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ISTANBUL AYDIN UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

MITIGATION FLUCTUATING POWER OF HYBRID RENEWABLE ENERGY- BASED SYSTEMS

MASTER'S THESIS

Elmi Fouad AHMED

Department of Electrical and Electronics Engineering

Electrical and Electronics Engineering Program

MARCH, 2024

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APPROVAL PAGE

DECLARATION

I declare that all knowledge in this document has been achieved and presented with academic rules and moral standards. I proclaim that, in accordance with the requirements of these rules and management, I have fully quoted and recommended all data and results that are not related to this thesis.

Elmi Fouad AHMED

FOREWORD

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March 2024 Elmi Fouad AHMED

MITIGATION FLUCTUATING POWER OF HYBRID RENEWABLE ENERGY- BASED SYSTEMS

ABSTRACT

Nowadays, with the development of power systems, considering environmental pollution is one of the most important challenges for designers and electricity market activists. These factors have caused the planners to use all the current services, including the penetration of renewable resources, reactive power controllers, operation of the reserve systems, stabilizers of the power system, and load management methods in operation. In this project, the dynamics of DG units integrated with the main grid are evaluated. So, distributed voltage controllers are used to restore the voltage values to their corresponding reference values for all DGs in a limited period of time, and a distributed frequency control based on aggregation of units is used. In the frequency recovery mode, there is a challenge that the control inputs must be equal to each other in the steady state to satisfy the power sharing property. For this purpose, a distributed PI controller has been used to mitigate the power flucyuations and recover the frequency. During the first stage, the voltage range of the distributed generator is greatly reduced while the frequency is synchronized with the load at a certain value. In this regard, both voltage and frequency have significant differences with their reference values. Therefore, it is necessary to restore them in the secondary control layer. When the distributed secondary control is activated, both the power value and the frequency value are quickly restored to their reference values. In fact, although a series of transitory states are observed at first, the frequency stabilizes at its permanent value. By examining the obtained results, it is clear that the distributed secondary control level can eliminate the amounts of violations created in the field of power and frequency control. In fact, when the secondary control level is activated, the active power distribution is well managed by the participation of different sources.

Keywords: Mitigation Fluctuation, Hybrid Renewable Resources, Microgrid, Primary Control, Secondary Control

AZALTMA DALGALANMA GÜCU HİBRİT YENİLENEBİLİR ENERJİ TABANLI SİSTEMLER

ÖZET

Günümüzde güç sistemlerinin gelişmesiyle birlikte çevre kirliliğini dikkate almak, tasarımcılar ve elektrik piyasası aktivistleri için en önemli zorluklardan biridir. Bu faktörler, planlamacıların yenilenebilir kaynakların yaygınlaştırılması, reaktif güç kontrolörleri, rezerv sistemlerinin işletilmesi, güç sistemi stabilizatörleri ve işletmedeki yük yönetimi yöntemleri dahil olmak üzere mevcut tüm hizmetleri kullanmasına neden olmuştur. Bu projede ana şebekeye entegre olan Genel Müdürlük birimlerinin dinamikleri değerlendirilmektedir. Bu nedenle, sınırlı bir süre içinde tüm DG'ler için gerilim değerlerini karşılık gelen referans değerlerine geri döndürmek için dağıtılmış gerilim kontrolörleri kullanılır ve birimlerin toplanmasına dayalı bir dağıtılmış frekans kontrolü kullanılır. Frekans kurtarma modunda, güç paylaşımı özelliğini sağlamak için kontrol girişlerinin kararlı durumda birbirine eşit olması gerektiği gibi bir zorluk vardır. Bu amaçla güç dalgalanmalarını azaltmak ve frekansı geri kazanmak için dağıtılmış bir PI denetleyici kullanılmıştır. İlk aşamada, frekans belirli bir değerde yük ile senkronize edilirken, dağıtılmış jeneratörün voltaj aralığı büyük ölçüde azaltılır. Bu bakımdan hem gerilim hem de frekans referans değerleriyle önemli farklılıklar göstermektedir. Bu nedenle bunların ikincil kontrol katmanında geri yüklenmesi gerekir. Dağıtılmış ikincil kontrol etkinleştirildiğinde hem güç değeri hem de frekans değeri hızlı bir şekilde referans değerlerine geri döner. Aslında ilk başta bir dizi geçici durum gözlemlense de frekans kalıcı değerinde sabitlenir. Elde edilen sonuçlar incelendiğinde, dağıtılmış ikincil kontrol seviyesinin, güç ve frekans kontrolü alanında oluşturulan ihlal miktarlarını ortadan kaldırabileceği açıktır. Hatta ikincil kontrol seviyesi devreye girdiğinde aktif güç dağıtımı farklı kaynakların katılımıyla iyi yönetiliyor.

Anahtar Kelimeler: Azaltma Dalgalanması, Hibrit Yenilenebilir Kaynaklar, Mikro Şebeke, Birincil Kontrol, İkincil Kontrol

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

ADN : Active Distribution Network

DG : Distributed Generation

DR : Demand Response

GHG : Green House Gas

MG : Micro Grid

MPPT : Maximum Power Point Tracking

PV : PhotoVoltaic

SG : Smart Grid

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. Introduction

Nowadays, with the development of power systems, development of renewable resources has great importance. For this purpose, a concept called microgrid has been developed in the field of power grid operation. Microgrids (MGs) integrate a large number of renewable energy sources, energy storage systems and local loads to form small-scale low-voltage (LV) and medium-voltage (MV) power electrical systems [1-3]. Compared to traditional fossil fuel-based power grids, the advantages of MG include lower emissions, faster demand response, and relatively simpler implementation [4-5]. In general state, a MG can be operated in two different modes [6-7] consists of Main grid connected mode and Islanded mode.

In grid-connected mode, MG is connected to the main grid by closing the isolation switch (IS) at the point of common coupling (PCC). Due to the larger capacity of the main grid, MG dynamics is dominated by the main grid. Therefore, the task of MG control in this situation is to deliver the scheduled active/reactive power to the main grid [6]. When the isolation switch is opened and placed in the island mode, it must not only maintain its voltage/frequency in the specified reference values, but also manage the distribution of active/reactive power between distributed generators (DGs) and loads [7].

Recently, in order to standardize the microgrid performance, hierarchical control has been proposed to manage MG networks [8-9]. In this structure, the control approach is divided into three layers, primary, secondary and tertiary control. Primary control is defined in line with local DG resource control [10]. In this layer, a series of challenges including the voltage and frequency deviation caused by the droop system are appeared [11]. The secondary control is used to restore the frequency and voltage to the considered reference values. In tertiary control, issues such as economic and optimal load distribution are managed.

B. Research assumptions

- Complete information about the MG, including the amount of power demanded at different hours, the production power of renewable resources, the parameters of the distribution network lines, etc. is available.
- There is a possibility of two-way information exchange between energy generating resources and control systems.

C. Microgrid

Microgrids are low voltage distribution networks that are composed of many distributed resources (DR) and different types of loads and can operate in the mode of connection to the main grid as well as disconnected from it (islanding mode). These microgrids can also include energy storage sources. Microgrids can be considered as the main building blocks of smart grids (SG), because they are able to implement many smart city functions. It is expected that in the near future, smart grids will be introduced as an integrated system of plug-in microgrids that can exchange commands, data, and electrical power among themselves with good quality.

First, it should be noted that distributed generation units (DG) located in microgrids mainly use renewable energy sources that do not have environmental pollution. In addition, power electronic interface converters (for example, inverters used to convert AC to DC power) which are used to connect DGs to the grid, can provide several control functions. In fact, the main task of the DG inverter is to adjust the amplitude and phase angle of the output voltage in order to control the amount of active/reactive power injected. However, compensating the challenges in the field of power quality can also be solved through the adoption of appropriate control strategies. Among the challenges raised in the field of power quality, voltage unbalance is very common and common. Voltage unbalance can lead to negative effects on equipment and power system. In fact, under unbalance conditions, network losses also increase and system stability decreases. Also, this factor can have negative effects on equipment such as induction motors, power electronic converters. According to the recommendation of the International Electrotechnical Commission (IEC), the allowed voltage imbalance in the network should be less than 2%, which is usually due to the connection of unbalanced loads [12]. Another main error for sensitive equipment that occurs from the grid is the lack of voltage (decrease between 60% to 90% of the nominal voltage) in the time interval between 10 ms and 100 ms [13]. This lack of voltage has different reasons, such as a short circuit in the network (the occurrence of a short circuit causes an increase in current and thus an increase in voltage deficiency), inrush currents caused by turning on large machines or switching in the network. Especially in sensitive production industries, the occurrence of voltage shortage can lead to many losses on production. Even though the occurrence of a fault and as a result the power cut is more critical compared to the lack of voltage, but because the lack of voltage occurs more often, as a result, this lack of voltages will lead to power quality problems.

D. Problem Statement

About 90% of all outages and failures in the entire main grid occur in the distribution network sector. For the above reasons, moving towards the intelligentization of the network should be done from its low voltage part, i.e. the distribution network. In other words, with the increase in power loss and voltage drop and the growth in the amount of power demanded by customers, it is necessary to update the infrastructure of the distribution network. One of the possible options in this regard is the use of distributed generation (DG) resources. The optimal use of DGs can not only reduce losses and improve the voltage level, but it can also reduce the amount of total harmonic distortion (THD).

Due to the connection of distributed generation sources near the load location, not only the transmission power losses of the lines are reduced, but also the amount of investment risk and construction time are greatly reduced. As a result, using an optimal method that can provide the best method for connecting distributed generation sources to the distribution network is very useful for power system planners. It should be noted that with the increase in the penetration of renewable resources, it is expected that changes in the voltage of network buses will become a major challenge. All the mentioned achievements are strongly dependent on the method of installation and exploitation of renewable resources. Therefore, it is necessary to study the effects of DGs on the voltage level, line losses, short-circuit current, the amount of harmonics injected into the network and reliability before connecting them to the grid. In addition to these cases, the uncertainty in the production capacity of renewable resources has created major challenges both in the field of operation and in the planning sector, and definitely for analyzing the behavior of the system and maintaining power quality indicators. The network should develop new methods within the standard range. On the other hand, voltage fluctuation in the power network is one of the types of disturbances that can severely affect the reliability of the network. The standard range of voltage fluctuations in distribution networks is approximately 3% of voltage level changes.

E. Research Importance

A microgrid is defined as a low-voltage distribution network that consists of local energy sources, loads, energy storage sources (ESS) with the ability to connect to the main grid or self-standing [14]. When connecting to the main grid, the frequency of the microgrid is controlled by the main grid. When the microgrid is suddenly separated due to a unpredictable fault, due to the unbalance between supply-demand and the low main inertia of the microgrid, severe frequency variations occur in the microgrid [15]. In this situation, sufficient reserve power with high speed responsiveness is necessary to prevent blackout. Since the response speed of distributed generation (DG) sources and microturbines (MT) do not have the necessary performance, therefore, the use of equipment with fast response such as energy storage sources (ESS) is vital in this field [16]. In fact, renewable energy sources, in the form of distributed generation (DG), have been significantly integrated into distribution networks in recent years.

With the increasing penetration of DGs, distribution networks have experienced a major change from structure to operational mode. Fluctuations of DG's output power making the management of active distribution networks (ADNs) more complex and challenging. In particular, intermittent sources consisting of wind turbines and solar photovoltaics and controllable loads such as electric vehicles have significant uncertainty in spatial/temporal distribution, which often leads to a severe fluctuation of active power and voltage overshoot. These disturbances increase operational losses and even lead to ADN stability problems [17].

F. Thesis Innovations

- Reducing the power and voltage fluctuations with using hierarchical control strategy
- Combination of batteries with supercapacitors for storing and injecting the electrical energy

G. Thesis Structure

- Photovoltaic systems will be introduced in the second chapter. In the following, the important components of these systems will be described and each part will be discussed in detail. In the following, we will talk about batteries, inverter and their relationship with each other.
- In the third chapter, explanations will be given about the concept of maximum power point tracking, and then the chaotic and observing method and the incremental guidance method will be fully explained. The performance of these two algorithms in fixed step and adaptive step modes will be expressed and flowcharts corresponding to their functions will be drawn.
- In the fourth chapter, firstly, a model will be designed about extracting the maximum power in normal conditions and considering the inherent fluctuations of solar energy radiation using the genetic algorithm, and then the obtained results will be shown. In the following, the effect of dust on the panels will be investigated and the results of real measurements will be evaluated and compared, and then computer modeling will be designed and implemented for the implementation of the maximum power point tracking algorithm using the genetic algorithm. At the end of this chapter, the results will be analyzed with other articles.
- In the fifth chapter, a review of the designs made in the thesis will be done first, and then suggestions will be presented at the end of the chapter.

II. LITERATURE REVIEW

A. Introduction

Due to the growing demand of consumers, which is affected by population growth, the need for electricity generation has increased. The increase in fossil fuel prices and the emphasis of regulations on limiting green house gas (GHG) emissions have increased the cost of electricity production using fossil fuels (traditional sources). Also the progress made in the structure of semiconductor power electronic equipments, high frequency nanocrystalline transformers, with the ability of high throughput and improving the performance of advanced sensors and processors, it has led to the development of the path of progress in the use of DGs that are connected to the power grid through an inverter. Due to the reasons mentioned, the approach of using other energy sources for electricity production has increased. In fact, power systems are transitioning to a situation where the penetration of renewable resources at the low-voltage level of the distribution network is increasing rapidly. Historically, distribution systems have rarely had dynamic stability problems, because renewable resources were rarely used. However, the emerging generation of flexible distribution systems is expected to allow parts or even entire distribution feeders to continue operating in islanding mode in emergency situations. In such a situation, the issue of dynamic stability has become a serious challenge.

In [18], it is stated that voltage source inverters (VSIs) should be used in voltage-controlled mode for proper regulation of voltage/frequency as well as accurate power distribution in the microgrid apart from the grid. In order to operate VSIs in this mode, their current must be controlled directly, and this requires communication between DGs. In this project, a new method is proposed to operate VSIs in current controlled mode. So, by taking advantage of the inherent property of Droop method indicators in voltage source inverters set based on resonant currents, we will have acceptable voltage and frequency, as well as appropriate power distribution in the microgrid, without the need for direct connection between scattered production sources.

The writers of [19] described that the voltage/frequency of the microgrid are strongly influenced by the fluctuations of reactive/active powers. The variation in the load changes the balance between generation and consumption in the microgrid, and this causes a change in the output voltage/frequency of the VSIs, according to the equations of the Droop method, and if the load changes are huge, the installed DGs may not be able to stabilize the microgrid. Since the optical control method is dependent on the line parameters and to eliminate this dependence, the fuzzy control method was used to optimize the control coefficients of the Droop method to adjust the voltage/frequency in an AC microgrid.

In [20], an optimal power control strategy is presented for distributed inverter generation sources in a microgrid which isolated from the main grid. This research has been done for the time durations which is separated from the main grid. The parameters investigated in this research were microgrid voltage/frequency, dynamic response, steady state response and harmonic distortions. This controller includes an internal current control loop and an external power control loop based on relative integrator regulators. The power controller is designed for voltage-frequency mode. In this reference, the particle swarm optimization (PSO) algorithm is used, and a new control strategy has been designed so that when the microgrid is separated from the main grid, the resources are placed in the voltage-frequency control mode and adjust the voltage/frequency of the system. In [21], the practical investigation of secondary control in a microgrid has been discussed. So, a controller has been designed which ensures the supply of reactive power in addition to voltage and frequency recovery at the secondary level. This controller has been tested in two modes (centralized & decentralized) and its results show that the secondary controller obtains better results in a decentralized (distributed) method. Although photovoltaic arrays cannot directly react to changes in grid frequency, recent studies show that their capacity can be used in the field of frequency control.

B. Structure of Microgrid

The existing power grids are the product of the expansion of urbanization and the rapid development of various infrastructures in different parts of the world in the past centuries. Although power plants are located in different regions, they usually use similar technologies. However, the growth of the electrical power system has been affected by economic, political and geographical issues that are unique to each company. Despite such differences, the overall structure of the existing power system is the same. Since the beginning, the electricity industry has been operating with a clear boundary between the generation, transmission and distribution parts, and as a result, each automation part has formed a different evolution and transformation. The existing power grid is a fully hierarchical system where power plants at the top of the chain ensure the delivery of power to customer loads at the bottom of the chain. The system is essentially a one-way line with no real-time information source about the customers.

In order to maintain reliability, the power grid is planned and designed in such a way that it can supply the maximum predicted demand. As a result, since this peak demand occurs only in a fraction of the hours of the day, the aforementioned system is intrinsically "non-optimal". In addition, the unprecedented increase in power consumption, along with the delay in investing in the power system infrastructure, reduces the system's stability. In the absence of a sufficient margin of safety, any unexpected heavy demand or unusual event in the distribution network that causes a fault in a part of the network can lead to a catastrophic shutdown. Energy shortages and environmental pollutants, wasted energy in transmission lines and structures. Hierarchy is another weakness of this network, which was mentioned in the initial part.

To facilitate troubleshooting and protect expensive equipment, utility companies have introduced various levels of control mechanisms. A common system of this kind is the supervisory control and data acquisition system (SCADA). Although such systems allow companies to have limited control over system performance, the distribution network is outside their control. For example, in north America, which is the founder of the most advanced electricity systems in the world, less than a quarter of the distribution network is equipped with information and telecommunication systems, and the penetration of automation in the distribution system, at the level of the feeder system, is only 15% to 20%. One of the goals of using such systems is to control the level of power losses in power networks. In fact, digital technology that enables two-way communication between power producers and customers along transmission lines is what makes a grid smart. Like the world of the Internet, smart power grids also consist of controllers, computers, automation, and technologies and equipment that work together. But in this case, these technologies will work together with the grid to respond to the rapid changes in our electricity demand. The smart grid offers a unique opportunity for the electricity industry to enter a new level of reliability, availability and efficiency that will contribute to the health of our environment and economy.

During the transition period to this new smart grid, it is critical to run tests, develop technology, educate customers, develop standards and rules, and share information between different projects to make sure the benefits of this smart grid. Today, a power failure, for example, a blackout, can dominovar causes a series of failures. For example, to challenge the banking system, communication, transportation and security systems. Due to the two-way interaction feature, the smart grid makes it possible to automatically reconnect the grid when the equipment is damaged or an outage occurs. This issue minimizes the failures. When power outages occur, smart grid technologies identify and isolate these outages before large-scale outages occur. New technologies also ensure that the power recovery system continues power supply quickly and strategically through emergency routing, i.e. to emergency systems first. In addition, it can make better to use of electrical power generators when main grid is not available. By combining these distributed sources of power generation, the smart grid can keep medical centers, police stations, traffic lights, telephone systems active in emergency situations. The smart grid is not only for power generation units and their technology. But also, it provides the information and tools to make choices about how you consume. As you bank from home, imagine being able to manage your electricity in a simpler way. A smart grid enables an unprecedented level of consumer engagement (Figure 2-1).

Figure 1: Schematic of smart grid with two-way communication system [22]

A smart grid gives flexibility to power system and prepares it for better exposure in emergency situations such as severe storms and earthquakes. For example, you will no longer need to wait for your electricity bill. With a smarter network, you will be able to have a clear and timely monitoring of your consumption. This allows you to lower your consumption, for example, during the hours when electricity is more expensive and more expensive. The smart network will consist of millions of control parts, computers, power lines, and new equipment and technologies, and it will certainly take time to install, test, and launch these equipments, but what is clear will bring changes to our lives, just like the world of the Internet, and changed our work, play and education.

Today, the electricity industry is not only challenged with providing resources to supply the energy demand of industries, but on the other hand, minimizing and reducing the effects that humans have on the environment in connection with the production of this energy is also another matter of interest and the smart grid is a solution for these kind of challenges that has a lot of profit and efficiency. From the consumer side, the smart grid means that they can intelligently manage their consumption to pay less during peak hours when energy prices are expensive, and for environmental experts, this grid using modern technologies to alleviate harmful changes in water levels and air pollution and avoiding the production of excessive carbon gases, and for the colleagues of the electricity industry, it is an opportunity to make smart decisions and provide accurate information about the state of the network.

Smart electrical energy distribution networks are one of the latest technologies in the world and the result of the efforts of experts to modernize distribution networks and enter the digital century. The main goal is to provide reliable electricity and respond to the growing needs of customers with the least damage to the environment. The world's first smart network was introduced in March 2008, and the city of Balder, Colorado, USA, was awarded the title of the first city with a smart electricity distribution network. The goal of designers by using smart technology is around the three main axes of subscribers, equipment and communication. Smart technology has the ability to make fundamental changes in the production, transmission, distribution and use of electric energy along with economic and environmental benefits, which ultimately ends in meeting the needs of customers and the availability of reliable and stable electricity. On the other hand, the system can make decisions in critical situations by using collected information and prevent unwanted shutdowns.

1. Advantages of Microgrid

In summary, the advantages of smart grids are as follows:

- ❖ Peak shaving: which is the main result of using smart grids along with advanced technologies in distribution substations and subscribers' homes.
- ❖ Reducing the consumption of fossil fuels: which is obtained as a result of reducing peak and energy losses along with reducing the loss of distribution lines.
- ❖ Reduction the blackouts: this is an important result of the ability to predict or potentially prevent power outages and effective response in case of power outages to fix the problem.
- ❖ Reducing the cost: reduction the investment required for distribution and transmission projects in order to improve load balance and reduce peak load due to advanced demand management.
- ❖ Clean resources: Using green and renewable energy sources (Figure 2-2).

Preventing power outages is the main factor of customer satisfaction. The smart distribution grid quickly identifies and removes from the circuit the devices that are likely to cause errors in the distribution network, and also quickly identifies the leakage current and announces the places that require the power to recover the network.

Figure 2: Schematic of Generation resources connection [23]

The use of advanced measurement software quickly identifies subscribers who are out of service. Providing such information to incident personnel who are at the blackout location is very valuable and increases operational efficiency. Smart distribution networks reduce the outages of subscribers by using the following solutions:

- Resetting the system with the help of intelligent automatic switches
- Remote fault diagnosis
- Determining the size and location of the out-of-circuit load remotely and instantly
- Remote control of generation resources and their aggregation for use with the help of communication through underground transmission lines (Figure 2-3)
- Remote detection of disconnection and connection of the network

2. Characteristics of Microgrid

Considering the intermittent nature of renewable energy resources, which are generally wind turbines, subscribers need information on its production rate and availability in order to choose, so that they can make the right choice according to their income and environmental priorities, which requires training and empowerment. Home residentials and preparation them need a cultural basis, so proper investment should be made in this field as well. Real-time pricing software helps manage demand by increasing retail prices whenever electricity is expensive and lowering retail prices when electricity prices are low.

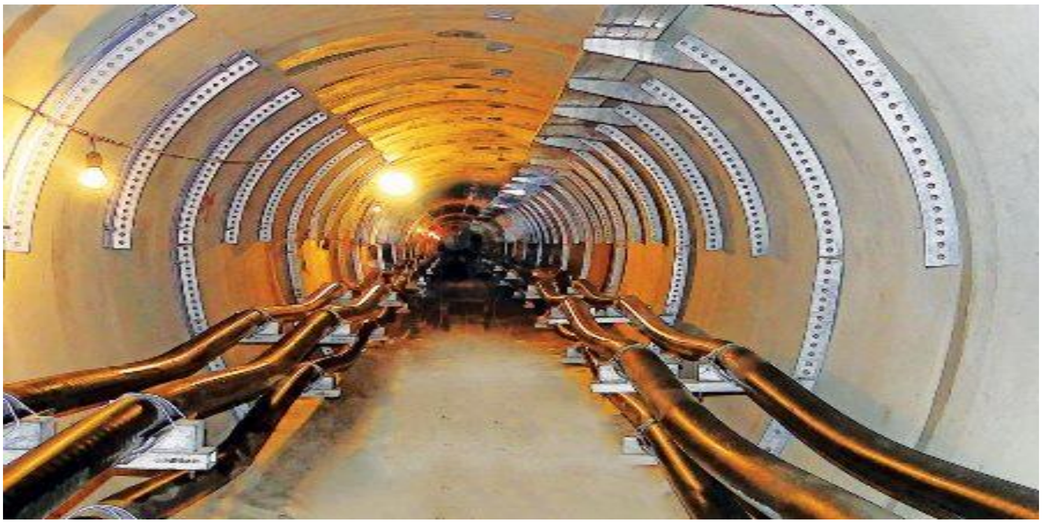

Figure 3: Underground Transmission lines [23]

Anyway, people are not familiar with such software, but now a system has been designed that controls the shared energy consumption based on its settings (made by the subscriber) based on price and time. These systems enable customers who are concerned about their environment to control the source of energy production and can use the type of energy that causes less damage to the environment. The components of such programs are shown in Figure (2-4). Some of the most important advantages of using them are as follows:

- Reducing costs related to increasing the efficiency of meter reading
- 50% reduction in manpower required for periodic reading of meters
- Reduction of calls to the control center (one million dollars of annual benefits)
- Annual benefits from preventing energy theft of 10 million $ to 20 million $
- Remote connection and disconnection (Save 5 million $ to 10 million $ from avoidance of using the technicians)

Losses of transmission and distribution lines, which are the result of the impedance of the conductors and low efficiency grid operations, which are currently between 8% to 14%. By reducing these losses, power plants can be placed at a lower generation level, and as a result, pollution will be less. The smart distribution network enables us to calculate and minimize line losses by creating an optimal balance between voltage/frequency and reactive power. A 20% reduction in transmission line losses reduces production by 500,000 tons/year [24].

Figure 4: Effective factors to form smart management [24]

The intelligent distribution network uses the following methods to reduce system losses:

- Placing remote capacitor banks to reduce the required current for reactive power
- Measuring the power factor of subscribers in distribution transformers
- Load balancing using distribution automation
- Controlling and bringing into circulation distributed energy (DG) sources
- Capital optimization

The smart distribution network enables us to know the conditions and reliability of the grid. Collecting and transmitting data creates a system that is able to make automatic decisions. The result of this work is the ability to use the capital optimally, the reasons for which are:

1- Avoiding breakdowns by timely replacement of cables, equipment, substation and distribution transformers

2- The dynamic adjustment of trans to help postpone investment in this field

3- Increasing the life of production equipment, which prevents reinvestment to produce the required energy.

3. Motivation for using Microgrid

Almost 90% of outages and disruptions are caused by the distribution network, and as a result, moving towards a smart network in order to solve problems should start from the bottom of the chain, that is, the distribution system. In addition to the rapid increase in the price of fossil fuels, along with the inability of power plants to increase their generation capacity according to the increase in demand, the need to improve the distribution network and use technologies is increased.

This can help the system by improving the management of the demand side and protecting the facilities.

The idea of a smart grid started with the idea of advanced metering infrastructure (AMI) to develop demand-side management, increase energy efficiency, and a self-recovery electrical grid to improve resource reliability and response to natural disasters or intentional sabotage. But subsequent developments have improved the basic aspects considered for the smart grid and have helped shape the new face of the electricity industry. Among these developments, the following can be mentioned:

a. Emphasis on environmental protection, which includes the use of distributed generation (wind, solar, etc.) and load response (Figure 2-5).
b. Incentive for better using of equipment, including operation at points closer to the curved knee or maintaining reliable operation of the system.
c. The need to increase the customer's right to choose.

One of the important factors for using of smart grids is the establishment of two-way communication between the wholesale market and transmission operation, the retail market and distribution operation. The desire to increase the demand response capacities of loads, renewable resources usage and applying storage systems at the distribution level will cause to better operation’s situations. The development of technologies, such as the advancement in information and communication technology, provides the possibility of converting these new capabilities into controllable useful products for the operators of the wholesale market and the transmission system. Power flow from centralized production sources (power plants) to demand in traditional power plants is almost one-way and information flow is from lower voltage centers to higher voltage levels. On the other hand, in the smart grid, the circulation of power and information is two-way.

Figure 5: Sample of Wind farm [22]

It is expected to use new thermal storage to shift the peak load, reduce the cost of solar photovoltaic production at the urban residential level and, as a result, increase its use, predict the replacement of transportation or conventional fuel with rechargeable electric cars, the emergence of smart sensors sensitive to the price of electricity and create a A two-way secure communication network across the territory of power companies will significantly change the nature of power generation resources and power system operation in the future, as well as the behavior of subscribers. The transmission of network information widely to the control center with the implementation of the smart network provides the possibility of monitoring and displaying the performance of the power system in real time throughout the vast and connected geographical areas. The information of all network equipment is continuously and permanently sent to the control center and the necessary decisions are made based on the large amount of information in a timely manner.

C. Demand Response in Microgrid

Today, power companies all over the world are facing many problems. For example, currently only one third of the used fuel energy is converted into electrical energy and the lost heat is not recovered. In this situation, 8% of the power output of power plants is lost during transmission to loads. 20% of the power plant capacity is used only for peak hours (the peak period occurs in 5% of the total time). Also, energy shortages and environmental pollutants are among these problems. The current electricity network has a one-way communication by nature. In addition, due to the hierarchical structure, the existing power grid suffers from hierarchical errors (Figure 2-6). Such problems cannot be solved with the current electricity grid. The smart grid was proposed with the aim of solving the problems of the current power grids and better and more efficient management of the power system. These networks provide the possibility of complete monitoring and real-time control of equipment for power companies. It is expected that the creation of these networks will improve the control and operation of the power system and enable the widespread use of distributed generation.

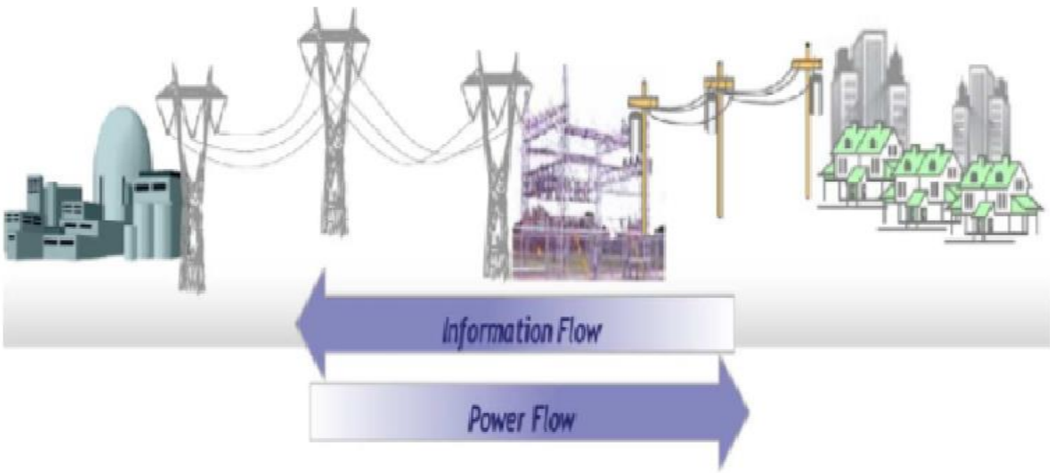

Figure 6: The Flow of power and information in traditional structure [25]

The smart grid should be able to repair itself and quickly return to optimal conditions, despite the faults occured. Also, the smart grid will help its operators to find new solutions to make economic exchanges of energy in the power system. The features of smart networks related to the load side have received more attention than other sectors. AMI measurement systems, smart displays and smart controllers are among the demand management issues on the load side in these networks. As it has been said so far, with the use of advanced measurement systems, the electrical energy consumption of each consumer will be available at all times. Therefore, unlike the current power systems, consumers who do not consume electricity during the hours when the price of electricity is high, will not have to pay additional fees for the electricity consumption of other subscribers during these hours**.**

Smart display systems inform consumers of the current price of electricity. With the help of communication systems and AMI, this technology will improve the conditions for implementing load response programs, because by being informed about the price of electricity, consumers will save more on electricity consumption or shift their consumption to other hours. Also, in these emerging networks, the use of sensitive sensors at low electricity prices has provided the conditions for the use of smart controllers. These controllers can control the electricity consumption of subscribers according to the price of electricity and related settings, which will be an important step in controlling the consumption of electrical energy. In local mode, these controllers will be adjusted according to the consumer's request and according to the price of electricity and sensors sensitive to the price of electricity, during the hours when the price of electricity is high, the corresponding common electricity consumption (according to the settings made in advance by consumers themselves) will decrease. In general, these controllers will be interconnected and controlled by a hierarchical system. (Figure 2-7).

In the second case, retailers may take control of these controllers themselves in order to reduce their risk. The system operator may even use these controllers to increase system security. It is worth noting that this mode may conflict with the privacy of subscribers. In most of the existing electricity markets, the response share is often low. In these markets, only big consumers have the chance to participate in the wholesale market directly.

Small consumers have not been able to participate in these markets for two reasons. The first reason is that it is necessary for the company of small consumers in the market to measure the real time of their consumption at all times. Also, consumers should always get information about the price of electricity in different periods. The use of such measurement and communication systems in the current electricity system requires spending a lot of money. This cost will not be compensated by the profit obtained from participating in the market for small consumers. The second reason is that the number of these consumers is very large, so the information that must be collected or sent by the system operator is very high. The development of AMI and smart displays in the smart network can be considered as a suitable solution to solve this problem. The use and application of smart grids will bring a favorable effect in distribution networks. The correct use of this knowledge can be beneficial for the electricity administration and customers in various ways.

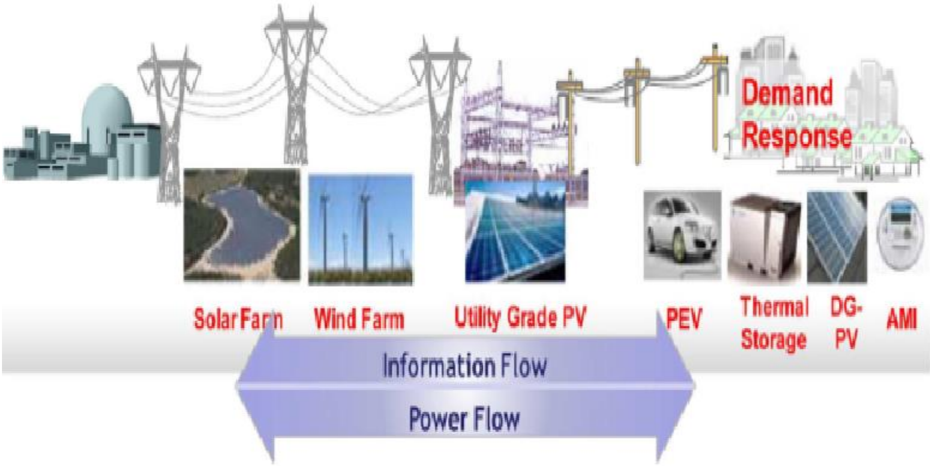

Figure 7: The Flow of power and information in smart structure [25]

In traditional power systems, the distribution system is an interface between the transmission and distribution network and is considered as a passive part. By using smart grids and using sources such as wind turbines, solar arrays and fuel cells to the distribution system, this part of the power system has become an active element, and this itself causes many problems of power systems such as load distribution, stability, Reliability, security and short circuit, etc. will be affected by this network. With these conditions, the use of microgrids will definitely affect the control systems, power control centers and operation of distribution networks. On the other hand, determining the time and amount of production of energy sources as well as time control of the use of household equipment in order to apply load and energy management programs in order to reduce the electricity consumption costs of the subscribers and their satisfaction to cooperate with the smart grid plan. will be needed In this project, it has been tried to evaluate these networks from different aspects such as power quality, economic exploitation and control safety.

Challenges such as increasing energy demand, climate change, wear and tear of network equipments, increasing energy prices, and countries' dependence on energy imports are among the main motivations for moving towards achieving stable, safe and competitive energy with existing energy sources. For this reason, policy makers around the world are implementing programs to increase the efficiency, security and reliability of the electricity transmission and distribution system by developing the current network and moving towards a smart network.

One of the controllable and constructive components of smart networks can be called microgrids. According to the definition, a microgrid is a part of a distribution network that is able to supply its local load in grid-connected and independent (island) operating modes. Electric utility customers currently have the choice of purchasing their needs from existing utilities or using distributed generation sources to meet their needs. With extensive research and development in the field of distributed generation technologies, many of the sources that are currently available in consumer markets are distributed generation sources in the range of domestic to commercial and industrial use. The prices of various distributed generation technologies are decreasing day by day and after a short period of time, these prices will reach such a level that subscribers will easily and willingly purchase distributed generation resources.

With the increase of scattered production units in the system, especially in the distribution network, the control system, exploitation and its methods should be changed in such a way that the maximum use of these production resources can be achieved. Important things include the growing development, the wide range of technologies used, the possibility of exchanging energy and buying and selling it by being common and economical in the field of distributed production, as well as the dynamics of distributed production based on two traditional bases with low inertia and based on the use of electronic technology.

Fast power but without inertia, along with intelligent operation using modern telecommunication infrastructure and intelligent load demand response, has created wide challenges and opportunities in using microgrids as the foundations of smart networks. The basic concept of the smart grid is to add monitoring, analysis, control and telecommunication capabilities to the power grid to increase system efficiency while simultaneously reducing consumption. Also, the smart grid creates many economic and environmental advantages. From an economic point of view, the smart grid reduces the overall consumption of consumers by increasing the efficiency of the system, training subscribers and making them a partner in the overall performance of the network, as well as by implementing load management programs and responding to demand. Gives. From an environmental point of view, the smart grid can reduce the overall amount of production and emission of carbon dioxide by increasing the power of load and consumption management, reducing production related to peak load time and increasing the use of renewable energy. The smart grid in the electrical energy distribution sector is a modern grid with increased penetration of new energies in the form of distributed generations (DGs), which will lead to the following results:

- Reducing network losses and air pollution
- The appearance of electric cars charged by the grid
- Network peak load control through demand response (DR)
- Improving reliability through distribution network automation
- Measuring and controlling electricity consumption using telecommunication infrastructure
- Reducing implementation and maintenance costs
- Increasing the efficiency of the power grid
- Improve system security

D. Implementation of Microgrid

After installing the smart metering system, the distribution network will have the necessary infrastructure to implement the smart network. In this network, the necessary telecommunication platform is provided for the transmission of information, and the smart meters are exchanging information between subscribers and the network, and the possibility of selling energy is also provided. In the control center, the equipment related to the smart metering infrastructure is installed. The intelligent measurement infrastructure has the ability to collect measurement information such as voltage, current, equipment status, events and incidents in close proximity at strategic points of distribution networks. This feature will improve the monitoring and control of the distribution system and enable the operators of the distribution network to make important decisions in critical situations with high precision and always keep the network in the best condition due to the vital information it provides. The smart grid consists of a large number of sensors and equipment that are installed throughout the network. These devices enable optimal network management. The main problem in this way is the heavy costs of the telecommunication platform. There are two general approaches to establish communication with these sensors and all the equipment in smart networks:

- Creating a telecommunication infrastructure separate from the smart measurement system

- Development of telecommunications, smart metering infrastructure to all parts of a power grid

Therefore, the telecommunication platform of the smart metering infrastructure provides the possibility of advanced control and monitoring, which is a part of the smart grid of the future. The first approach will take a lot of money and cause a lot of rework and waste of time and money. In the second approach, it has been implemented by implementing the intelligent measurement infrastructure of its telecommunication infrastructure, and it is enough to expand the influence of the telecommunications infrastructure of the intelligent measurement infrastructure To be used in order to read the sensors and the rest of the smart network equipment. In the control center, necessary modules are added to the smart measurement system and finally the smart network is built. The information in the smart network will be used in addition to the aforementioned matters to adjust and control the feeders, provide correct load models using the information management system, energy management, demand side management, etc.

Smart network softwares get a lot of their information from the existing softwares of the smart data collection system. This system is exchanging information with peripheral software such as GIS and GPS and they help to manage network assets. In the smart grid, there are smart homes that have a close exchange with the grid and generate the necessary electrical power through renewable energies. The management of this wide range of equipment is done in the intelligent network control center. In fact, the smart measurement infrastructure is the foundation of the future smart network, and its telecommunication system can be used to connect and read sensors and other equipment in the smart network and send information to the control center, and its hardware and software infrastructure is necessary for the development of the smart network.

E. Measurement devices of Microgrid

Smart metering equipment will probably be the symbol of smart grids. This equipment is known as more than measuring instruments. Companies and governments around the world are investing billions of dollars to install metering systems that inform power companies in real time how much energy is being consumed at each system node (Figure 2-8). The need for accuracy and simultaneity of measuring devices on both the producer and consumer sides has various reasons, including the following: With the growth of distributed generation, power companies can buy or sell electricity from subscribers, so these companies They need correct information on the amount of energy that both sides deliver or inject into the network.

Figure 8 phase smart power measuremnt device [26]

The implementation and implementation of the goals of the smart network is possible only by using a suitable measurement system that measures the amount of power consumption and production in different nodes of the system. Due to the importance of the issue, here is a review of the existing measurement systems.

Distribution system metering devices are the focus of recent infrastructure investments. At first, the metering systems that were considered were the automatic measurement reading (AMR) metering system in the distribution network. AMR devices allow utility companies to remotely read usage records, alerts, and customer status. Although the usefulness of AMR technology was proven at first. But later companies realized that AMR is not able to solve their main problem, i.e. demand side management. Due to the one-way nature of the AMR telecommunication system, its ability to read the measured data is limited, and the power companies do not have the ability to take corrective measures in the amount of power consumed based on the information received from the measuring devices, and consumers do not have accurate information about the price of electricity in real time. do not receive In other words, AMR systems do not allow the transition to a smart grid, where comprehensive control at all levels is a basic principle. As a result, AMR technology was short-lived.

Instead of investing in AMR, companies around the world are turning to Advanced Metering Infrastructure (AMI). AMI provides companies with a two-way communication system with measurement tools as well as the ability to change customer service parameters. With the help of this measurement system, not only the power companies will be informed about the amount of power used by each consumer, but the consumers will also be able to adjust the amount of electricity consumption according to its cost and the profit from this use by knowing the exact price of electricity in real time. In this way, companies can achieve their basic goals in load management through AMI. In this way, companies can receive real-time information on individual and collective demand and also apply certain limits on the amount of consumption as well as different models to control their costs. As mentioned, AMI, along with other factors such as distributed production, led to the emergence of the smart grid. Therefore, one of the important criteria of the company in choosing between different AMI technologies is the possibility of compatibility with the current structures and technologies of the smart grid.

Demand side management and load response can be mentioned as one of the basic factors in the emergence of smart networks. The smart grid is actually a response to the economic, security and environmental obligations imposed on energy producers and suppliers. The smart grid provides access points (much like computer equipment), which can be identified in the Internet environment with an address based on Internet protocols. The smart network uses Internet protocols to transfer information from beginning to end, between users and subscribers. With two-way communication between subscribers and operators, both departments can have more control over network consumption and its physical structure and cyber security.

F. Characteristics of distributed generators

Intelligentization of resources includes important issues such as regulations, power balancing, and shifting of productions in 24 hours a day. This part of power grid can be analyzed in three general categories:

- Distributed generators
- Microgrids
- Electric energy storage systems

The first category of intelligentization of resources in the network, the use of distributed and renewable production includes the implementation of productive and renewable distributed production resources in industrial, commercial and domestic buildings. The use of new control methods along with distributed production resources, taking into account the levels of security, quality, reliability and availability of power in distribution networks, forms the second category of resource intelligence, called micro-grids, which generally pushes the network in the direction of Change from passive to active. Microgrids are weak pressure networks that include distributed generation sources, power storage, controllable loads and a robust control system. The micro-grids are connected to the global average pressure network in the upstream and have the ability to work in a separate mode from the network. From the consumer's point of view, on the one hand, a microgrid can provide electricity, and on the other hand, it can increase power quality, increase reliability, reduce pollution, boost voltage, and make energy cheaper.

Microgrids have a coordinated operation to respond to the generation load of distributed generation resources while maximizing the benefit to the subscribers and the upstream network. With the advancement of technologies and their economic development, it is possible to use scattered production sources along with energy storage. As a result, it is possible to create microgrids at low consumption levels and connect them to distribution networks and commercial and domestic consumers. Electric energy storages are widely used as a key component in improving the reliability and stability of the smart grid, the third category of resource smartness in the grid. The ability of the smart microgrid is as follows:

- Use of small production resources

- Appropriate energy efficiency and network optimization
- The possibility of energy storage
- Smart measurement
- Increasing network security
- Prediction of the future situation and its correction

Advances in power electronic semiconductor equipment, nanocrystalline high-frequency transformers with high bandwidth, and the improvement of the performance of advanced sensors and processors have led to the development of the development process of using resources that are connected to the national grid through an inverter. turn around These sources include renewable energy production sources with high capacities, scattered production sources, active filters, storage sources and low-volume energy converter modules. Unlike traditional low-frequency systems, the power switches used in this type of equipment are required to operate at frequencies in the range of 20 to 50 kHz. However, one of the challenges of using such an approach is their adverse effects on power quality indicators in the network.

In this regard, the authors [27] investigated the efficiency of the hybrid modulation (HM) pattern, which was recently developed and is able to reduce the switching losses of converters by about 66%. This also leads to an improvement in the effective use of voltage compared to the support vector machine (SVM) approaches and reduces the generated current stress. In [28], two patterns of current control converters used in the integration of renewable energy sources with a single-phase network have been evaluated and compared using multi-stage high-frequency transformers. The performance, advantages and disadvantages of both approaches are discussed in their own waveforms. Several characteristics including the power factor of the transmission line, the total harmonic disturbance (THD) factor of the line current, the size of the power electronic equipment, the convenience of connecting to the operating line and its control, the risk of transformer saturation, the losses and nominal values of the power electronic equipment , the design of high rate power exchange and most importantly, the size and cost of electrolytic capacitors have been compared.

In [29], a novel strategy for a hybrid energy management system consisting of a photovoltaic array, a polymer electrolyte membrane fuel cell (PEM-FC) as energy sources and a Li-ion battery as an energy storage source is presented. . Such a combined system leads to providing reliability, taking into account the reserve capacity and overall energy efficiency of the system. DC/DC converters are used for power exchange between photovoltaic components – fuel cell - battery. Energy management between these three sources is done by exploiting them in three different working modes based on the type of load requirement.

Photovoltaic panels operate in maximum power point tracking (MPPT) or desired power control (DPM) mode. Batteries operate in voltage control mode and simultaneously maintain both state of charge (SOC) and DC connection level. The fuel cell is also used in power control mode (PCM). The amount of active power demand is controlled by adjusting the DC connection voltage. In [30], a new dual-input dual-output (DIDO) DC/DC converter is presented that can exchange power between photovoltaics (PV) and fuel cells to a low-voltage dc microgrid. This non-isolated converter topology is efficient, small in size and has fewer circuit components that uses only one inductor in its circuit. The presented topology is suitable for a weak voltage bipolar type dc microgrid. In this situation, the power extracted from two sources is injected into the bipolar bus of the DC microgrid. In addition, the provided converter guarantees the maximum power point tracking (MPPT) function and also adjusts one of the DC bus pole voltages.

In [31], a novel intelligent energy management model for a microgrid is presented, which consists of a diesel generator and an electronic power converter, which is an interface for renewable generators such as photovoltaics and fuel cells for frequency regulation and does not have any storage source. In the presented strategy, the output of the photovoltaic panel is controlled in coordination with other generators using a neuro-fuzzy controller. With the simultaneous control of the frequency in the permanent mode and the transient mode, which depends on the type of load, the need for a huge amount of storage resources is eliminated. Load control on the demand side is also considered during the production control process. In order to quickly and accurately track the point of maximum power and reserve power related to the photovoltaic panel, in this article, a new adaptive-predictor-corrector tracking mechanism is also presented.

In [32], a control structure for a hybrid renewable energy source connected to a direct current (DC) motor is presented. The said system consists of a photovoltaic array as the main driving source and a fuel cell as a secondary or auxiliary source. The control system is designed in such a way that it ensures the adjustment of the engine speed and the production of maximum power from the energy sources under all kinds of environmental conditions and different loads, for example, when the radiation level of the sun is low or the amount of demand for torque is high. There is a load. Real environmental data is used for simulation in this article.

Today, photovoltaic-fuel cell energy production systems have received a lot of attention as electrical energy production systems. These energy sources are clean, environmentally friendly, modular and independent of fossil fuels. The costs of such solar-hydrogen systems are greatly reduced with the development of technology and mass production of its key components, including electrolyzers, fuel cells, and hydrogen storage sources. In [33], a model of PV-fuel cell system was developed using Simulink environment, which consists of a photovoltaic cell, fuel cell, electrolyzer, converter, inverter and electric motors. PV panels have been used to feed DC electricity to the electrolyzer. In this case, the fuel cell can use this hydrogen to produce energy when there is no solar energy. AC and DC electric motors have also been used to show the characteristics of fuel cells in different loading conditions. In [34], the performance maximization of a hybrid photovoltaic-fuel cell system connected to the grid by using a two-loop controller is discussed. The first loop is a neural network controller whose purpose is to track the point of maximum power and extract the maximum available solar power from solar arrays under different environmental conditions in terms of radiation, temperature and various loads. A real/reactive power controller is used as the second loop, which provides the real/reactive power requirements of the system by controlling the amount of fuel in the fuel cells and with the help of switching control signals. In the following, a number of advantages of using a smart microgrid are stated:

- ❖ Prevention of simultaneous load synchronization: In general, it is desirable for electric energy distribution companies that no simultaneous synchronization occurs among the household appliances of different consumers. This should be done in order to prevent strong shock waves in the home system. By introducing a short-term random start-up delay of a few seconds, the start-up moments of different equipment can be dispersed to a good extent and this destructive phenomenon can be avoided.

- Announcement of the consumption plan to the production company: one of the most fundamental challenges created for the production companies is the need to predict the load demanded by the end users. It is clear that by knowing the required load demand, electric power production companies and regional power plants can provide better dispatching. By expanding the use of home automatic load control strategies presented in this project, end users have the potential to communicate their load demand to the manufacturing company through a two-way digital communication infrastructure. takes place By receiving all the required loads from all users, the production company has an accurate estimate of the required load that must be provided in the coming hours. Therefore, the presented load control structure can not only help users to respond better to real prices, but can potentially inform production companies about the amount of energy required and the amount of energy consumed by end users.
- Implementation of load reduction request: load reduction request is usually issued by production companies when the load demand has increased to such an extent that it has jeopardized the reliability of the network or the increased demand requires the imminent activity of the complex. The products are expensive. In a smart network, the electric energy supply company can apply the appropriate function through the communication infrastructure. This can automatically postpone a part of the upcoming energy consumption for a few hours and cause a huge reduction in the total consumption load.
- Electric energy storage: With the expansion of the use of electric vehicles, there is a growing interest in using the storage capacity of their batteries in order to return some energy to the grid when needed [32]. In other words, users buy electric energy to charge their batteries at a cheap rate and then sell the electric energy to the grid by discharging the batteries during peak hours. In this case, it not only helps to balance supply and demand, but also generates income. Due to the fact that it is difficult to continuously observe and follow the real prices in order to decide the best time to charge and discharge the batteries, it is possible to use the optimal load control model presented in this project with the participation of negative loading for the activity. High discharge used.

G. Operation management in Microgrid

Writers of [35] investigated the optimal planning of batteries in the active production network by considering different technologies in uncertain technical and economic conditions. In this study, the optimal planning of all types of batteries is presented with the aim of comparing all types of technologies. In a long-term planning, the type, installation location, capacity and rated power of the batteries should be optimally determined. The objective function includes real demand coverage of investment consumptions, repairs and maintenance, network operation and reliability indicators. Voltage level restrictions, equipment capacity and power balance in the network must be observed in the entire planning period. On the other hand, each technology has its own uncertain technical and economic parameters that change in different times and situations. Therefore, in a comprehensive study, the uncertainty of battery parameters has been considered, along with other uncertain characteristics of the system. The problem of uncertainty is modeled using algorithmic analyzes based on artificial intelligence, and gradual cooling algorithm has been used for optimization. The results obtained in this study show that Zn-Br technology is more suitable than other types in average conditions. However, in uncertain conditions, NaS technology can compete with Zn-Br and be an optimal option. Finally, by performing sensitivity analysis, the obtained results are generalized to different networks.

In [36], the efficiency of a real-time voltage estimation neural network in active networks has been investigated. This study presented a systematic validation of the neural network method for voltage estimation in active generation networks using measured data from two feeders of the re-voltage generation network. This approach enabled real-time voltage estimation at locations in the generation grid, where otherwise only real-time measurements would be performed. This method showed good behavior in all analyzed aspects, which is crucial for real-world applications. A method was presented to select the most important input variables and find the best achievable performance for a certain number of inputs. Furthermore, the study showed that the performance is not sensitive to the number of neurons in the hidden layer of the neural network as long as the model is uncertain. This study has investigated the amount of historical information needed to create a suitable performance model. The effect of network changes and seasonal effects, the effect of different training intervals were investigated. To reconcile network evolution and seasonal effects, the effect of different training intervals was investigated.

In [37], different strategies for synchronizing energy systems have been analyzed from the point of view of simultaneous optimal exploitation characteristics. Challenges are found in implementing coordinated strategies for optimal simultaneous exploitation. This study summarizes the demonstration challenges that correspond to systems engineers. Methods have been proposed to address these issues, including multilevel multilevel coordination and intelligent coordination of operational mode switches. The island's energy system including diesel and microwave generators with renewable energy sources is presented in this research as an example of the optimal simultaneous operation network. Various aspects of the coordination of productive systems are presented in this network to show how the selection and implementation of coordination strategies enable simultaneous optimal operation.

Reference [38] investigated the creation of systems compatible with the main component system of the arrowhead framework. The goal of the Arrowhead framework was to effectively support the development, deployment, and operation of connected collaboration systems. It is based on the philosophy of service-oriented architecture. Building elements are framework systems that provide and consume services. Some commonly used systems such as orchestration, licensing or service registry are considered core. It can be used by any system that follows the guidelines of the Arrowhead framework. In the framework, systems using different information technologies help in collaboration through different methods. This includes the so-called compatibility layer, as well as translation systems and services. In addition, one of the main problems of developing such highly interactive systems is the lack of understanding between different development groups. Development methods and appropriate documentation services can help to overcome this problem. The design, development and approval method for each service, the system supports in the arrowhead framework, which can be implemented, approved, launched and implemented. This research provides a summary of the framework and its main elements and provides guidelines for the design and implementation of arrowhead compatible cooperative systems.

In [39], the formulation of simultaneous optimal operation and disturbance analysis for several critical main structures are designed. In this study, they described critical national infrastructure as a system of systems and methodology to perform a multidimensional disturbance analysis. To achieve this goal, we show functional pathways between network resources and capitalists across a wide range of operational scales. Customer requests are assigned to these routes and used to build a weight network. A set of performance routing results and a weight network were used using failure analysis, which provides information on long-term capabilities within and between infrastructures, information on failure propagation, and functional dependencies that exist between assets of multiple sectors. They complemented the development of the methodology with detailed national demonstrations in England and Wales, using a unique representation of the integrated power grid and the internal flight network. The results showed that the large potential disturbances that can be caused by the failure of individual assets of a wide range of different subsystems. This research provides a method for calculating the optimal size and location of the power grid in the production network based on the characteristics of the network load and its traffic, the paths of the power grid deployment. This planning is implemented with the aim of maximizing the profit of production companies that have used gas-fired generators in their network to achieve several advantages. It is from a social group whose members behave abnormally to improve their position. In most of the articles, simultaneous optimization of gas generators and gas network is assumed to transfer the flow of gas generators to fixed network loads. Since loads are sensitive to voltage and frequency, analysis assuming a constant load leads to incorrect and misleading results. Therefore, in this research, the proposed method has been implemented on the radial production network of 38 busbars with the presence of real loads sensitive to the system voltage including residential, commercial and industrial loads.

Writers of [40] investigated the determination of the optimal location and size of solving the problem of simultaneous operation of the electricity and gas network using innovative algorithms based on artificial intelligence based on the indicators of the electricity market. In this research, a new method for the simultaneous optimization of gas-fired generators and the gas network for current transmission and determining the optimal size to solve the problem of simultaneous use of electricity and gas networks using innovative algorithms based on artificial intelligence of gas-fired generators in the electricity market based on the optimal power distribution of simultaneous operation Gas and electricity network is provided. The results of the simulation show that the proposed method satisfies the economic and operational issues of the market and by determining the optimal location and size of gas burner generators under this method in the environment of the electricity market, the increase in public welfare and the profit of scattered productions are guaranteed. Also, the proposed method can perform the simultaneous optimization of gas-fired generators and the gas network to transfer electricity network current in a way that is favorable both from the point of view of the resource owner and ISO.

The reference [41] suggested that due to environmental problems, it is not possible to install a solution to the problem of simultaneous operation of the electricity and gas network using innovative algorithms based on artificial intelligence in all buses. In this project, environmental restrictions have also been taken into account. In each bus, a type of integrated electricity and gas network can be installed, and in some buses, it is not possible to install an integrated electricity and gas network. The source [42] discussed that the issue of using generators of the integrated electricity and gas network (gas generators) is one of the major issues that is mentioned a lot in scientific societies today. In fact, the integrated electricity and gas network means the production of electric power using small local generators. Among the cases that justify the use of solving the problem of simultaneous operation of the electricity and gas network using algorithms based on artificial intelligence can be to issues such as economic issues in the development of production, reducing environmental pollution, the high efficiency of these resources in production, increasing the quality of electricity supply to customers, reducing the problem of simultaneous use of the electricity and gas network by using innovative algorithms based on artificial intelligence in the network, improving Voltage profile, network capacity release and many other things mentioned. Some theories are based on the fact that the penetration of the integrated electricity and gas network can decentralize power so that there is no need for transmission networks or large centralized generators. Algorithms used in this project are genetic optimization algorithm. Genetic optimization algorithm is due to the nature of jumping to routing and due to the continuous nature in the simultaneous optimization of gas-fired generators and gas network for current transmission and measurement to solve the problem of simultaneous operation of the electricity network. Vegas is applied using innovative algorithms based on artificial intelligence.

H. Frequency compensation with solar panels

In [43], a new control strategy is presented for photovoltaic panels that can manage their output active power based on frequency control indicators. In [44], a series of solar panels are used, which are equipped with the capability of frequent disconnection/connection through dc relays in order to control the frequency. In this situation, it is necessary to take part of the capacity of solar arrays during emergency situations, which of course leads to the waste some part of the generation capacity. On the other hand, due to the inherent fluctuation of solar energy, its reserve power is not reliable. However, it is stated in [45] that PVs can participate in frequency control when the frequency exceeds the value of 50.67 Hz. According to the codes made for the German grid, if the grid frequency increases more than 50.2 Hz, the PVs connected to the main grid must reduce their output power with a slope of 40% of the rated power per Hz [46]. The set points for the output of solar array capacities can severely weaken the potential of PV participation in the network. From the perspective of controller design, inverter are divided into 2 main categories [47]:

- Grid following
- Grid forming

The grid following model is widely used for inverters connected to the main grid. In this case, the inverter acts like a current source. In recent years, studies show that the penetration level of grid affecting inverters has increased [48]. In this situation, the control of this group of inverters is integrated in the power system and they show a behavior similar to a voltage source. In fact, they can greatly contribute to improve the stability of the power system in small microgrids [49]. However, until now, modeling the behavior of solar array inverters in combination with energy storage sources by considering load responsing has not been studied significantly.

İ. Microgrid control strategies

Traditionally, secondary control is based on the use of a MG central controller (MGCC). This unit is responsible for collecting all MG's information and sending the commands for devices. This approach has weaknesses such as low control dynamics and the need for a central computing unit to process and exchange information. Also, if there is a disturbance in this control center, the entire system will be affected. To solve these challenges, a distributed control strategy can be used for secondary control, so that each local DG controller communicates with its neighboring DGs and there is no need for a central controller [50-52]. In [50], a distributed cooperative secondary control using feedback linearization method is proposed. In this reference, it is assumed that none of the DGs placed in the system can directly access the reference voltage and frequency values. By communicating the controllers with each other, they can make sure that the voltage/frequency converge to the reference values. However, in the mentioned article, the inherent coupling between frequency and voltage is not considered. Similarly in [51], this approach is used to transform the secondary voltage control into a linear second-order tracker synchronization problem.

A distribution approach is proposed in [52] to regulate frequency and voltage in addition to reactive power. However, the implementation of this distributed control scheme requires that each local controller can communicate with all other controllers in the entire system, which has almost the same telecommunication costs as a centralized controller. In addition, dynamic conditions and stability of the system is not evaluated. Also, a proportional-integrator (PI) controller with distributed mean is presented in [50] to alleviate the frequency deviation while maintaining the power sharing property. A first-order inverter model is also designed using the results of the theory of coupled oscillators. This condition is achieved with the assumption that the voltage of the node remains constant. In this situation, voltage recovery is not considered.

In this project, firstly, the dynamics of DG units and the main grid are evaluated. Assuming the existence of a transmission line with pure inductive capacity, a simple dynamic model of the islanded MG is presented. Then, distributed voltage controllers have been used to restore the voltage values to their corresponding reference values for all DGs in a limited time. Then, a distributed frequency control based on aggregation of units has been designed. In the frequency recovery mode, there is a challenge that the control inputs must be equal to each other in the steady state to satisfy the power sharing property. For this purpose, a distributed PI method has been used to establish such conditions. In this case, frequency recovery to the considered values is also guaranteed.

III. RESEARCH METHODOLOGY

A. Hierarchical control approach

The designed hierarchical control method includes primary and secondary stages. The first stage of control is related to the local management of renewable generation units. In the second stage, the deviation of the frequency from reference point is recovered. The main focus of the current project is on improving the power quality level so that each power generating unit includes a primary driver, an intermediate inverter and an LC filter (Figure 3-1). The schematic diagram of a normal MG in island mode is shown in Figure (3-2). Each DG is connected to the respective local loads. They are integrated through a network. Therefore, the island MG model mainly consists of two parts:

1. DG model

2. MG network model

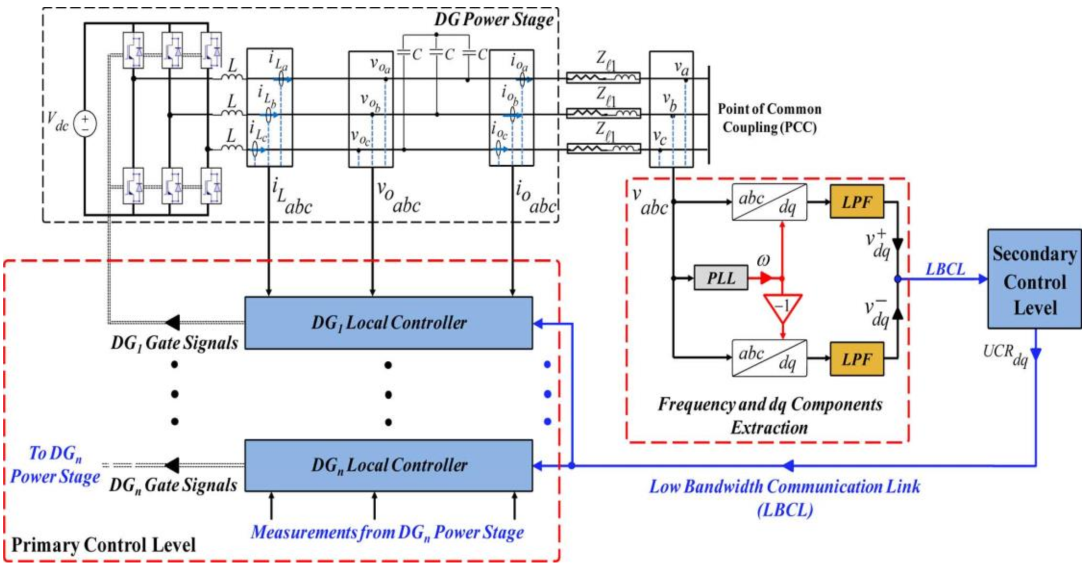

Figure 9: The structure of hierarchical model [53]

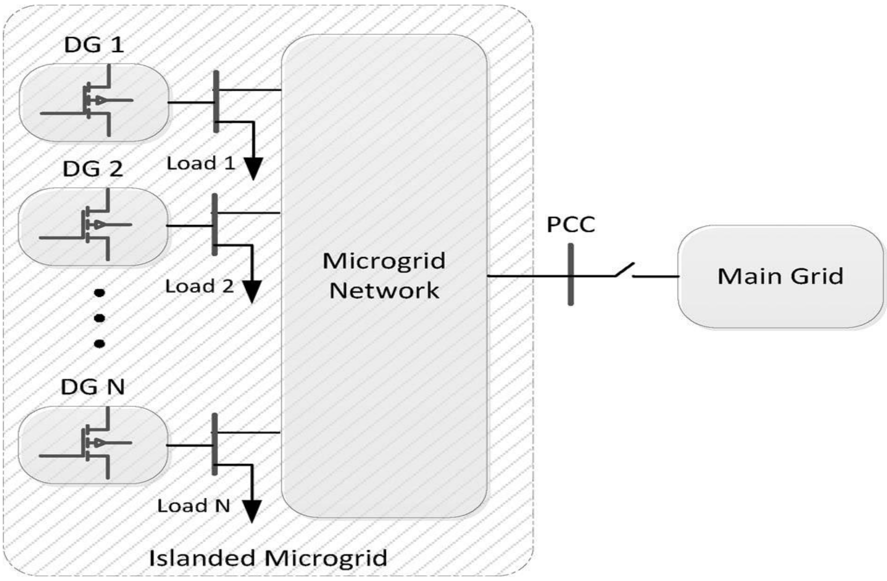

Figure 10: Schematic of connection between MG and DGs [54]

B. DG unit modeling

In a MG, each DG unit usually consists of a main DC source, a DC/AC inverter, an LCL filter and an RL output connector. Such characteristics are shown in Figure (3-3) [8]. During the operation of the microgrid as an island, the inverter operates in the voltage control mode. Generally, there are three control loops in the main DG controller:

- Voltage control loop
- Current control loop
- Droop control loop

In this condition, a wide frequency range can be defined for the primary controller. Since the dynamics of the LCL filter, RL output interface, and voltage/current control loops are much faster than the droop control function, the primary controller is modeled only by considering the droop control function dynamics. The task of droop control is to adjust phase angle (δ_i) and voltage amplitude (V_i) based on measured active and reactive powers. In this case, the phase angle and voltage drop for the DG units used are determined according to Equ. (3-1) and Equ. (3-2)[55]. The values of the active/reactive powers measured through the first-order low-pass filters are obtained according to the Equ. (3-3) to Equ. (3-4).

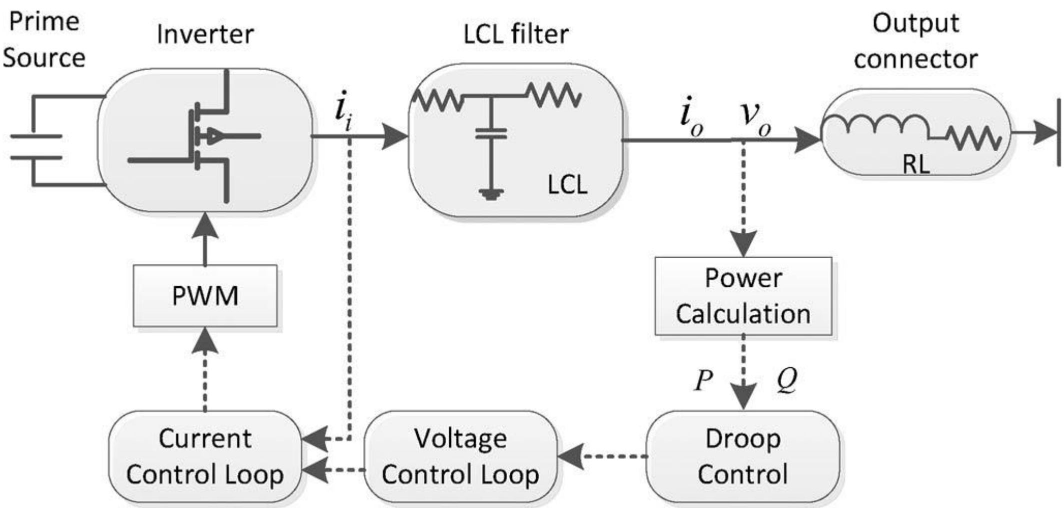

Figure 11: Schematic of local inverter controller [56]

$$\dot{\delta}_i = \omega^d - k_{P_i}\left(P_i^m - P_i^d\right) \quad (1)$$
$$k_{V_i}\dot{V}_i = (V^d - V_i) - k_{Q_i}\left(Q_i^m - Q_i^d\right) \quad (2)$$
$$\tau_{P_i}.\dot{P}_i^m = -P_i^m + P_i \quad (3)$$
$$\tau_{Q_i}.\dot{Q}_i^m = -Q_i^m + Q_i \quad (4)$$

ω^d : Reference frequency
V^d : Reference voltage amplitude
k_{V_i} : Voltage control gain
k_{P_i} : Active power control gain
k_{Q_i} : Voltage droop gain
P_i^m : Measured active power
Q_i^m : Measured reactive power
P_i^d : Reference active power
Q_i^d : Reference reactive power
τ_{P_i} : Time constant of filter active power
τ_{Q_i} : Time constant of filter reactive power
P_i : Output active power of DG
Q_i : Output reactive power of DG

The derivative of the phase angle variations is the expression of the phase angle changes, which is calculated in the form of Equ. (3-5). The simplified equations for DG modeling can be defined in the form of Equ. (3-6) and Equ. (3-7).

$$\dot{\delta}_i = \omega_i \quad (5)$$
$$\tau_{P_i}.\dot{\omega}_i + \omega_i - \omega^d + k_{P_i}\left(P_i - P_i^d\right) = 0 \quad (6)$$
$$\tau_{Q_i}.k_{V_i}.\ddot{V}_i + \left(\tau_{Q_i} + k_{V_i}\right).\dot{V}_i + V_i - V^d + k_{Q_i}\left(Q_i - Q_i^d\right) = 0 \quad (7)$$

C. Microgrid modeling

For this project, a microgrid is used as a network connecting DGs with loads through distribution lines. Suppose there are N distributed generation units (DG) in the network. The Y_{ik} defines the admittance between the DG ith and the DG kth, which is defined as Equ. (3-8). If there is no connection between these two DGs, the admittance value becomes zero. Local loads are also considered as connected to their corresponding DG, and their power demand is determined by Equ. (3-9). To include different types of loads, the ZIP load model is used which are described by Equ. (3-10) and Equ. (3-11) [7]. Based on the power balance relations presented in [54], the amount of active/reactive power injected into the grid are obtained by Equ. (3-12) to Equ. (3-13), respectively. Then, generated active and reactive powers of DG are calculated by Equ. (3-14) to Equ. (3-15).

$$Y_{ik} = G_{ik} + jB_{ik} \tag{8}$$

$$S_{L_i} = P_{L_i} + jQ_{L_i} \tag{9}$$

$$P_{L_i} = P_{1_i}.V_i^2 + P_{2_i}.V_i + P_{3_i} \tag{10}$$

$$Q_{L_i} = Q_{1_i}.V_i^2 + Q_{2_i}.V_i + Q_{3_i} \tag{11}$$

$$\hat{P}_i = V_i^2.G_{ii} - \sum_{k\in N_i} V_i.V_k.|Y_{ik}|cos(\delta_i - \delta_k - \varphi_{ik}) \tag{12}$$

$$\hat{Q}_i = -V_i^2.B_{ii} - \sum_{k\in N_i} V_i.V_k.|Y_{ik}|sin(\delta_i - \delta_k - \varphi_{ik}) \tag{13}$$

$$P_i = P_{L_i} + \hat{P}_i \tag{14}$$

$$Q_i = Q_{L_i} + \hat{Q}_i \tag{15}$$

G_{ik} : Conductance
B_{ik} : Susceptance
V_i : Voltage amplitude
δ_i : Phase angle
$|Y_{ik}|$: Admittance amplitude
φ_{ik} : Admittance phase
P_{1_i} : Active power of fixed impedance loads
P_{2_i} : Active power of fixed current loads
P_{3_i} : Active power of fixed power loads
Q_{1_i} : Reactive power of fixed impedance loads
Q_{2_i} : Reactive power of fixed current loads
Q_{3_i} : Reactive power of fixed power loads

D. Secondary control system

The frequency of the steady state can be obtained by Equ. (3-16) [57]. Since the frequency is defined as a general state in the system, the droop control function can share the active power through the inverse of the droop gain (Equ. (3-17)). In this situation, the secondary control operations must be controlled in such a way that both voltage and frequency are reached to the desired values. So, the distributed control strategy in the secondary layer has been developed according to Figure (3-4).

$$\omega_{ss} = \omega^d + \left(\sum_{i=1}^{N}(P_i^d - P_i)/\sum_{i=1}^{N}\left(1/k_{P_i}\right)\right) \tag{16}$$

$$k_{P_i}(P_i - P_i^d) = k_{P_k}(P_k - P_k^d) \tag{17}$$

In this project, the following control objectives are considered:

- Restoring the network voltage/frequency to the determined reference values (Equ. (3-18) and Equ. (3-19)).

- Providing the required active power with proper quality (Equ. (3-20)).

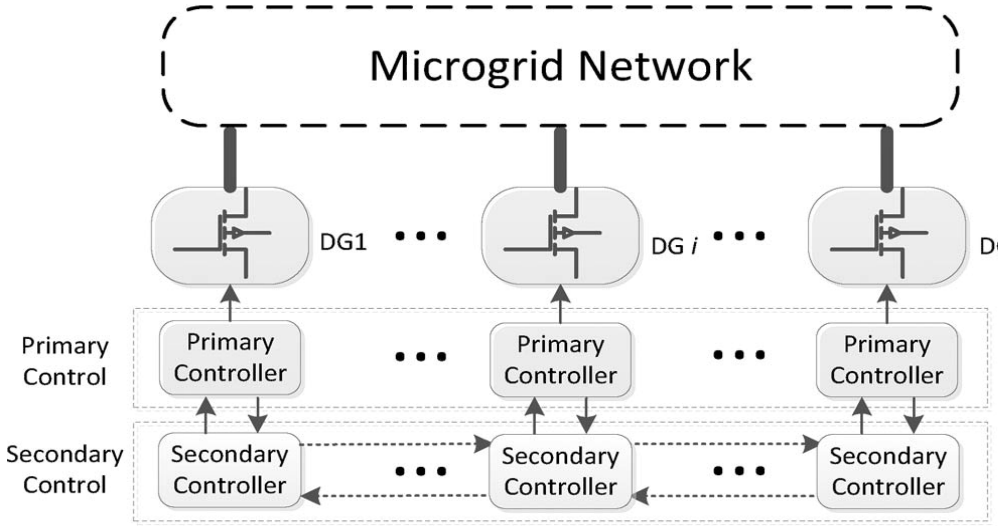

Figure 12: Schematic of the secondary controller in a microgrid [56]

$$\lim_{t\to\infty} \omega(t) = \omega^{ref} \tag{18}$$

$$\lim_{t\to T} V(t) = V^{ref} \tag{19}$$

$$\frac{P_i}{P_k} = \frac{m_i}{m_k} \qquad \forall i, k \in N \tag{20}$$

m_i , m_k : Gains of sharing active power

The presented control approach is implemented locally through communication with existing controllers in the neighborhood of the target area. In

$$\tau_{P_i}.\dot{\omega}_i + \omega_i - \omega^d + k_{P_i}(P_i - P_i^d) + u_i^{\omega} = 0 \tag{21}$$

$$\tau_{Q_i}.k_{V_i}.\ddot{V}_i + (\tau_{Q_i} + k_{V_i}).\dot{V}_i + V_i - V^d + k_{Q_i}(Q_i - Q_i^d) + u_i^V = 0 \tag{22}$$

u_i^{ω} : Secondary frequency control input

u_i^V : Secondary voltage control input

this situation, the secondary control inputs $u_i = [u_i^{\omega} \quad u_i^V]^T$ are applied to the primary control model according to Equ. (3-21) and Equ. (3-22).

E. Objective function

Local controllers are responsible for generating signals for DG interface inverters. These controllers consist of current and voltage control units, virtual impedance loop and active/reactive power droop controllers. The secondary controller manages the frequency unbalance by sending appropriate control signals to the local DG controllers. In order to stabilize frequency stability in microgrids with low inertia, the objective function is defined as Equ. (3-23). According to Equ. (3-24), virtual inertia is calculated by its effective factors.

$$\min \Delta f = \frac{1}{2Hs + D}\left(\Delta P_m + \Delta P_w + \Delta P_{pv} + \Delta P_{inertia} - \Delta P_L\right) \tag{23}$$

$$\Delta P_{inertia} = \frac{k_{VI}}{1 + sT_{VI}}\left(\frac{d\Delta f}{dt}\right) \tag{24}$$

Δf : Frequency variations
H : Network inertia
D : Damping coefficient
ΔP_m : DG generated power variations
ΔP_w : Wind turbines generated power variations
ΔP_{pv} : Photovoltaic panels generated power variations
$\Delta P_{inertia}$: Virtual inertia variations
ΔP_L : Demad variations
k_{VI} : Virtual inertia controller gain
T_{VI} : Virtual inertia time constant

When a severe imbalance between supply and demand occurs in the system, the kinetic energy of wind turbines can be released through the control converter to damp the frequency variation rate [56]. It has been shown in [35] that in a period of 10 seconds, up to 0.1 perunit of the wind system can prevent frequency changes by injecting active power. However, the frequency support of wind turbines is not as stable as that of conventional generators. For example, when the wind speed is low, the capacity that can be provided in wind turbines for support is much less than when the wind speed is medium or high. Moreover, the support of wind turbines cannot be maintained for a long time.

Except for increasing wind speed, the power released by decelerating the rotor cannot be sustained for long. From one condition to the next, the kinetic energy released from the rotating mass of the wind turbines must be recovered with the help of the current wind power so that the rotor speed and kinetic energy return to their pre-disturbance values. Therefore, after the participation of the wind power plants in the frequency response process system, the system needs to find other sources in a short time to reduce the secondary frequency drop caused by their kinetic energy recovery.

In the proposed system, a diagnostic loop is used to measure the frequency of the system. When a small disturbance occurs in the system (for example, a trip of due to a fault), the diesel generators and wind turbines in the system operate simultaneously in the primary frequency response mode to reduce the frequency drop. If the frequency drop is in the frequency deadband, the applied detection loop will not generate any control signal frequency for the HVDC link and the backup frequency response control system will not be activated. If the frequency drop crosses the frequency dead band, the frequency event detection loop will send a signal to ensure the operational security of the system, and then the backup will be activated. The frequency response loop is activated by the control signal of the event detection loop. When the system fluctuation is smaller than the set frequency, the frequency stability detection loop sends a signal to stop the power transmission by the frequency response control loop and at the same time stop the backup frequency response control. In fact, the purpose of frequency compensation control is to compensate for the frequency drop caused by kinetic energy recovery in wind turbines. The frequency compensation control signal also includes frequency detection, compensation control and frequency stability detection control.

IV. RESULTS AND DISCUSSION

A. Introduction

In order to test the designed secondary controller approach, a microgrid in island mode at distribution network is considered as the test system. The simulation was performed in the MATLAB/Simulink environment (Figure 4-1). The values of the system parameters are shown in Table (4-1) and Table (4-2). In this situation, the primary control is activated at time t = 0 and the secondary control at time t = 3 (s). The simulations are done in 4 stages:

i. First stage (0 to 3 seconds): In this mode, only the primary control is activated.

ii. Second stage (3 to 5 seconds): Secondary control is applied in this stage.

iii. Third stage (5 to 7 seconds): Constant demand is applied to the assembly.

iv. The fourth step (7 to 10 seconds): Inductive load is cleared from the total demand.

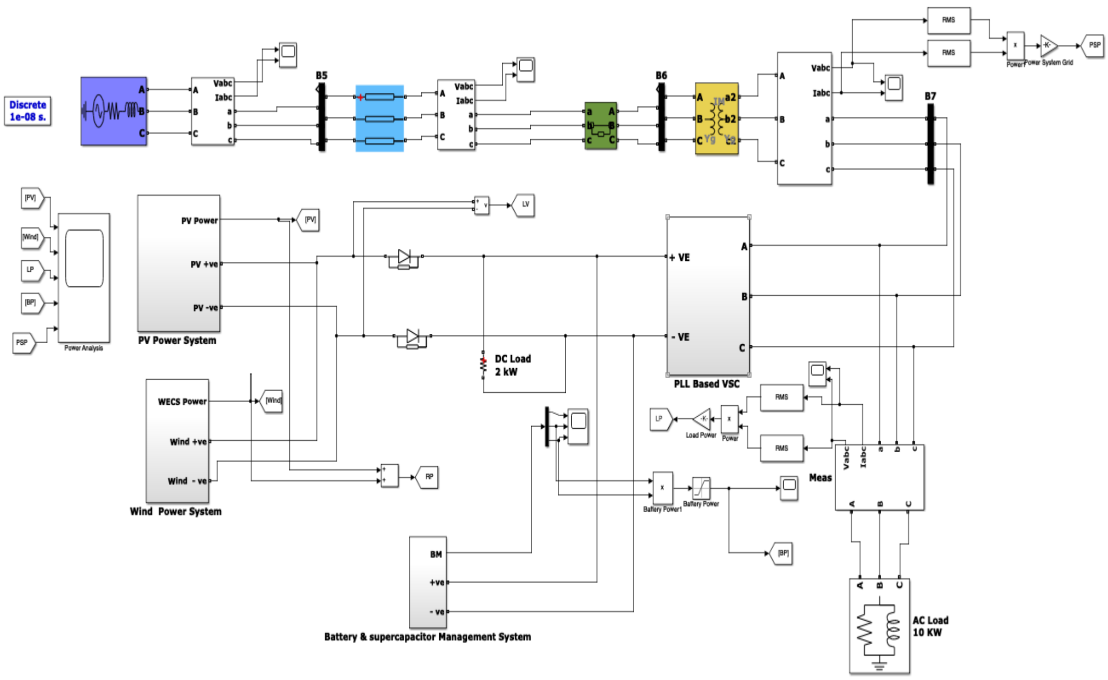

Figure 13: Simulink model of the under study microgrid

Table 1: Primary controller parameters

τ_{P_1}	τ_{Q_1}	k_{P_1}	k_{Q_1}	k_{V_1}
0.016	0.016	0.00006	0.00042	0.01

Table 2: Secondary controller parameters

Frequency controller			Voltage controller			
α_1	β_1	γ_1	k_1	k_2	α_1	α_2
0.2	250	500	100	10	1/3	½

B. Details of renewable resources

In this microgrid, diesel generator, energy storage system, photovoltaic array and wind turbine are used as green energy equipments for power generation and storage, and the information about green resources are shown in Table (4-3) and Table (4-4). If we consider just an economic point of view, the optimal way to supply all the required demand is using diesel generators, but this causes the emission of GHG gases, which are harmful for the environment. The profile of wind pattern of the area is shown in Figure (4-2). As can be seen, there is a relatively good wind blowing, so that more than 40% of the blown winds have a speed of more than 10(m/s). For solar irradiations, the intensity of irradiation in the middle of the day is slightly more than 700 W/m^2, which indicates that there is not strong possibility for solar irradiations in this area. Table (4-5) shows the average amount of daily irradiation (W/m^2) for Istanbul city. This information was obtained from the NASA website [58]. In this regard, the average annual radiation in this city is equal to 4.83 (W/m^2) (Figure 4-3).

Table 3: Characteristics of wind turbine, solar module and battery [59]

Wind Turbine		Solar Module		Battery	
Cut-in Speed (m/s)	2.5	Rated Voltage (V)	12	Capacity (Ah)	200
Rated Speed (m/s)	14	Rated Power (W)	150		
Cut-off Speed (m/s)	25	Short Circuit Current (A)	8.4	Rated Voltage (V)	12
Rated Power (W)	5600	Open Circuit Voltage (V)	21.6		
Output Voltage	48	Efficiency Coefficient	0.74	Cost ($)	416
Cost ($)	8870	Cost ($)	900		

Table 4: Characteristics of regulator and inverter [59]

Regulator		Inverter	
Rated Current (A)	30	Rated Voltage (V)	48
Rated Voltage (V)	48	Rated Power (W)	3500
Cost ($)	230	Short Circuit Current (A)	2799

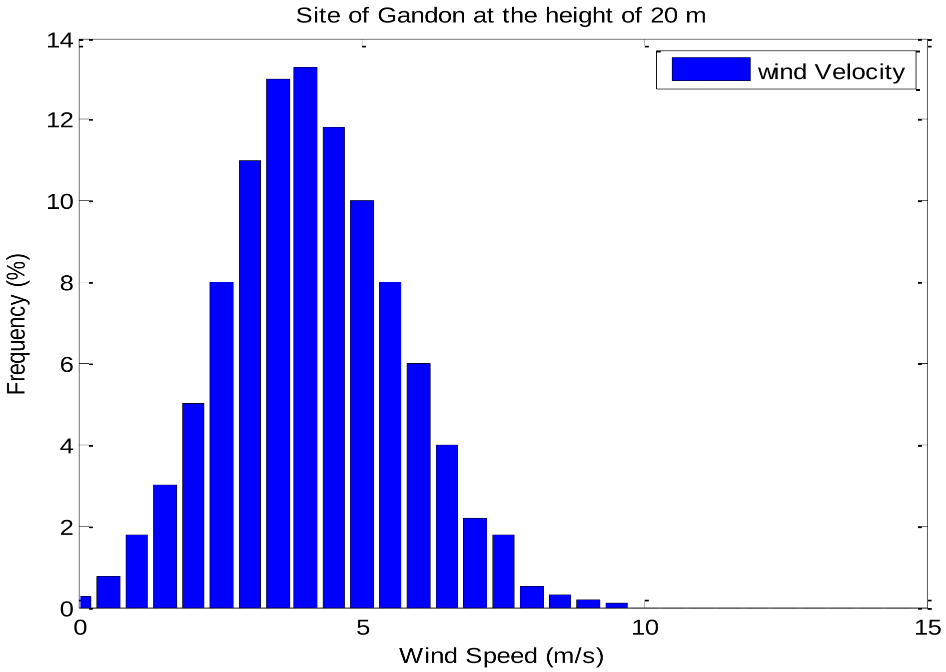

Figure 14: Wind pattern in the area [60]

Table 5: Average daily irradiation for Istanbul city [58]

Month	Daily Irradiation (W/m2)	Month	Daily Irradiation (W/m2)
Jan.	2.33	Jul.	7.64
Feb.	3.03	Aug.	7.14
Mar.	3.58	Sep.	5.72
Apr.	4.92	Oct.	4.11
May.	6.50	Nov.	2.86
Jun.	7.81	Dec.	2.17

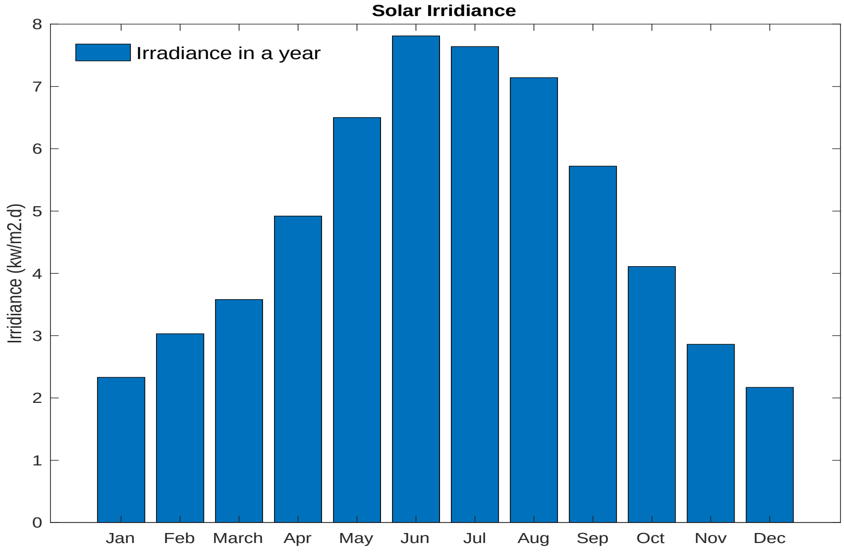

Figure 15: Average monthly irradiation [58]

C. Results Evaluation

During the first stage, due to the droop function in the primary control level, the DG voltage amplitude is greatly reduced while the frequency is synchronized at a certain value with the load. Voltage variations of different parts of system is shown in Figure (4-4). The variations of frequency and stochastic demand are shown in Figure (4-5).

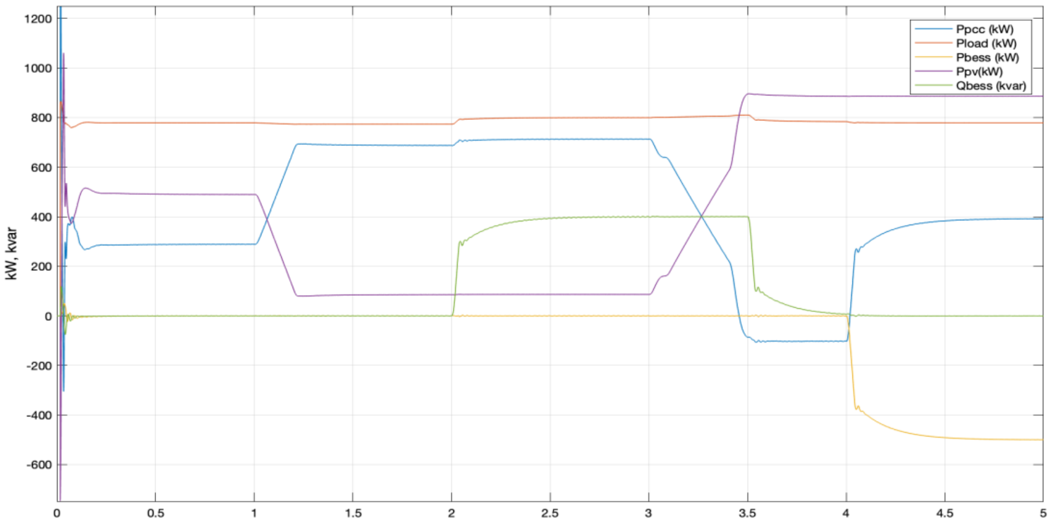

Figure 16: Voltage variations of different parts of system

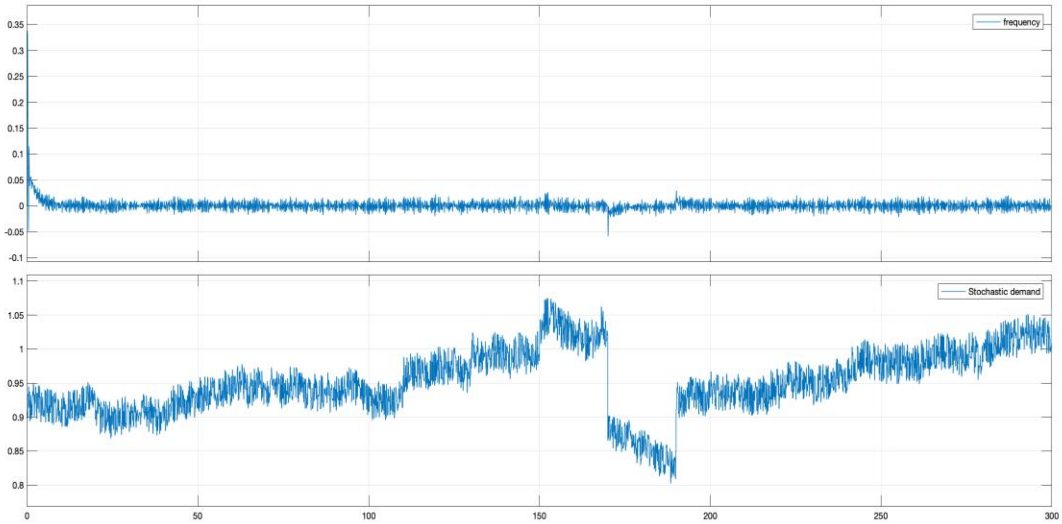

Figure 17: Demand variations and frequency stability

In order to evaluate the performance of the proposed approach, variable irradiation is considered. For this purpose, the amount of intensity changes as well as variation of boost converter, photovoltaic voltage and current variations are shown in Figure (4-6). Next, changes in active power and frequency in tracking of the determined reference values are shown in Figure (4-7).

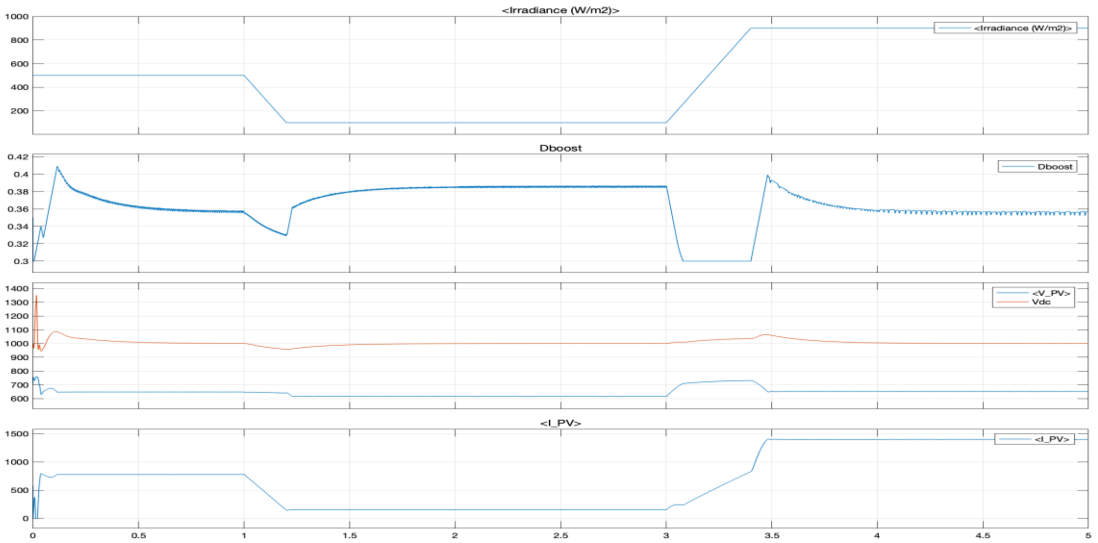

Figure 18: Irradiation variations, boost voltage level, PV voltage and current

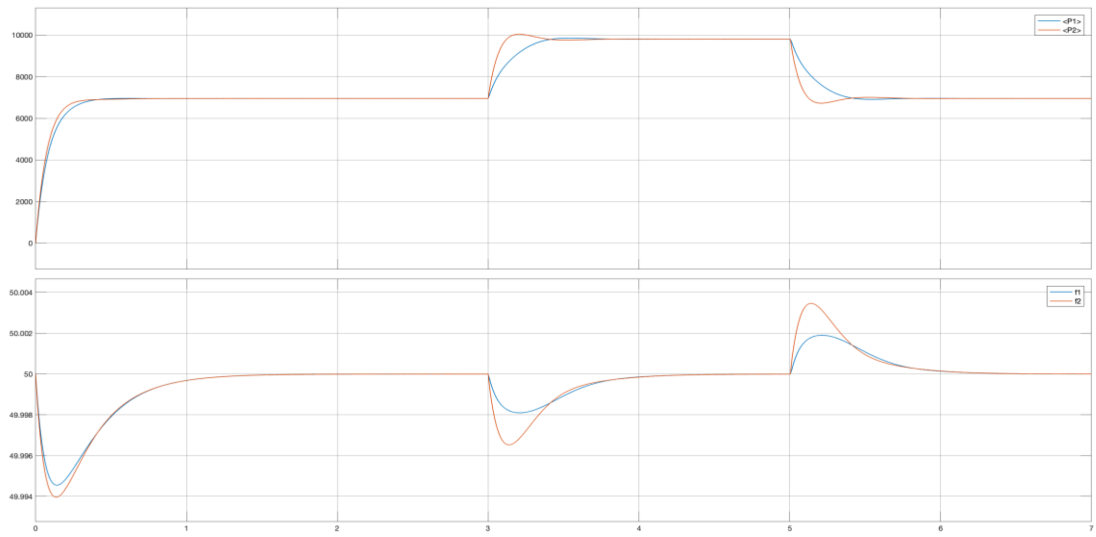

Figure 19: Power & frequency variations for tracking reference points

In Figure (4-8), the inverter voltage variations, the current extracted from the battery and the state of charge (SOC) of the batteries are presented. In this regard, both voltage and frequency have significant differences with their reference values. Therefore, it is necessary to restore them in the secondary control layer.

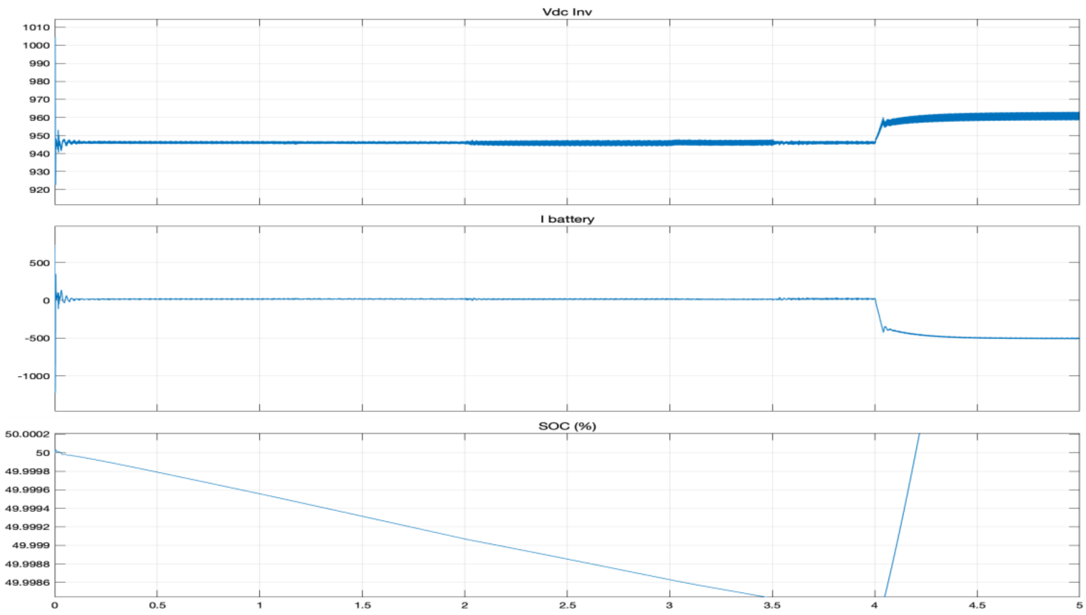

Figure 20: Variation of inverter voltage, battery current and state of charge

When the distributed secondary control is activated at t = 3(s), both the voltage and the frequency are quickly converged to related reference values. Although a series of transient states are observed at the beginning, the frequency regulated at its steady state value. The amount of fluctuation created in the energy of flywheels and battery storage systems are shown in Figure (4-9). By evaluating the obtained results, it is clear that the secondary control stage can eliminate the violations generated in the amplitude of voltage and frequency. In fact, when the secondary control level is activated (t = 3(s)), active power distribution is distpatched properly by the participation of different energy sources, according to the demand variations.

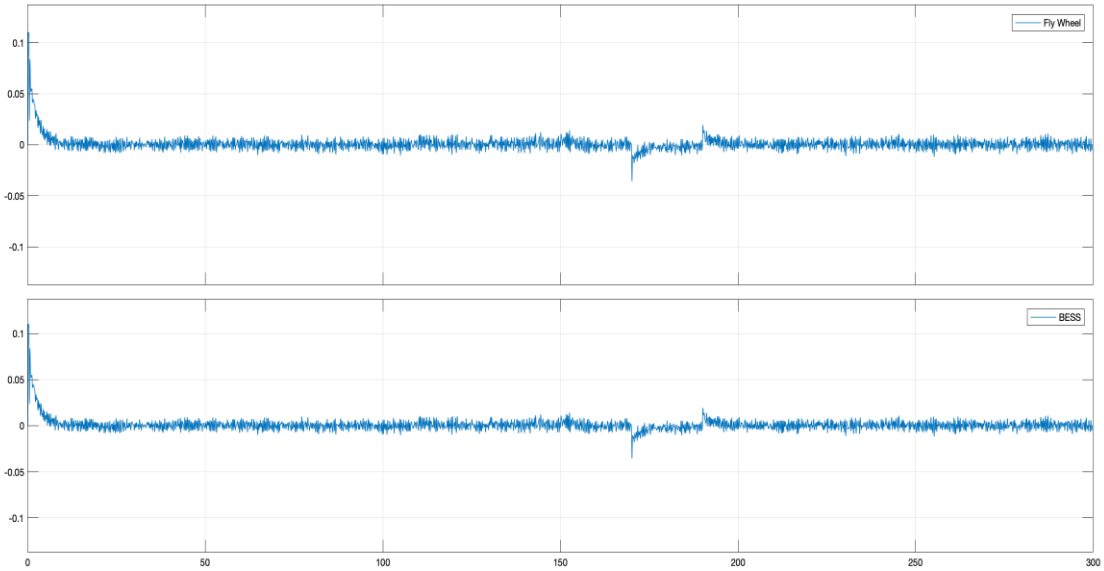

Figure 21: Flywheels and batteries energy variations

V. CONCLUSION AND SUGGESTIONS

A. Introduction

Electric utilities are continuously planning the development of electric networks in order to supply the consumer’s demand. The classical method used in order to supply new requirements is the construction of new power stations or the development of existing infrastructure. With the implementation of new government policies for using renewable resources, the use of reneable generation resources has attracted significant importance. These sources can supply local loads separately and capable to inject their excess generated power into the distribution network. The integration of DGs with the main grid can expand the capacity of energy generating sources, improve efficiency and security, increase power quality and reliability, and reduce environmental pollution. However, connecting DGs to the distribution network causes significant changes in the operation of the network and has several effects on its power quality. In this project, two-stage control structure has been used to restore the voltage and frequency to their corresponding reference values in a limited period of time. By evaluating the extracted results, it is obtained that the distributed secondary control level can eliminate the amounts of violations created in the voltage and frequency primary control stage. In fact, when the secondary control level is activated, the active power distribution is regulated by different resources.

B. Conclusion

It should be noted that one of the most important sources of distributed generation units are renewable resources that will play a large role in power generation in the future. These resources, which are intermittent, need energy storage resources, which are used as an innovation in this thesis, two of the most important energy storage resources. The following suggestions are made in order to achieve more optimal results:

1- Investigating the load variations in the grid and evaluating the sensitivity of resource capacities to load changes

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