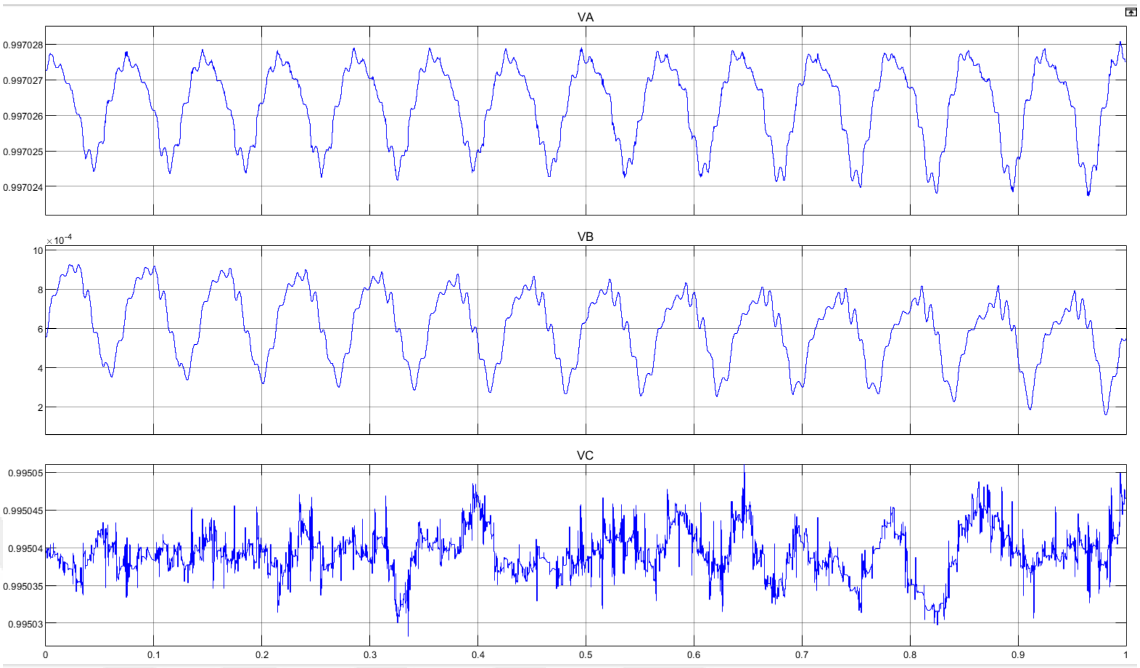


Figure 4.24. *Per unit voltage values in January*

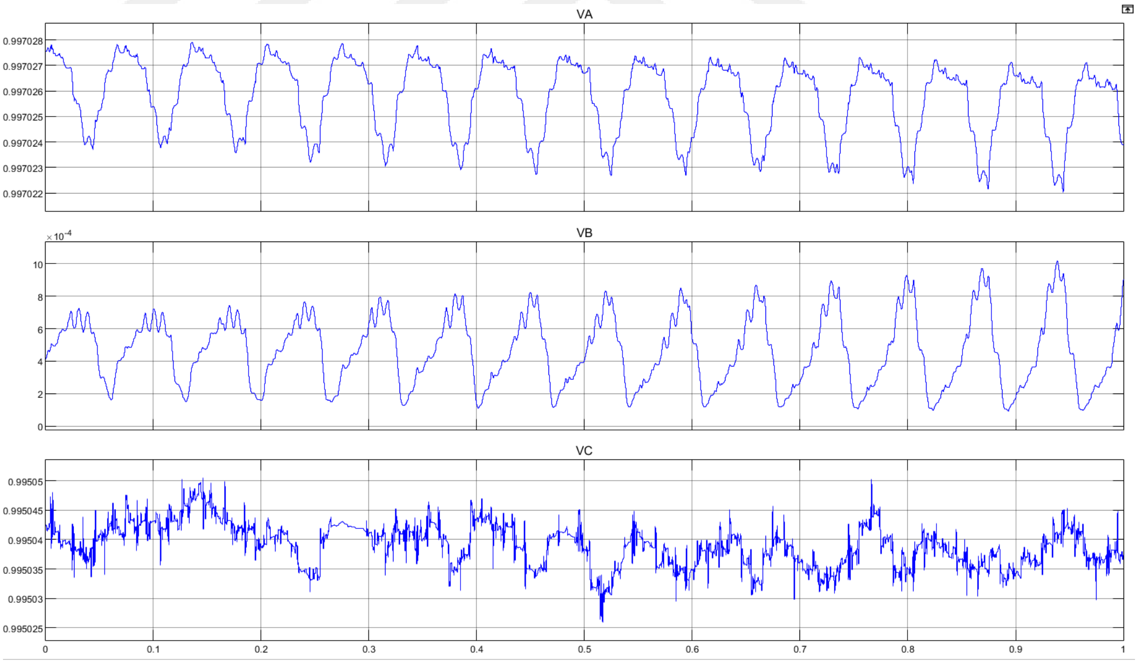


Figure 4.25. *Per unit voltage values in April*

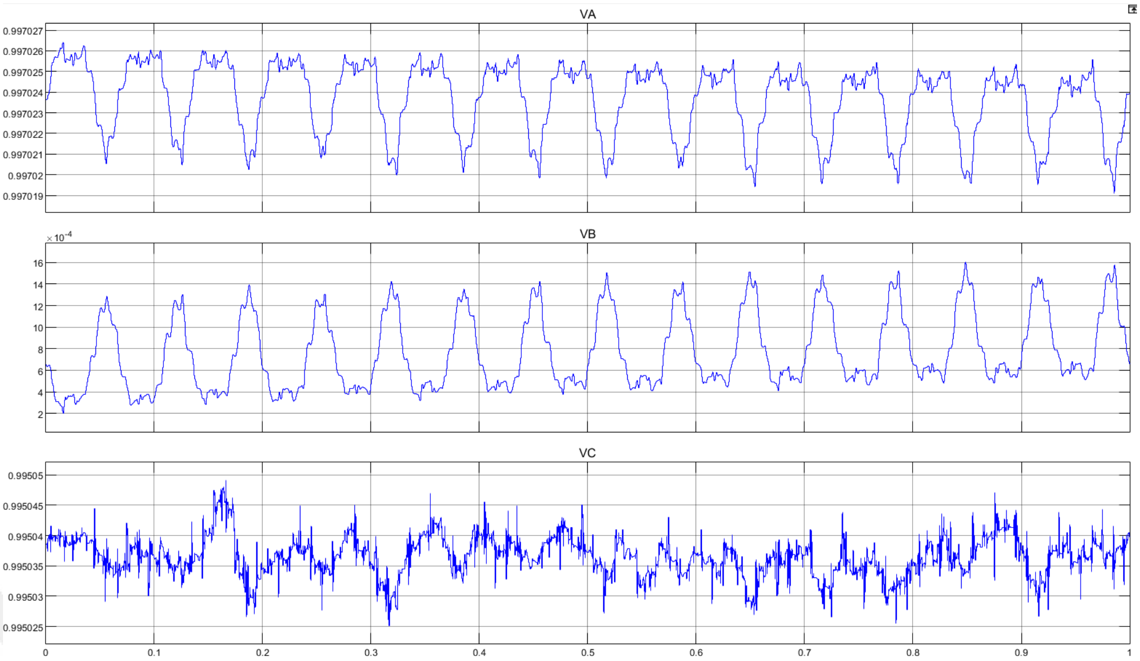


Figure 4.26. *Per unit voltage values in July*

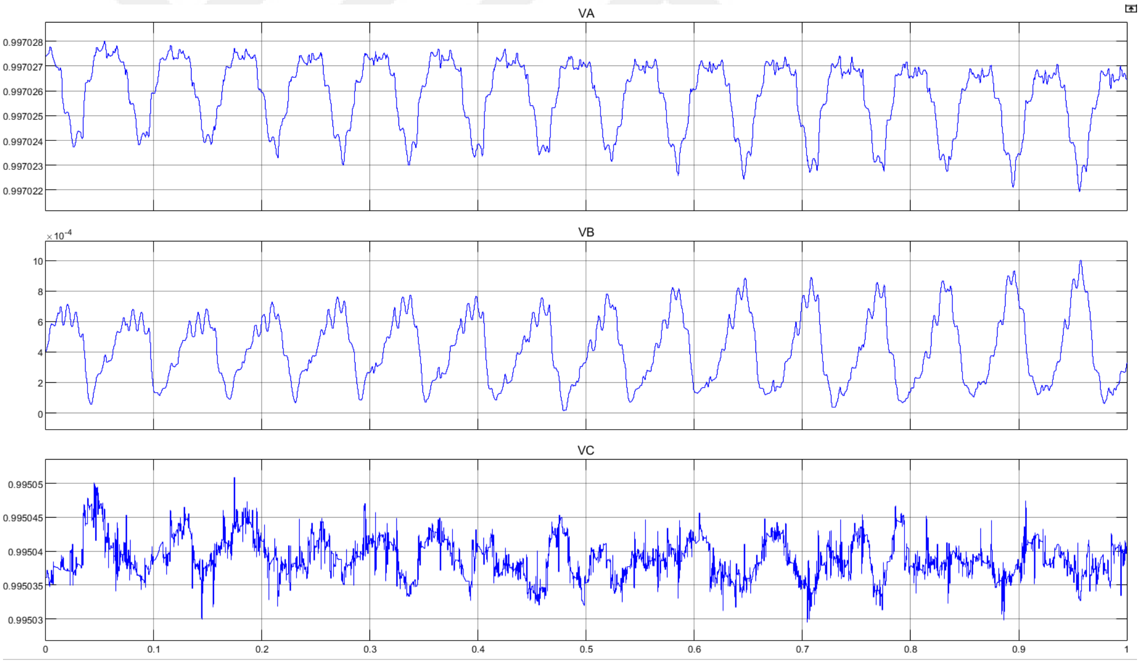


Figure 4.27. *Per unit voltage values in October*

PQ values are shown in Table 4.9 for DG.

Table 4.9. *PQ values for DG.*

Season/Month	P_{DG} max value	P_{DG} max time	Q_{DG} max value	Q_{DG} max time
Winter/January	0,002826	0,962	-0,0008111	0,986
Spring/April	0,003024	0,037	0,001348	1
Summer/July	0,002148	0,432	0,01817	0,974
Autumn/October	0,002773	0,024	0,001578	0,952

Season/Month	P_{DG} min value	P_{DG} min time	Q_{DG} min value	Q_{DG} min time
Winter/January	-0,01007	0,007114	-0,01053	0,031
Spring/April	-0,004616	0,021	-0,006541	0,030
Summer/July	-0,01106	0,984	-0,0009127	0,002335
Autumn/October	-0,003959	0,008730	-0,005310	0,018

PQ values are shown in Figure 4.28, 4.29, 4.30, 4.31 for DG.

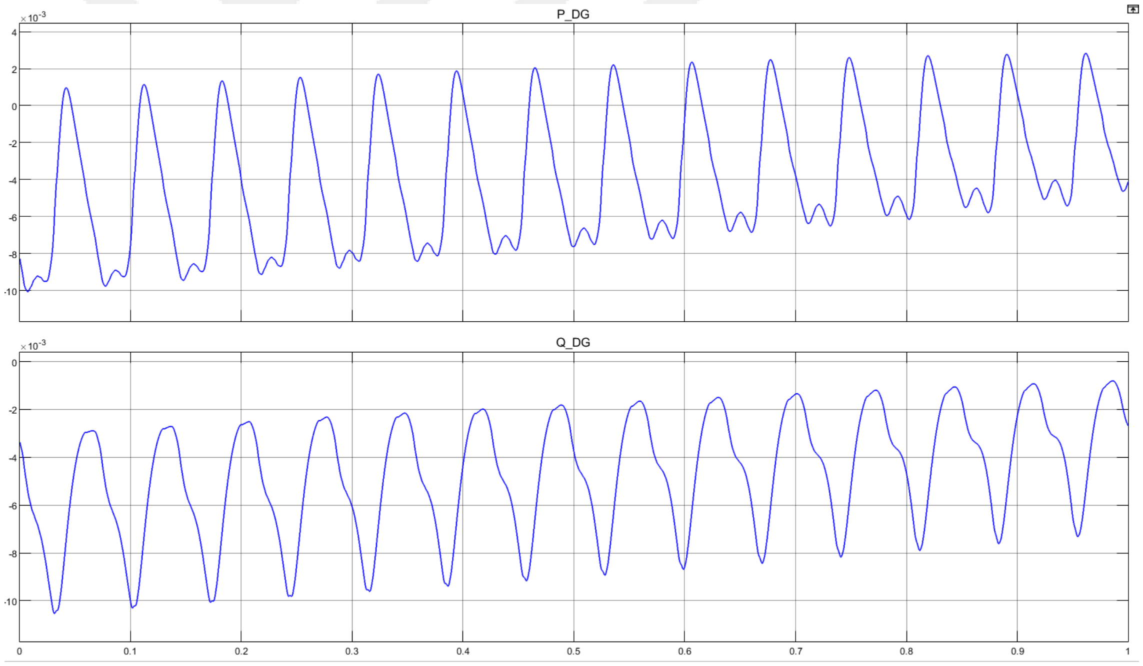


Figure 4.28. *PQ values in January for DG.*

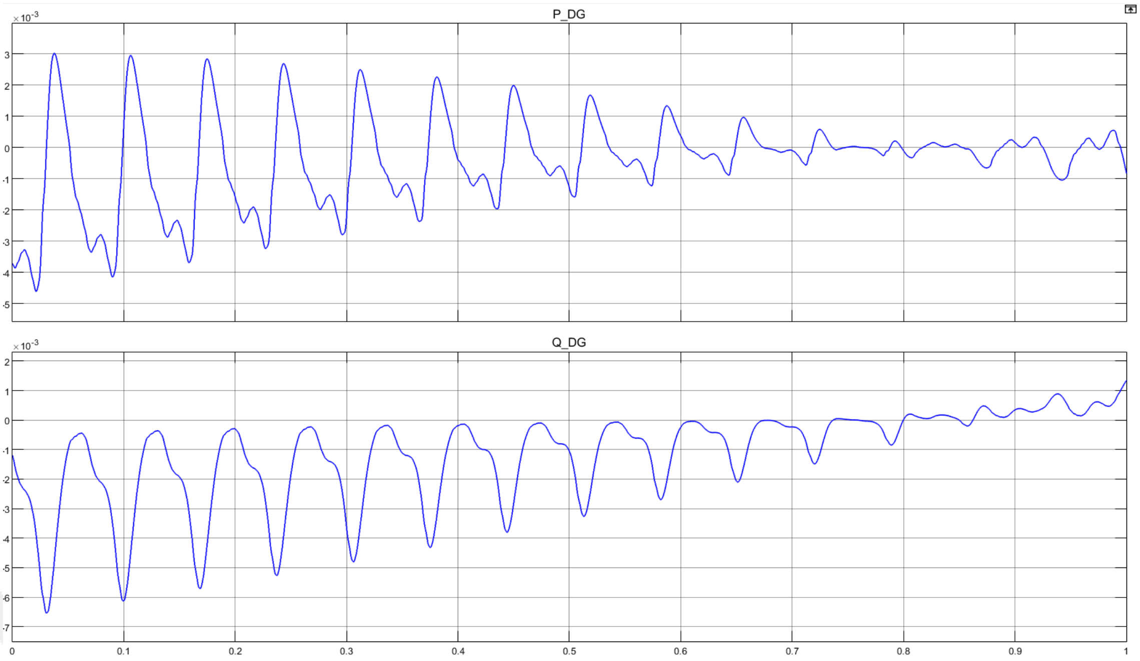


Figure 4.29. *PQ values in April for DG.*

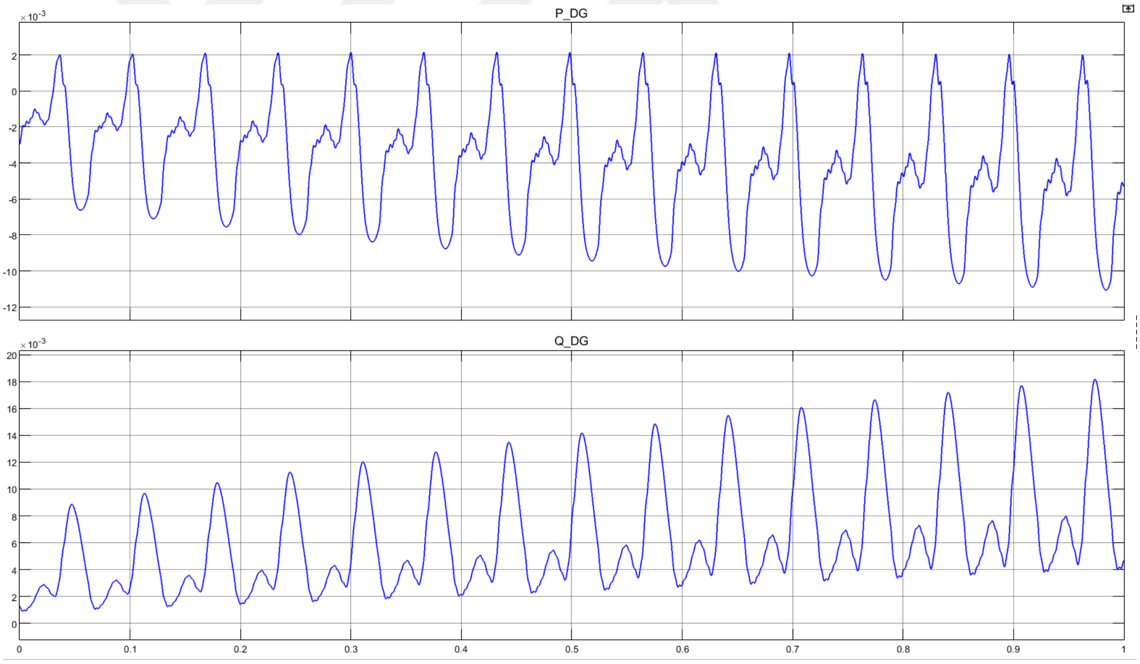


Figure 4.30. *PQ values in July for DG.*

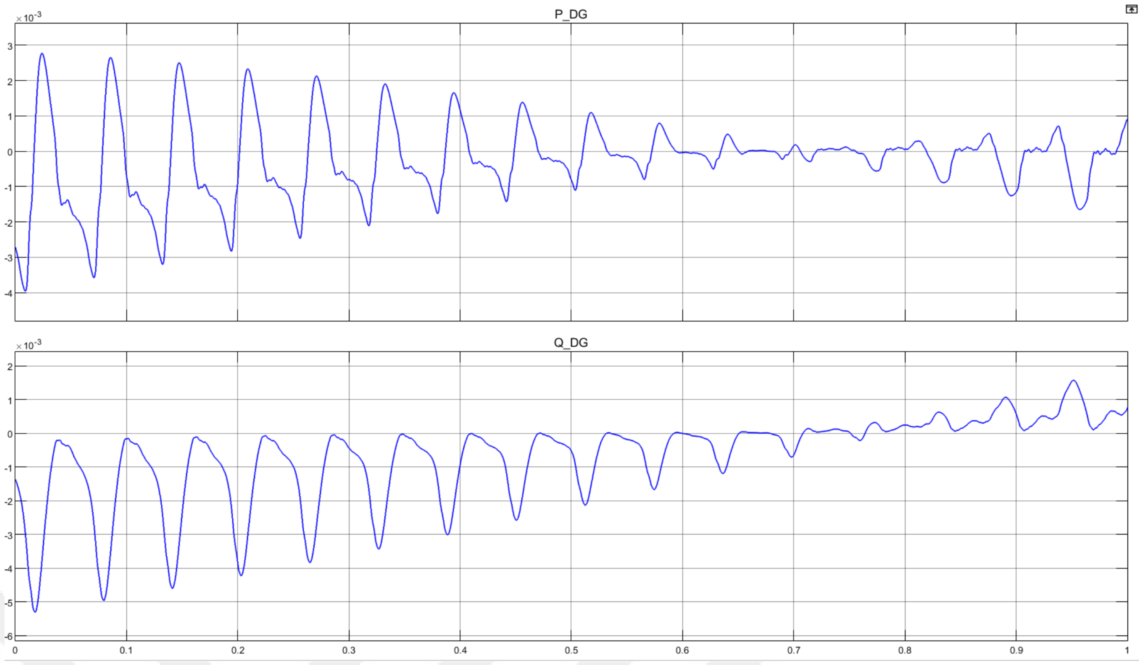


Figure 4.31. *PQ values in October for DG.*

Energy storage bus PQ values are shown in Table 4.10.

Table 4.10. *Energy storage bus PQ values*

Season/Month	P_{ESS} max value	P_{ESS} max time	Q_{ESS} max value	Q_{ESS} max time
Winter/January	3,302	0,108	-0,0001098	0,013
Spring/April	3,302	0,488	0,001634	0,313
Summer/July	3,302	0,188	0,002634	0,973
Autumn/October	3,301	0,548	0,0001549	0,073

Season/Month	P_{ESS} min value	P_{ESS} min time	Q_{ESS} min value	Q_{ESS} min time
Winter/January	3,272	0,418	-0,02863	0,804
Spring/April	3,270	0,518	-0,02965	0,524
Summer/July	3,271	0,798	-0,02904	0,464
Autumn/October	3,270	0,498	-0,02920	0,264

Energy storage bus PQ values are shown in Figure 4.32, 4.33, 4.34, 4.35.

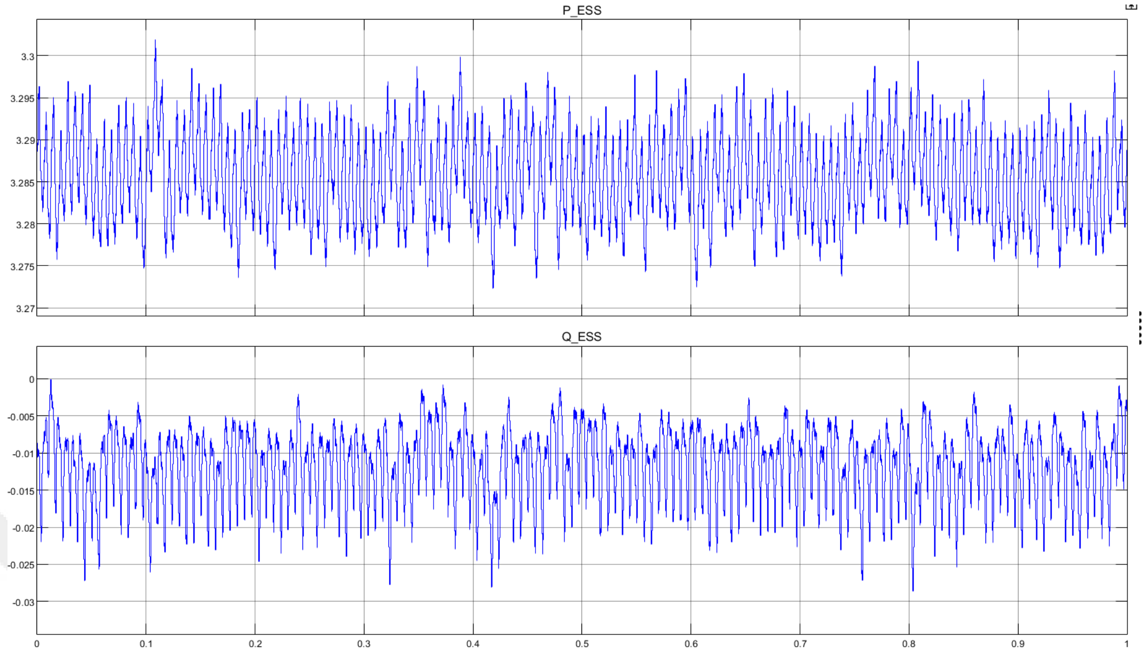


Figure 4.32. *Energy storage bus PQ values in January*

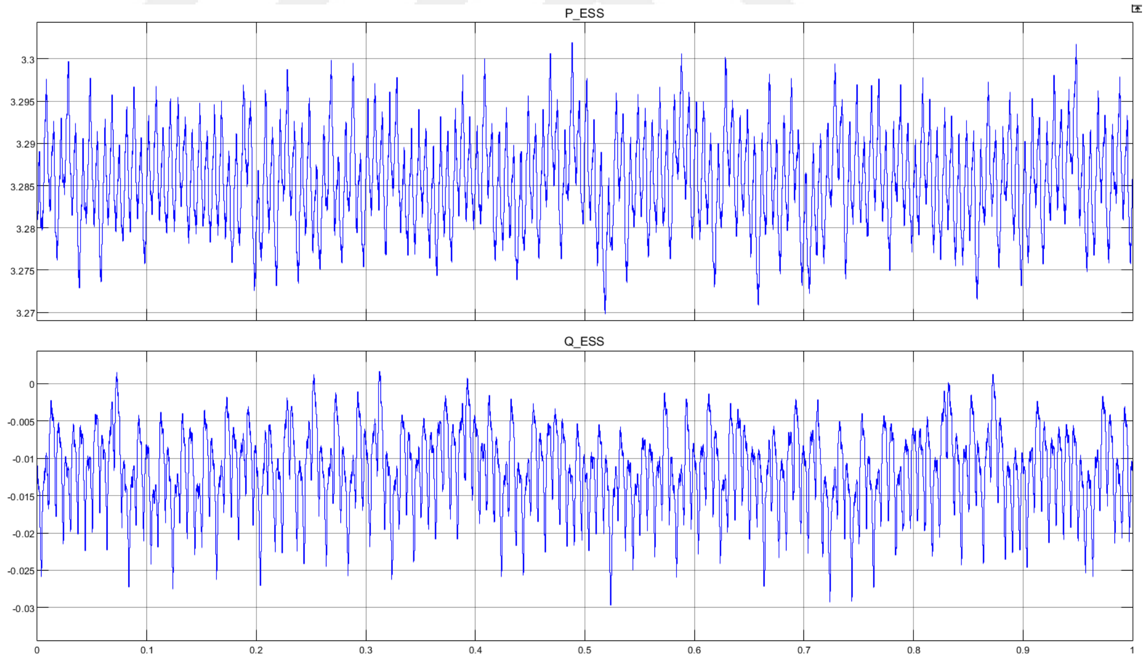


Figure 4.33. *Energy storage bus PQ values in April*

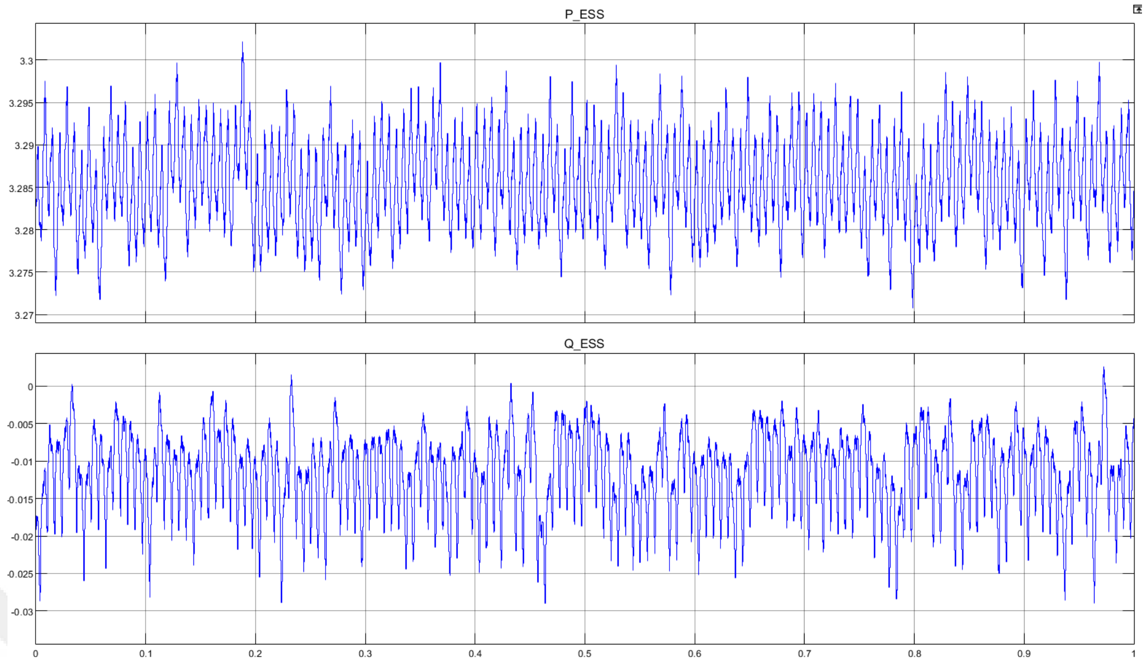


Figure 4.34. *Energy storage bus PQ values in July*

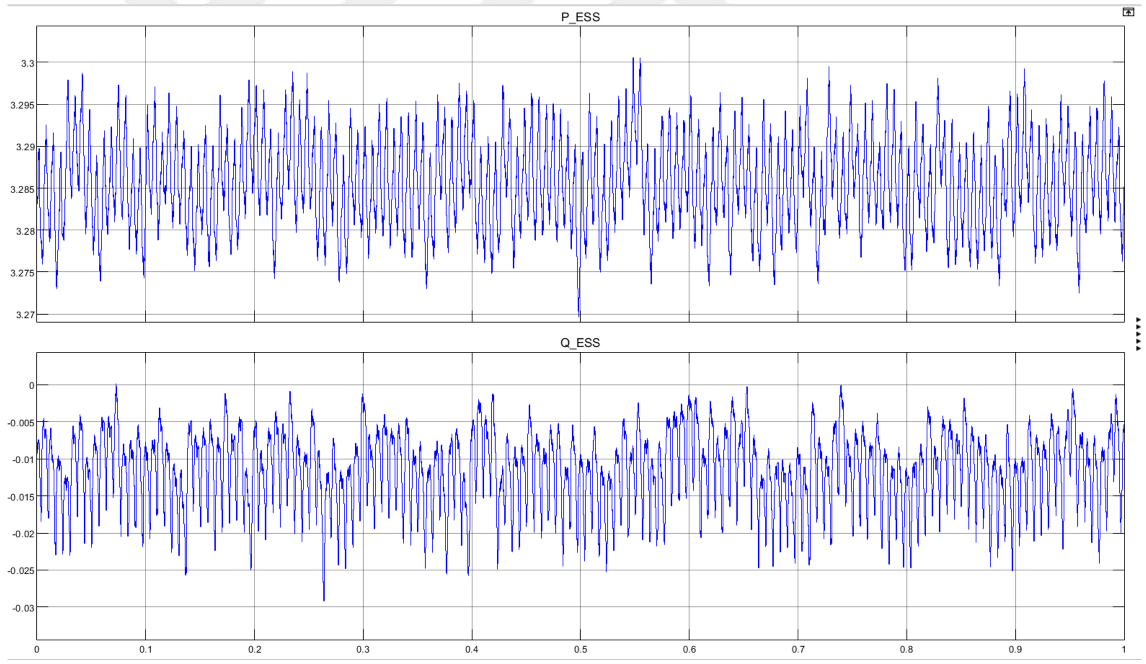


Figure 4.35. *Energy storage bus PQ values in October*

Bus voltage values are shown in Figure 4.36, 4.37, 4.38, 4.39.

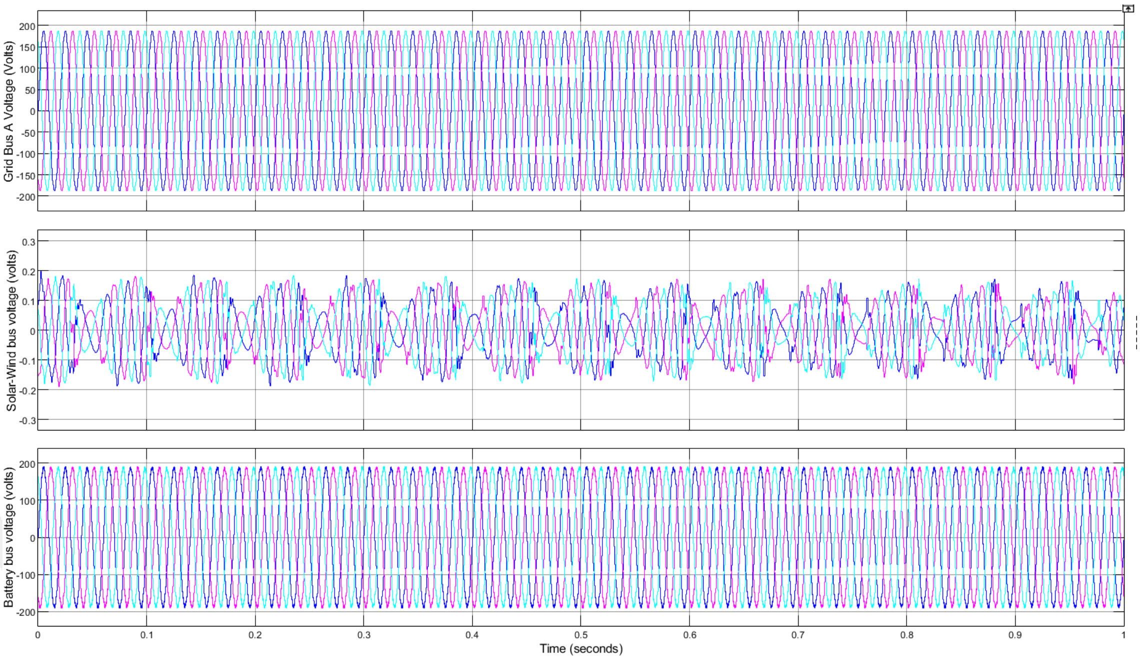


Figure 4.36. *Bus voltage values in January*

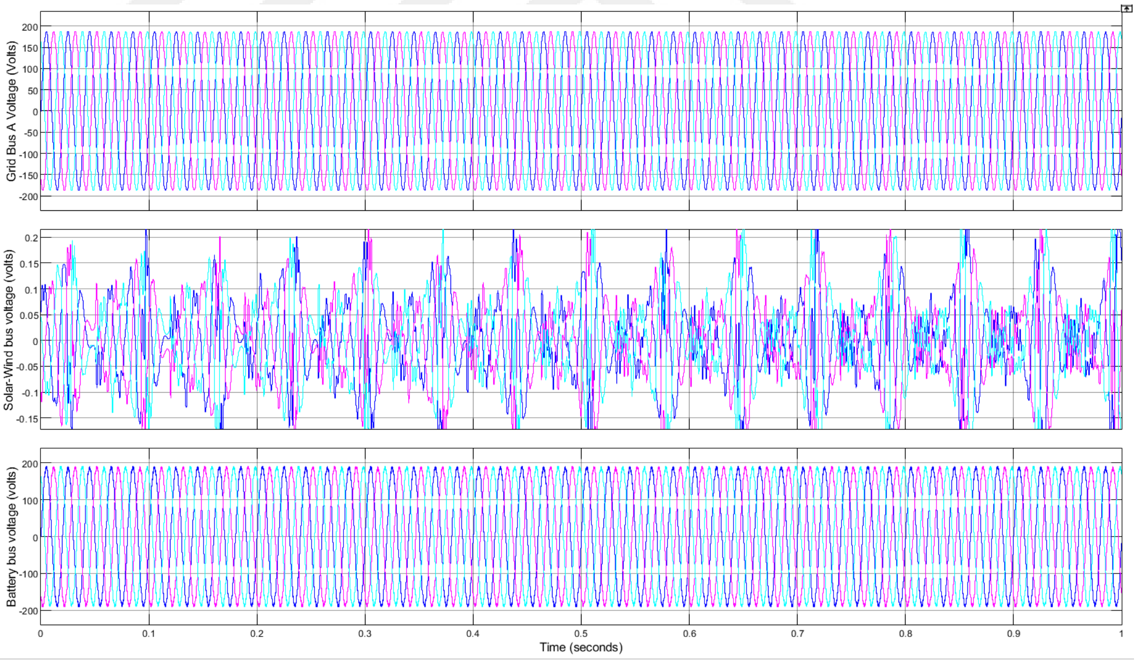


Figure 4.37. *Bus voltage values in April*

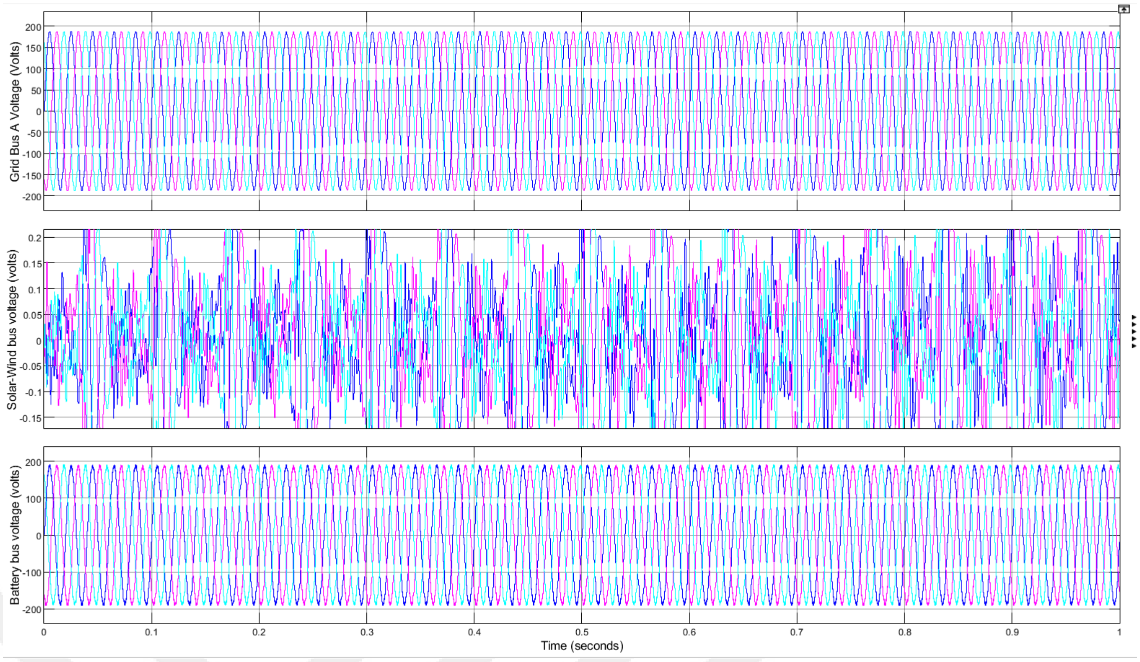


Figure 4.38. *Bus voltage values in July*

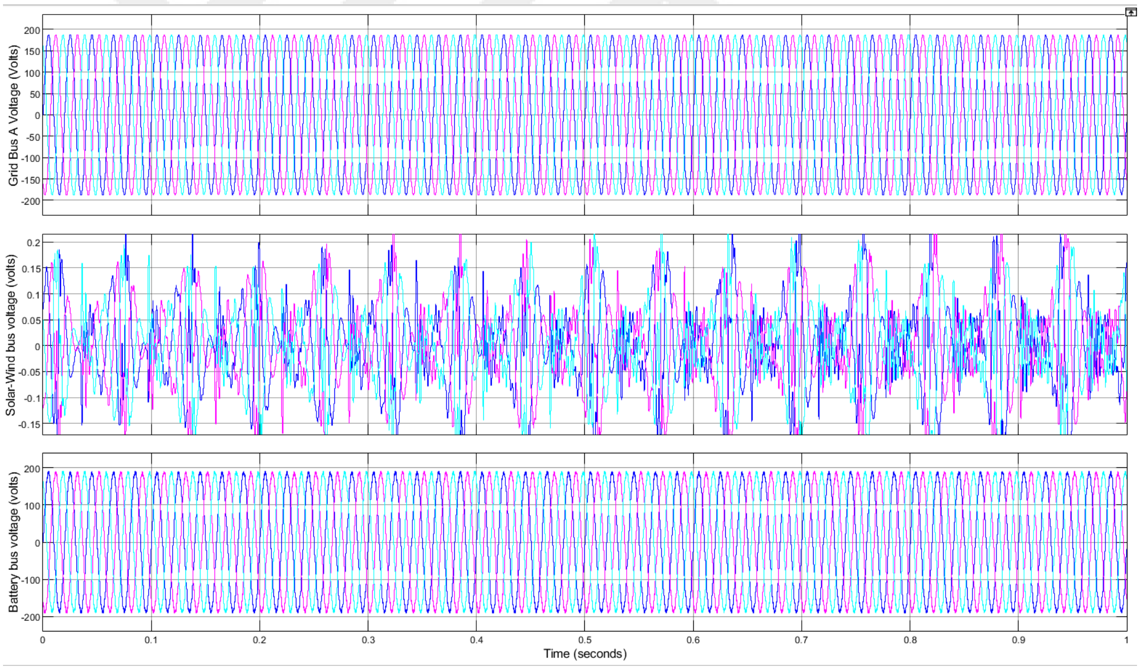


Figure 4.39. *Bus voltage values in October*

4.1.3. Comparison PSO with GA

The most consumed power from DG is in the range of 16:00-17:00 hours in January with PSO. When it is looked at the DG data in this hour range, irradiation and wind speed are the highest. Besides, it is seen that the energy storage system has the most energy between 02:00-03:00 hours. In the DG busbar voltage, a voltage drop is observed in the time interval of 0.65-0.80, while a voltage increase is observed in the time interval of 0.00-0.13.

With GA, the most consumed power from DG is between 23:00-24:00 hours, while ESS has the highest occupancy between 02:00-03:00 hours. In the sun-wind bus, the situation is as follows. Starting from 0.05 s, errors occur with 0.1 s time intervals. There are also voltage spikes and fluctuations. This situation is seen in four seasons.

The most consumed power from DG is between 13:00 and 14:00 hours in April with PSO. It captures near-maximum irradiation and wind speed in this hour range. At the same time, ESS has the highest occupancy. When the voltage values on the DG bus are examined, a voltage drop is observed in the time interval of 0.5-0.7, while a voltage increase is observed in the time interval of 0.75-0.8.

With GA, the most consumed power from DG is between 00.00-01.00 hours, while ESS has the highest occupancy between 11.00-12.00 hours.

The most consumed power from DG is between 08:00 and 09:00 hours in July with PSO, while ESS has the highest occupancy between 02:00 and 03:00 hours. When the voltage values on the DG bus are examined, the voltage drop is observed in the 0.38 - 0.46-time interval, while the voltage increase is observed in the 0.6 - 0.7-time interval.

With GA, the most consumed power from DG is between 10.00-11.00 hours, while ESS has the highest occupancy between 04.00-05.00.

The most consumed power from DG is between 13:00 and 14:00 hours in October with PSO, while ESS has the highest occupancy between 11:00 and 12:00 hours. When the voltage values on the DG bus are examined, a voltage drop is observed in the time interval of 0.5-0.65, while a voltage increase is observed in the time interval of 0.74-0.84.

With GA, the most consumed power from DG is between 00.00-01.00 hours, while ESS has the highest occupancy between 13.00-14.00 hours.

It is noted that circuit breakers are switched on and off according to the voltage values on the A, B, C busbars. The low voltage values appearing on the B bus on the voltage graphs are instantaneous graphs according to the position of the circuit breakers.

4.2. Control in MG

There are two types of MG mode which are grid-connected and islanded mode. If main grid connects to the MG, this point is called a point of common coupling. If there are problems in the system, the operation is changed to islanded mode and a circuit breaker separates the MG and main grid.

Grid-connected distributed control method is used because of the listed advantages in the upper part in this thesis. Circuit breakers are used in the simulation. In addition to this POWERGUI which is MATLAB control provides synchronization. Voltage frequency control is provided.

4.2.1. Wind Turbine Control

Park's transformation is called dq0 (direct quadrature zero) transformation which is generally used to abbreviate the analysis of three-phase circuits. With this transformation, the signs in the reference system $\alpha\beta$ are transformed into a rotational coordinate system (dq) (Vatansever, 2019).

In this study, Park's transformation is used which is shown in Figure 4.40.

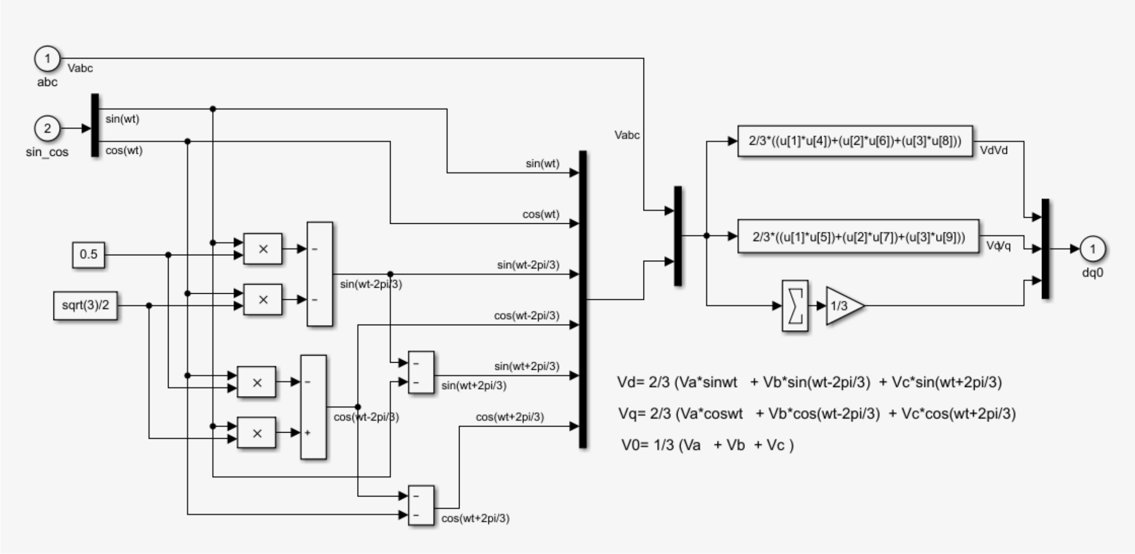


Figure 4.40. *Park's transformation of the study.*

The phase-locked loop (PLL) which is shown in Figure 4.41 is the most popular grid synchronization technique is used (Zhou, Song, & Blaabjerg, 2018).

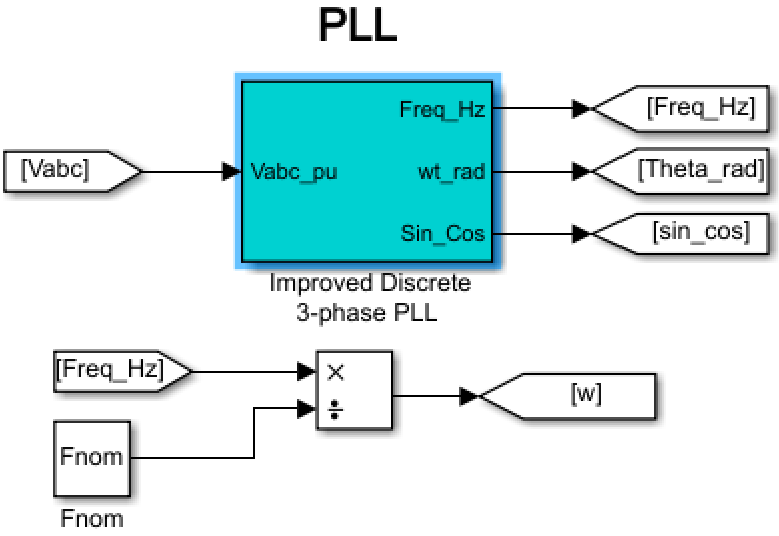


Figure 4.41. *Phase locked loop of the study*

4.2.2. Solar PV System Control

Maximum power point tracking (MPPT) is provided with PSO in the solar PV system which is shown in Figure 4.42.

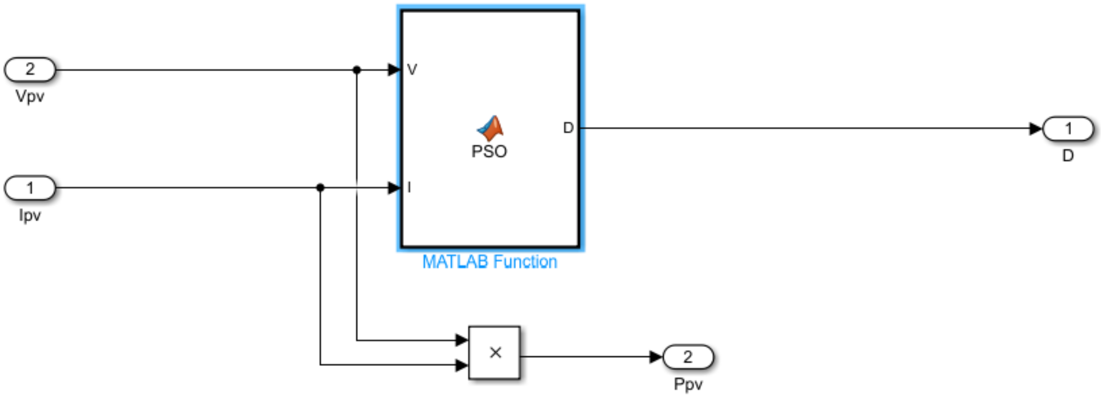


Figure 4.42. *MPPT control*

4.2.3. Battery Control

Battery control is provided with PI controller which is shown in Figure 4.43.

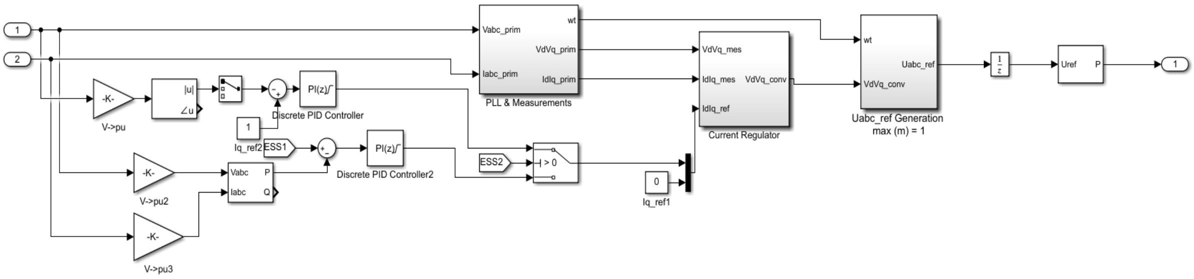


Figure 4.43. *Battery control*

5. CONCLUSION

MG systems are different from conventional electrical systems because of the optimization and control strategies. Optimization is used to find the optimal solution by using different methods. Meta-heuristic techniques are more efficient and modern than the other optimization techniques. To be programmable is a useful situation to control in MG systems.

MG systems have new generation properties with developing technology. RES can be integrated into MG systems. It is very important for reducing carbon emissions in the environment. The other issue is to need uninterruptible energy. MG systems can solve this issue by using different energy sources at the same time. The efficient way the electric energy systems are to provide uninterruptible and clean electric energy by using MG systems.

In Turkey, the main grid is an alternative current (AC). So, in this thesis, a grid-connected AC MG is preferred. In addition to this, solar and wind energy is used in grid-connected AC MG because of the being RES. There was no other energy source configuration in the MATLAB version so only solar and wind energy could be integrated into the MG system.

Metaheuristic techniques which are PSO and GA are preferred because of being efficient optimization techniques. Although the number of iterations varies according to the number of particles, PSO gives the optimal solution between 50 and 100 iterations in an average population generally. So, 50th iteration is accepted as an optimal solution at PSO in this thesis. A month is chosen for each season which are January, April, July, and October. The optimal solutions are found for the designed MG system by using a written PSO algorithm and GA MATLAB toolbox.

The PSO and GA results are compared for chosen each month of the seasons. PSO provides a more efficient solution than GA in the results. The distributed control method is preferred for control of the designed MG system because of the being combination of centralized and decentralized control methods.

In the future, hybrid systems can be designed by using PSO and GA. In addition to this, a different MG system can be modeled by adding electric vehicles and some different generation sources like fuel cells and micro sources.

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MATLAB SYSTEM SCHEMA AND PSO CODE

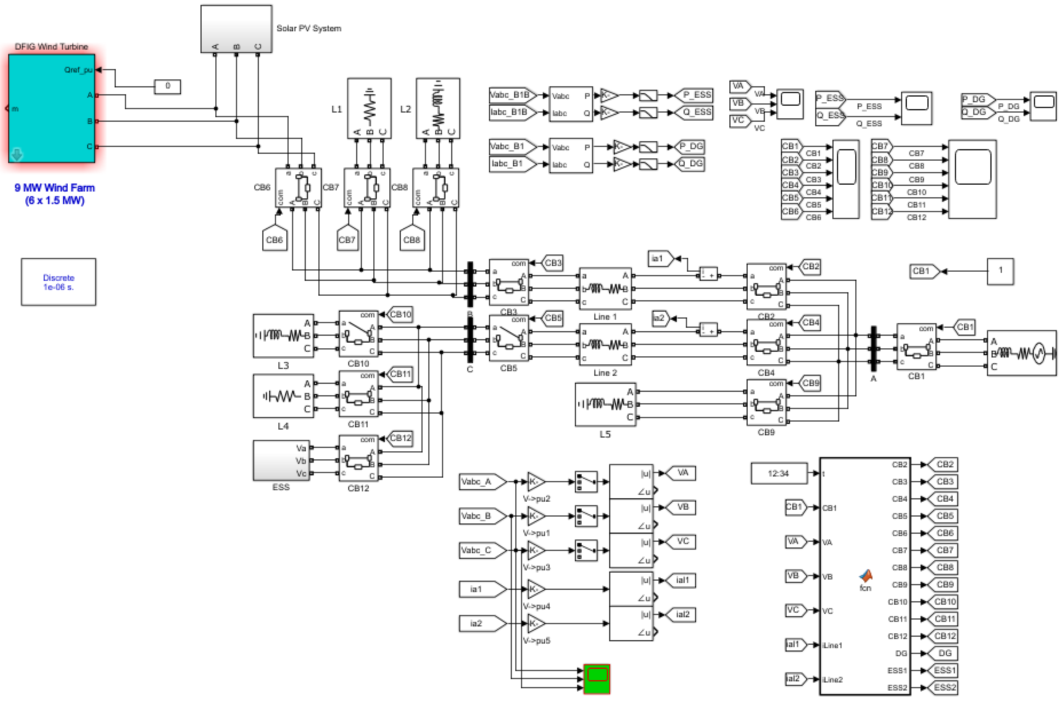

Figure 0.1. *Matlab System Schema*

PSO code in January:

```
%% Start of the program.
clc
clear
close all

warning off

t1 = clock;

%%
%==================================%
%       Initializing variables     %
%==================================%
popsize = 2; % Size of the swarm
npar = 4; % Dimension of the problem
maxit = 50; % Maximum number of iterations
c1 = 1.5; % cognitive parameter
c2 = 2.0; % social parameter
C=1; % constriction factor
wmax=0.95;
wmin=0.15;
y=[0
0
0
0
0
0
0
56
206
268
299
311
300
289
269
204
28
0
0
0
0
0
0
```

```
0];
for i=1:length(y)
    time(i)=i;
end
plot(time,y);

z=[1.11
1.09
1.1
1.08
1.07
1.11
1.11
1.07
1.1
1.19
1.27
1.28
1.28
1.3
1.35
1.43
1.44
1.39
1.32
1.25
1.24
1.23
1.22
1.22];
for i=1:length(z)
    time(i)=i;
end

plot(time,z);

%%
%====================================%
% Initializing swarm and velocities %
%====================================%
Pop=rand(popsize,npar); % random population of
continuous values
vel = rand(popsize,npar); % random velocities
%%
%==========================================%
% Evaluate fitness for initial population %
```

```
%=========================================%
% Lower limit/bounds/ a vector
Lb=0.9*ones(1,npar);
% Upper limit/bounds/ a vector
Ub=1.2*ones(1,npar);
p=0;
for i=1:popsize
    p=p+1;
    Pop(i,:)=Lb+(Ub-Lb).*rand(1,npar);
    Kp=Pop(i,1);
    Kp1=Pop(i,2);
    Ki=Pop(i,3);
    Ki1=Pop(i,4);
    opt = simset('SrcWorkspace','Current');
    [tout,xout,yout] = sim('CASE1_2017b_test',[0
0.5]);
    Error(i,:)=0.5 *  (mean(abs(a1))+mean(abs(a))) %
calculates population fitness using ff
end
%%
%===========================%
% initialize global minimum %
%===========================%

minc(1)=min(Error); % min Error
meanc(1)=mean(Error); % mean Error
globalmin(1)=minc(1); % initialize global minimum
%%
%============================================%
% Initialize local minimum for each particle %
%============================================%

localPop = Pop; % location of local minima
localError = Error; % Error of local minima
%%
%=============================================%
% Finding best particle in initial population %
%=============================================%
[globalError,indx] = min(Error);
globalPop=Pop(indx,:);
%%
%==================%
% Start iterations %
%==================%
disp('     iter       Kp       Kp1       Ki        Ki1
Jmin')
```

```
iter=0;
disp([iter globalPop globalError]);
while iter < maxit
    iter = iter + 1;
    %============================%
    % update velocity = velocity %
    %============================%
    w=wmax-(((wmax-wmin)/maxit)*iter); %inertia
weiindxht
    r1 = rand(popsize,npar); % random numbers
    r2 = rand(popsize,npar); % random numbers
    vel = C*(w*vel + c1 *r1.*(localPop-Pop) +
c2*r2.*(ones(popsize,1)*globalPop-Pop));
    %===========================%
    % update particle positions %
    %===========================%
    Pop = Pop + vel;
    % Apply the lower bound vector
    for i=1:popsize
        ns_tmp=Pop(i,:);
        L=ns_tmp<Lb;
        ns_tmp(L)=Lb(L);

        % Apply the upper bound vector
        U=ns_tmp>Ub;
        ns_tmp(U)=Ub(U);
        % Update this new move
        Pop(i,:)=ns_tmp;
    end

    %================================%
    % Evaluates fitnessfor new swarm %
    %================================%
    for j=1:popsize
        p=p+1;
        Kp=Pop(j,1);
        Kp1=Pop(j,2);
        Ki=Pop(j,3);
        Ki1=Pop(j,4);
        opt = simset('SrcWorkspace','Current');
        [tout,xout,yout] = sim('CASE1_2017b_test',[0
0.5]);
        Error(j,:)=0.5 * (mean(abs(a1))+mean(abs(a)))
    end

%====================================================%
```

```
    % Updating the best local position for each
particle %

%====================================================%
    betterError = Error < localError;
    localError = localError.*not(betterError) +
Error.*betterError;
    localPop(find(betterError),:) =
Pop(find(betterError),:);
    %=============================================%
    % Updating global fitness and global particle %
    %=============================================%
    [temp, t] = min(localError);
    if temp<globalError
        globalPop=Pop(t,:); indx=t; globalError=temp;
    end
    disp([iter globalPop globalError]); % print output
each iteration

    minc(iter+1)=min(Error); % min for this  iteration
    globalmin(iter)=globalError; % best min so far
    meanc(iter+1)=mean(Error); % avg. Error for  this
iteration

    %%
    %============================%
    % Display The Result in plot %
    %============================%
    figure(1)

    plot(globalmin,'k*','Linewidth',1.5);
    xlabel('Iterations')
    ylabel('objective function')

end% while
%==============================%
% Display The optimal solution %
%==============================%
optimal_solution=[globalPop]
Best=[globalError]
t2 = clock;

comuputation_time = etime(t2, t1)
```

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