REPUBLIC OF TURKEY
YILDIZ TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

ACTIVE AND REACTIVE POWER SHARING OF PARALLEL INVERTERS IN MICROGRID BY USING DROOP CONTROL

AHMED ISMAIL

MSc. THESIS
DEPARTMENT OF ELECTRICAL ENGINEERING
PROGRAM OF POWER SYSTEMS

ADVISER
ASST. PROF. DR. MUSTAFA BAYSAL

İSTANBUL, 2014

REPUBLIC OF TURKEY

YILDIZ TECHNICAL UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

LOCATION ANALYSIS OF THE EMERGENCY SERVICE CENTERS OF A CASE COMPANY

A thesis submitted by Ahmed ISMAIL in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE** is approved by the committee on 19.12.2014 in Department of Electrical Engineering, Power Systems Program.

Thesis Adviser

Prof. Dr. Mustafa BAYSAL

Yıldız Technical University

Approved By the Examining Committee

Asst. Prof. Dr. Mustafa BAYSAL

Yıldız Technical University ______________________

Asst. Prof. Dr. Arif KARAKAŞ, Member

Yıldız Technical University ______________________

Assist. Prof. Dr.Muhammed GARIP, Member

Yıldız Technical University ______________________

ACKNOWLEDGEMENTS

First, I would like to thank deeply my mother who was my role model, and to whom I dedicate this thesis.

I want to express sincere gratitude to my father and family who have helped and inspired me and all my colleagues at Electrical Engineering Department in Yildiz Technical University who made it a comfortable place to work.

I would like to thank my advisor, Professor Mustafa BAYSAL, for his guidance and support throughout the course of this work.

Equally, I am thankful to YTU research team for creating and maintaining an excellent academic environment, a factor which had a positive impact on this work. Also, I would like to thank Professor Muhtesem from power system department for his hospitality and supporting me during period of my study and research.

Really, I want to thank ministry of abroad Turks and Related Communities (Yurtdışı Türkler ve Akraba Topluluklar Başkanligi -YTB) and turkey government to give me this chance to complete my master study and their financial supporting through my study and research.

Thanks for all people and friends who help me to do this work and take this study out in this form.

December, 2014

Ahmed ISMAIL

TABLE OF CONTENTS

Page

LIST OF SYMBOLS

H_2	Hydrogen
O_2	Oxygen
H_2O	Water
R_{sh}	Shunt resistance
R_s	Series resistance
kW	Kilo watt
mW	Mille watt
m	Mass
v	velocity of the wind
P_w	wind power
ρ	power density
A	Area
µ	Energy conversion efficiency
E	Turbine Energy
P1	Active power
Q_1	Reactive power
E1	Inverter output voltage
Vg	Grid voltage
$\emptyset_1$	Phase angel between output inverter and grid voltage
X	output reactance of an inverter
ω^*	Output voltage angular frequency
E^*	Amplitude of the voltage at no load
P_i	Actual active power rating
Q_i	Actual reactive power rating
Zo	VSI impedance
Z_g	grid impedance
i_{pcc}	point of common coupling current
V_{pcc}	point of common coupling voltage
n	Q-V droop proportional coefficient
m	P- φ droop proportional
P^*	Active power reference
Q^*	Reactive power reference
θ	Phase of the output impedance
F_g	Frequency grid
L_1	Virtual Inductor #1
L_2	Virtual Inductor #2
r_{l1}	Parasitic resistor #1
r_{l2}	Parasitic Resistor #2

S	Nominal output power
P_L	Active power load
Q_L	Reactive power load
r_{l1}	Parasitic resistor #1
r_{l2}	Parasitic Resistor #2
F_g	Frequency grid

LIST OF ABBREVIATIONS

3C	Circular Chain Control
ACS	Average Current Sharing
AFC	Alkaline Fuel Cells
CLC	Central Limit Control
CSI	Current Source Inverters
DER	Distribution Energy Resources
DG	Distributed Generation
DG	Distributed Generation
DLC	Distributed Logical Control
DMAF	Direct Melhanol-Air Fuel Cell
DP	Distributed Power
EMS	Energy Management Systems
GHG	Global GreenHouse Gas
HAWT	Horizontal-Axis Wind Turbines
HV	High Voltage
IBS	Intelligent Bypass Switch
ICT	Information and Communication Technologies
LPF	Low Pass Filter
LV	Low Voltage
MCFC	Molten Carbonate Fuel Cells
MG	MicroGrid
MSC	Master–Slave Control
PAFC	Phosphoric Acid Fuel Cell
PCC	Point of Common Coupling
PEMF	Polymer Electrolyte Membrane Fuel Cells
PID	Proportional–Integral–Derivative
PLC	Power Line Communication
PV	Photovoltaic
RES	Renewable Energy Sources
SOFC	Solid Oxide Fuel Cells
UPS	Uninterruptable Power Supply
VAWTs	Vertical-Axis Wind Turbines
VSI	Voltage Source Inverter
WC	Wireless Control

LIST OF FIGURES

Page

LIST OF TABLES

Page

ABSTRACT

ACTIVE AND REACTIVE POWER SHARING OF PARALLEL INVERTERS IN MICROGRID BY USING DROOP CONTROL

Ahmed ISMAIL

Department of Electrical Engineering

MSc. Thesis

Adviser: Asst. Prof. Dr. Mustafa BAYSAL

The spread of greenhouse gas emissions in the atmosphere resulting from generating electricity based on fossil fuels and emergence of distributed generation systems as a clean energy sources (wind turbines, PV, Fuel cells, etc.) lead to begin transfering from conditional electrical grids to smart grids. These grids have a features to integrate distributed energy resources and use communication technologies. So utilization of distributed renewable energy sources for domestic energy consumption will increase in the near future. This trend allows more efficient energy consumption because of reducing transmission loses and dependence on domestic appliances to grid distribution.The distributed energy resources are connected into the grid via power electronic interface such as inverter or ac/ac converter.

In this thesis, it is studied the methods used to manage and control active/reactive power sharing of inverters. Also it is reviewed the advantages and disadvantages of many types of control methods used for power sharing of parallel inverters. This study is aimed to propose a controller for active and reactive power sharing of inverters operated in parallel. At first we designed droop control to make power sharing of parallel inverters on several cases. After that we modify a droop method by designing PID controller and connect it with droop control. The proposed controller consisting of droop and PID controllers gives more accurate power sharing by removing signals in transient response and gives more accurate results especially in reactive power sharing.

Key words: Active and Reactive power sharing, Distributed energy resources, Droop control, Inverters, Microgrid, PID controller

YILDIZ TECHNICAL UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

ÖZET

MİKRO ŞEBEKEDEKİ PARALEL İNVERTERLERİN DÜŞÜM YÖNTEMİYLE AKTİF VE REAKTİF GÜÇ PAYLAŞIMI

Ahmed Ismail

Electrik Mühendisliği Anabilim Dalı

Yüksek Lisans Tezi

Tez Danışmanı: Yrd. Doç. Dr. Mustafa BAYSAL

Eş Danışman: Yrd. Doç. Dr. Arif KARAKAŞ

Eş Danışman: Yrd. Doç. Dr. Muhammed GARIP

Fosil yakıtlara dayali elektrik üretimi nedeniyle atmosferdeki sera gazların yayılması ve rüzgar tribünleri, PV, yakıt hücreleri vb. dağıtık üretim sistemlerinin temiz enerji kaynakları olarak ortaya çıkması, klasik elektrik şebekelerinden akıllı şebekelere dönüşümün başlamasına neden olmuştur. Akıllı şebekeler dağıtık enerji kaynaklarını enetgre etme ve iletişim teknolojilerini kullanabilme özelliklerine sahiplerdir. Dolayısıyla, konutların enerji tüketimi için dağıtık yenilenebilir enerji kaynaklarının kullanımı yakın gelecekte artacaktır. Enerji sistemlerindeki bu trend, azalan iletim kayıpları ve ev aletlerinin şebeke dağıtımına bağlılığından dolayı daha verimli enerji tüketimine olanak tanımaktadır. Dağıtık enerji kaynakları, inverter veya ac/ac dönüştürücü gibi güç elektroniği ara birimleri ile şebekeye bağlanmaktadır.

Bu çalışmada, inverterlerin aktif ve reaktif güç paylaşımını yönetmek ve kontrol etmek için yöntemler incelenmiştir. Ayrıca, paralel inverterlerin güç paylaşımında kullanılan bir çok kontrol yönteminin üstünlükleri ve eksiklikleri gözden geçirilmiştir. Bu tezin amacı, paralel inverterlerin aktif ve reaktif güç paylaşımı için bir kontrol mekanizması önermektedir. Öncelikle, paralel inverterlerin farklı durumlarda güç paylaşımını yapmak için bir düşüm (droop) yöntemi tasarlandı. Daha sonra, PID kontrol mekanizması tasarlamak suretiyle bir düşüm yöntemi oluşturuldu ve düşüm kontrolüyle bişleştirildi. Düşüm (droop) ve PID kontrolörlerinden oluşan önerilen kontrol mekanizması, geçici tepkideki sinyalleri ortadan kaldırarak daha doğru güç paylaşımı vermekte ve özellikle reaktif güç paylaşımında doğru sonuçlar ortaya koymaktadır.

Anahtar Kelimeler: Aktif and Reaktif güç paylaşımı, Dağıtık enerji kaynakları, Düşüm (droop) kontrolü, İnverter, Mikroşebeke, PID kontrol mekanizması

CHAPTER 1

INTRODUCTION

1.1 Literature Review

Today, as we know, the main source of energy in the world is based on fossil fuels; however there is a need for economic environment and environmentally friendly alternative energy generation systems, in addition to (a) continuously increasing demand of electric energy by developed and developing countries, (b) many developing countries suffer from lacking power resources and networks [1]. Furthermore increasing energy consumption overloads the distribution grids and power generators which cause a negative impact on power availability, security, and quality [2] led to make decentralized renewable energy production more and more important. So the key point is to transfer to more intelligent, more reliability and more voltage and frequency stability by using small and smart grid energy systems including renewable energy resources, micro-generators, loads and storage systems called Smart Grid which we can divided it to Micro Grids for controllability (active and reactive power flow control), by using Micro Grids we can integrate Distributed Generation to Grid, by this way the energy will be generated and stored near consumption areas so we can reduce the losses generated by power transmitted lines and getting more reliability grid, on the other way Micro Grid open up new markets to alternative energy, This allows more power to travel with less resistance to far markets (cities, towns, rural areas, etc.). One of the major favorites of using Micro Grids that are working in two modes; grid connected mode which the Micro Grid is connected to the essential electrical grid through intelligent bypass switch (IBS) and Islanded Mode which the Micro Grid is isolated from electrical Grid and the energy is generated by alternative Distributed Energy

Resources (DER) such as wind generators, biomass power plants, hydro power turbines, PV sources, fuel cells, energy store systems and uninterruptible power supplies (UPS) [3, 4]. Alleviating all system losses in transmission and distribution processes also getting more security, reliability, and high power quality by preventing centralizing of generation stations and make decentralizing of the grid by exploitation renewable energy sources (RESs) and interfacing them with energy conversion systems (ECSs) to the power grid which are called Distributed Energy resources Systems (DESs); For most distributed energy resources (DER) which are connected in parallel in LV-grid like micro-turbines, wind plants, fuel cells and PV cells electrical power is generated as a direct current (DC) and converted to an alternative currents (AC) by inverters. So the inverters are assumed to be a primary components in the grid cause of many functionality process that have to perform; they have to convert the DC voltage to sinusoidal voltage and make connection between (ECSs), The inverters influence the frequency and the voltage of the grid for this reason has been made control systems over inverters to alleviate their influencing. Inverters interface with the grid in parallel which increase reliability over a single centralized sources because in case one fails the remaining inverters (n-1) units will deliver the needed power to the load and excess energy caused by failed inverter will distribute proportionally to the other paralleled inverters; therefore inverters are considered to be main universal unit building block of future smart grids especially in law and medium voltage [1].

There are many control techniques of parallel inverters to improve the power quality of (DESs) which contribute to make proportional distribute of power for parallel inverters and managing active and reactive power of the Micro Grid. Control strategies for the parallel-connected inverters can be classified into two types; **active load sharing/current distribution** with all types of this controller must be utilized communication links between inverters with some cases there is master control station or master inverter and **droop control** with no any communication links between inverters so its preferred from the other controllers[1,5].

1.1.1 Micro-Grid Concept

A Micro grid is a cluster of distributed energy resources systems (DESs) and loads working as controllable system which provides power to its local area, therefore a Micro grid is a new type of power systems consisting of generation sources, loads, and energy storages, In other words it's a combination of small modular energy resources, a low voltage distribution network and load units interfaced by means of fast controllable power electronics, so the Micro grid is a main application allow to integrate (DESs) into distributed networks[6].

Micro grid uses a technology of smart grid that utilizes digital technology allow dual communication between electrical generators and customers; which led to use electrical devices in homes when the electricity be inexpensive and abundant, also allow to electrical managers detect the system to recognize problems and avoid it as well as gives rapid information about blackouts and power quality, these facts led to insert technologies that can discover the problems since comprehensive measurements of the network. As a result rapid communication, Diagnosis and feedback control turn back the system to stable status after interruptions or disturbances are occurred.

The main idea of a Micro grid that can be connected with the main grid or make connection between micro grids with tie lines forming clusters or we can define micro grid as a part from main grid contains micro generators, loads, storage units, UPS and energy conversion systems working on autonomous status but connecting with main grid but it has special feature that can separate from main grid seamlessly and working in island mode when there is enough energy from micro generators in micro grids or faults in main grid. Tie lines act to exchange energy stations to get a balance in micro grid so it will be alleviate power flow in these tie lines. Micro grid is a new pattern for low voltage distribution systems because generation depend on small main engines like PV plants, small wind turbines and fuel cells that requires for power electronics interfaces such as ac–ac or dc–ac inverters[3].

Micro grids have two operation modes, they can operate in Island mode (autonomous mode) in other words off-grid mode. In this case the energy is generated from micro grid without need energy from low voltage utility grid; however micro grids must contains one or more micro turbines such as wind turbines, PV plates, fuel cells, batteries and local loads; which are fed by these energy sources. In other case a micro grid is connected to the point of common coupling (PCC) of the main grid through intelligent bypass switch (IBS) which is called grid-connected mode. In this operation mode the micro grid acts as a backup system or as a part of main grid. The purpose of backup mode is to feed local loads when there are faults in the main grid for any reasons. This mode is also called emergency mode. Also the configuration of micro grid in grid connected mode needs a power sources and a large battery bank. Batteries or super capacitors are required in micro grid to store excess of the generated energy and support energy resources inside the micro grid when the loads increase. The size and type of batteries are chosen by system's conditions. During grid connected mode operation the aim of micro grid is to make full charge battery bank so it will be ready for emergency operating. When micro grid operate in grid connected mode the energy resources of the micro grid feed local loads; if the generated power exceeds the demand power inside micro grid, excess of the energy is exported to the main grid. In the opposite case if the micro grid cannot full supplying of its local loads the required energy is imported from the main grid. Cause of all loads in micro grids are required AC power which is adverse of DC powers generated by Distributed Energy Resources (DERs) and batteries mast be used inverters to invert power from DC to AC and to control electrical power in both operation modes [6].

1.1.2 Micro-Grid Configuration

Micro grid involves two primary components; micro sources (DERs) and energy conversion systems. Typical micro grid architecture with micro sources is shown in figure 1. The system consist of feeders which are called distributed generations (DG). The distribution generation unit contains a micro source and DC/AC inverters in the other words (DGs) are called distribution resources systems (DRSs). Micro grid also contains sensitive and non-sensitive loads, which appear of a part of distribution system. The part of system contains sensitive loads must be interfaced to the utility grid by static switch, see figure 1. Due to isolate sensitive loads from faults and disturbances of the utility grid, the single point which makes interfacing between micro grid and main grid is called point of common coupling (PCC). When micro grid is connected with the main grid the power flows from micro sources directly to non-sensitive loads. However in case of faults the micro grid operates in island mode which is required to disconnect micro grid from the main grid. This supposes the change in the output control of the generation units from a delivery power mode to frequency controlled operation mode along with the load needs[7].

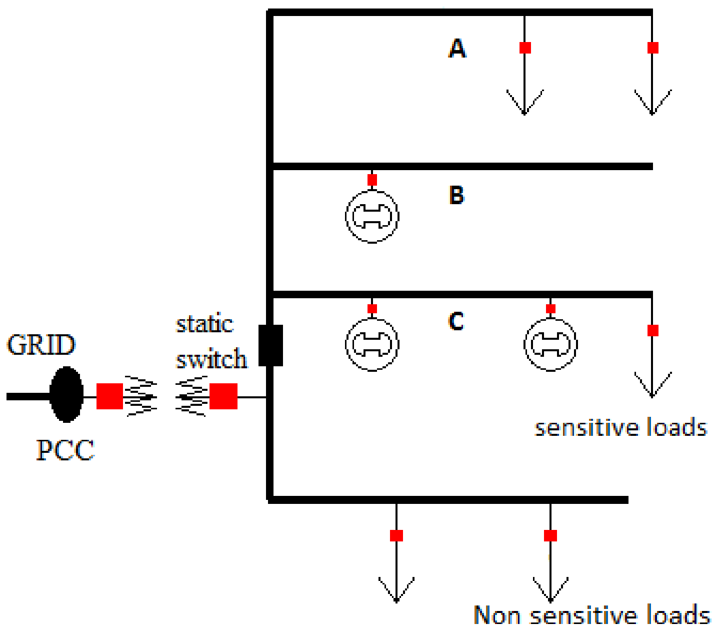


Figure1.1: Micro-Grid Architecture. [7]

1.2 Objective of the Thesis

Today the world is transferring from conventional electrical girds to smart or micro-grids. These transferring process integrate distributed generation sources like alternative sources (wind turbines, PV, fuel cells, etc.) with the main grid. Integration process of these resources is operated by power electronics such as inverters. Since integration DGs with the utility appears many problems. One of the main problems of integration process over inverters is management of the power sharing. This thesis offer some controllers as solutions of active and reactive power sharing of inverters according to their capacity. In addition to that the thesis explains advantages and disadvantages for every control method and offers the best solution for this problem by analysis and design droop control techniques. So the main aim of this thesis is to make analysis, design, model, and develop for the droop control. In the first analyze the droop control method by mathematical equations to model it by MatLab/SIMULINK program. Modelling process is performed by establish a small micro-grid composed from parallel inverters, load, switches, and main grid. After modelling the micro-grid, it must be experimented during the two connected cases; grid connected mode and island (autonomous) mode. During operation process we can notice from the results in two cases the status of the system and modify the variables according to active and reactive power flow. From analyzing the system we notice that droop control can’t solve some problems as we will see in chapter 4 and chapter 5. Develop the system modeling based on the variables useful for an optimal control of active and reactive power flows. The use of voltage source inverters (VSI) as electronic interface with the Micro-grid, needs for new analysis tools. As a primary goal, an accurate model derived from the electrical scheme of a grid interactive VSI system is demanded. The control variables of such VSIs will be the amplitude, frequency and phase of the output voltage. So solving these problems operate by integrating other control method work as assistant controller to modify droop controller and gives more accurate results in reactive and active power sharing. So this gives accurate power flow control during transients. Used decentralized control method (droop functions) to improve system stability and dynamic performance, being able to share power with the grid in function of its nominal power. Finally proposed controller achieves our goal to share active and reactive power of parallel inverters accurately and we will see that in chapter 5 the results of controllers.

1.3 Hypothesis

This thesis is organized in 6 chapters, as follows:

Chapter 2: introduces smart grid with its definitions, architecture, management methods for the grid and communication technologies and protocols. Also focusing on micro-grid and its architecture, the benefits to transfer using micro-grid, types of micro-grid, distributed energy resources that can be integrated to MG (fuel cells, PV, wind turbines, etc.) with explain every one of them, energy storage devices such as batteries, ultra-capacitor with summarized of the advantages and disadvantages for every one and make a comparison of storage devices, explains MG operation modes and the seamless transfer between the two operations, inverter topology which is the main part of our thesis to make power sharing and understand the idea of its work with types of topology, and issues of MG such as islanding detection, protection and active and reactive power sharing must be known to understand the status of MG and how to make security and safety for MG also understanding these issues can be help to design more accurate controllers achieve stability and reliability for the grid. Finally chapter 2 offers some application of MG in the word especially in Turkey in Yildiz Technical University with some explanations.

Chapter 3: introduces Control strategies for parallel operation of inverters in microgrid begins from idea of parallel operation of inverters with reviews the control types in parallel operation of inverters and the advantages and disadvantages for every type also make the comparison for all types and conclude the best control method for sharing power process, finally explains the droop control method with review its advantages and disadvantages.

Chapter 4: explains the design and Modelling the system by using droop control Matlab / SIMULINK. First begins with design and model the structure of MG then explain the idea to design and model the inverter. Moreover contains designing and modelling the power calculator, power filter and droop control. We see from the results in chapter 5 that just using droop control has some restrictions so at the end of chapter 4 we will find the way to design assistant controller to modify droop control.

Chapter 5: reviews the results of many case studies which represent to different types of MG. These micro-grids can be contained equal power capacity parallel inverters or different power capacity of parallel inverters. In each case study we can see some comments and conclusion of the response of the used control.

Chapter 6: contains the conclusion of using droop control in micro-grid in near future especially with alternative energy sources. Also the future works that can be done to modify reactive power sharing and achieving more accurate reactive power sharing.

CHAPTER 2

MICRO-GRID

2.1 Smart Grid

Today electrical power systems suffer from lack of energy duo to increasing demand especially in industrial networks. In addition to that the revolution in information technologies and developing in communication protocols encouraged researches to emerge new protocols with power systems. Also intelligent networked devices can be integrated to monitor and manage power networks. These smart grids will be designed and applied to provide more reliability and stability of electrical power and support economic and operational requirements of large distributed control systems [100]. So the smart grid is a Mixture of open and proprietary networks enables the much larger network of measurements, controls, metering, and automation. Furthermore one of the major causes to integrate smart grid is that has ability to merge distributed energy generations such as alternative energy sources with the electrical power, because the clean energy is becoming an imperative to our modern society [101]. Smart grid has many definitions from different sources like “A Smart Grid is a modern electricity system. It uses sensors, monitoring, communications, automation, and computers to improve the flexibility, security, reliability, efficiency, and safety of the electricity system” [98]. In short we can say smart grid is applied to achieve these aims: (1) improve the efficiency of power systems. (2) Benefit from several technologies such as power electronics, communications, information storage and exchange and new materials. (3) Ability to integrate renewable energy generation sources such as wind turbines. (4) Reduces green-gas emissions. (5) Improve the quality and reliability of the power supply. (6) Improve the efficiency of Transmission and Distribution network. (7) Ensure security and safety of the power system [99].

2.1.1 The Reasons for Trend to Smart Grid Infrastructure

The infrastructure of electrical grid has not changed over 100 years. So the hierarchal components are near to end of their lives, therefore electrical grid has become in the stage of rickety. The demand of electrical energy is gradually increasing. According to U.S department of energy the demand and the consumption of electricity has increased 2.5% annually over the last 20 years. Recently days the electrical grid is complex and not suitable for needs of 21st century, because there are many deficiencies in this grid such as lack of automated analysis, poor visibility. All of these lacks contributed to occurrence blackouts in last 40 years. Also there are some other additional factors like increasing the population, growing energy demand, changing in the climate, equipment failures, problems in energy storage, capacity limitations for electric generations, one way communication, decreasing the fossil fuels, also emission of greenhouse gas from transportation and electricity factories have been a threat over the earth [8].

2.1.2 Smart Grid Definitions

For these challenges ought to scientists to develop recent grid to more intelligent, reliability, and safety grid which it uses two way communication technology that resulted smart grid. There are many definitions for smart grid; it can be defined as an electrical network that can intelligently management of actions and processes that occur between all consumers and generators inside the grid. Or it is an electrical grid controlled by digital technology, or updating the recent grid by using information and communication technologies (ICT), or a smart grid is a digital grid that interfaces customers with utility grid by using two way communication technologies [9]. Or a smart grid is an improved utility grid with ability to smooth integration of distribution energy resources (DERs) uses communication technologies and automated control to get more reliability, efficiency, security, and safety modern grid. So smart grid technologies uses renewable energy sources (RES) which are decreased the greenhouse gas emissions and provide demand side management and energy storage which reduced the losses that needs to transfer energy from power stations to rural sites and increased the reliability. One of the most features of smart grid that can give real time information to deliver and manage power from generators to customers by using (ICT) containing sensors, intelligent monitoring systems and controllers. Also smart grid is a promising technology for disposal of failures, capacity constraints, power disturbances and outages. The recent grid is lacking from communication technologies but the smart grid is full of communication technologies and sensors increase the grid capacity and flexibility by integration many (DERs) which is shown in figure 2.1 [8].

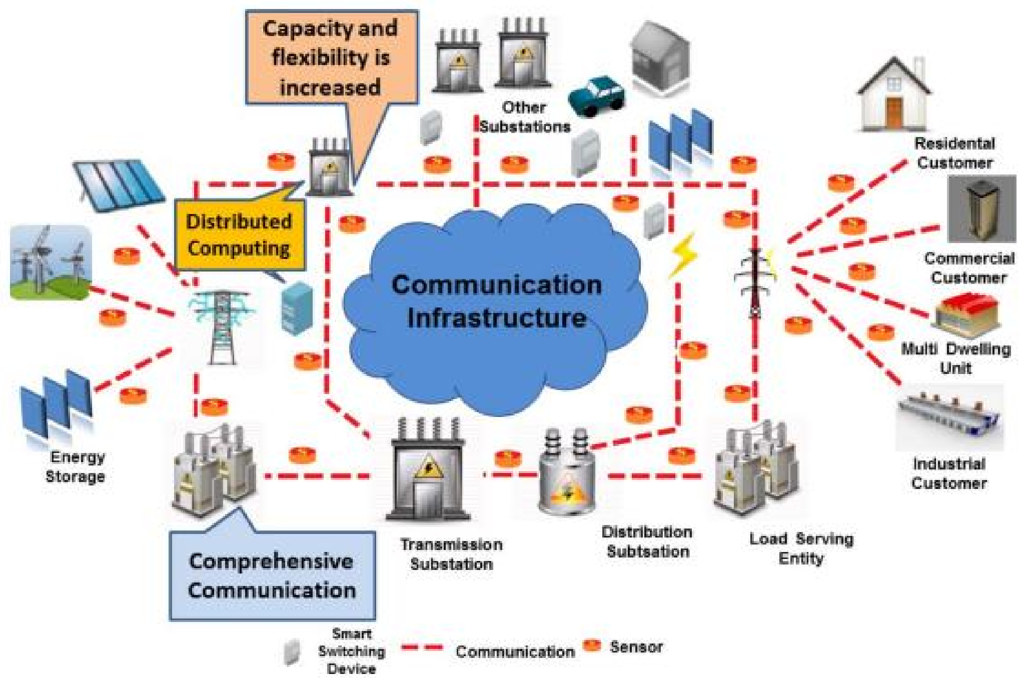


Figure2.1: Infrastructure of Smart Grid with Sensors and (RES) [8]

2.1.3 Smart Grid Architecture

In recent years there are many investments to design more intelligent, smart, complex and reliability grid that ensure excess capacity in the system. The new grid is able to manage and control of power between generators and essential, commercial and industrial customers and uses (ICT). This technology allow us to use green energy such as wind turbines, PV solar systems and fuel cells and making decentralized of resources in utility network. Smart grid allow to all customers to contribute their energy to the grid. Smart grid contains of some elements such as:

- Power generation,

- Transmission systems,
- Distribution systems,
- Distribution substations,
- Renewable energy resources,
- Storage systems,
- Energy conversion systems,
- Uninterruptable power systems (UPS),
- Residential , commercial and industrial customers (loads),
- Two way communication system,
- Control systems,

Also there are some complex elements such as telecom hybrid power system used for telecommunication equipment power feeding which included smart meter, traditional energy sources, (RES), and storage systems[9,10].

2.1.4 Smart Grid Management

The recent power grid suffer from lacking efficient management between loads and the network; as there are losses in transmission lines, failures, and not total monitoring of the grid, however smart grid infrastructure solve these problems and insure permanent monitoring the network by smart metering. Management of smart grid involves improvement of these subjects [9];

- Smart metering; monitoring and customers contribute in their energy.
- Demand side management
- Home energy controlling
- Effective administration of renewable energy sources
- Efficient management of distribution networks

2.1.5 Communication Technologies Used For Smart Grids

A communication technology is considered a main component in the smart grid infrastructure to achieve intelligent and smarter electrical grid. Huge amount of data flow from applications which are connected of grid have been analyzed and controlled. Different communication technologies in smart grid divided in to two main types: wire communication and wireless communication which are used in transmission data between smart meters and electric utilities. In some cases wireless communication is preferred over wire media that because it is easy to be extended to difficult and unreachable areas also it has low cost infrastructure, on the other hand wired communication don't has interference problems like wireless and their functions don't depend on batteries. There are two types of information infrastructure for information flow in smart grid system, the first data flow from sensors and electric applications to smart meters and this way is transferred by power line communication or wireless communications such as ZigBee or others, and the second information data flow from smart meters to utility's data centers by cellular technologies or internet. We will review some communication technologies used in smart grid systems with their advantages and disadvantages.

A) ZigBee

It's a wireless communication technology low in power usage, data rate, and complexity. ZigBee technology used in smart lighting, energy monitoring, home automation, and automatic meter reading and it has some advantages such as that it operating with unlicensed spectrum, has 16 channels each one has 5MHz from the band width, the MAX power output of radios is 0dbm (1mw), and the coverage range from (30-50m). On other hand there are some disadvantages that it has small memory size, low processing capabilities and interference with other appliances.

B) Wireless mesh

A flexible network consists of group of nodes, so that new nodes can connect with the group and each one of the node can act as a router. The advantages of this technology improvement the efficiency of the network make balancing of loads on the network, expansion the network coverage and good coverage in urban areas. On the other hand there are some disadvantages of this method like fading, interfacing and capacity.

C) Cellular network communication

It's a good option to make communication between smart meters, utilities, and far nodes. Because the infrastructure is found and available, there is no any extra cost to build new communication infrastructures. Cellular communication available in 2G, 2.5G, 3G, WIMAX, and LTE in utilities for smart metering deployments. Some advantages of this type that its available don't need to build so no extra cost for building, and widespread for example in the GPRS performs up to 170kb/s. However the disadvantages of this technology in some cases when there is pressure on the network by customers the network don’t response or the network performance will decrease in emergency situations. In bad weather situations such as a wind storm cellular network providers may not supply good service.

D) Power line communication (PLC)

It’s a technique that uses power lines to transmit high data (2-3) Mb from one device to the others and depends on LV distribution network in the smart grid. PLC considered as promising technology that exciting the infrastructure of it in the smart grid decrease the cost of building communication infrastructures. It will be suitable for urban areas and have high security. However there are some technical disadvantages such as network topology, the number and types of devices connected with PLC and distance between transmitter and receiver affect the quality of the signal. Also it has low bandwidth that encloses the application which needs higher bandwidth [8].

2.2 Micro Grid Background

Micro grid is considered as a link connects local loads, local generations, and utility grid. When it connected with the main grid there are some standards and qualifications in safety and protection must be taken. Micro grid operation system is required several supporting systems such as (protection, supervisory control, dynamic control, and power electronics interface like inverters, filters, and transformers). Successful integration for micro grid inside the distribution system is required main control of interference between micro grid and utility grid. Implementation of micro grid system provides several features both for users and for electric network provider; from user’s application micro grid can improves network quality, reduces emissions, and eliminates the cost to be disbursed by users. From electrical network provider micro grid reduces power flow on transmission and distribution power lines therefore it reduces loses and costs. Moreover micro grid can be eliminating the loads on the network by decrease electricity needs and helps in maintenance of the network in cases of errors. One of the main feature of micro grid that can be operate in island mode (not connected with the utility grid) however must be built up advanced control scheme to allow safe operation for generators when they disconnected with the main utility[11].

2.2.1 Classifications of LV Micro Grid Applications

Micro grids can be divided to the following types: residence micro grids, utility micro grids, commercial and industrial micro grid, and remote micro grid [12].

2.2.1.1 Residence micro grid

A micro grid is a very good grid to movement toward smart homes which contain energy management system (EMS) that manage smart devices with sources of generation. As a basic definition of micro grid that is able to provision controllable interface for distribution system able to make integration for every local generation and smart loads. Micro grid operate to minimize costs by manage time of use energy pricing, and strategies for utilizing.

2.2.1.2 Utility Micro Grids

Micro grids can be built on full or partial feeder of distribution substations, micro grid can accommodate local loads growth, manage overcrowding in the network and use large alternative distribution sources (wind farms, storage, UPS, biomass, etc.). Micro grid able to operate parts of network as distinct islands during maintenance activities or happening disturbances and faults in main grid while maintaining power delivery to customers. Additional services will be available by using utility micro grid such as district heating and cooling and ancillary services.

2.2.1.3 Commercial and Industrial Micro Grids

Micro grids can be used to provide reliable power to critical and sensitive loads. Large customers with multiple loads (university campus, hospital, industrial plants, shopping center) can benefit from full control over their power systems by applying micro grid. Also end customers can improve their power quality and availability by provided them tools when the main utility doesn't meet their needs. As well as the customer can use energy savings such as peak shaving and integration of renewable resources [12].

2.2.1.4 Micro Grids for Remote Communities

Many of remote communities suffer from weak connection or no connection with the main utility, these communities need separate infrastructure of electrical grid can operate without any supporting from main grid, and the micro grid is a good option to provide remote communities with energy without need any connection with utility and allowing the integration of renewable energy sources also controlling remote network [12]. An example of remote micro grid architecture is shown in figure 2.2

2.2.2 Benefits of micro grids

There are many benefits for using micro grid technologies; first of all it can improve the performance of local network distribution system by [13]:

- Using micro grid technology due to decrease the energy losses from transmission lines which connect power stations with the network because micro grid is utilizing local generators.
- Minimum voltage distortion by reactive power control.
- Dispose of overcrowding and peak loading by utilizing local generators and demand management.
- Improve reliability of the network through islanding capabilities.
- Make a power management to enclose reliable power to local loads.

On the other hand the coordination between micro grids is important to achieve local distribution improvements. Moreover it shown that utilizing micro grids participation in real market has an advantages that reducing energy cost for customers and increasing income for operators [14].

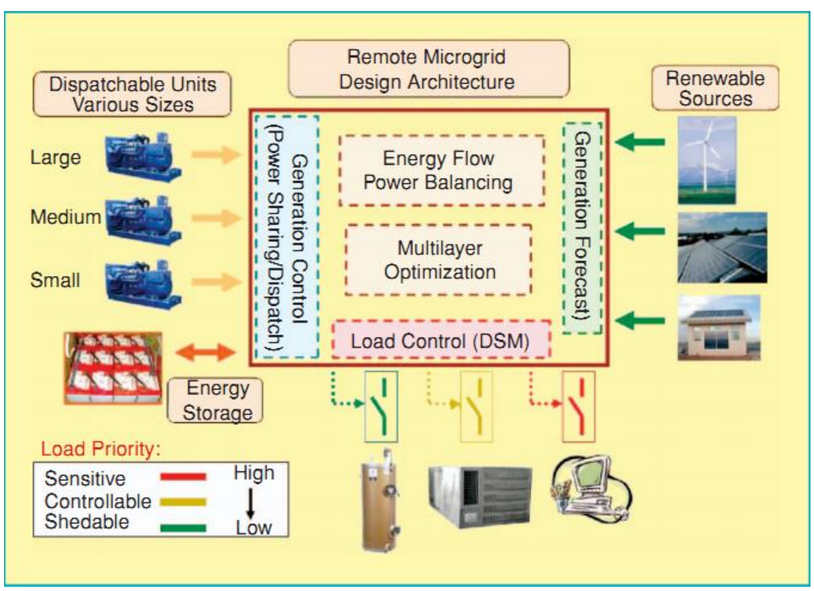


Figure2.2: Remote micro grid architecture [12]

2.2.2.1 Constructing Energy Management System

Some decisions can be made by energy management system (EMS) on power generation. These decisions can be based on: load demand, weather, electricity price, fuel costs, storage levels and future demand predictions. Generators which are integrated with building are an important factor to construct future EMS. The ability of EMS in using local generation allow to cost saving strategies such as peak- shaving, power, waste heat management and centralized load management[15]. So the concept of implementation the micro grid is the fittest for this type of application.

2.2.2.2 Integration of Multiple Sources

Micro generation technologies such as photovoltaic, micro turbines, fuel cells, wind turbines and storage can be interfaced directly with LV networks. It is utilized beside customer loads and can be used to ensure LDC reliability and high quality. The problems which be considered challenge for micro grid are ability to make coordination for these resources and intermittent nature of renewable sources. So each generators in the micro grid is prepared with droop controller manage active and reactive power with an internal voltage regulator, moreover micro grid can meet dynamic needs within it [16].

2.2.2.3 Environmental Benefits

From features of using micro grids that it allows to make integration for alternative energy resources with the grid, as a result it decreases green emission from fossil fuels and increases the efficiency of consumption energy. Micro grid helps to find solutions for reducing environment impacts that resulting from consumption fossil fuels. Moreover micro grid can make good management for peak demand which is help to remove load over the grid which reduce the demand from generation plants that support peak demand that are always a heavy polluters from fossil fuels.

2.3 Micro Grid Components

Micro grid operates at low voltage distribution and figures 1.1 and 2.3 shows the micro grid structure. As shown in the figures the micro grid is interfaced with utility grid by point of common coupling (PCC) through fast acting switch which is called static transferred switch (IBS). The tasks of the static switch are separate the portion of MG which contains sources, power electronics interfaces and sensitive and non-sensitive loads with the rest of the world (main grid), so it is responsible for making islanding by disconnecting the clusters of MG from the utility system. In addition it is also responsible for automatic resynchronization. [3, 17]

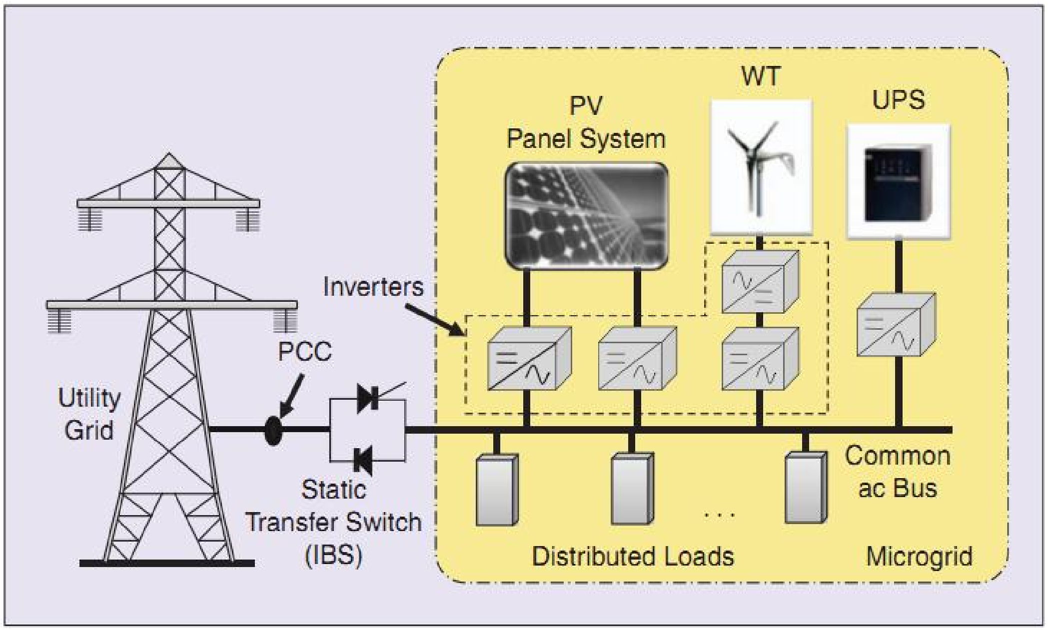


Figure2.3: Micro grid architecture [3]

Micro grid has a radial shape and contains distributed energy resources, feeders, power electronic interfaces (inverters), control systems, energy storage, and sensitive and non-sensitive loads. There are two types of feeders; the first with non-sensitive loads connected with utility grid and the second type with sensitive loads located behind static switch and distribution resources connected with it. Electronic interfaces (inverters) connected at the output of energy resources to conversion energy from DC to AC and regular the voltage of MG to be as utility voltage. So it must be able to regulate voltage magnitude at the feeder where they are installed to improve voltage quality. Also there are different control strategies to manage both frequency and voltage within grid connected and island modes. In grid connected modes the utility grid determines the frequency of micro grid and recompense for any changes or faults for loads in micro grid with some control techniques. However in island state the integration of large number of distributed energy resources (PV, wind turbines etc.) increases instability of the MG system; for this reason to maintain safe operation states for MG it must be make isolation between energy resources and feeders of MG by using (VSI) inverters with different control strategies[18].

2.4 Distributed energy resources (DER)

One of the most advantages of MG that has ability to integration the distributed generations in the medium or low voltage part in the main gird. This integration allows making decentralization of the energy which can lead to significant benefits of higher energy efficiency and enhanced economy [19]. Utilization of distributed energy storages and integration of distributed generations are main concerns for stakeholders involved in the architecture of future grids [20].

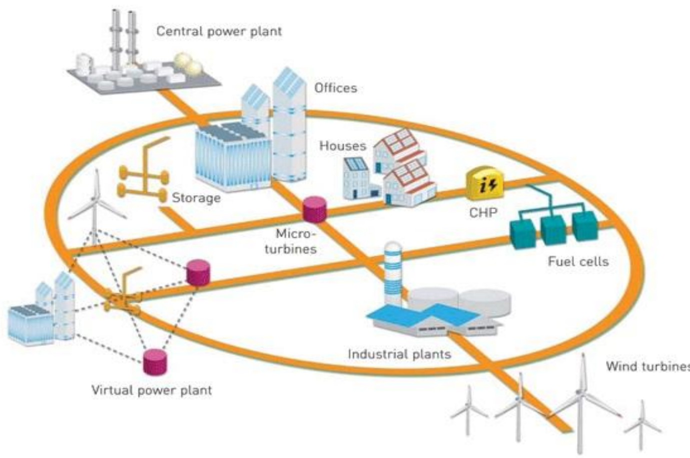


Figure2.4: illustrate connection DER with micro grid [21]

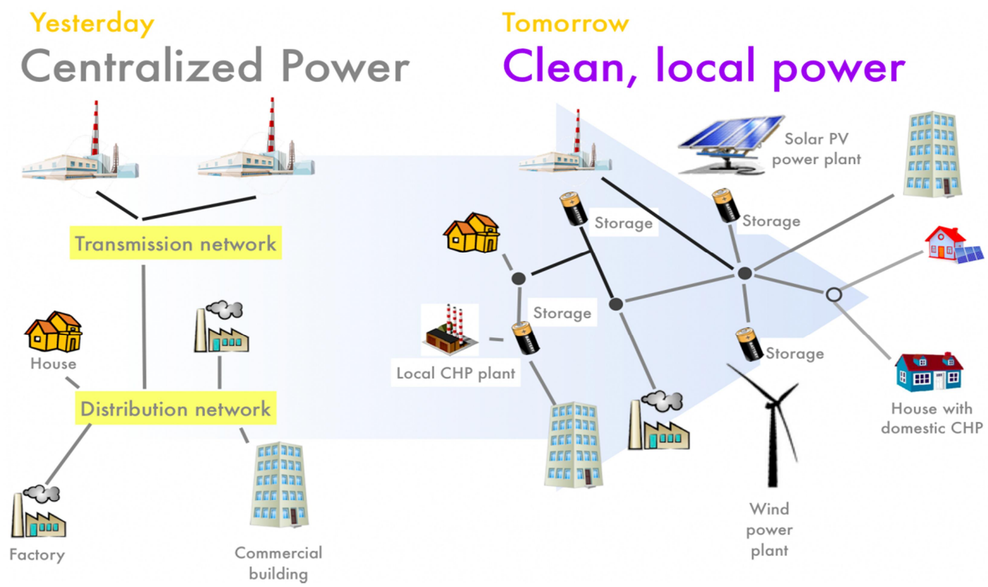


Figure2.5: The comparison between centralized and decentralized grid architecture [22]

As seen in figure 2.3 the electrical network is receiving more deployment of distributed energy resources (DER). To control impacts of (DER) with controllable loads and storage devices on exciting grid, it is suggested to divide them into more manageable smaller units which are called "micrograds". Figure 2.4 illustrate the main benefit from utilizing (DER) that convert the main electrical network from centralized power to decentralized power which are used inside them alternative sources like (wind turbines, PV, fuel cells, etc.). This conversion that occurred on electrical networks develops it to be more reliability and higher efficiency; decentralization technology saving these sets (micrograds) from blackouts and interruptions by using different energy generations and working in some times without main plant station (island mode).

There are many reports and studies of several international magazines and scientific institutes around the world proof that the energy demand will increase scientifically in near next years. The energy report of the International Energy Outlook 2009 (IEO2009) published in May 2009 that the world energy demand will rise from 472 quadrillion Btu in 2006 to 552 quadrillion Btu in 2015 and 678 quadrillion Btu in 2030 [23]. The net electricity generation worldwide totals 18.0 trillion kWh in 2006 while in 2030 the projection electricity generation worldwide totals 31.8 trillion kWh as a reference [24]. However these reports depend their studies on fossil fuels (natural gas, oil, etc.) to generate electricity. That causes global greenhouse gas (GHG) emissions will boost further causing an increase to the surface temperature which will lead to irreversible and possibly tragic changes to the earth's environment [24]. Depending significantly on fossil fuels in future days will be cases increasing CO_2 emissions in the atmosphere. The challenge is to reduce CO_2 emissions especially from industrial areas from 50% to 80% by replacement fossil fuels by distributed alternative resources at the beginning of 2050 [24].

2.4.1 Distributed Energy Resources (DER) definitions

DER has many scientific definitions from several research institutes and magazines around the world. DER refers to the wide range of technologies that provide power to the user outside of the grid, and includes demand-side measures. So DER includes three parts; distributed generation (DG), distributed power (DP) and demand side measurements.

Distributed generation (DG): It's any technology or unit that provides energy outside of utility grid such as (fuel cell, geothermal, wind turbines, biomass, etc.).

Distributed power (DP): It's any unit or technology that provides power or stores power such as (batteries, super capacitors, flywheels, etc.) [25].

Due to several definitions used in literature from many scientific institutes and organizations; DER are defined according to some determinants such as (purpose, location, the rating of distributed generation, the power delivery area, the technology, the environment impact, the mode of operation, the ownership, and the penetration of distribution generation) [26].

2.4.2 The purpose

The ability of distributed energy generation is to provide active power; so the purpose of DG is to generate active power without need to provide reactive power [26].

2.4.3 The location

According to location the authors have different definitions for DERs, some of them define the location of distributed generation as a customer's side, but the most of them define the location of DG as a distribution side of the electric network, but some even include the transmission side of the electrical network [27]. The appropriate definition of DER location is defined as interface the installation of distributed generation units directly with the distribution network or with customer side, so the location will be near the load [26].

2.4.4 Rating of distributed generation

The maximum rating of DG relies on capacity of DG. It seems that the maximum capacity of distributed power stations be in the 100-150MW range. However some authors consider the rating of DG from couple of kilowatts to up to ~300MW. Some authors classify DGs to some categories determine the rate of DG. Micro distributed generation: ~1 Watt < 5kW;

Small distributed generation: ~5 kW < 5 MW;

Medium distributed generation: ~5 MW < 50 MW;

Large distributed generation: ~50 MW < 300MW [27].

2.4.5 Other determinants

Other factors like (power delivery area, the technology, the environment impact, etc.) are not relevant for the proposed definition in literature.

In general DERs are electric power sources connected directly on the customer side of the meter or small-scale power generation sources (typically in the range of 3 kW to 50 MW) located within the electric distribution system at or near the end user. Provide an alternative to the traditional electric power grid. They are parallel to the utility grid or stand-alone generators. DERs have been available for many years, and are known by several names such as generators, back-up generators, or on-site power systems [25]. On the other side IEEE defines distributed generation as the generation or supplying electrical energy by different facilities such as alternative energy sources (PV, fuel cells, wind turbines, etc.) which are smaller than central generating plants [28].

2.5 **Distributed Energy Resources (DER) Technologies.**

DERs essentially consist of energy generation and storage systems as shown in figure 2.5 installed at or near customer side. DERs include a range of technologies like fuel cells, PV, wind turbines, biomass, micro-turbines, load reduction, and other energy management technologies. DERs also encompass power electronic interfaces, as well as control and communication devices for active operation of generating units and various system packages. The main fuel for many distributed energy resources is natural gas; however the hydrogen will be important fuel in the future as well as the alternative sources such as PV, biomass, wind energy, etc.

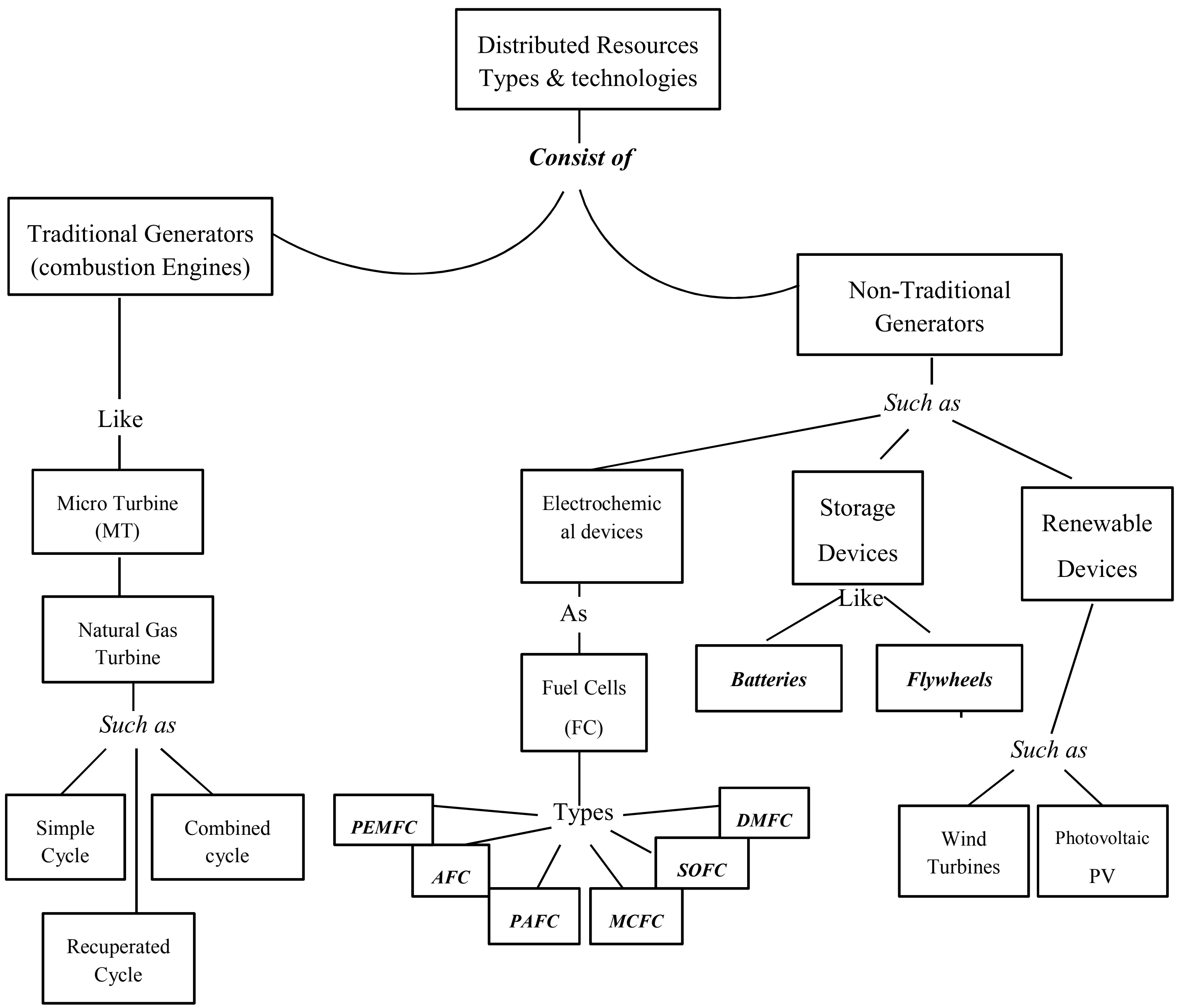


Figure 2.6: Distributed Resources Types & Technologies [29]

2.6 Distributed Generation Technologies

Distributed generation technologies divided into two types traditional generators like micro turbines and non-traditional generators such as renewable devices like (wind energy, PV, etc.) and electromechanical devices like fuel cells.

2.6.1 Micro Turbines

Micro turbine is a small gas turbine and one from the newest alternative energy that available in markets. Micro turbines are the most recent of all technologies and if they correctly used they will give efficient and dependable power. These micro turbines are new combustion type used for stationary generation applications. There is no accurate data recorded about the efficiency of these micro turbines but if the waste heat reserve they can be supply high efficiency levels of power reach to 80%. They have sizes approximately like refrigerator and output from 25 to 500KW. In addition to generate energy micro turbines offer clean and efficient solution to mechanical engine markets such as conditioner and compressor [56, 57]. Essentially micro turbines can be considered as small versions of conventional gas-fuelled generators. A typical commercial 60-kW micro turbine is 0.76 m wide×1.93 m long×2.08 m high. The five manufacturers are Capstone, GE, Ingersoll Rand, Solar-Turbines Incorporated, and United Technologies. The important differences between micro turbines and normal turbines are that they run at much higher speeds and are connected to the grid with a power electronic converter (PEC). The speed of the turbine is mainly in the range of 50,000 – 120,000 rpm .It needs a frequency converter for connection to the grid. Micro turbines like other alternative resources can locate at or near the point of use (at distribution side). They are usually used as a backup source for micro grid when the main grid failure. In some cases can be connected in parallel with local electric grid and used for peak sharing or sold power back to grid. Micro turbines can be used to supply remote rural villages which difficult to connect these remote areas with main utility, also micro turbines can connected in hybrid with other alternative resources such as wind turbines or PV to provide remote rural places. Micro turbines are composed of a compressor, combustor, turbine, alternator, recuperator, and generator. The turbine technology has been developed on a refinement of automotive turbo chargers, commercial airplane on-board generators for ancillary systems and military engines. Micro turbines can also be classified as simple-cycle or recuperated. In a simple-cycle, turbine mixed fuel and air with compressing and burned under constant pressure conditions. Simple-cycle micro turbines have a lower cost, higher reliability, and more heat available for cogeneration applications than recuperated units. Recuperated units have a higher thermal-to-electric ratio than simple-cycle units and can produce 30 to 40% fuel savings from preheating [56, 57]. Using micro turbines has several advantages such as high efficiency, strength in working so that it can work for 11,000 hours of reliable operation, has a fuel flexibility which can be used multiple fuels include diesel, ethanol, landfill gas, and biofuels. In addition to that has a clean emission system so that it can use methanol and natural gas to generate power with near zero emissions. However of all these advantages, micro turbines have some disadvantages such as high initial cost per kW [56, 57].

2.6.2 Fuel cells

A new alternative technology appeared at the middle of 19^{th} century, and increasing attention to develop this technology in the last decades. These disruptive technologies (fuel cells) are developed to offer green energy to compensate energy market needs with reliability, portable, high quality, cheap energy and reducing greenhouse gases. Fuel cells are used to generate electricity for portable particularly transport, small and large-scale stationary and automotive purposes [42, 43]. Many researches have a great attention to create develop of fuel cells which are used in distributed generation systems that are called fuel cell distributed generation systems (FCDG). These fuel cells (FCDG) can be placed at any site of power grid particularly at distribution sites near the user places, so that will reduce the losses result from power lines. In addition to that (FCDG) has many advantages like high efficiency, flexible unit structures and low emissions [42]. A fuel cell is an electrochemical energy conversion device that converts chemical energy of hydrogen and oxygen to DC electrical energy. The principle work of fuel cell belongs to generate electricity from chemistry reaction between hydrogen and oxygen as shown in formula 2.1. The oxygen for a fuel cell can be supplied from air to one of the cells electrodes. However, there is no ready source of hydrogen available today. Most fuel cells use natural gas that they convert to hydrogen in a process known as reforming. This reaction is exothermic produces heat and water [42, 44]. Fuel cell is often consists of two electrodes, a negative anode and a positive cathode These are separated by a solid or liquid electrolyte that carries electrically charged particles between the two electrodes as shown in figure 2.6 [44].

$$2H_2 + O_2 = 2H_2O \tag{2.1}$$

Fuel cells are classified according to the nature of the electrolyte. Each type requires particular materials and fuels and is suitable for different applications. There are six types of fuel cells three of them polymer electrolyte membrane fuel cells (PEMFC), solid oxide fuel cells (SOFC), and molten carbonate fuel cells (MCFC) are most likely be used for distributed generation (DG) applications. The other three types Direct melhanol-air fuel cell (DMAFC), Alkaline fuel cells (AFC) and Phosphoric acid fuel cell (PAFC) are mostly uses in transportation sector [42].

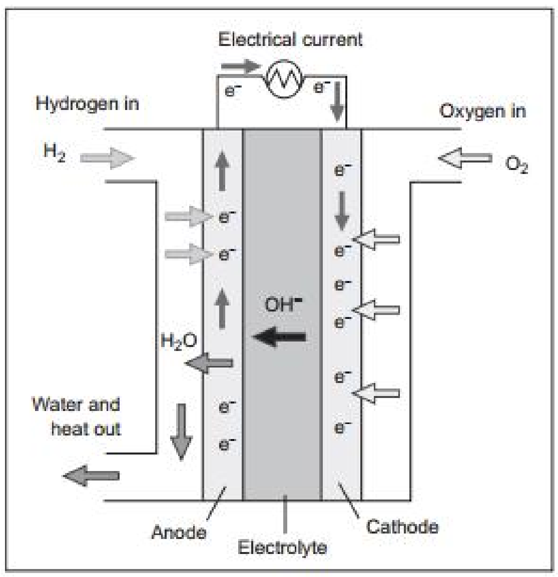


Figure2.7: basic structure of fuel cell

2.6.3 Photovoltaic cells (PV)

A PV cell is electrical device convert sunlight to DC electricity through an electronic process that occurs in certain types of material called semiconductors. The solar energy release electrons in these materials and let them travel through an electrical circuit, powering electrical devices or sending electricity to the grid. PV cell was first appeared in 1839 with high cost. Today the world has more attention to this alternative technology to decrease demand on fossil fuels, supplying remote villages which are difficult to connect them with main utility and alleviate green gases. Photovoltaic systems are used today in many applications such as battery charging, calculators, water pumping, home power supply, satellite power systems, microgrid and so forth. Although PV cells have the advantage of providing clean source of energy, their installation cost are high and still have relatively low efficiency [45]. A typical PV cell generates approximately 0.5 V and a current that very much depends on the intensity of the sunlight and the area of the cell. To get more usable values of voltage and current, PV cells are connected in series creating a collective voltage, and the series of cells are connected in parallel to yield a higher current. All cells are packaged together with a pellucid cover (usually glass) and a watertight seal to compose a module, these modules are wired together in a series–parallel combination to form a panel that best meets the needs of the application. Modules can be interconnected to create an array with the desired peak DC voltage and loading current capacity. An array is a group of panels that have been linked mechanically and electrically, as shown in figure 2.7[45, 47].

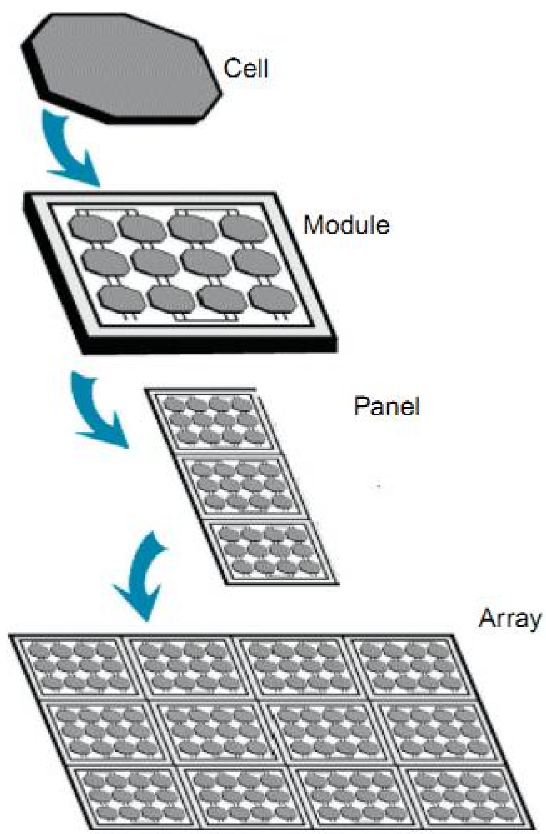


Figure2.8: Photovoltaic array designation [45]

The equivalent circuit that can describe the behavior of the solar cell can be shown in the figure 2.8. The equivalent circuit of a solar cell consists of the current source, IL, which is a function of the irradiance, or light intensity. Diode, shunt resistance, Rsh, series resistance, Rs, Photo generated current, IL, Ideal diode current, Id. PV systems can be classified according to some external factors such as moving clouds. PV systems can be divided to two types: grid connected systems are used in residential and industrial systems and standalone systems. There are two types of standalone systems depending on the load: power needs primarily lighting, communication, entertainment, and resistive loads [45].

- Stand-alone PV system with DC loads; with battery storage.
- Stand-alone PV system with AC loads; with battery storage.

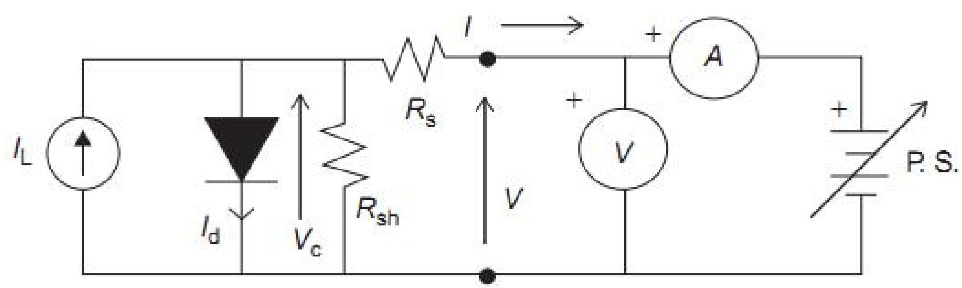


Figure2.9: Equivalent circuit of solar cell [45]

PV systems vary according to their output power so they can be very small (less than5 W), small (5 W–1 kW), Kilowatt size (1 kWto a few 10s of kW), and intermediate size (10kW–100 kW), or a large-scale system (1 mW or larger) which is connected to a utility grid for commercial or utility power generation [45, 46]. Today PV cells can be made from three main different technologies determined by the materials that are used to manufacture them. The first one is Crystalline silicon Made from thin slices cut from a single crystal of silicon (monocrystalline) or from a block of silicon crystals (polycrystalline), with an efficiency ranging between 16% and 19%. The second is Thin Film Made by depositing extremely thin layers of photosensitive materials onto a low-cost backing such as glass, stainless steel or plastic. Lower production costs counterbalance this technology’s lower efficiency rates (from 10% to 15% average) [47, 48]. The third are multi junction cells are being developed today including concentrated photovoltaics. Consist of multiple thin films, are originally developed for special applications such as satellites [46, 47].

2.6.4 Wind Turbines

Wind turbine is a machine which converts the kinetic energy of the wind into electrical power. So wind turbines used to convert wind power to mechanical power generating electricity. Wind turbines usually connecting with each other to form wind farm feeding main grid. The largest size single turbines can have an output of around 5-6 MW [49]. The equation for wind power is $P_w = \frac{1}{2}mv^2 = \frac{1}{2}\rho AV^2$ (2.1)

Where:

- m = mass = density × volume
- v = velocity of the wind
- P_w = wind power
- ρ = power density
- A= area that air is passing from it.

The equation 2.1 can be written by terms of wind velocity v and energy conversion efficiency μ, as shown: $E = \frac{1}{2}\mu mv^2$ (2.2)

The energy extracted by the turbine is given by the kinetic energy of the air flowing into the turbine blades minus the kinetic energy of the wind flowing out of the turbine blades minus any frictional energy lost in the moving parts of the turbine and the generator:

$$E = \frac{1}{2}mv_{in}^2 - \frac{1}{2}mv_{out}^2 - frictional\ losses \tag{2.3}$$

If there are no any frictional losses the efficiency of wind turbine will not be more than 59.3% of the total kinetic energy of the air flowing through the turbine [50, 51]. Turbines can be divided into three main components as shown in figure 2.9:

- The structural support component: All machines need a supporting tower to raise themselves up into the free wind stream. The structure is approximately 15% of the wind turbine cost. Includes the tower and rotor yaw mechanism.
- The generator component: that is approximately 34% of the wind turbine cost, includes the electrical generator, the control electronics like a gearbox component for converting the low speed incoming rotation to high speed rotation suitable for generating electricity.
- The rotor component, which is approximately 20% of the wind turbine cost, the rotor is the heart of the wind machine because it is the component includes the

blades and gathers the wind to converts the kinetic energy of the wind into mechanical power that can be used to generate electricity. Also, the shape and location of the rotor defines the kind of device and how it works [53].

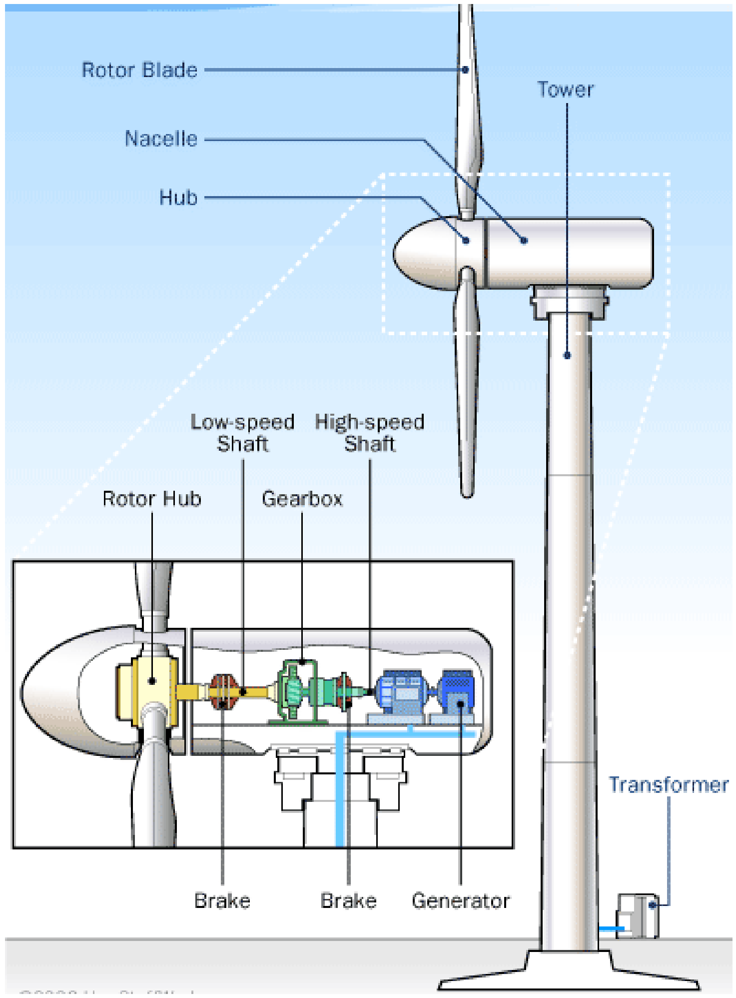


Figure2. 10: Components of wind turbine [52]

Wind turbines can be classified into two types: Horizontal-axis wind turbines (HAWT); have the main rotor axis and electrical generator at the top of a turret, and pointed into the wind as shown in figure 2.10. And Vertical-axis wind turbines (VAWTs); have the main rotor axis arranged vertically. Main advantage of this arranging is that the turbine does not need to be pointed into the wind to be efficient, which is an advantage on a location where the wind direction is highly changing [49]. Using wind turbines have some environmental impacts; they create noise and visual pollution, so the people live beside them suffer from shadow flicker and eyesore. Also people complain that wind farms destroy view shed and cause immigration of birds and bits [50].

2.6.5 Biomass energy

Biomass includes all living species or recently living organisms such as plants, forests, animal wastes, and some industrial wastes and by-products. Biomass energy is a process that derives fuel from biomass materials. It is old energy on the earth and may become one of the most significant energy resources in the future. One of the most significant biomass types is Cellulosic biomass that derives bioethanol from starch then it can be used as a biofuel for transportation and power plant [54, 55]. Biomass resources can be classified into three categories: the first organic waste such as livestock excrement and food residues. The second unused biomass includes inedible parts of agricultural products. And the third resource crops such as corn and rice which can be used to produce bioethanol and biodiesel. The end products that are derived from biomass can be divided to six types: (1) materials such as plastics, (2) thermal energy, (3) electric energy, (4) fuel, (5) fertilizers and feed, (6) raw materials of chemical products such as amino acids. Using biofuels which are extracted from biomass instead of fossil fuels in transportation and power generation reduces carbon oxide in the atmosphere which is helping to attenuate global warming [56]. There are three types for biomass conversion process; the first process by high temperature heat which is called thermal conversion. This mechanism is used to convert biomass to another chemical form. The second mechanism is the thermochemical process uses combustion and chemical process to convert biomass to gaseous fuel or produces a liquid fuel. The third is a biochemical route in this case; the fermentation process can produce biogas, alcohol, and hydrogen generation. Also, the photosynthesis process conducted by some phototrophic organisms can finally generate hydrogen [54]. Using technology of biomass energy has many advantages: Reduce the carbon oxide in the atmosphere by achieving the balance between emission and absorption of carbon oxide by photosynthesis process of plants. Also it is easy to use; it is available almost anywhere on earth. A diversity of biomass can be converted into different products in the form of solid, liquid, gas, and power. Biomass has able to transportable and storage among several renewable energy sources so that its production can be adjusted to accommodate changes in output demand. Its use is not limited to energy; fuel is only one option among the many other potential uses. Biomass has been used for multiple purposes: food, animal feed, fertilizer, fiber, fuel, medicines, and materials for various crafts and buildings. Waste biomass that has been viewed as detrimental to environment can be used to extract energy [54, 55]. In despite of these advantages of biomass, it also has some disadvantages. Biomass gives low energy intensity than fossil fuels. It has less efficient than fossil fuels in conversion to liquid fuels. The resources of biomass usually distributed in small amount across extensive areas. One of the modern applications of using biomass energy appearing recently in Turkey is botobus (buses uses biomass energy instead of diesel) which is designed and manufactured by Istanbul municipality (IETT). The idea of these buses depends on biodiesel that is derived from plants by some chemical process. These buses are new eco-friendly public transport option that features an organic rooftop as a garden. The project aims to reduce carbon oxide from the atmosphere in the city and mitigate global warming. Furthermore the existence of plants at rooftop of buses decreases the temperature degree inside the buses, so that will save the energy used by air conditioner.

2.7 **Energy storage devices**

It is a technology that believed to be used extremely in the future. Because energy storage able to store energy during peak hours. By doing this the grid can be designed for less than peak power. There are a few ways to store energy. There are a variety of storage devices such as batteries, super-capacitors, super-inductors, flywheels, and water pumping [58]. These devices vary in their characteristics; method of operation, and accordingly, the tasks that they can perform. It is difficult to store AC current. And it is easy to store DC currents. Energy storage devices can have important roles in DG systems, such as enabling fast load pick-up, confirming the reliability, and enhancing the generation profile in non-dispatchable sources [60]. In battery storage the energy is stored chemically in batteries. Kinetic energy can be stored in flywheels and potential energy in pressured air. Energy storage generators are connected with the utility or load via a power electronic converter; generally a voltage source inverter [59].

2.7.1 Batteries

The batteries are the traditional storage energy systems so that there is considerable attention to develop battery systems. Batteries have a feature that able to store high energy. Batteries come in all sizes and shapes to fit a diversity of applications. Portable devices are based on lithium, cadmium, nickel, silver and zinc chemistries providing high power densities, but are very expensive. Lead- acid batteries are the new technology that is suitable for utility applications, because of the good balance between high density of energy storage and their cost [60]. Lead-acid batteries are available in almost any size and are already used in many applications that require back-up power, such as UPS systems. Lead-acid batteries are 80 to 85% efficient. New technology improvements have raised the energy storage density and have extended the battery lifetimes. The design of the battery and chemical reactions that used for energy storage is determined by discharge rates. Batteries store energy in chemical form and are charged and discharged by means of a DC current. Figure 2.10 make a comparison between some types of batteries and ultra-capacitor which we will explain it in the next section [58]. It's clear from the figure that batteries have high energy density with low power density; that means batteries have ability to store high energy with low charging and discharging when they compare with ultra-capacitors.

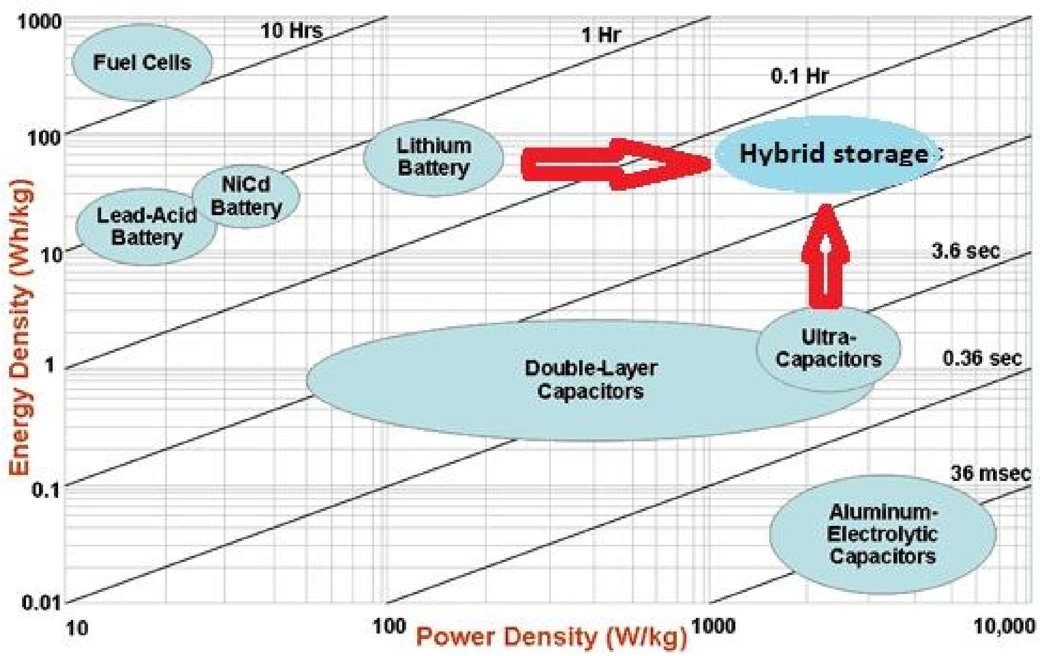


Figure2.11: Comparison between batteries types and ultra-capacitor [61]

2.7.2 Ultra-capacitors (Super-capacitors)

A capacitor is an electronic device that stores energy in the electric field created between a pair of conductors that have equal and opposite charges. Energy can flow quickly in and out of capacitors with extremely high efficiency. Super-capacitors Like traditional capacitors, they are composed of two electrodes with a very thin separator. Super-capacitors are very-high-capacity electrolytic devices that store energy in the form of electrostatic charge [58]. Their technology is not yet mature so it is very rare to find them in current applications but its new storage technology famous in new transportation (buses and trains), hybrid systems and new microgrids. Energy storage capability is proportional to the surface area of the electrodes. The system uses power electronics to charge and discharge the DC field in the super-capacitor where the energy is stored. Because super-capacitors can have very high discharge rates so they use to handle fast load changes in a microgrid, although they don't provide large storage capability like a battery system [58, 59]. The performance characteristic of a super-capacitor is similar to the flywheel that have low energy density with high power density as we will see in the next section, but these devices have the advantage of containing no moving parts. Figure 2-11 [62] shows comparisons between ultra-capacitors and batteries versus their energy density and power density. There are some famous manufacturing companies that produce super-capacitors such as Epcos, Maxwell Technologies, TJTechnologies, and Zeon Chemicals.

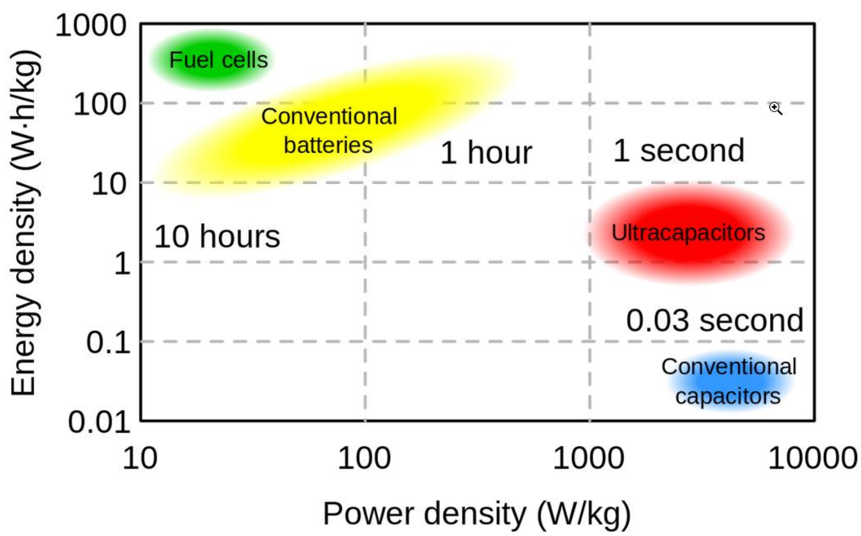


Figure2. 12: comparison between ultra-capacitors, batteries, and fuel cells of energy stored

2.7.3 Flywheels

Flywheel technology is usually used to support grid with power when there is failure in the main utility and electricity is shut down to when the backup generators get up to speed. A flywheel is a heavy metal wheel attached to a drive shaft, having most of its weight concentrated at the circumference, The wheel resists changes in speed and helps steady the alternation of the shaft where a power source, such as a piston engine. The defining property of a flywheel is the spinning of a body on an axis. The basic components of flywheel are rotor (desk), evacuated chamber, Bearings, and transmission system [58, 60]. A unit on the market today consists of two 600 pound steel flywheels rotating at 7000rpm in a vertical axis configuration and operating in vacuum to ensure low noise emissions. They are provided with an integrated motor-generator coupled with power electronics to convert the variable frequency of the power created by the flywheel to a steady DC output. This system can provide up to 250kW for 15 seconds. Flywheels applications in UPS systems are usually used in conjunction with batteries: the flywheel picks up the transient requests, while the battery takes care of the longer time request. This setup increases the lifespan of the batteries that is degraded when they are required to repeatedly respond to short term dips in the power supply. Flywheels like super-capacitors have a high power density with low energy storing. There are some of famous manufacturer companies of flywheel such as Active Power, AFS Trinity Power Corp., Beacon Power, Pentadyne, and Precise Power.

2.8 Micro-Grid Operation Mode

2.8.1 Grid connected mode

Energy management of micro grid has been operated by energy storage systems and control of energy flows in both operation modes; its means with connected and without connected to utility grid. In this case the micro grid must be able to operate importing and exporting from and to the main grid to manage active and reactive power flows and energy storage. In case of grid connected mode because the main grid is connected with micro grid so it is effect on dynamic system of micro grid and has a large range because of small size of DG units. Another problem of this mode is the slow response of control signals when occur changes in power output. It must be vertical inertias prepared with loop control of the power electronics interfaces because the lack of the synchronous machines connected with low voltage grid. Moreover the power balancing process in transient response is supported by power storage devices such as super capacitors, batteries, or flywheels. After blackout (connected with main grid) the micro grid start progressively interfaces loads and DG and imposes itself the frequency and amplitude conditions. Then all DG generate a specified power to reduce importing power from the main grid [3].

2.8.2 Islanded mode

Micro grid can operate without connected with utility grid by open the intelligent bypass switch between it and main grid, then micro grid operates as a separated area with own DG units that regulate frequency and amplitude voltage of micro grid. Micro grid can operate in this status in the following two cases;

- **Preplanned islanded operation:** when the main grid has some abnormal events such as long time voltage drops, faults and errors, islanded operation mode must be started.
- **Nonplanned islanded operation:** when happen blackouts due to disconnect with utility grid then micro grid must detect this event by suitable algorithms.

In islanded mode (autonomous mode) it can be noticed that frequency and amplitude of micro grid has deviations from the nominal frequency and amplitude of the main grid due to inject different types of DG units to micro grid which make proportionally these deviations. So in autonomous mode DG units are responsible for nominal voltage and stability of frequency in micro grid. When operating participation of power by DG units inside micro grid it’s important to avoid overloading on inverters and make suitable control to ensure changes of loads. Some of these control techniques based on communication links as master slave scheme and be more economic and more reliable when it connected through a low bandwidth system. The micro grid must satisfy the following issues in autonomous mode operation:

- **Voltage and frequency management:** The system operates as a voltage source and controls the power flow through adjusting frequency and voltage by voltage loops.
- **Supply and demand balancing:** In grid–connected mode the frequency is fixed by main grid but in islanded mode it can be obtained the change in power angle between main grid and micro grid.

Power quality: can be achieved by two levels, the first is reactive power compensation inside the micro grid; the second is the harmonic compensation at PCC.

2.8.3 Transition between Grid-Connected and Islanded Mode

Intelligent bypass switch (IBS) is responsible for disconnecting the micro grid from the main grid and converting the operation of micro grid from grid connected mode to islanded mode as shown in figure 2.3, when the power supply or power station shut down or when some faults and errors occur in the main grid IBS is opened and the micro grid is disconnected from the utility grid and the restoration process be reduced to ensure a high reliability level. The amplitude of voltage and frequency can be measured inside the micro grid, and operation points (Pand Q) avoid the frequency deviation and amplitude of the droop method. When the micro grid is in islanded mode, and IBS detects utility grid fault-free stability, synchronization among voltage, amplitude, phase, and frequency must be obtained for connecting operation [3].

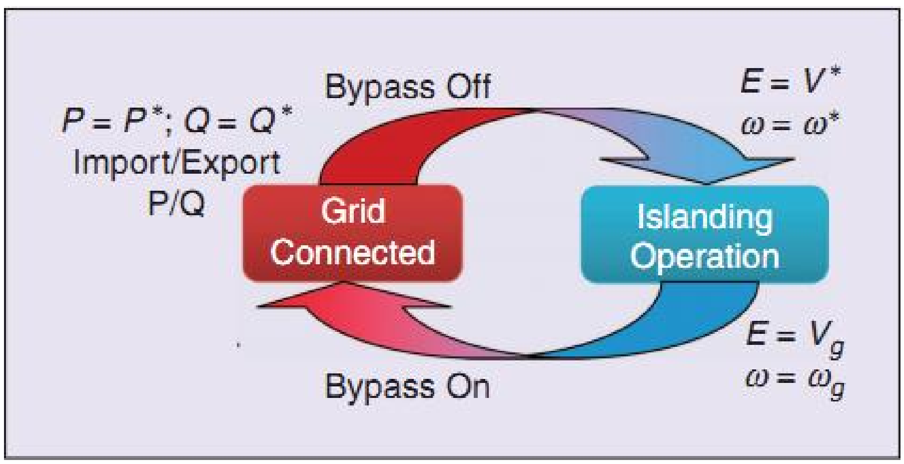


Figure2.13: Operation modes and transfer between the two operation modes by IBS [3]

2.9 **Inverter Topology**

Inverters are electrical devices convert direct voltage or current to alternating voltage or currents. So to generate sinusoidal ac waveforms from dc power supplies must be used inverters with making a controller for magnitude, frequency and phase to get pure sinusoidal waveforms. The aim is to create a clean and reliable AC voltage where only a DC source is available. Inverters are used in many applications such as adjustable speed drives (ASDs), uninterruptible power supplies (UPSs), computers, emergency equipment, telecommunications, industrial processing, online management systems static var compensators, active filters, flexible ac transmission systems (FACTSs), and voltage compensators. Ac output waveforms determine the type of inverters; so if ac output is a voltage waveform then this inverter will be considered as voltage-source inverters VSI. These structures are the most widely used because they naturally behave as voltage sources as required by many industrial applications. If ac output is a current waveform then the inverter will be considered as current-source inverters (CSIs). These types are mostly used in medium-voltage industrial applications [63, 64]. Inverters can be classified to stand alone and grid connected inverters. Both types have several similarities but are different in terms of control functions. A stand-alone inverter is used in off-grid applications with battery storage. The inverters have additional control functions such as operating in parallel with diesel generators and bi-directional operation (battery charging and inverting). Grid influenced inverters must follow the voltage and frequency characteristics of the grid generated power presented on the distribution line. For both types of inverters, the conversion efficiency is a very important estimation [65]. Inverter consist as shown in figure 2.14 of DC power part connected with capacitor with approximately value 2000 µF. the capacitor connected with six IJBT transistors or MOSFET structure to compose three legs for three phase transistor. IJBT structure interfaced with LCL filter or LC filters. To get a single phase inverter, it can be used one leg or two legs. These IJBTs works like gates by powering them with PWM, it can be generated pure output sin wave signal. The values of voltage and currents are calculated by sensors which send these values to controller make a modifying of them and then send these modified values to PWM to get more pure sin-wave signals [63]. Inverters can be classified to four topologies as shown in figure 2.15. in the first structure in figure 2.15 if we have DC source as a PV source or battery with 30V value and it is needed to get 300V AC, the first structure consists of two parts the first part boost DC converter make step up of the DC value then this value be converted by inverter to AC value which connected with DC boost converter in series. In the second structure which is commercial part and mostly used in applications consists of inverter that convert DC source to AC then this small AC values are stepped up by transformer that connected with inverter in series connection. In the third structure the first part make inverting and step up. So if there is a PV source interfaced with it at first inverting DC to AC then step up AC value by transformer and rectifier it to DC value. After that inverter convert this value to AC. The last structure imposes that inverter connect with many PV modules that give high DC values, so the inverter then just convert these values to AC [64, 65].

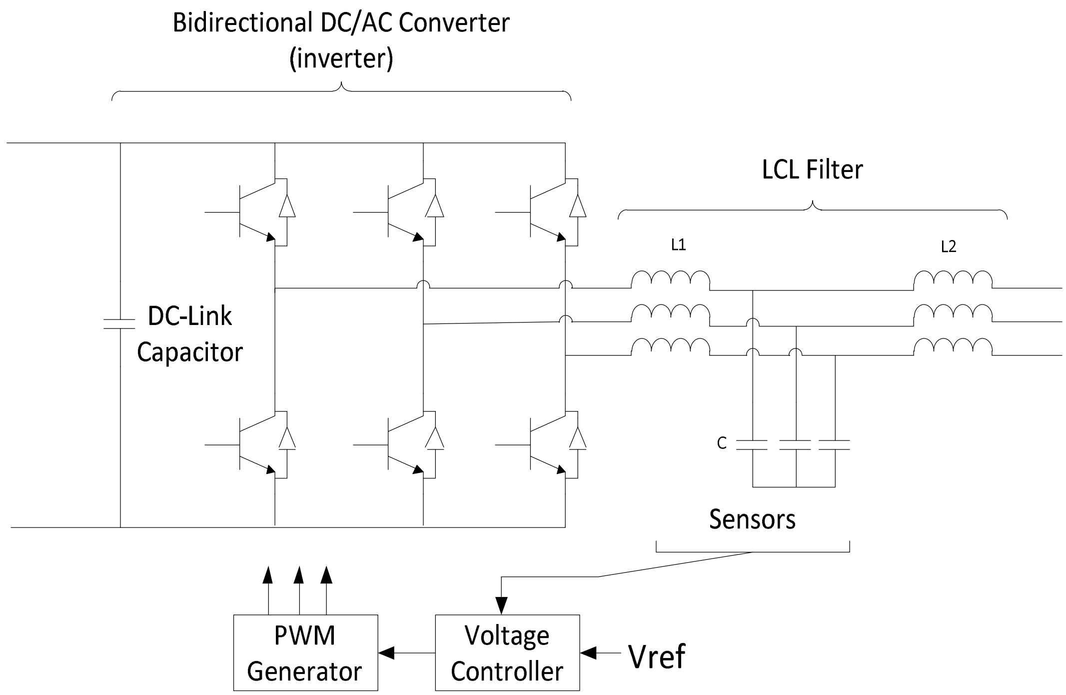


Figure2.14: Three phase inverter structure

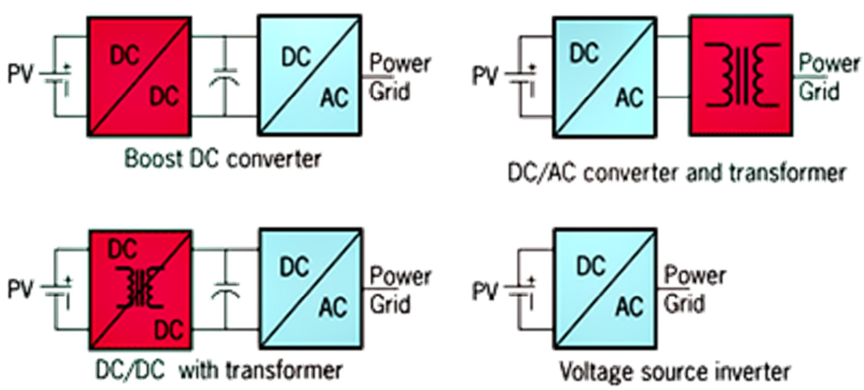


Figure2.15: Topologies of inverter

In many research and papers boost DC converter is used because it has many advantages such as high efficiency, economic, and achieves high voltage conversion ratio with low duty ratio. DC/AC converter with transformer has many disadvantages and not be advised to use in power systems because it is not economic, low efficiency, and it must be use a huge transformer to get required AC voltage. DC/DC topology uses high frequency transformer and has a good efficiency but lower than boost converter.

However voltage source inverter has a high efficiency to transform from DC to AC but it be used with many PV panels to get high DC voltage.

2.10 **Issues of micro grid**

There are several issues and technical problems which are caused by microgrid during its operation and control. Microgrid sometimes passes through cases of power shortage causing power interruption, in this case microgrid shifts to autonomous mode of operation. So there are some features and issues must be available in MG to operate efficiently. MG must be switched to suitable mode of operation either grid connected or island mode and ability to synchronize safely with main utility. Also MG must provide voltage and frequency protection during island operation and ability to resynchronize safely interfaced with main grid. In addition to that MG must ensure stable operation during faults and various network disturbances. Furthermore there are issues like power quality, voltage and frequency control, power flow balancing, load sharing during islanding, protection, stability, integration of small scale renewable energy generation, and grid synchronization must be considered and achieved during MG operation [66, 67].

2.10.1 Islanding detection

One of the critical aspects of microgrid operation is the detection of islanding conditions. The disconnection of the main source is called islanding. Microgrid must be operating efficiently in grid connected with utility and in island mode. Some technical problems can be occurred during operating MG with utility like power shortage or burning in some transformers that connected the MG; in these cases according to IEEE 1547–2003 standard the maximum delay should be cutoff MG from the main grid is 2 seconds. Because if MG is continuing connected with utility and assuming that local load can be need high power more than the ability of inverter then this inverter will be burn. Or assuming that local load will be smaller than the ability of inverter in this case the electrical lines which don't have electricity will have electricity and this zone will be dangerous to maintenance workers [68]. The islanding can be can be either intentional or unintentional. In the case of intentional islanding make a structure "island" during system disturbances because of the errors. However, in zones where island mode operation the active part of the distribution system should sense the disconnection from the main utility and cut off the power on the distributed generators. Undetected island MG is usually called "unintentional islanding" in this case undetected or occurrence delaying on detection of MG to cut off it from main grid more than 2 seconds may lead to many problems of power quality, safety, voltage and frequency stability, and interference [68-71, 72]. Today there are many researches on unintentional islanding detection to ensure that the system is operated under the standard requirements. Also in some different researches islanding detection can be classified to planned and unplanned islanding. Planned islanding is defined as microgrids still supply electric power to local load reliably when they are disconnected from main grid. This status is called controllable operation. Unplanned islanding is an undesired event due to line tripping, equipment failure, and human errors, with microgrids disconnected from the utility. And this situation is uncontrollable operation mode [72, 73]. Islanding detection can be applied by various techniques and methods and can be classified to central (remote) methods and local methods. Remote methods are based on the communication between microgrid and main grid to monitor breakers immediately, Signal Produced by Disconnect, and Supervisory Control and Data Acquisition. Remote methods are very effective in huge systems composed from multiple-inverter systems, and don't use for small systems because they need large amount of investment. Local methods are based on measurement of some parameters or variables on the microgrid side. Local method is divided to passive methods and active methods. Passive method monitors parameters or variables and includes Voltage and current harmonics detection, Over/under voltage and over/under frequency, Rate of change of frequency, Rate of change of power output, and Phase jump detection. However active method injects a disturbance to detect whether it affects voltage, frequency, power or impedance parameters, and includes some functions such as detection of impedance at specific frequency, impedance measurement, negative-sequence current injection, and variation of active and reactive power [68-70, 73].

2.10.2 Protection

The microgrid is formed the protection of the system which is the major attention particularly in islanded mode of operation. However Protection system in microgrids is required to operate in both interconnection and isolated operating modes. Whereas the distributed generation (DG) is the biggest changes to the distribution system by integrate renewable energy sources into the distribution system, traditional protection schemes used need to be re-evaluated with the integration of DG associated with customer loads. The interconnection protection varies widely depending on factors such as: generator size, point of interconnection to the utility system (distribution or sub-transmission), type of generator (DC, synchronous, asynchronous) and interconnection transformer configuration [67, 74]. Newer DG systems are using electronic power converters (inverters) which results in particular consideration for DG protection. The influence of DG on present systems must be tested through detailed simulations and protection studies. In case of fault on the main grid's side during the interconnecting operating mode, it is required to isolate the microgrid from the grid as fast as possible to protect the microgrid loads. And in case of error inside the microgrid it is required to isolate the faulted part of the system [74].The protection systems of microgrids are based on short circuit. That is meaning microgrid protection systems are used usually protective devices. Among them are the fuses, circuit-breakers and over-current definite devices. The distribution protection is a short circuit current sensing based [75].The protection system must clearly determine the boundary between abnormal and normal operating modes of the utility grid. A suitable circuit-breaker must be installed at the point of common coupling (PCC). The speed of isolation is dependent on the specific properties of the microgrid's loads. There are some kind of Micro-sources which are based on power electronic devices cannot supply the required scale of short circuit current. Some power electronic devices cannot response to high level of overcurrent. In these situations the microgrid should be disconnected from the main grid during the time less than 50 milliseconds after an abnormal mode in the network is started. Protection system can't achieve high speed operation with usual circuit breakers; in this case the microgrid design requires new approaches in relaying design. For the protection of the microgrids generally differential protection system or zero sequence voltage relays are used or a very fast disconnecting transfer trip system must be installed between the circuit-breaker and the main grid [74, 75]. High amplitude currents are appeared because very high speed disconnection operations are achieved. Due to this, suitable grounding of microgrids must be supplied. Furthermore the protection system that operates with the microgrid in the island mode must determine the error currents from the maximum load currents when the microgrid operates in the grid-connected mode, because these currents can also be very high [75]. When there is a fault inside the microgrid during grid connected mode, the protection system must operate to isolate the smallest area that contains the faulted part to eliminate this section from the grid [75].

2.10.3 Active and reactive power sharing

Today there is a big attention to high quality and uninterruptable power systems (UPS). Critical and sensitive loads are widely used specially in the industrial sectors. Therefore it is important to supply these loads continuously with power. These applications need high quality and continuously power so that UPS is mostly used in these applications such as health equipment, data acquisition and processing systems and telecommunication services [76-78]. So there is increasing in needs and demands on using UPS. However the capacity of UPS has can be increased to limit capacity. Whenever users increasing the load with be increased, so the grid with be bigger. High electrical grid requires high power UPS and these UPS always have high costs. In addition to that any fault occurs in this UPS unit will effect to the whole system. To solve these problems it must be used small parallel UPS units instead of the big one to be more efficiently [78, 79]. In addition to that these small units provide the system with high power capacity so grid will be more reliable. Because when fault occurs in one unit, it will not prevent the other units providing power to the grid. These units (UPS or inverters) can be controlled and there are various methods to control these units. The idea to make these controllers depends on sharing active and reactive power on loads proportionally with the capacities of inverters or UPS [78, 80]. There are several types of controller and classified to two main types. The first type depend on communication lines and includes concentrated control method, master slave method, and distributed logic control method. The concentrated control is performed by independent inverter sends a synchronization signals to the other inverter units then each unit computes its own output error and modifies its own variables to correct this error. Master-slave control method; one of the inverters be a master and the others will be work as slave, so the master inverter control of voltage whereas slave units will be control of current. Distributed logic control; the controller generates signals by collecting voltage and current information from the units and send them to UPS unit to obtain synchronization and current control [78, 81-82]. The biggest problem of these methods is the requirement of a communication line between the units. Noise related problems on the communication lines cause unreliable operation and generate constraints on the locations of the units [83]. To overcome communication problems, data transfer through power line at a different frequency is suggested for the systems that do not have a communication-line between the units. Droop control method is used. Each controller uses only the output information of the unit which is designated to control. Active power sharing depends on the frequency of the system and the calculated output frequency. Whereas the reactive power sharing is performed by using the voltage of the system [83].

2.11 Micro grid applications in the world

The significance of MG lies in its ability to intelligently manage and control the main grid with integration distributed energy resources such as (wind turbines, PVs, etc.) with utility. Also using MG is enabled to supply remote villages with electricity by connected them with small distributed energy resources. In addition to that the utilizing MG leads to easily solve the electricity problems, remote controlling and monitoring the main utility, and discover the faults and solve them automatically. MG depends on integration distributed energy resources with the grid and this leads to decrease the green houses gases by reducing use the fossil fuels. All of these factors promoted scientists and researchers to integrate and develop MG with the main gird. So today we can find many applications of microgrid around the world for instance we have a practical example of MG in Turkey at Yildiz Technical University. The project which has produced by YTB can be classified below Customer Systems (CS). The project is Development of a Smart Grid-Compatible Smart Home Prototype with the aims of Improving Energy Efficiency and Lowering Carbon Emission. The budget of the project is over 0.5 million dollar. The project is a smart home firstly will be applied in the campus of the university then will be available in many aspects to apply them in Turkey. The purpose of the project is to reduce dependence on natural gas to generate electricity and generate it from alternative energy sources. This project generates electricity by using hybrid system consists of PV cells and wind turbine. Also there are batteries for store energy. Furthermore uses new communication technologies to provide communication of the appliances in the house. Finally, the data required by end user such as daily and weekly consumption values of each appliance will be provided online with a user. The system will lower the energy consumption by controlling the appliances without tumbling the rest level. This system will achieve high efficiency in the house and easily to use. Beside this project there are many other projects around the world such as Acea Distribuzione smart metering in Rome in Italy and Energie AG in Austria [84].

CHAPTER 3

CONTROL STRATEGEGIES IN PARALLEL OPERATION OF INVERTERS

3.1 Introduction

Today fossil fuels are the essential factor in generation electricity. Attention to integrate distribution energy resources in main grid to mitigate depending on fossil fuels leads to great interest on developing recent grids. Due to increasing green gases at the atmosphere from burning fossil fuels, friendly alternative energy generation systems such as (fuel cells, biomass power plants, wind turbines, photovoltaic solar systems, and hydro power turbines) have been developed to interface with the grid or smart grid and also will be part of future power generation systems [1]. So there are many control and operation strategies have been developed to interface these distributed generation sources into the grid or microgrid in order to maintain the power quality of the distribution system. The control strategies manage active and reactive power of the power electronics (inverters) that connected distributed generation systems with the microgird. In addition to that control techniques manage the power of storage devices and uninterruptable power systems (UPS). So the main grid has been decentralized by many and small generators and storage devices. The decentralized system composed of small parallel electrical devices instead of whole power plant for more efficiency and avoiding interruptions with grid when faults occur [5]. So that's mean the microgrid concept is required to achieve an autonomous control and a continuous operating of the systems even in case of loss of any components or generators and to supply unhindered connection of the additional micro-sources. A microgrid should be open so that new device can be connected to the grid. Anyone should be able to connect his own generating, load units or additional subsystems. In other words, it should operate and changed automatically without support from engineers. It is called that the system possesses "plug and play" properties [86]. The inverter is considered a fundamental component at the microgrid side of such systems due to the wide range of functions it has to perform. It has to convert the DC power to sinusoidal current to supply the grid. It also has to handle the variations in the electricity due to altering levels of generation by the distributed generation systems, loads and grid voltages [85]. So the inverter appears to be the main universal unit building block of future smart grids especially at low and medium voltage. Each unit of the grid supplies a group of functions under managing from the power electronic control devices. These control systems should be able to manage the power flow on the feeders, regulate the voltage at each micro-source and ensure that each micro-source increases or decreases immediately its generating power according to the requirements of the microgrid when the systems transforms to island [86]. .

3.2 Principle of parallel operation of inverter

Power system can be in stable status when there is a balance between generated and consumed active and reactive power. So make a control system for P and Q is very important to maintain distribution system in stable status. The real (P1) and reactive (Q1) power transferred from the inverter to the common bus or grid can be calculated as described in the following equations [87].

$$P_1 = \left[\left(\frac{E_1 V_g \cos\emptyset_1}{Z_{g,1}} - \frac{V_g^2}{Z_{g,1}}\right)\cos\theta_{g,1} + \frac{E_1 V_g}{Z_{g,1}} sin\emptyset_1 sin\theta_{g,1}\right] \tag{3.1}$$

$$Q_1 = \left[\left(\frac{E_1 V_g \cos\emptyset_1}{Z_{g,1}} - \frac{V_g^2}{Z_{g,1}}\right)\sin\theta_{g,1} + \frac{E_1 V_g}{Z_{g,1}} sin\emptyset_1 cos\theta_{g,1}\right] \tag{3.2}$$

E1: inverter output voltage.

Vg: grid voltage.

Vg and E should have the same amplitude with a phase angle difference for real power. Reactive power circulation can be result from different amplitude of voltage with the same phase. However real and reactive power flow can be resulted When both of the magnitude and phase angle differ between the two voltage sources. So to control real power flow, it must be making a control of frequency which controls the power angel. output impedance of the inverter must be small also $\emptyset_1$ (the phase angel between output inverter and grid voltage) must be very small to maintain good real power flow, and any small change in $\emptyset_1$ will result a very large imbalance in the active power flow [88]. In the parallel operation the output voltage of all inverters must be maintained accurately in phase to guarantee equality of the output active power for the corresponding inverters [5]. if inverter output voltage magnitudes differ from each other this status will result overload over inverters and this condition is undesired. There are two ways to prevent dc link over-voltage and circulating current. The first by using isolation transformer and this method is called passive control measure. But in high power systems the size of transformers are so big and this is a problem. To solve this problem they use some active methods such as zero-sequence current control loop and coordinate control [89]. Recent researches on parallel operation of inverters in distribution system interested in two applications; island mode grid and grid connected mode. In island mode distribution generation systems supply the load of all the power needed. In grid connected mode DER connected in parallel to the grid and supplies it with power to cover increased power required by the loads. The power system may become unstable under the heavy load condition and resulting voltage drops that can lead to a voltage collapse, so when DER connected with grid the voltage must be stable and the system must provide optimum energy. So there is a wide attention of control strategies of parallel inverters in microgrids [5].

3.3 Control strategies in parallel operation of inverters

The control strategies in parallel operation of inverters in distribution systems either connected with grid or off the grid can be categorized to two types. Active load sharing/current distribution and droop control. Voltage source inverters and uninterruptible power supply (UPS) operate in parallel and they are sensitive to disturbances from the load and can be damaged or burned by over current. When two or more inverters operate in parallel, the following conditions must be achieved: (1) amplitude, frequency and phase synchronization among the output voltages of inverters, (2) suitable current distribution according to the capacities, and (3) flexibility [5].

3.3.1 Active load sharing/current distribution

The work idea in this type of controller is to generate a reference current for each parallel-connected inverter. This model of controller can be categorized to these types:
(1) central limit control (CLC);

(2) master–slave control (MSC);

(3) Average current sharing (ACS)/distributed logical control (DLC);

(4) Circular chain control (3C);

In CLC controller all units of controller must have the same configuration, and every unit tracks the average current to distribute equal currents. DSP-based control for the voltage and current controller can achieve the perfect currents in this type of control [90]. In the MSC method, one inverter is specified as the master to control the voltage, and all others are specified as the slaves to control the currents. So in this method voltage-controlled inverter is used as a master unit and current-controlled inverters as the slave units. The voltage-controlled inverter (master) is improved to maintain a constant sinusoidal wave output voltage. The current-controlled inverter modules are operated as slave controlled to track the distributive current [91]. In this method the inverters do not require a phased locked loop (PLL) circuit for synchronization since these modules are interlinked and are communicating with the power plant [1]. In this method if the master unit fails, the system will shut down. And this is a big problem. This problem can be solved by using a separate current-controlled PWM inverter module to create the distributing current independent for the slave inverters. Accurate current division between the inverters is very important. This strategy is easy to accomplish in the parallel operation of UPS. The output current of all parallel connected inverters are collected and all inverters are known in MSC method. If one of the parallel-connected inverters fails, the parallel-connected system will fail [5]. In the ACS/DLC mode, a separate control circuit is used for each inverter. The current control mode is used to control its output current and to trace the same average reference current. When a fault is found in any unit, other units can still operate in parallel [92]. In the 3C method every unit tracks the current of the previous module to give perfect and equal current distribution. And the first unit tracks the last module to compose a circular chain connection. The output voltage and current of each inverter can also be changed and controlled to get a fast dynamic reply [93]. All of these types of load sharing control are be used to eliminate the circulating currents resulting from unbalance of parallel inverters. These techniques (load active sharing methods) have some features such as that have ability to make good load sharing, transient response and reduce circulating currents between inverters, however they have many disadvantages. The major problems for these methods that not truly redundant and have a single point of failure. Other disadvantages of these methods are that the stability of the micro grid system depends on the number of slave units in the distribution system. And need communication and interconnection between the inverters and this reduce the reliability of the system. Communication techniques have limited bands and can be influenced to disturbances, so using these techniques reduce the reliability and stability of power systems [5, 1]. To overcome of these problems and failures and avoid the communication techniques droop control methods have been used [5].

3.3.2 Droop control method

Droop control is also known as a wireless control because in this method there is no any interconnection or communication between the inverters. In this method the parallel inverters are controlled by the way of frequency and magnitude of the reference voltage signal follows the droop when load currents increase. Then these droops allow independent inverters to share the load in proportion to their capacities [94]. In droop control method active and reactive power depend on frequency and the magnitude of the output voltage of the inverter. So the phase and amplitude of voltage are the input parameters for the controller and the inverters are worked in voltage mode control as shown in figure 3.1 below that express the work idea of droop control. The real and reactive power drawn to the bus can be described by the two equations below [87]:

$$P = \frac{EV}{X} sin\emptyset \tag{3.3}$$

$$Q = \frac{EVcos\emptyset - V^2}{X} \tag{3.4}$$

$where$:

X: is the output reactance of an inverter

$\emptyset$: The phase angle between the output voltage of the inverter and the voltage of the bus

E: The amplitude of the output voltage of the inverter.

V: The amplitude of the output voltage of grid/load.

It's clear from the above equations that P depends on phase angle and Q depends on magnitude of voltage. The conventional droop control method can be expressed by the following droop equations [5, 87]:

$$\omega = \omega^* - m(P - P_i) \tag{3.5}$$

$$E = E^* - n(Q - Q_i) \tag{3.6}$$

Where: ω^*: the output voltage angular frequency

E^* : Amplitude of the voltage at no load.

m and n: the droop coefficients.

P & Q: active and reactive power rating

P_i &Q_i: Actual active and reactive power rating.

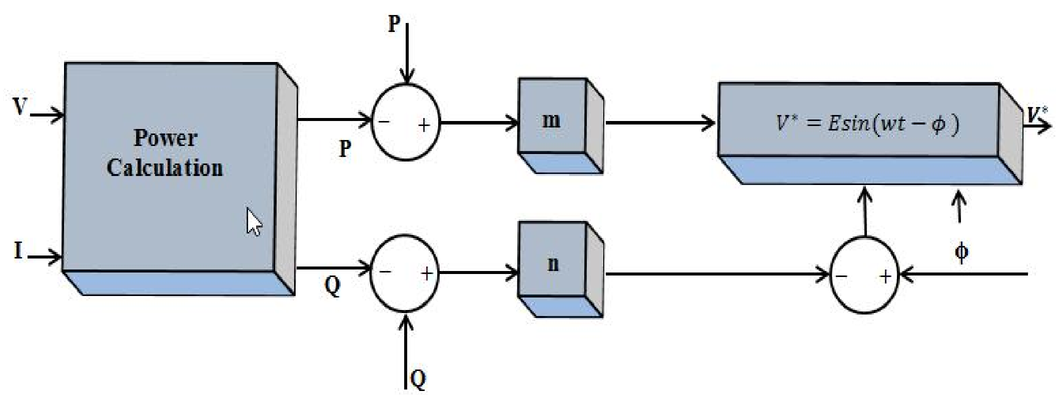
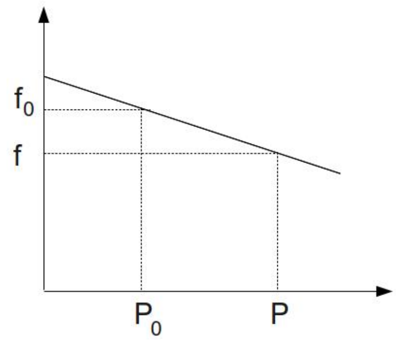


Figure3.1: Block diagram of P/Q droop controller



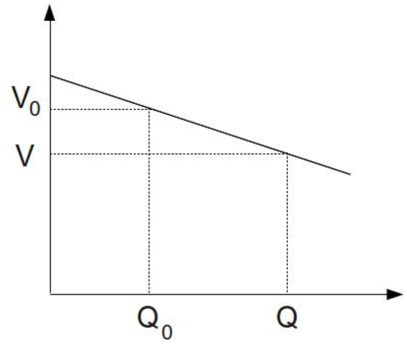


Figure3.2: Frequency droop characteristic   Figure3.3: Voltage droop characteristic

The frequency droop characteristic in the figure 3.2 above can be explained as follows: when frequency falls down from f_0 to f, the power output of the generating inverter will increase from P_0 to P. the decreasing frequency mentions to increase in loading and need more active power. Multiple parallel inverters with the same droop function can respond to the fall in frequency by increasing their active power outputs with each other. The increase in active power output will opposite the falling down of frequency and the models will locate at active power outputs and frequency at a steady-state status on the droop characteristic. Then the droop characteristic allows multiple modules to share load without fighting each other to control the load [5].

Some development in control has also been achieved to overcome its limitations such as poor transient response. M and n work as a gain control functions of nominal values P and Q respectively and it can be improved Transient response by adding proportional–integral–derivative (PID) terms to droop controller [95]. Also droop control can make sharing for non-linear (harmonic) components so the active and reactive power can be shared properly. Furthermore droop control or the wireless control with no interconnection of lines could be more useful for either active load sharing or for a distributed generation network connected to the grid or off-grid. Hot-swap function is another benefit of using the droop control method. Low sensitivity to line impedance unbalances and harmonic power sharing capability are the other advantages of a droop controller. Droop control method has a major feature that it can be combined with other methods to give more accurate results. As example of these methods using PID controller with droop control to improve transient response in active power or using the same controller with droop to improve transient and steady state response in island mode. In addition to that a novel fast control loops that improve the output impedance of the closed-loop inverters is used to give resistive behavior with the purpose to share the harmonic current properly [96]. Research mentions that most efforts are being put into droop control techniques because its capacity expansion flexibility, independent inverters and hot-swap facilities. The main advantages of droop control methods that depend on local measurements of the distribution network so they do not depend on cables/communication for reliable operation. It has many desirable features such as expandability, modularity, flexibility and redundancy. However, the droop control method has some limitation such as frequency and amplitude deviations, slow transient response and possibility of circulating current among inverters. These problems appeared because wire impedance mismatches between inverter output and load bus and/or voltage/current sensor measurement error mismatches. All of these features and advantages prompted many researchers at these recent days to use this method and make several improvements on it in order to compensate its limitations such as a small signal in transient response in grid connected mode. However using these strategies especially in distribution power systems instead of other control methods which use communication in their models will be more stable and reliable [1, 5].

CHAPTER 4

MODELLING THE SYSTEM BY USING DROOP CONTROL MatLab/SIMULINK

4.1 Introduction

In this chapter, we will describe several types of droop controller for good power sharing of parallel inverters. And as we review from the previous chapter there are several control techniques in integrating to achieve this aim. However, choosing the proper controller for this process is very important to obtain good results with high reliability, low harmonics and reduction faults in grid. For this reasons the design of our system must be built on the best controller. Droop control technique is one of the best control techniques that can achieve active and reactive power sharing of parallel inverters without communication techniques between inverters [5]. Using communication techniques in designing controller causes low reliability, and high cost of controller since they must have communication modules, as well as communication techniques need high bandwidth. So making a good power sharing between parallel inverters is a main factor at integration of distributed energy resources (DERs) with microgrid; because most part of these DERs such as (fuel cells, PV, etc.) need power electronic interfaces (inverters) to make up microgrids in parallel connection. Droop control is defined as a wireless control (WC) without interconnection between the inverters. The droop controller uses the amplitude and frequency of the reference voltage source to correct the power on inverters, so it allows parallel inverters to share the load in proportion to their capacities [30]. So power sharing technique based on P-F and Q-V droop control where the inverter frequency, F is drooped linearly with the inverter output real, P power and voltage amplitude, V is drooped linearly with the reactive power Q. Although the droop control method is one of the best methods to make sharing power on parallel inverters, there are some shortages such as high transient performance at grid connected mode, inaccurate reactive power control, and increasing of harmonics elements. These troubles occurred because there are small deviations in voltage and frequency due to droop control method uses them to correct the power and make sharing on parallel inverters. In this research we design new controllers like an auxiliary controller to improve droop controller performance and avoiding high transient response and we got good and stable results on active and reactive power sharing.

4.2 Design and modelling the microgrid

Micro grid is based on several modules: grid power, inverters, and loads. To design small micro grid we must design these parameters to illustrate power sharing process on parallel inverters. Any one of these inverters connect with distributed generators like (PV, wind turbine, etc.) to interface these distributed generators with micro grid and converting power from DC to AC power. A simple grid illustrates my design in island mode shown in figure: 4.1.

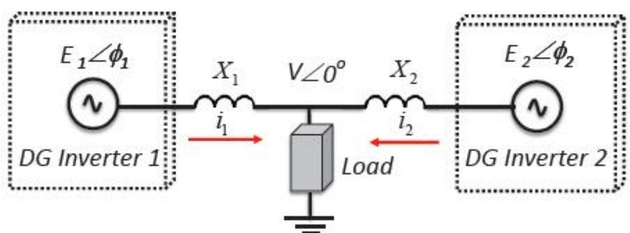


Figure 4.1: Illustrate two parallel inverters in island mode

4.2.1 Design the inverter

A simple inverter is essentially integrated with a dc power source and a full bridge and an L−C output filter [31]. The inverter is controlled by many types of controllers such as (DSP Controllers, TMS320F28XX). The voltage and current can be read by LEM sensors as shown in figure 4.2.

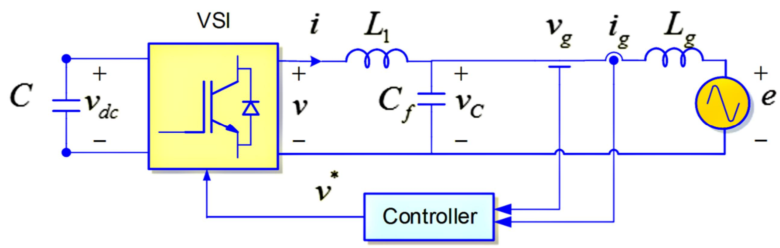


Figure 4.2: Basic schematic diagram of a single phase inverter

Two or more parallel inverters are submitting to the following restrictions:

- All the parallel inverters must operate synchronously.
- All the inverter output voltages must have the same amplitude, frequency and phase.
- The inverters output current requires to be distributed according to their nominal power.

Each inverter will have an external power loop based on droop control [32, 33] that called also as autonomous or decentralized control, whose purpose is to share active and reactive power among DG units (inverters) and to improve the system performance and stability. In order to design simple equivalent circuits for DC to AC interfaces (inverters) by SIMULINK it must be first determine the type of inverter that will be uses in the circuit. There are two types of inverters are used between distributed energy sources and the grid; current source inverters (CSI) and voltage source inverters (VSI). However CSI are commonly used VSI are needed to maintain the voltage stable in autonomous or island operation [34]. VSI are relevant with distributed energy resources since they don't need any external reference to be synchronized [35, 36]. Actually, they can operate in parallel with other inverters by using frequency and voltage droops, forming islanded Microgrids [37]. Also VSIs are suitable for distributed generation systems since they provide power quality enhancement to grid performance [38, 39]. In addition to that VSIs can change these behaviors from voltage to current sources in grid connected mode [40]. Therefore using VSIs are more convenient and efficient in our design and by determining and analyzing currents, voltages and grid parameters the circuit equivalent of VSI consist of power source with impedance connected with power grid and power lines and will be as shown in figure 4.3.

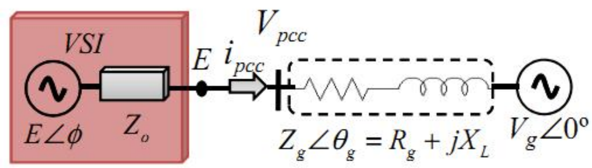


Figure 4.3: Equivalent circuit of the VSI connected to the grid.

Where the Zo is VSI impedance, Z_g is grid impedance; V_g is grid voltage, i_{pcc} point of common coupling current and V_{pcc} point of common coupling voltage.

4.2.2 Design VSI by SIMULINK

From the previous illustration we can conclude that equivalent circuit of VSI consist of AC power source and low series impedance which can be easily drawn by Simulink as shown in the figures 4.4 and 4.5 below.

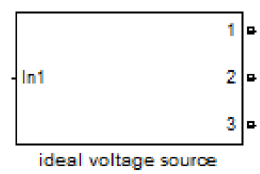


Figure4.4: VSI block by SIMULINK

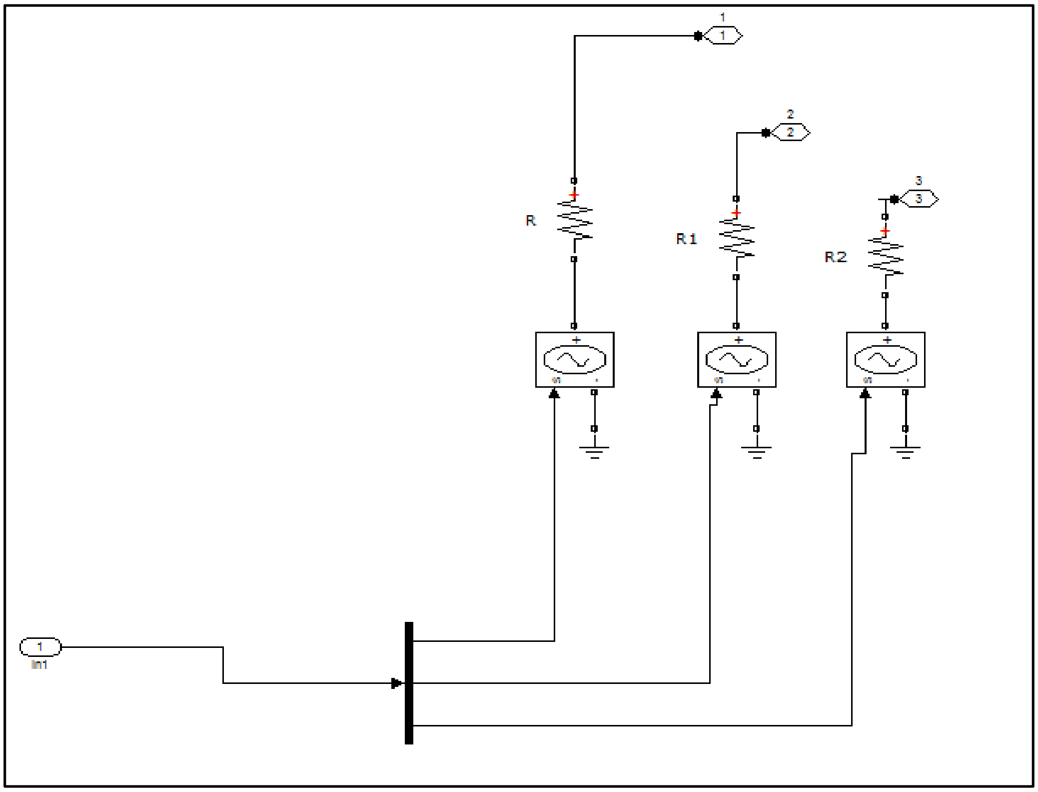


Figure 4.5: VSI by SIMULINK

4.2.3 Design the active and reactive power calculator with LPF (low pass filter)

The idea of design calculator for active and reactive power depending on power law which is relies on multiplication of voltage and current. $P = V.I.cos\theta$ And $Q = V.I.sin\theta$. So that the reactive power will delay 90º degree from the active power and this is mean ¼ cycle = ¼ T as shown in figure 4.6 below. The active and reactive power must be measured and averaged with a running average window over one cycle of the fundamental frequency. So the powers are evaluated at primary frequency. This operation can be performed by low-pass filters with a reduced bandwidth. Moreover the filters that calculate the mean values both the active and reactive power and the coefficients of the slopes are strong determinants of the system dynamic and performance, especially in paralleled power supplies.

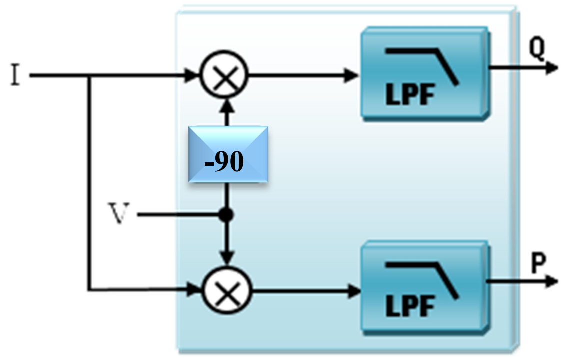


Figure 4.6: Active and reactive power calculating with LPF

According to this logic to calculate active and reactive power, it can be easily design schematic diagram with low pass filter by using SIMULINK as shown in figures 4.7 and 4.8 at the next page.

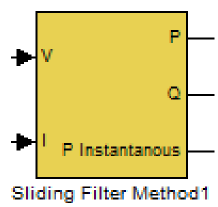


Figure 4.7: Active and reactive power calculator and LPF block

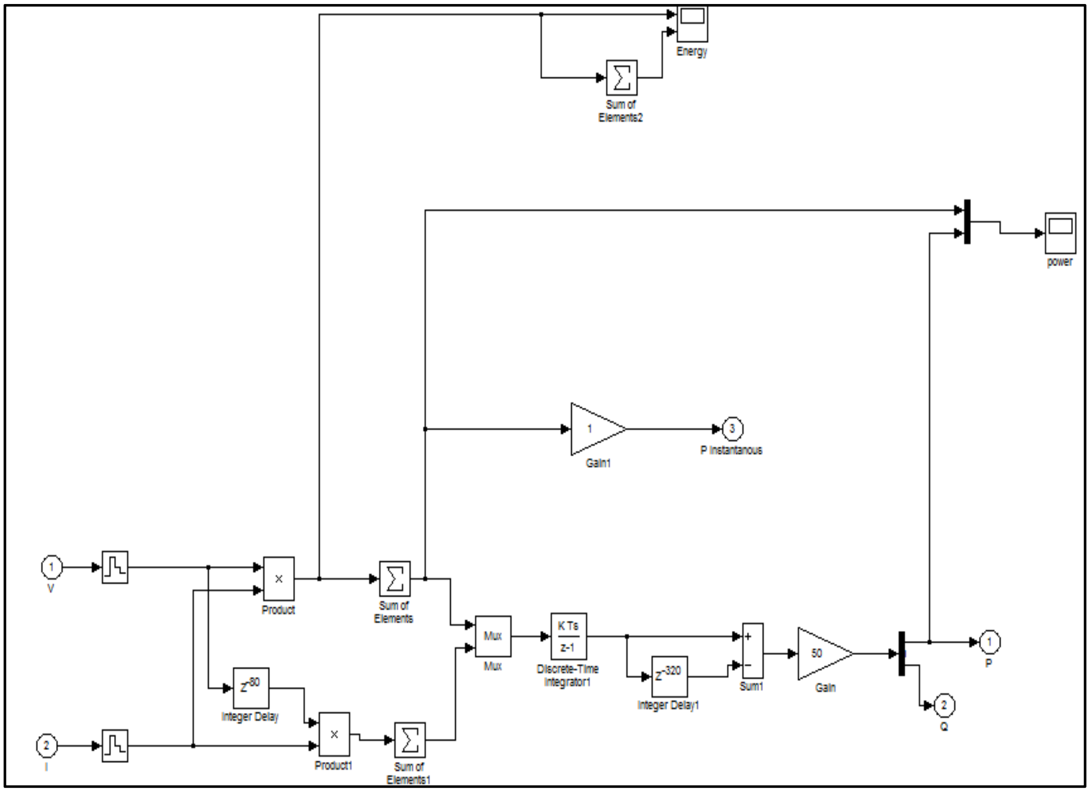


Figure4.8: Active and reactive power calculating with LPF

4.2.4 Design the droop controller

The droop method is often proposed for the aim of connecting several parallel inverters without control intercommunications. The applications of such a kind of control are typically industrial UPS systems or islanding Microgrids. The conventional droop method is based on the principle that the frequency and the amplitude of the voltage inverter can be used to control active and reactive power flows [41]. Hence, the droop method can be expressed as follows:

$$\omega = \omega^* - m.(P - P^*), \quad (4.1)$$

$$E = E^* - n.(Q - Q^*), \quad (4.2)$$

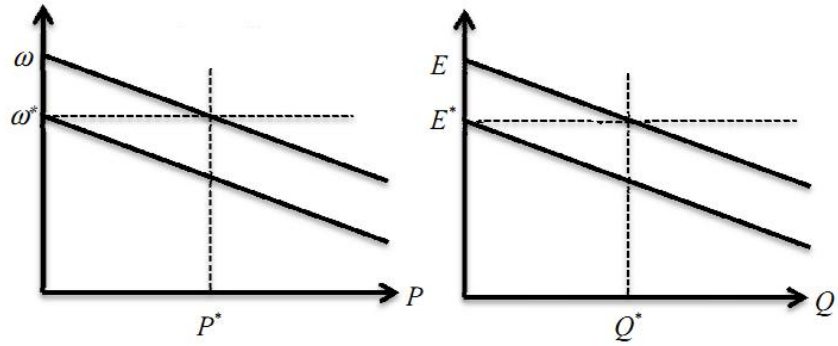


Figure 4.9: Droop method P- ω and Q-E grid using P* and Q* as set points

Where ω and E are the frequency and the amplitude of the output voltage. m and n the proportional droop coefficients define the corresponding slopes. P^* And Q^* are the active and reactive power references (nominal active and reactive powers), which are commonly set to zero when we connect inverter units in parallel autonomously, forming energetic island. This droop controller increases the system performance due to the autonomous operation among the modules. This way, the amplitude and frequency output voltage can be affected by the current sharing through a self-regulation technique that uses both the active and reactive local power from each unit [41]. In other words, if the droop slope coefficients are increased is possible to obtain good power equalization, even though regulation could be compromised.

The active and reactive powers flowing from an inverter to a grid through an inductor can be expressed as follows [5]:

$$P = \left[\left(\frac{EV_g\,cos\varphi}{Z_g} - \frac{V_g^2}{Z_g}\right)cos\theta_g + \frac{EV_g}{Z_g}sin\varphi sin\theta_g\right] \tag{4.3}$$

$$Q = \left[\left(\frac{EV_g\,cos\varphi}{Z_g} - \frac{V_g^2}{Z_g}\right)sin\theta_g + \frac{EV_g}{Z_g}sin\varphi sin\theta_g\right] \tag{4.4}$$

Where E and V_g is the inverter voltage output and grid voltage respectively, Z and θ are the magnitude and the phase of the output impedance, respectively; and φ is the phase angle between the inverter output and the Microgrid voltages.

The droop method is based on two main assumptions [5]:

Assumption 1: The output impedance is purely inductive, and Z_g = X and ω = 90° so the equations (4.3) and (4.4) will become as shown below:

$$P = \frac{EV_g}{X} sin\varphi \tag{4.5}$$

$$\frac{EV_g \, cos\varphi}{X} - \frac{V_g^2}{X} \tag{4.6}$$

This is proved by a large inductor of the filter inverter and to the impedance of the power lines.

Assumption 2: The angle φ is small; we can conclude that sin φ ≈ φ and cos φ ≈ 1, and consequently, so the equations (4.5) and (4.6) will be as shown below [5]:

$$P \approx \frac{EV_g}{X} \varphi \tag{4.7}$$

$$Q \approx \frac{V_g}{X} \left(E - V_g\right) \tag{4.8}$$

Taking these considerations into account, P and Q are linearly dependent on ω and E respectively. Note that droop method uses frequency to tradeoff between the active-power sharing and the frequency accuracy that causing frequency deviations. We conclude from the above explanation and equations how to make good droop controller that achieve a good power sharing above parallel inverters, UPSs or distributed energy generators by adjusting m and n (proportional droop coefficients). In my project I choose m and n in order to adjust a good steady state response of two parallel inverters in island mode with good transient response in grid connected mode and ensuring system stability, however there will appear some overshoot. m_p And n_p coefficients are chosen as a constant numbers. The mechanism of droop method will be like shown in the schematic at the next page:

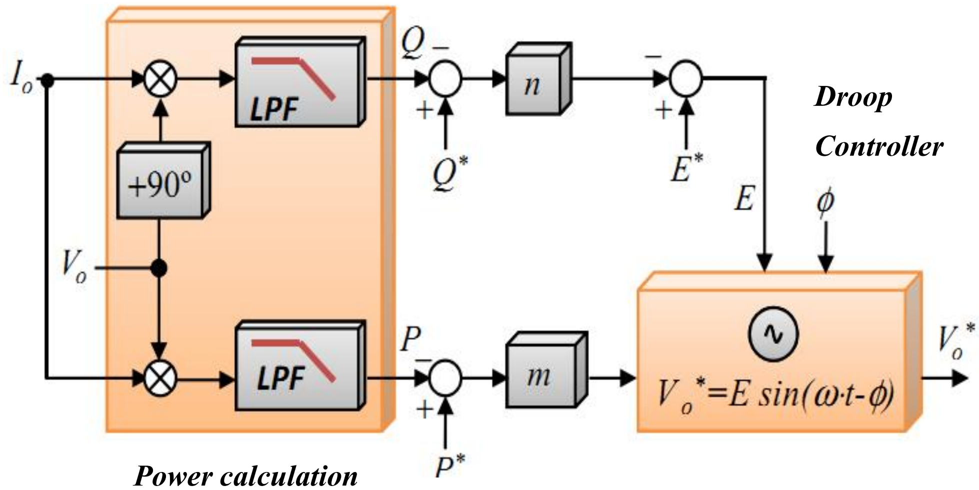


Figure 4.10: Block diagram of a P/Q droop controller.

4.2.4.1 Using SIMULINK to draw and design droop controller

According to the last equations and ideas of droop method; in this part we can design droop controller by using MATLAB/SIMULINK. We determine the important coefficients as shown in the table below 4.1. Then we draw the schematic according to the block diagram (figure 4.10).

Table 4.1: Parameters of the droop control

Parameter	***Symbol***	***Value***	***Units***
Voltage grid	V_g	311	V
Frequency grid	F_g	50	Hz
Virtual Inductor #1	L_1	1	mH
Virtual Inductor #2	L_2	1.1	mH
Parasitic Resistor #1	r_{l1}	0.08	Ω
Parasitic Resistor #2	r_{l2}	0.08	Ω
Nominal output power	S	30	KVAR
Nominal frequency	ω^*	2π*50	Rad/s
Nominal Amplitude	E^*	311	V
Active power load	P_L	10	KW
Reactive power load	Q_L	4	KVAR
Q-V droop proportional	n	3×10^{-4}	V/VAR
P- φ droop proportional	m	2×10^{-4}	Rad/W

Using the parameters listed in table 4.1 and considering the figure 4.10 as a base to design droop control by SIMULINK we can conclude the diagram of droop controller and design it as shown in the figures below:

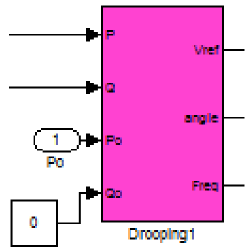


Figure 4.11: Block diagram of droop control by SIMULINK

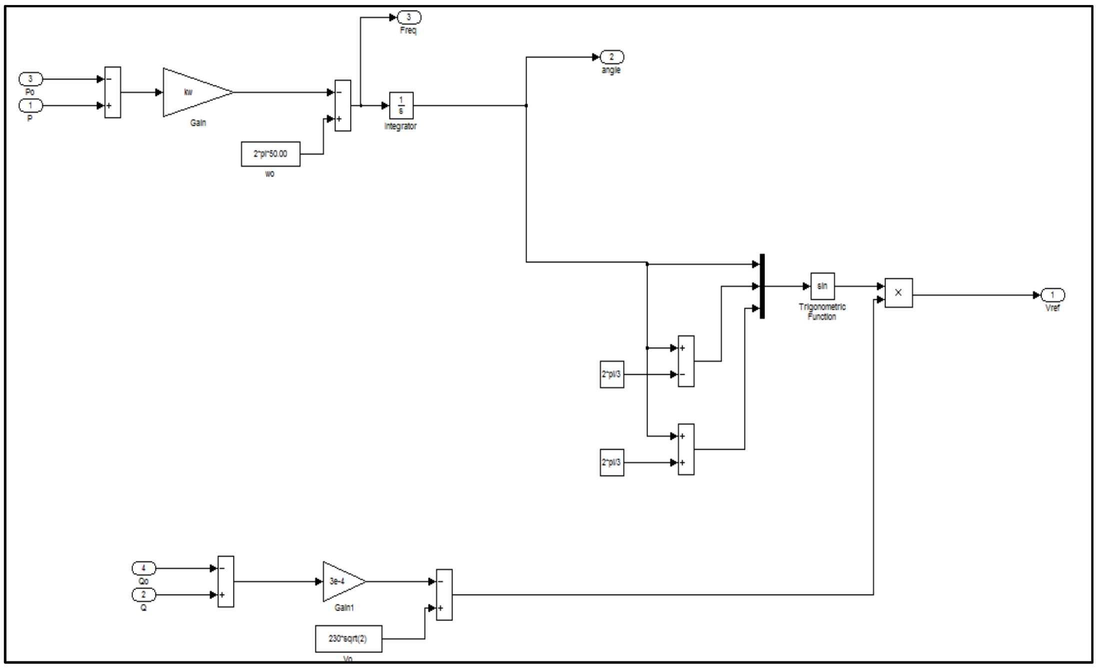


Figure4.12: Droop control method by SIMULINK

By collecting all the blocks we can build the inverter that connected in the other side with distributed energy resources and can be designed by SIMULINK as shown in the figure at the next page:

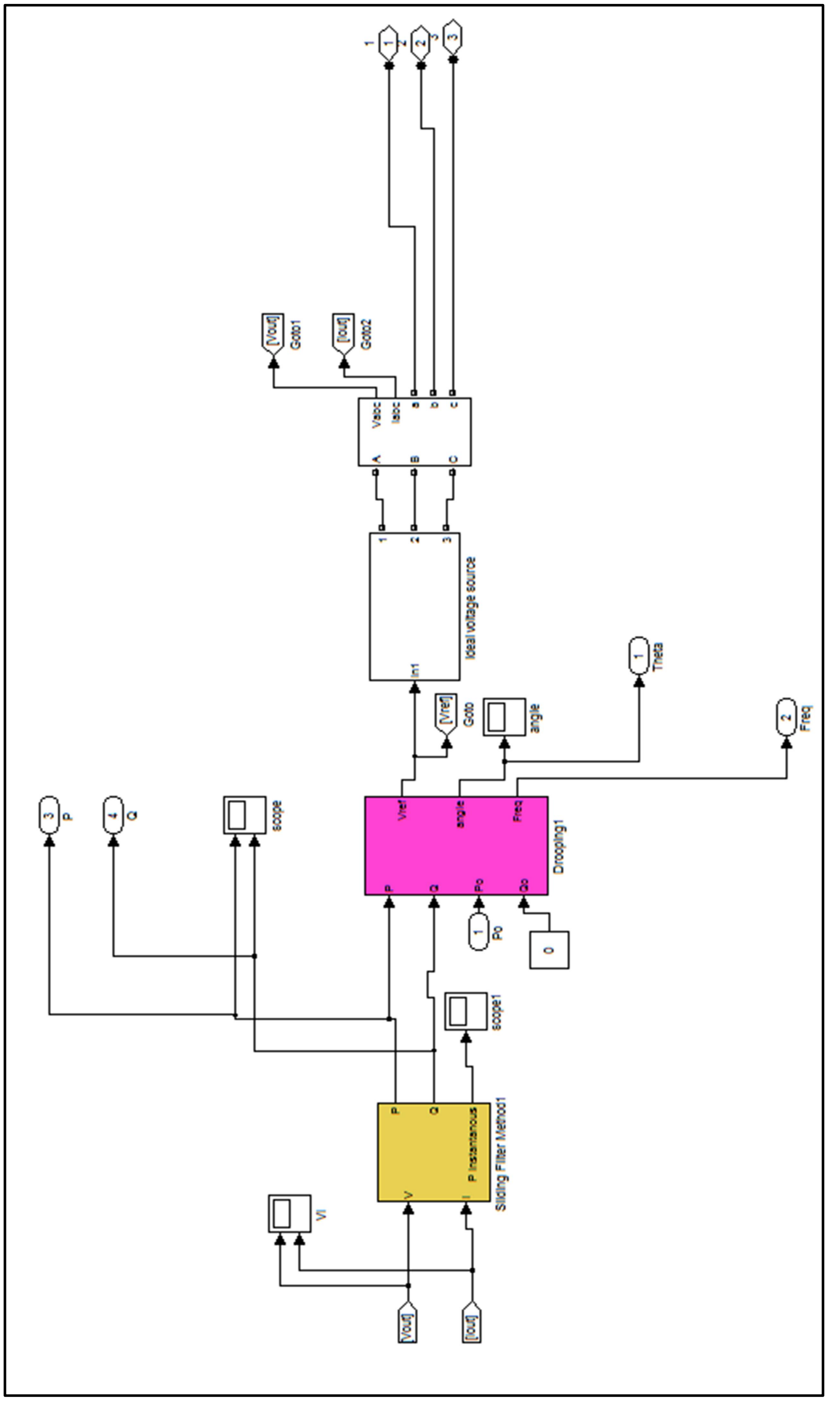


Figure 4.13: The inverter by SIMULINK

So in this way we can design a microgrid consist of two inverters connected with utility grid by power lines and breakers. The breakers connected with step response to order breakers close or open when change its states from one to zero at 2 mille second. Step response block perform the work of intelligent bypass switch to change the state of microgrid from grid connected mode when it at one states and after ten mille second it order to breakers to open (at zero state) to convert the state of microgrid to autonomous or island mode. The microgrid schematic can be shown at the next page:

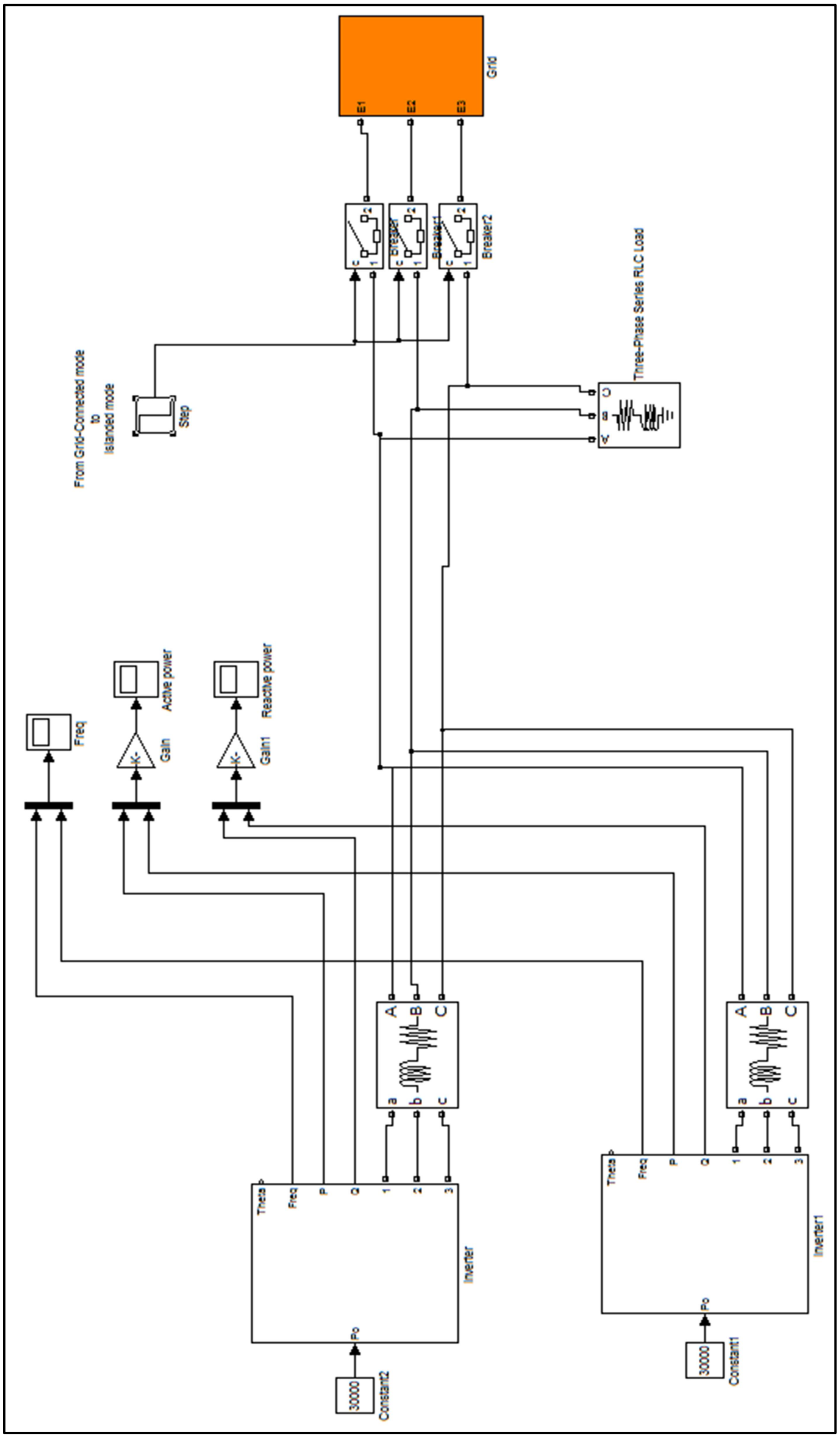


Figure 4.14: Microgrid by SIMULINK

4.3 **Adaptive Droop Control**

In this section we will try to modify the limitations of droop control method such as a high small signal in transient response at grid connected mode and non-accurate sharing of reactive power at steady state point of island mode. This modifying can be solved by many adaptive controllers such as injection PID controller or repetitive controllers. Based on the estimation of the grid parameters provided by the identification algorithm, an adaptive droop controller able to inject active and reactive power into the grid with high accuracy is proposed. To make analysis of power flow using equations (4.3) and (4.4) which they depend highly on the grid impedance (Zg∠θg) to transform P and Q to novel variables (Pc and Qc) that are independent from the magnitude and phase of the grid impedance [97].

$$P_c = \left(Psin\Theta_g - Qcos\Theta_g\right), \tag{4.9}$$

$$Q_c = \left(Pcos\Theta_g - Qsin\Theta_g\right), \tag{4.10}$$

By substituting 4.3 and 4.4 into 4.9 and 4.10, it yields the following equations:

$$P_c = EV_g sin\Phi \tag{4.11}$$

$$Q_c = \left(EV_g cos\Phi - V^{\,2}\right), \tag{4.12}$$

We notice that Pc depends on phase, while Qc depends on voltage difference between the VSI and the grid (E −Vg). These control variables (Pc and Qc) are obtained; we can use them into the droop control method to inject active and reactive power. Similarly, to inject the desired active and reactive powers (Pc and Qc), the following droop control method which uses the transformation (4.9) and (4.10), is proposed [97].

$$\emptyset = -G_p(s)Z_g\left[(P - P_c)sin\theta_g - (Q - Q_c)cos\theta_g\right], \tag{4.13}$$

$$E = E_c - G_p(s)Z_g\left[(P - P_c)cos\theta_g - (Q - Q_c)sin\theta_g\right], \tag{4.14}$$

Where E_c is the amplitude voltage reference that takes the values of the estimated grid voltage (Vg). By using these expressions we can obtain the voltage reference of the VSI:

$$V_{ref}^{*} = E.\sin(\omega * t + \emptyset) \tag{4.15}$$

ω is the angular frequency of the output voltage. The compensator transfer functions of Pc and Qc can be expressed as [1, 97]:

$$G_p(s) = \frac{m_i + m_p s + m_d s^2}{s} \tag{4.16}$$

$$G_q(s) = \frac{m_i + m_p s + m_d s^2}{s} \tag{4.17}$$

Bu injection these expressions which working as a PID controller with droop controls the sharing of active and reactive power of parallel inverters will be more accurate. But actually the variables of this control must be designed tried to give required results.

CHAPTER 5

CASE STUDIES OF MY DESIGN

5.1 Introduction

In this chapter we will illustrate and offer some study cases of our models and works as a results from our design by using MATLAB/SIMULINK. In the first we will see study case of design micro grid consists of two equal inverters connected in parallel and are controlled by droop controller which parameters are determined in chapter 4. In this study case we will illustrate the response of active and reactive power in the two states grid connected mode, island mode and seemly transfer from grid connected to island mode. In the results we will observe the transient response acting of active and reactive power of two parallel inverters in grid connected mode and try to reducing the overshoot of transient response by designing adaptive controller (PID) controller that decreasing the overshoot of transient response. Moreover we will notice that our droop control can give as a good response in steady state in island mode by making the two signals over each other which that mean the two equal inverters will give us same active or reactive power in autonomous or island mode. In addition to that we will offer the output frequency of the system. The other study cases will be such as connected three equal parallel inverters in parallel, connected two inverters in parallel one of them is one - third of the other or its power is half the other.

5.2 Case Study #1 of Two Equal Parallel Inverters.

In this study we design two equal inverters with S = 30KVA. And with load has P = 10KW with Q = 4KVAR. We will see the results of our design in grid connected mode and in autonomous mode. The parameter of droop control that is used in this study is shown in the table below:

Table 5.1: Parameters that are used in study case #1

Parameter	***Symbol***	***Value***	***Units***
Voltage grid	V_g	311	V
Frequency grid	F_g	50	Hz
Nominal output power	S	30	KVAR
Nominal frequency	ω^*	2π*50	Rad/s
Nominal Amplitude	E^*	311	V
Active power load	P_L	10	KW
Reactive power load	Q_L	4	KVAR
Q-V droop proportional	n	3×10^{-4}	V/VAR
P- φ droop proportional	m	2×10^{-4}	Rad/W

By using SIMULINK/MATLAB we design microgrid with step response to change the status of breakers which determine the status of microgrid and change it from grid connected mode (step at 1) to island mode (step 0) with two equal parallel inverters connected by breakers with utility grid that is shown in figure below:

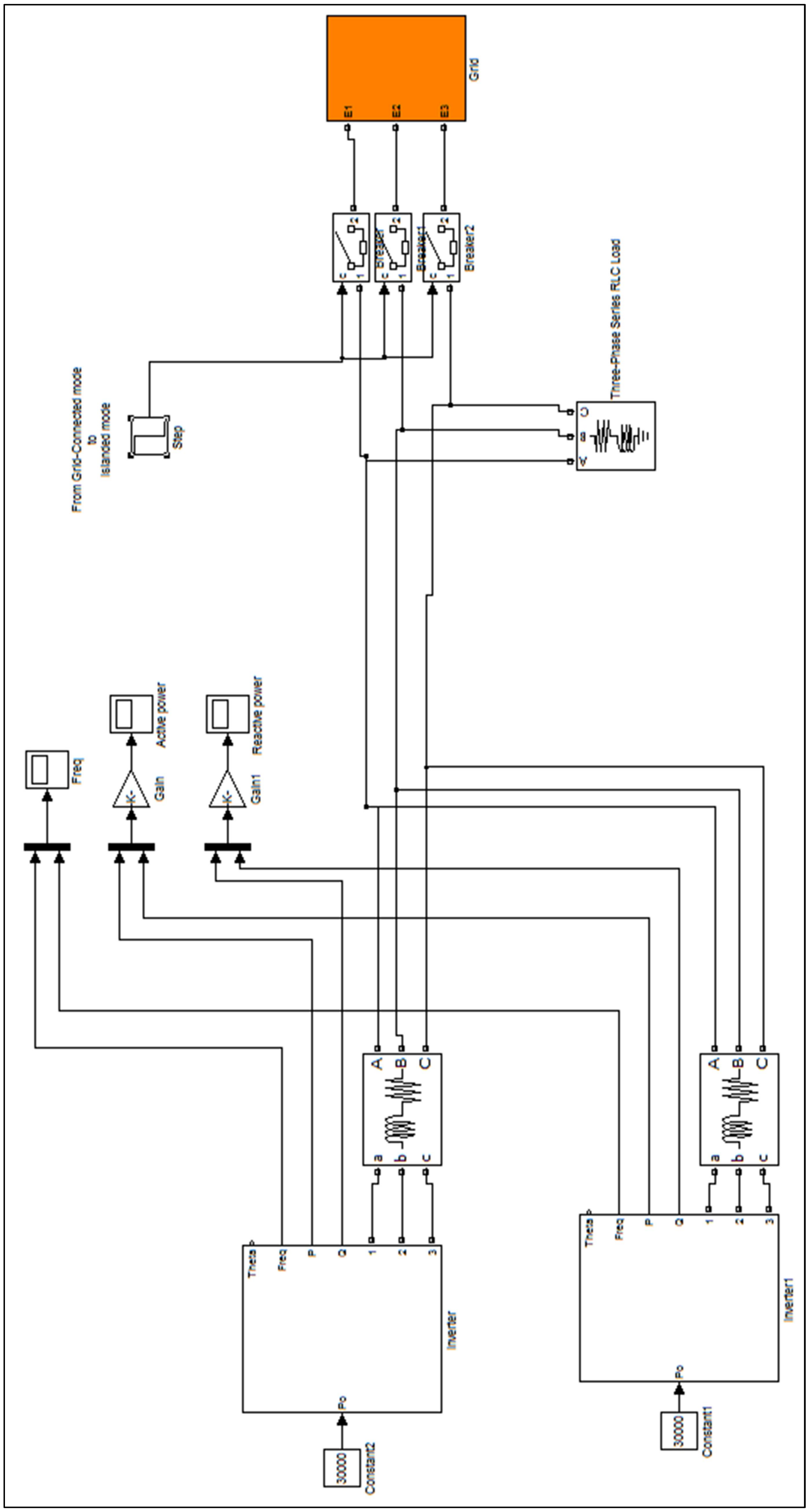


Figure 5.1: Microgrid of study case #1

The design in figure 5.1 was simulated with the parameters in table 5.1 and the scheme of active and reactive power and frequency shown in figures below:

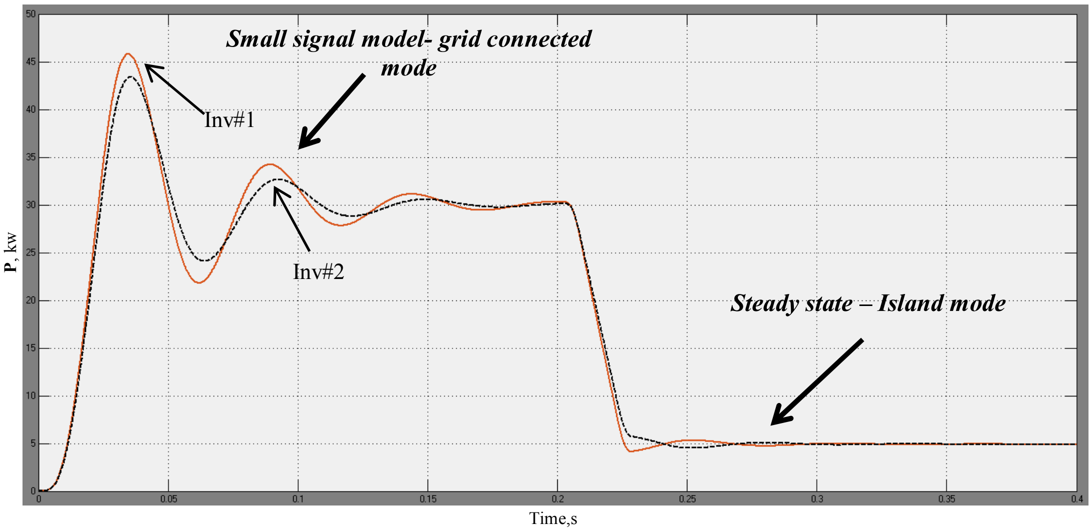


Figure 5.2: Seamless transfer of active power from grid connected mode

To autonomous mode

Figure 5.2 illustrates the active power of two equal parallel inverters. In grid connected mode we can see small signal in transient response which makes overshoot for the system and we will reduce it by improving the droop control by PID controller as we will explain in the next sections. In island mode we can see that the two equal inverters give 5KW so the droop control achieve the active power sharing between two equivellent inverters. In the other side we simulated the reactive power of our design as shown in figure 5.3 which illistrates the two cases of modes (grid connected and Island mode) also the seemless transfer from grid connected to island mode. We can observe from scheme 5.3 that the reactive power in grid connected mode has some signal (small overshoot) at transient response, and in island mode we don’t have accurate sharing of reactive power; so droop controller can’t make accurate reactive power and need adaptive or assistant controller to make sharing more accurate. In addition to that we simulate the frequency of the design as shown in scheme 5.4. We can observe from the figure 5.4 that there are some deviations in the values of frequency because the droop control uses it to share active and reactive power on the parallel inverters. So there is tradeoff between power sharing accuracy and the frequency. Moreover we simulated active and reactive power once in grid connected mode and the other in Island mode as shown in figures (5.5, 5.6, 5.7, and 5.8). We concluded that in grid connected mode

There is small signal in transient response produces overshoot and in this case the droop control must be provided by another controller such as PID controller to decrease the overshoot in grid connected and don't effect on steady state in Island mode.

In addition to that droop control achieve accurate sharing of active power in island mode but can't achieve accurate sharing for reactive power in autonomous mode and need adaptive control to make it more accurately.

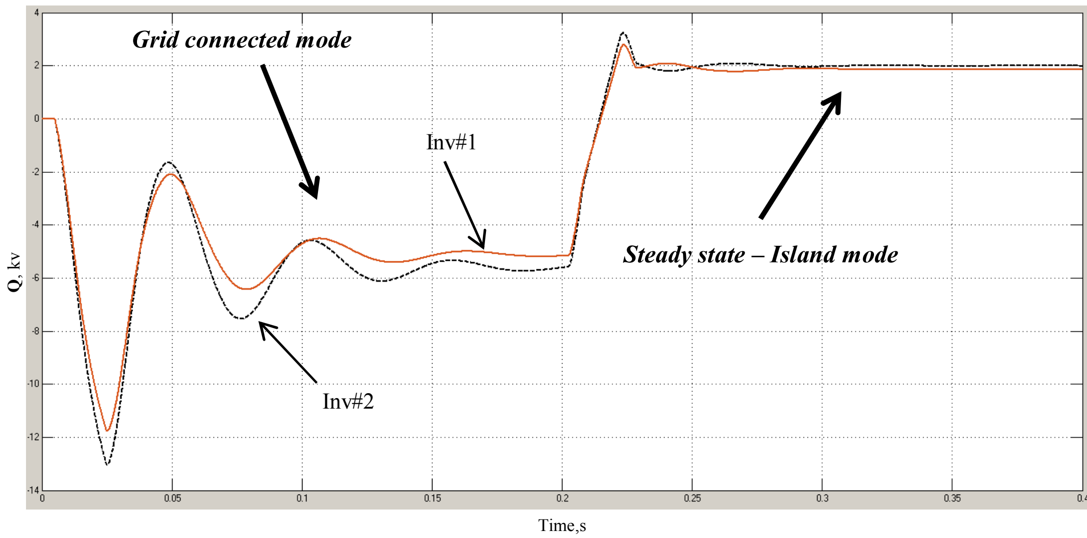


Figure 5.3: Seamless transfer of reactive power from grid connected mode

To autonomous mode

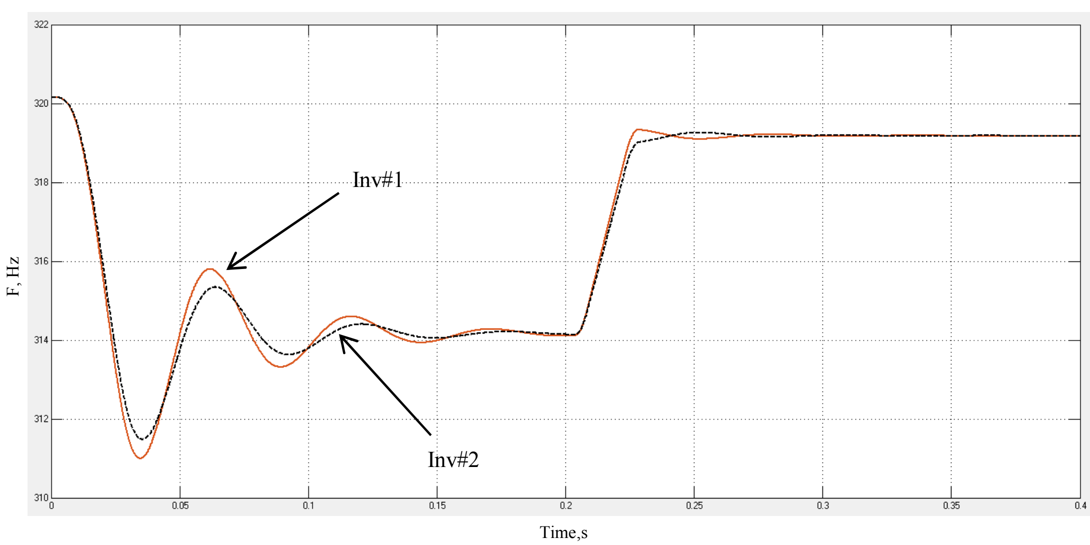


Figure 5.4: frequency scheme of case study #1

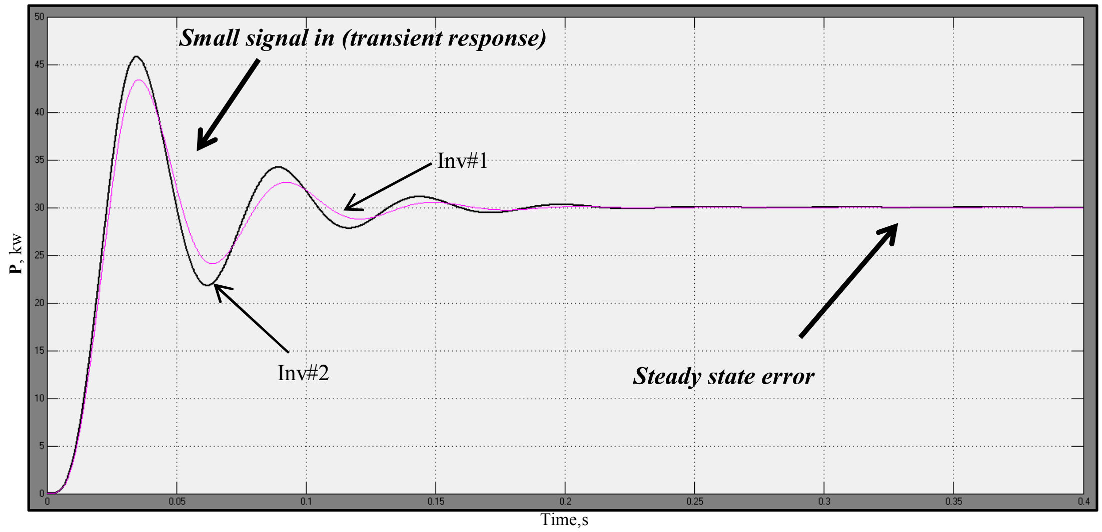


Figure 5.5: Active power response in grid connected mode

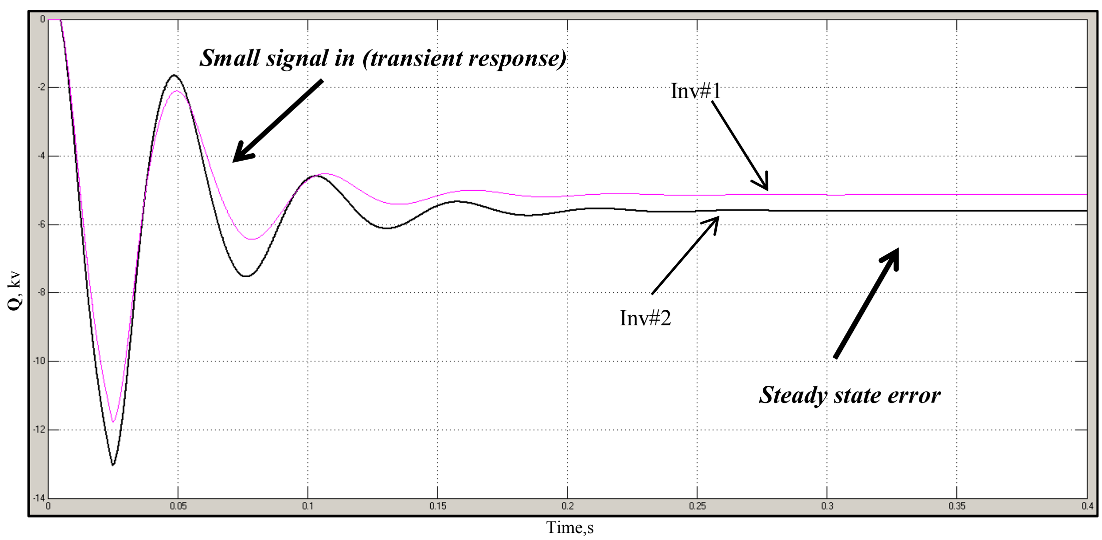


Figure 5.6: Reactive power response in grid connected mode

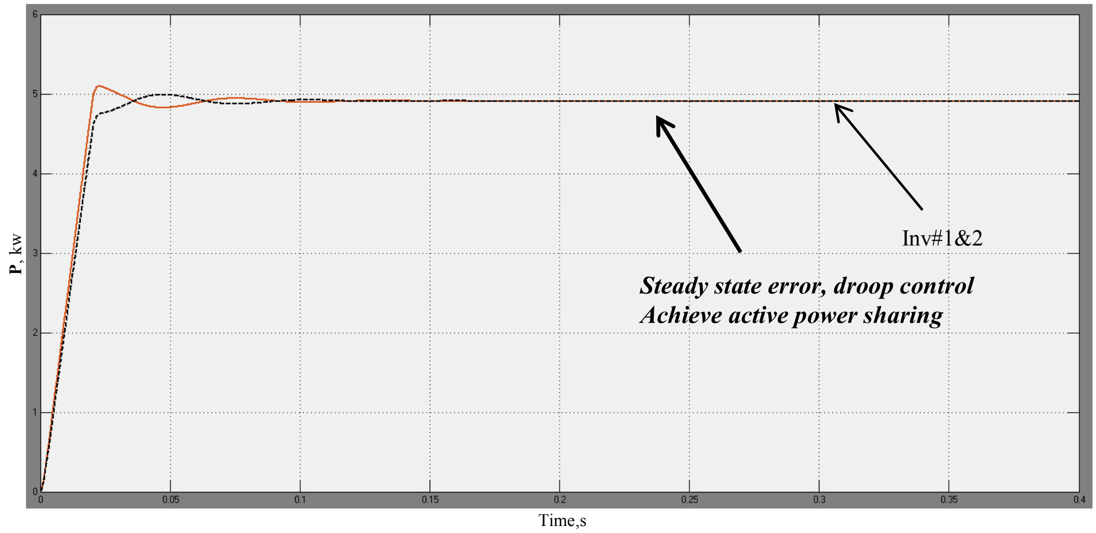


Figure 5.7: Active power response in Island mode

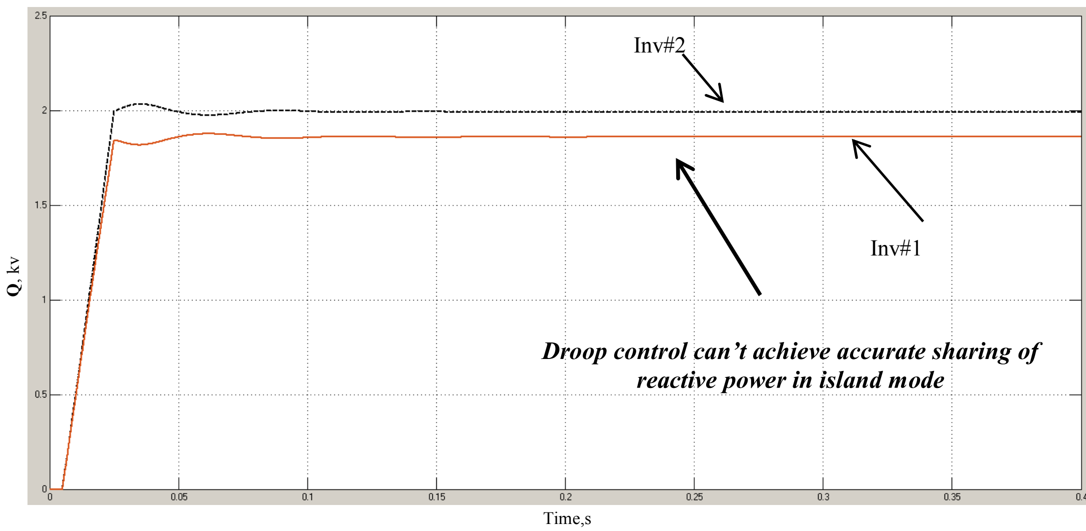


Figure 5.8: Reactive power response in Island mode

5.3 Case study #2 of two parallel inverters with power of one is half of another.

In this case study we simulated two parallel inverters in micro grid but they have different powers. The first one has S= 5KVA and the other one has S= 10KVA. The load has the same values as in case study #1 and the parameters of droop control has the same parameters in table 5.1. In the first we applied the microgrid with two states (grid connected and Island mode) by transferring the breakers from close state (1 state at step response) to open state (0 state at step response). The results are shown in the figures below:

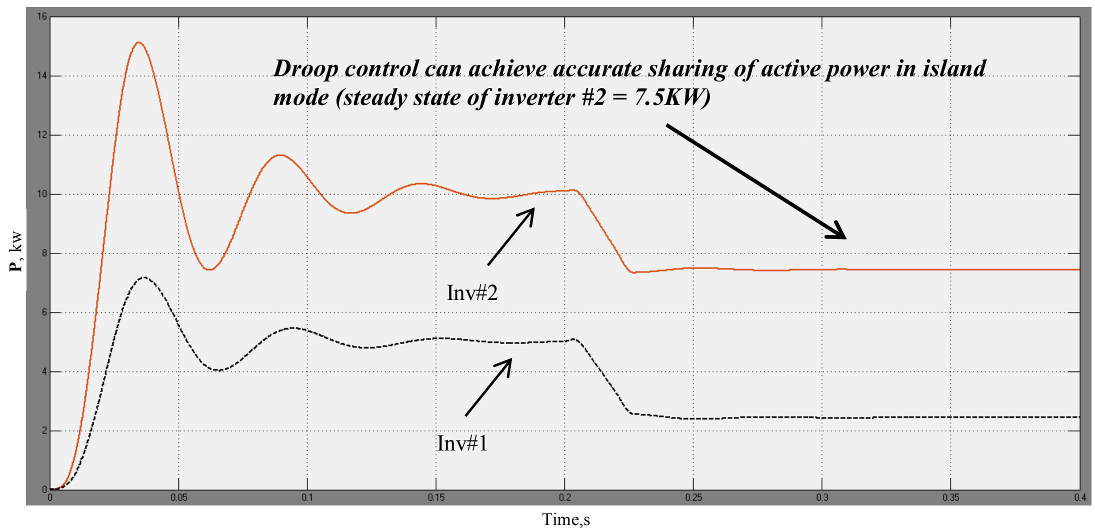


Figure 5.9: Active power response in transferring mode from grid connected To Island mode

Figure 5.9 illustrates the transferring from grid connected mode to island mode. We concluded from the figure that droop control can achieve accurate sharing of active power in grid and island modes; however in transient response of grid connected mode has a small signal generated small overshoot. In island mode we see that the steady state of inverter #1 has nearly 2.5KW and the next one has nearly 7.5KW. So droop control Active power response in transferring mode from grid connected to Island mode. achieves accurate active power. In addition to that the microgrid has seemly transfer from grid connected to autonomous state. In the other side figure 5.10 illustrates the reactive power of microgrid in transferring state from grid connected to island mode.

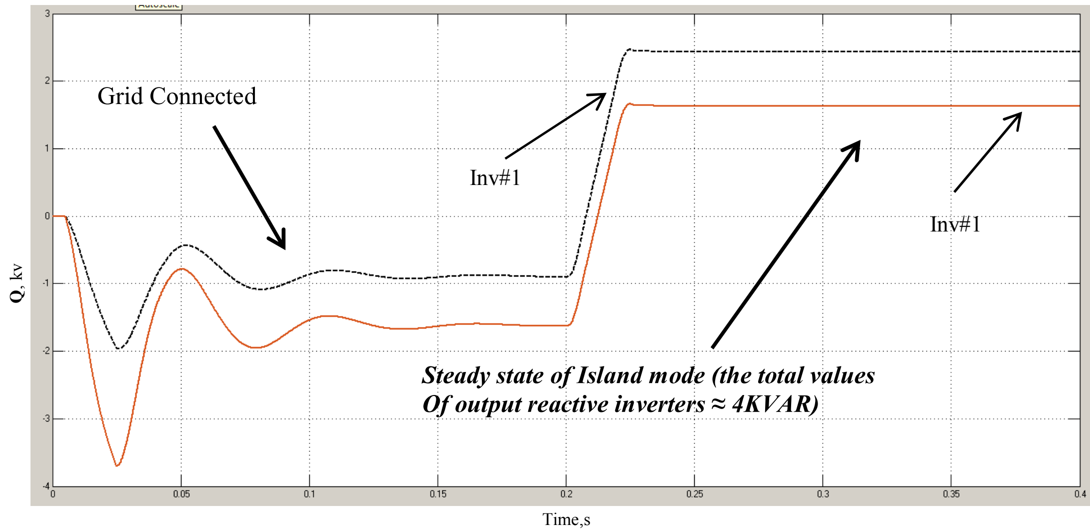


Figure 5. 10 : Reactive power response in transferring mode from grid connected

To Island mode

As shown in scheme 5.10 there is some overshoot in transient response in state of grid connected mode and we can get accurate 4KVAR in steady state of island mode. Figure 5.11 describes the frequency of the system, in case study #2 we have a good response of frequency, so the two signals have nearly the value of 314.5Hz.Moreover we simulated the active power, reactive power and the frequency in grid connected mode. In this response we have a good response and good sharing of active power with accurate steady state at grid connected mode as shown in figure 5.12. According to parameters of grid we get accurate active power P_1 = 5KW and P_2 = 10KW.

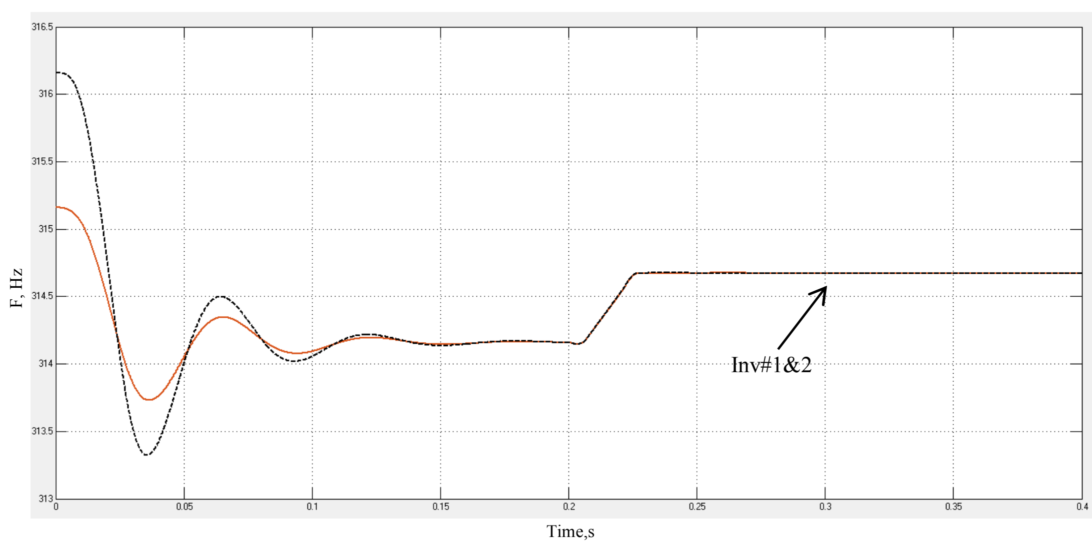


Figure 5.11: Frequency of the system in transferring mode from grid connected

To Island mode

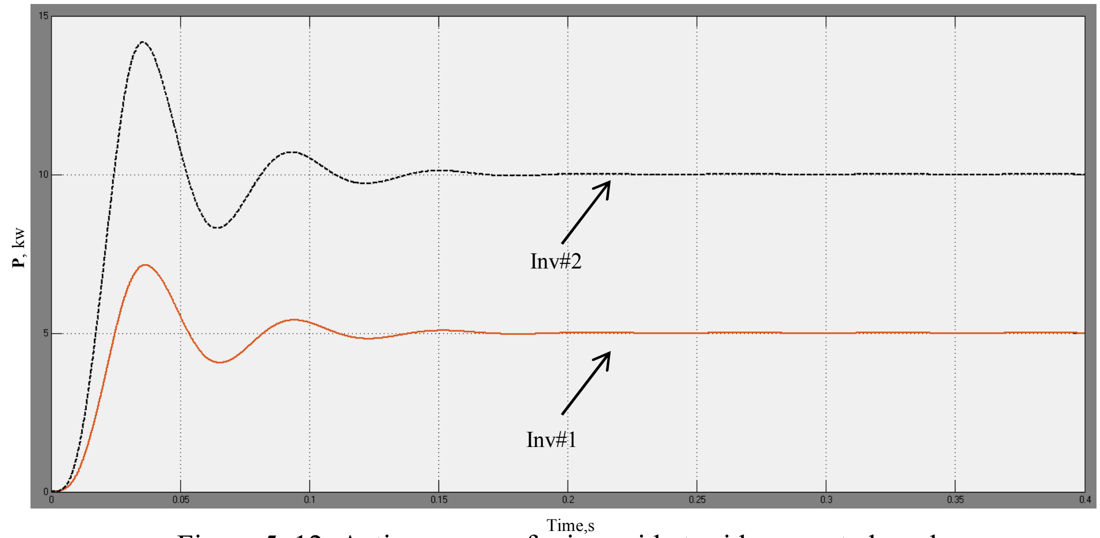


Figure 5. 12: Active power of microgrid at grid connected mode

The reactive power of parallel inverters that are composed the microgrid in case study#2 was simulated as shown in scheme 5.13. as shown in the figure there is small signal in transient response and a good response in steady state.

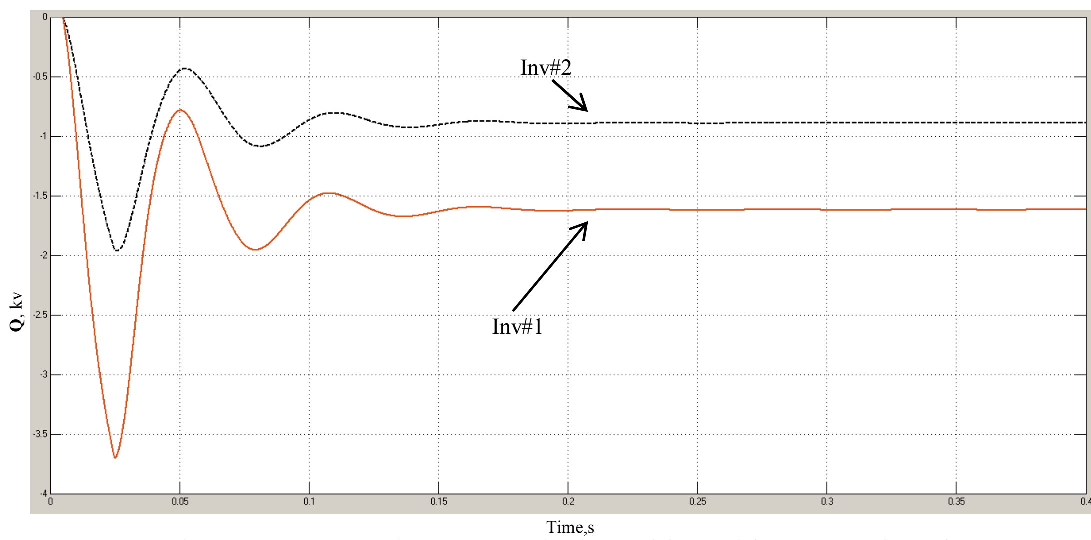


Figure 5. 13: Reactive power of microgrid at grid connected mode

The figure 5.14 describes the response of frequency in grid connected mode which gives a good response in steady state of the system nearly 314.5Hz.

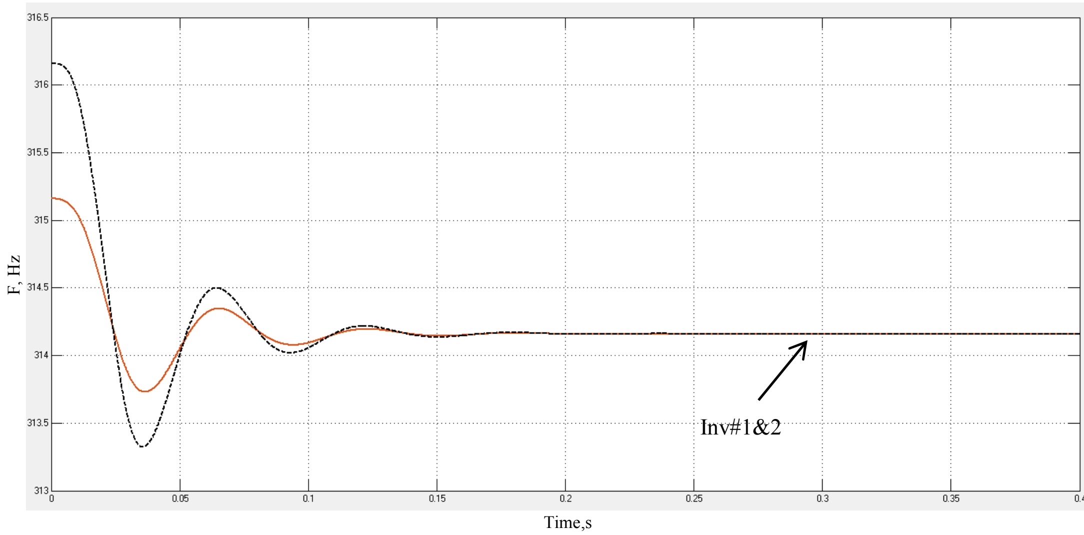


Figure 5. 14: Frequency of microgrid at grid connected mode

In the case of island mode we simulated the active power of two parallel inverters as shown in figure 5.15. The response of steady state of active power is good and we get the accurate active power sharing.

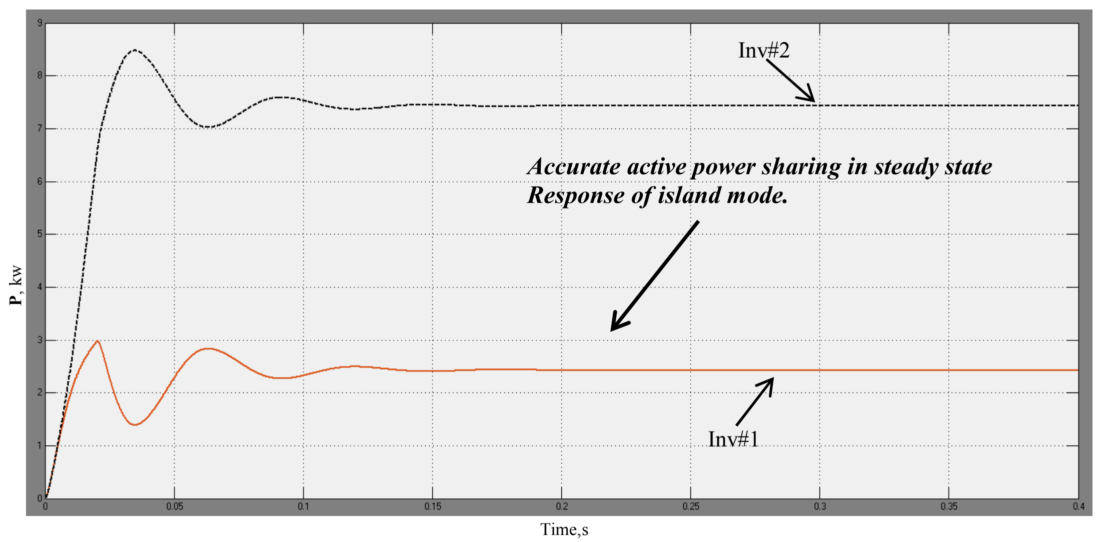


Figure 5.15: Active power of parallel inverters at Island mode

In addition to that we get a good result of sharing reactive power in case study #2 as shown in scheme 5.16.

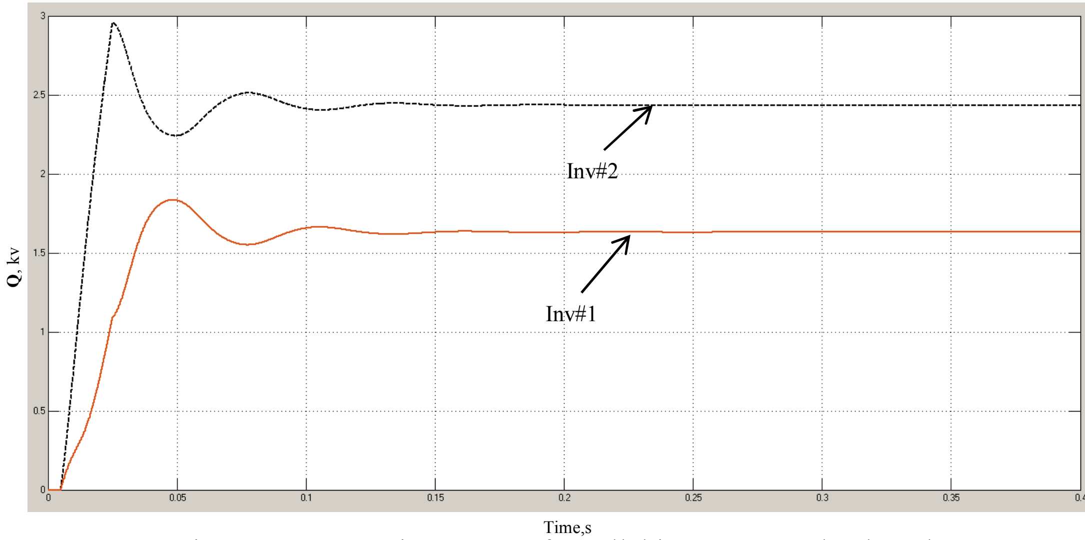


Figure 5.16: Reactive power of parallel inverters at Island mode

When we simulated the frequency of the system in island mode we will get the results as shown in figure 5.17. It seems that there is good sharing of frequency of two parallel inverters by using droop control in autonomous mode.

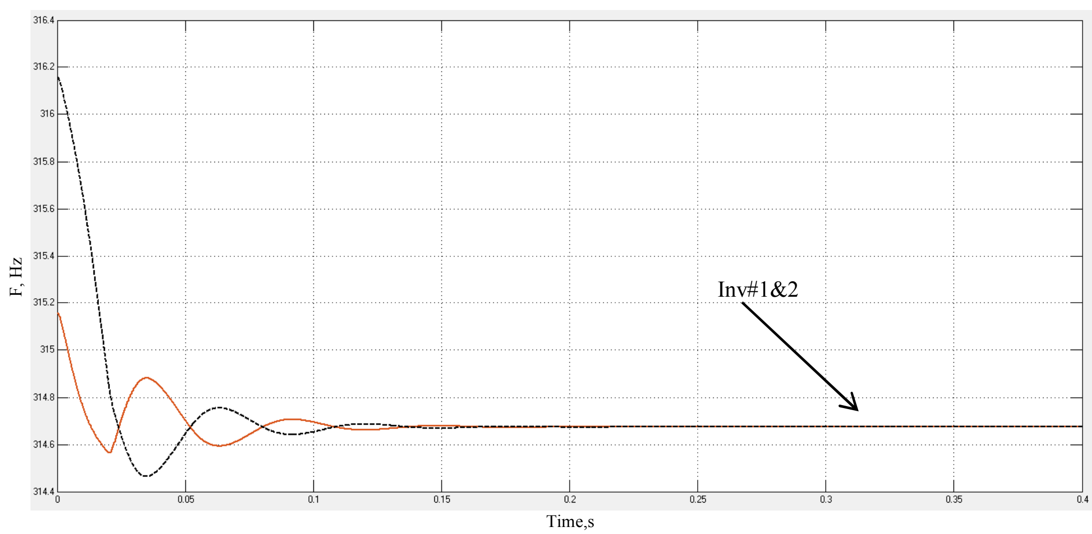


Figure 5.17: Frequency of parallel inverters at Island mode

5.4 Case study #3 of three equal parallel inverters.

In this case study we connected equal three parallel inverters to compose microgrid. Each one of the inverters has S= 30KVA as shown in figure 5.18. And we applied the parameters in the table 5.2.

Table 5.2: Droop control parameters that are used in simulation

Parameter	***Symbol***	***Value***	***Units***
Voltage grid	V_g	311	V
Frequency grid	F_g	50	Hz
Virtual Inductor #1	L_1	1	mH
Virtual Inductor #2	L_2	1.1	mH
Virtual Inductor #2	L_3	1.2	mH
Parasitic Resistor #1	r_{l1}	0.08	Ω
Parasitic Resistor #2	r_{l2}	0.08	Ω
Parasitic Resistor #2	r_{l3}	0.08	Ω
Nominal output power	S	30	KVAR
Nominal frequency	ω^*	2π*50	Rad/s
Nominal Amplitude	E^*	311	V
Active power load	P_L	10	KW
Reactive power load	Q_L	4	KVAR
Q-V droop proportional	n	3×10^{-4}	V/VAR
P- φ droop proportional	m	2×10^{-4}	Rad/W

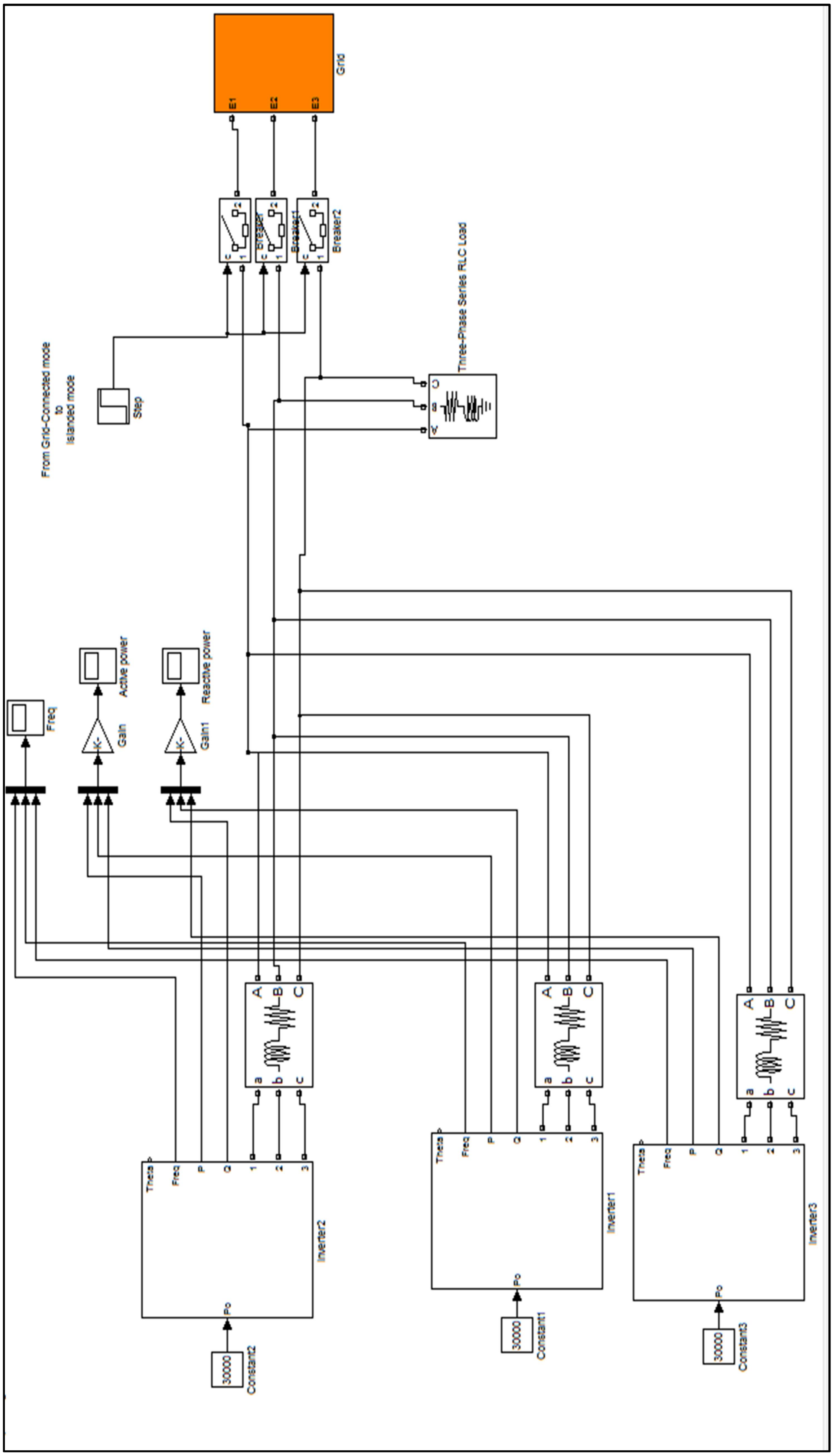


Figure 5.18: Microgrid consist of three equal parallel inverters

After we simulated the design of microgrid, we divided the results according to operation mode:

1. Transferring from grid connected mode to island mode, in this mode we get a good response of sharing active power of three parallel inverters, however we get a small signal in transient response of grid connected mode as shown in figure 5.19.

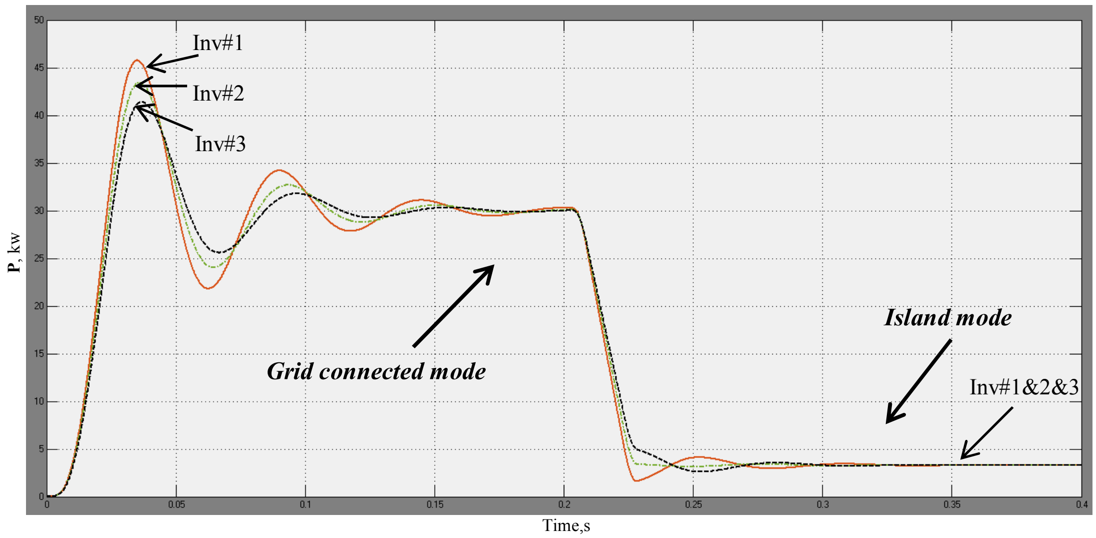


Figure 5.19: Active power sharing in transferring mode from grid connected to island mode

In addition to active power we studied sharing of reactive power on three parallel inverters and get the result in figure 5.20 as shown below. It seems from the figure that there are some small signals in transient response at grid connected mode but we have a good response in steady state at island mode and droop control achieves the seemly transfer from grid connected to island mode.

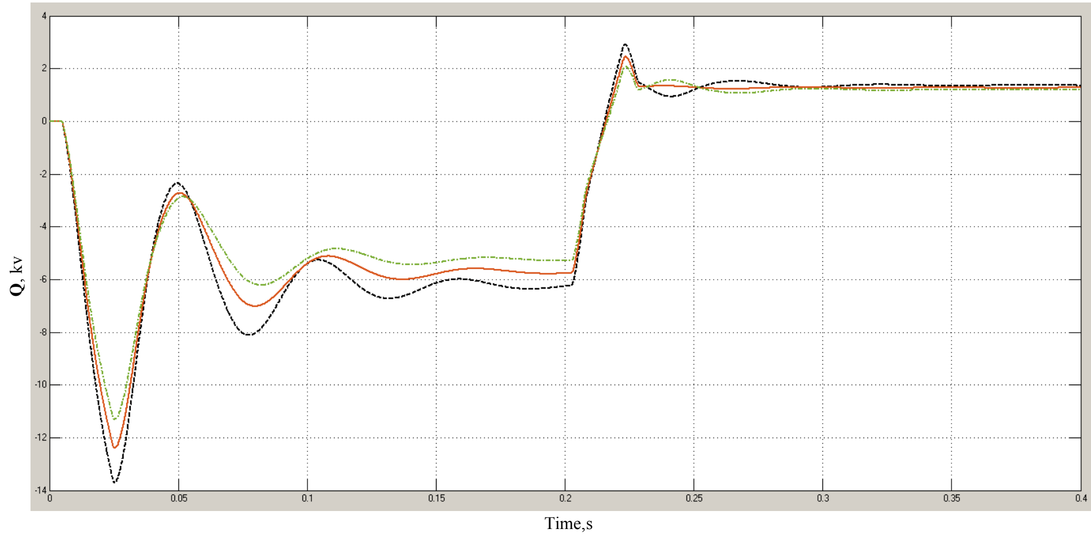


Figure 5.20: Reactive power sharing in transferring mode from grid connected to island mode

The response of frequency for three equal inverters is shown in figure 5.21 in grid connected mode and island mode. It seems there are some deviations at steady state of island mode because the control mode uses frequency to make accurate sharing of active power. However the general response of frequency is good and stable.

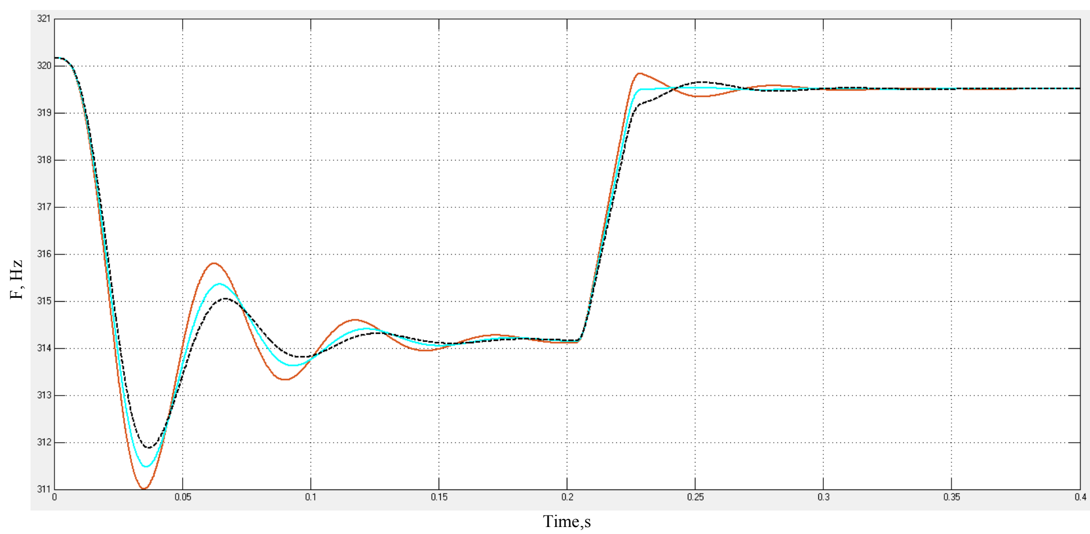


Figure 5.21: Frequency sharing in transferring mode from grid connected to island mode

2. Grid connected mode, in this mode we have accurate sharing for active power of three equal parallel inverters at steady state, however we get a small signal at transient response as shown in figure 5.22. In case of reactive power sharing at grid connected mode we get a good sharing without achieve accurate sharing of

reactive power as shown in figure 5.23. in addition to that we simulated the frequency and we get the same results of case study #1 with small signal generated overshoot and good frequency sharing response.

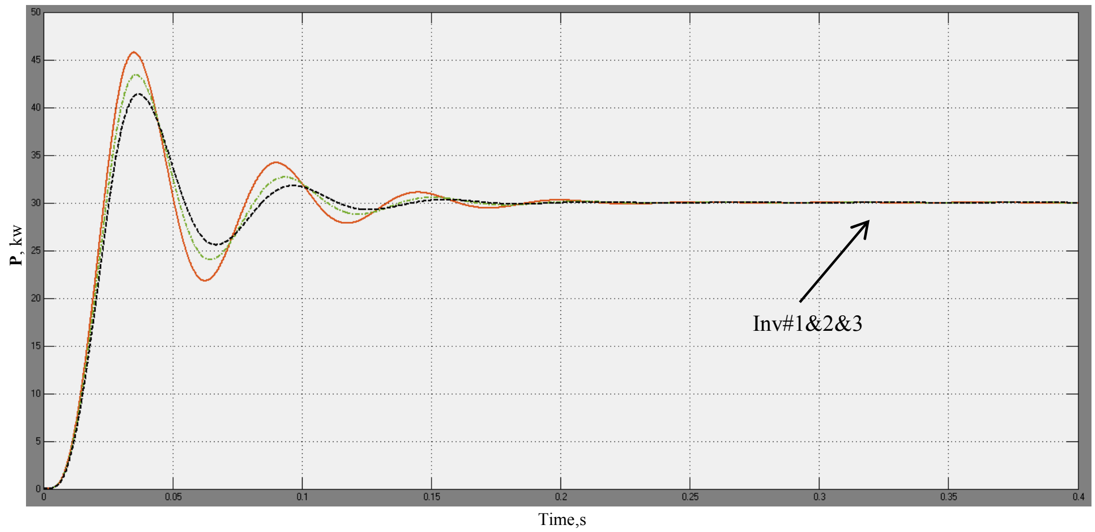


Figure 5. 22: Active power sharing of three equal inverters in grid connected mode

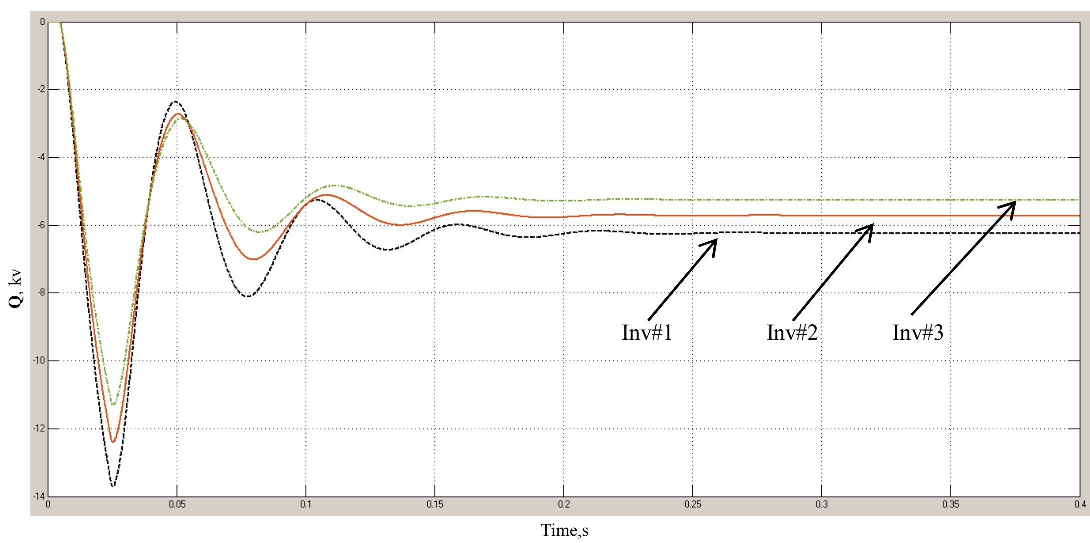


Figure 5.23: Reactive power sharing of three equal inverters in grid connected mode

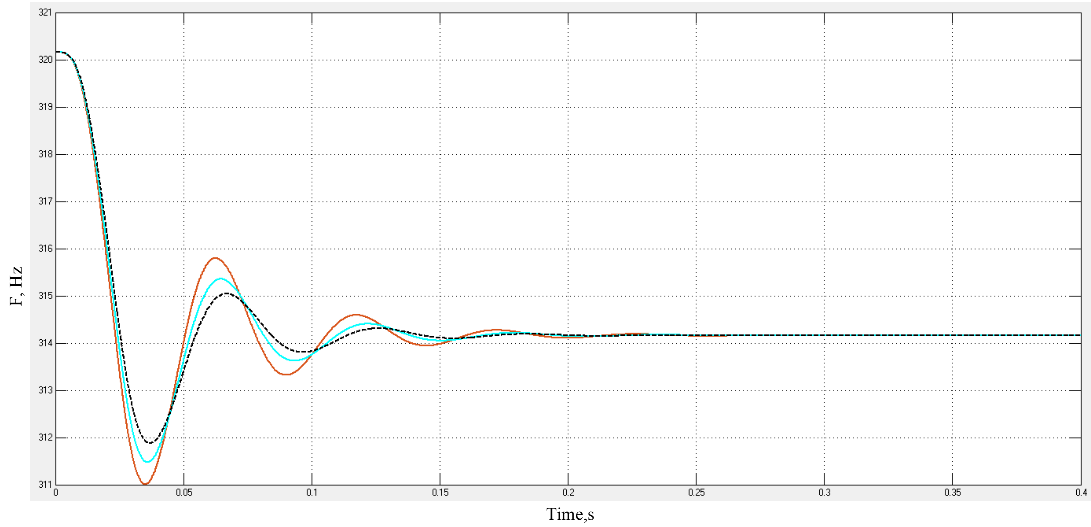


Figure 5.24: Frequency sharing of three equal inverters in grid connected mode

3. Island mode; in this mode we get accurate sharing of active power for three equal inverters as shown in figure 5.23 without overshoot and every inverter has the same active power of the another with 3.33KW achieving the total power 10KW. In case of reactive power droop control don't achieve accurate reactive power as shown in figure 5.24. The first inverter has 1.2KVAR, the second inverter 1.3KVAR and the third with nearly 1.4KVAR. The $Q_{total} \approx 3.9$KVAR. The frequency has a good response in island mode without overshoot with some deviations in values because the droop control uses the frequency to make active power sharing between the inverters.

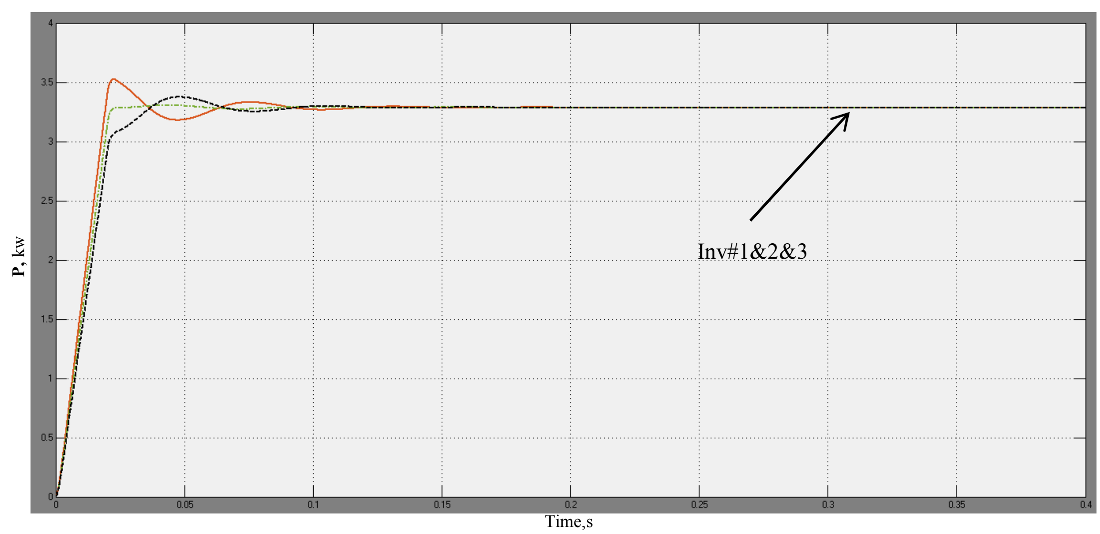


Figure 5.25: Active sharing of three equal inverters in island mode

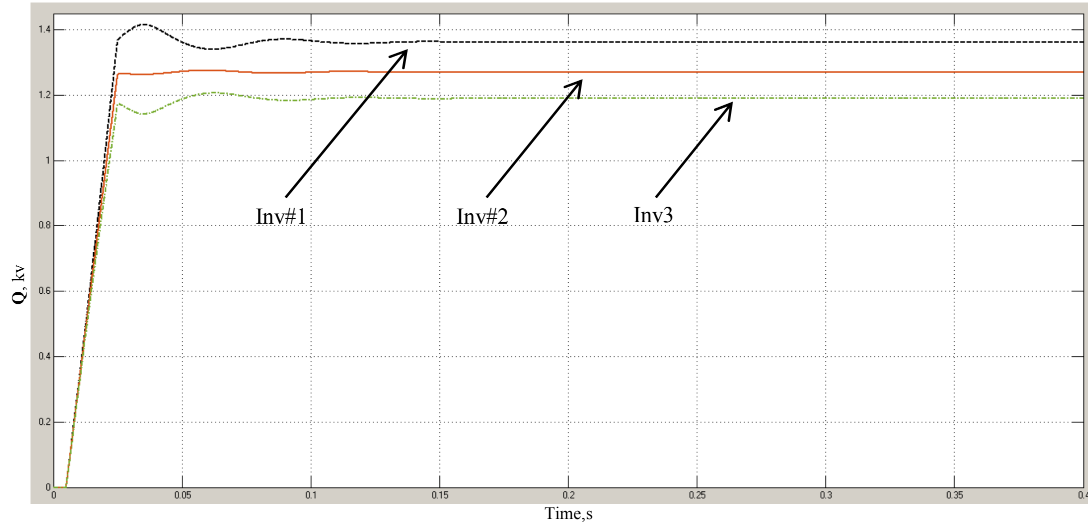


Figure 5.26: Reactive sharing of three equal inverters in island mode

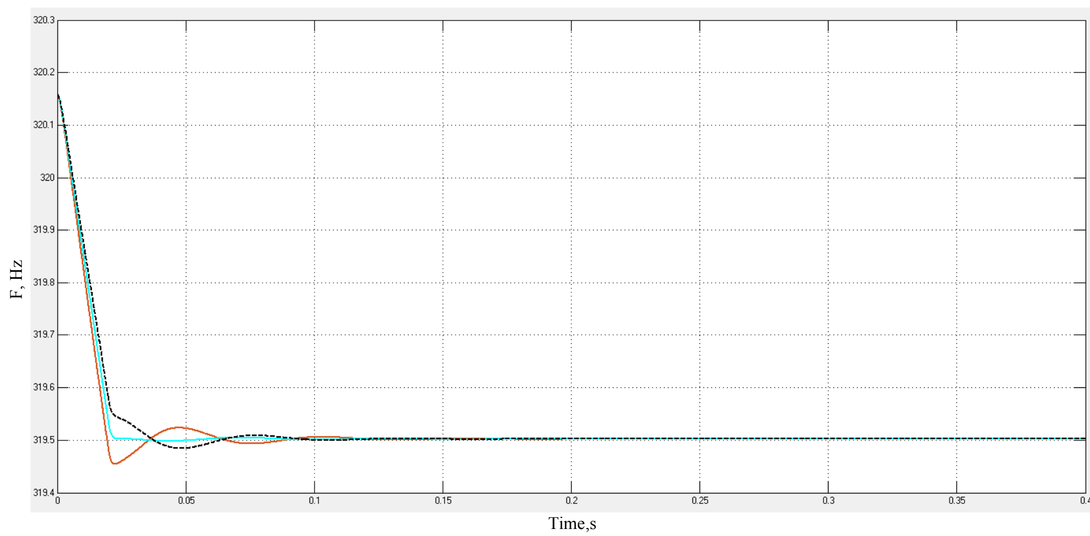


Figure 5.27: Frequency response of three equal inverters in island mode

5.5 Case Study #4 of two equal parallel inverters with PID controller

In case study #1we sees that droop control can make accurate active power sharing in three modes of two equal parallel inverters but the response has a small signal (overshoot) in grid connected mode and this overshoot may reduce the lifetime of inverters or in some times may burn the inverters. For this reason we try in this case study to improve droop control technique by applying PID controller with it. In this case we modify case study #1 to get more efficient results. To remove overshoot in transient response of grid connected mode we can design PD or PID controller. However PD controller effects on steady state of island mode, then we will not get accurate sharing of active power. For this reason we designed PID controller as shown in equation 5.1 and simulated the designed microgrid consists of two equal parallel inverters like in case study #1 with parameters in table 5.3 we get the results as shown in figure 5.26 in transferring mode from grid connected to island mode. As shown in figure 5.26 PID controller removes the over shoot at grid connected mode and save the steady state results accurate at island mode. At figure 5.27 illustrates the grid connected mode of active power sharing without overshoot and accurate active power sharing. At figure 5.28 we can notice that PID with droop control achieves accurate active power sharing at autonomous mode.

$$PID = 2 \times 10^{-4} \left[\frac{S + 5 \times 10^{-7}}{S + 10^{-4}} \right] \tag{5.1}$$

Table 5.3: Droop control and PID parameters of case study #1

Parameter	***Symbol***	***Value***	***Units***
Voltage grid	V_g	311	V
Frequency grid	F_g	50	Hz
Virtual Inductor #1	L_1	1	mH
Virtual Inductor #2	L_2	1.1	mH
Parasitic Resistor #1	r_{l1}	0.08	Ω
Parasitic Resistor #2	r_{l2}	0.08	Ω
Nominal output power	S	30	KVAR
Nominal frequency	ω^*	2π*50	Rad/s
Nominal Amplitude	E^*	311	V
Active power load	P_L	10	KW
Reactive power load	Q_L	4	KVAR
P- φ droop integral	m	1×10^{-4}	Rad/(W-s)
P- φ droop proportional	m_p	2×10^{-4}	Rad/W
P- φ droop derivative	m_d	5×10^{-7}	(rad-s)/W

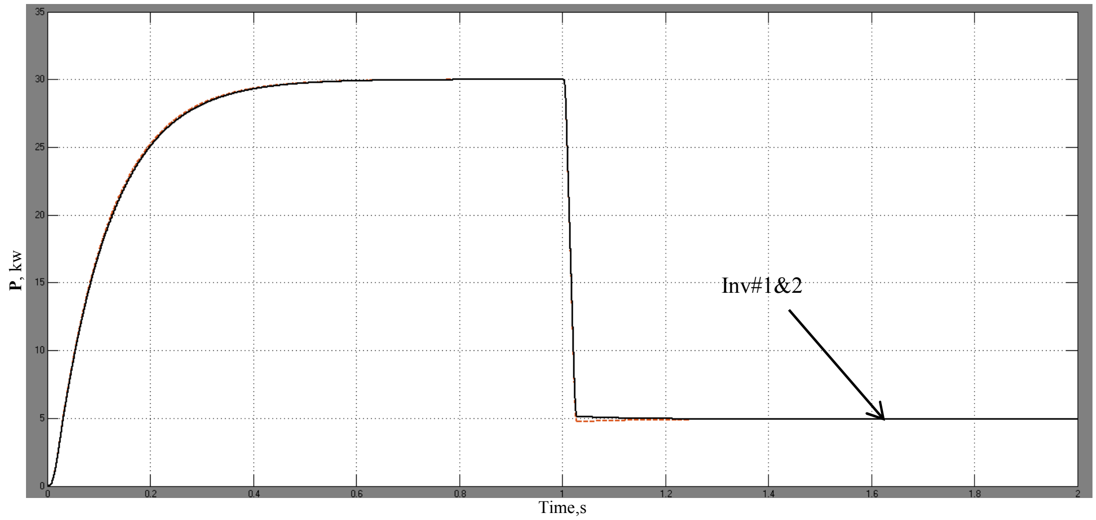


Figure 5.28: Active power sharing at transferring from grid connected mode to island mode

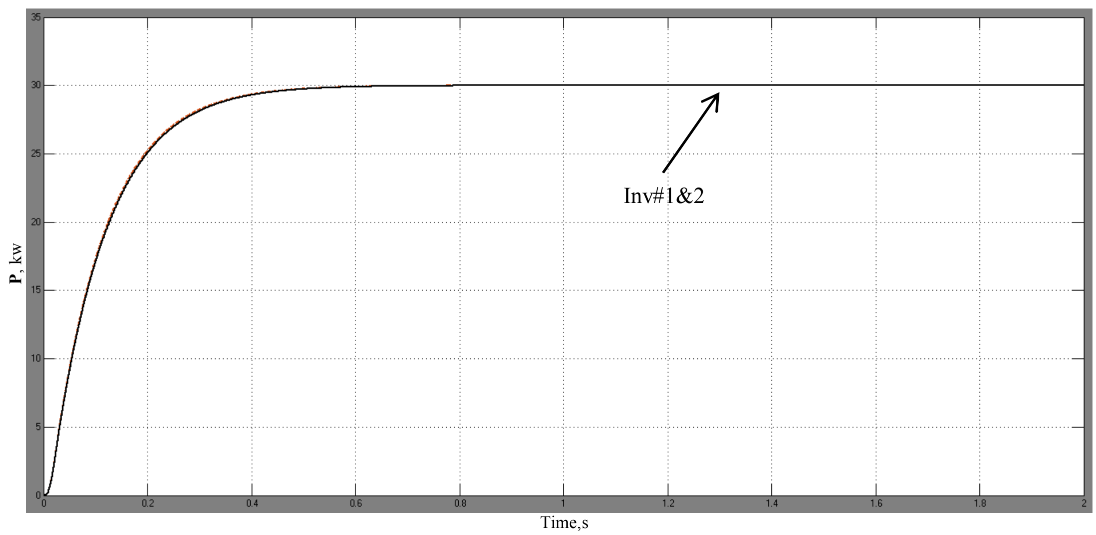


Figure 5.29: Active power sharing of two equal parallel inverters at grid connected mode

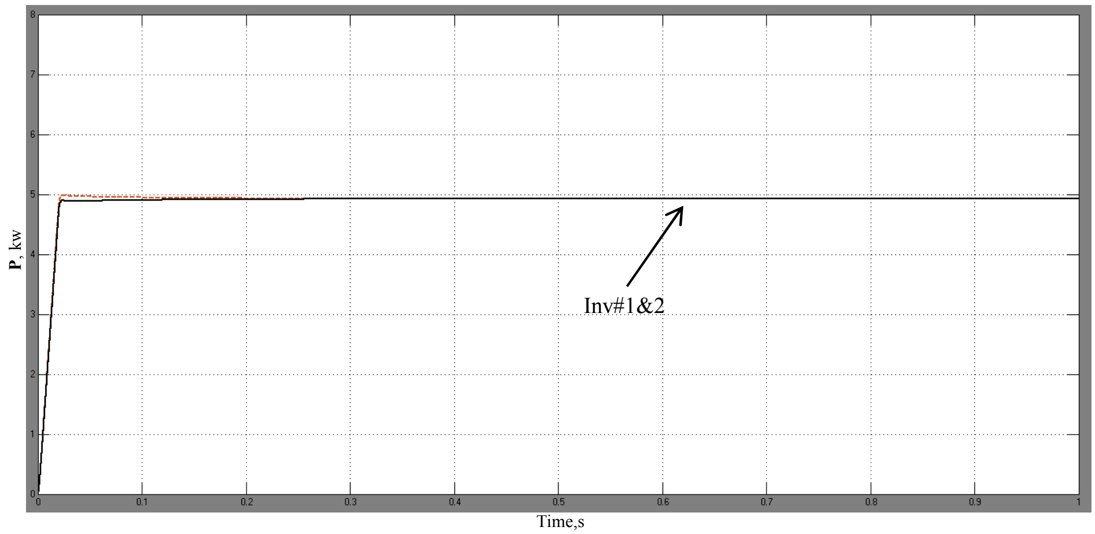


Figure 5.30: Active power sharing of two equal parallel inverters at island mode

As shown in case study #1 reactive power sharing has small signal in transient response of grid connected mode in addition to that droop control can't achieve accurate reactive power sharing at island mode. For these reasons we tried to design adaptive droop control by adding PID control to remove overshoot at grid connected mode and get more accurate sharing at autonomous mode. By uses PID controller as shown in equation 5.2 with the parameters at table 5.4 we get the results as shown in figure 5.29 without overshoot at grid connected and accurate reactive power at island mode. Figure 5.30 illustrates the response of reactive power sharing of two equal parallel inverters at grid connected mode without any small signals at transient response and good sharing of reactive power. Figure 5.31 shows reactive power sharing of two equal parallel inverters at island mode with more accurate sharing without overshoot because it is improved by designed PID controller.

$$PID = 3 \times 10^{-4} \left[\frac{S + 5 \times 10^{-7}}{S + 10^{-4}} \right] \tag{5.2}$$

Table 5.4: Droop control and PID parameters of case study #5

Parameter	***Symbol***	***Value***	***Units***
Voltage grid	V_g	311	V
Frequency grid	F_g	50	Hz
Virtual Inductor #1	L_1	1	mH
Virtual Inductor #2	L_2	1.1	mH
Virtual Inductor #2	L_3	1.2	mH
Parasitic Resistor #1	r_{l1}	0.08	Ω
Parasitic Resistor #2	r_{l2}	0.08	Ω
Parasitic Resistor #2	r_{l3}	0.08	Ω
Nominal output power	S	30	KVAR
Nominal frequency	ω^*	2π*50	Rad/s
Nominal Amplitude	E^*	311	V
Active power load	P_L	10	KW
Reactive power load	Q_L	4	KVAR
Q-V droop proportional	n_p	3×10^{-4}	V/VAR
Q-V droop Integral	n	1×10^{-4}	Rad/Var.s
Q-V droop Derivative	n_d	5×10^{-7}	V.s/Var

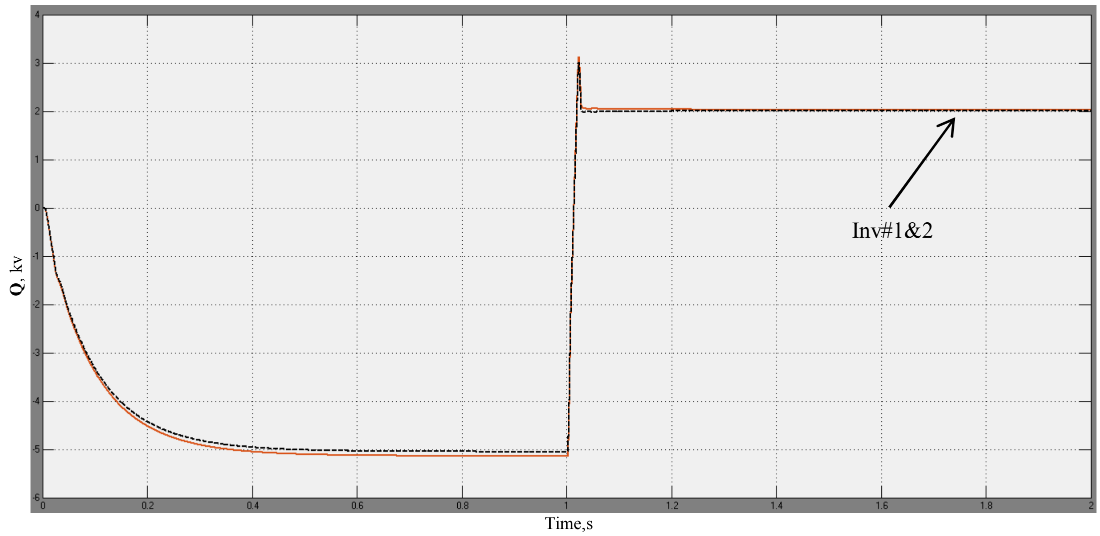


Figure 5.31: Reactive power sharing of two equal parallel inverters at transferring mode

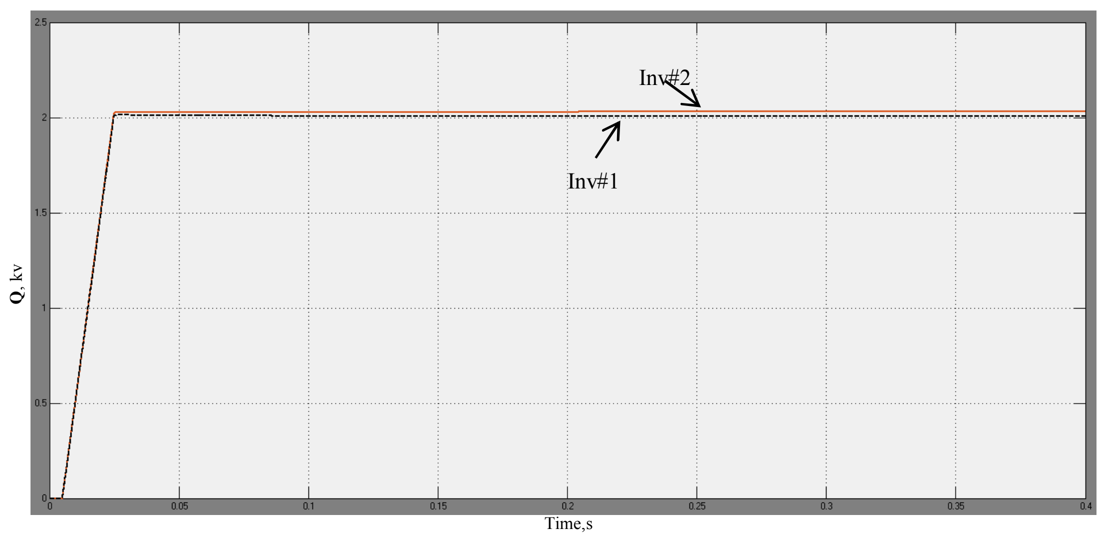


Figure 5. 32: Reactive power sharing of two equal parallel inverters at Island mode

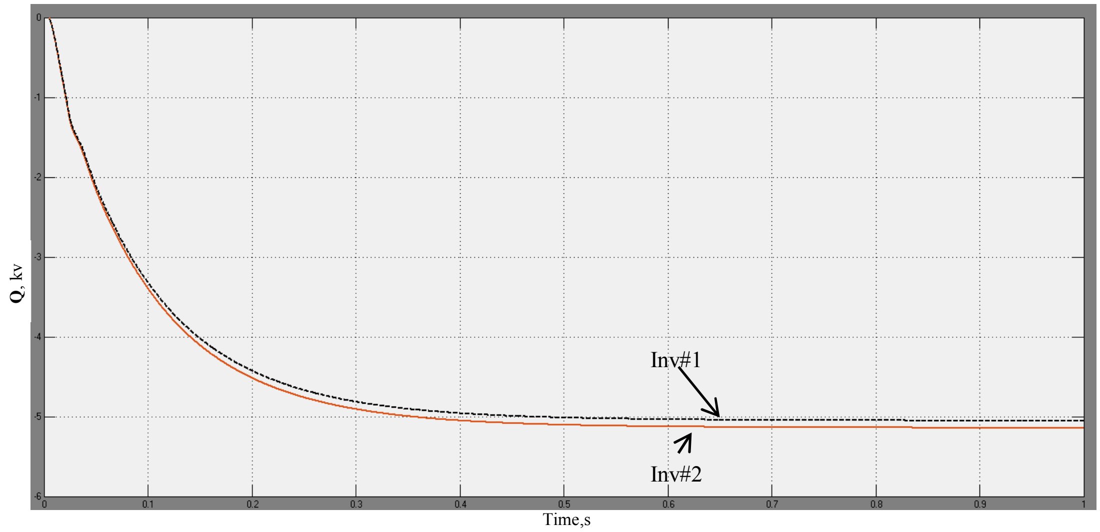


Figure 5. 33: Reactive power sharing of two equal parallel inverters at grid connected mode

5.6 Case study #5 of two parallel inverters with power of one is half of another with PID controller.

In case study #2 we sees that droop control can make accurate active power sharing in three modes of two equal parallel inverters but the response has a small signal (overshoot) in grid connected mode and this overshoot may reduce the lifetime of inverters or in some times may burn the inverters. For this reason we try in this case study to improve droop control technique by applying PID controller with it. In this case we modify case study #2 to get more efficient results. We use the same PID controllers in equations 5.1 and 5.2 and have accurate reactive and reactive power sharing as shown in figures in the next pages:

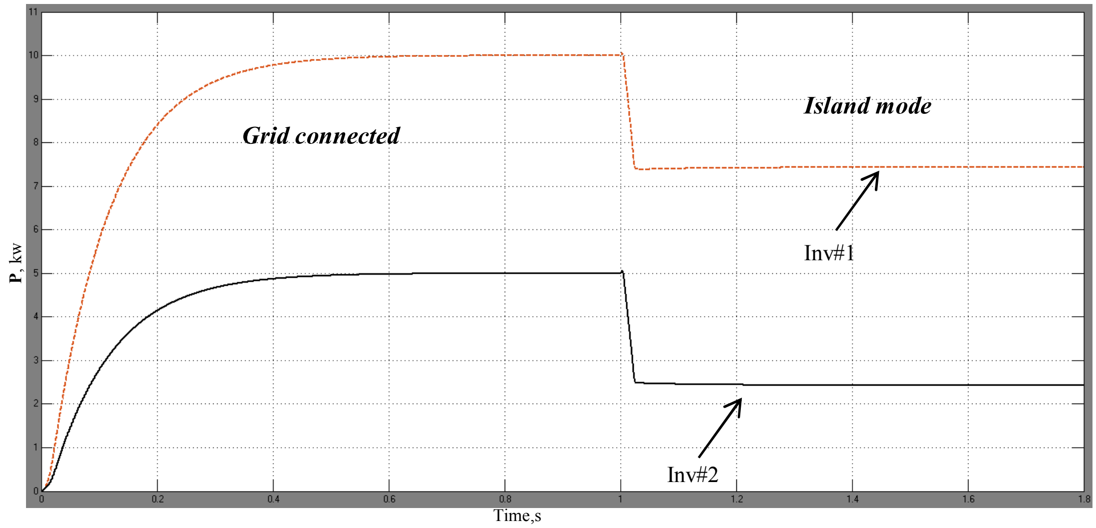


Figure 5.34: Active power sharing at transferring mode from grid connected mode to island mode

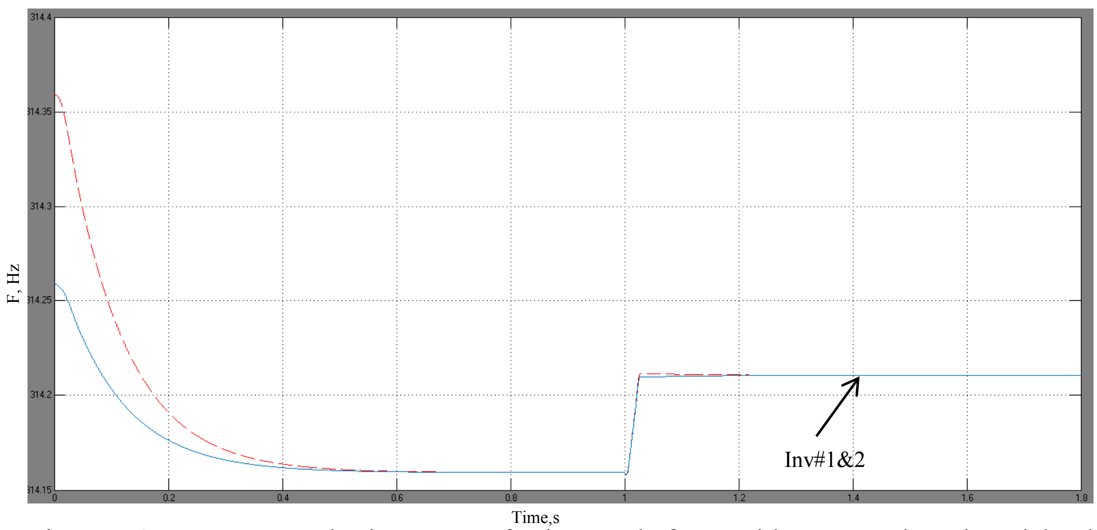


Figure 5.35: Frequency sharing at transferring mode from grid connected mode to island mode

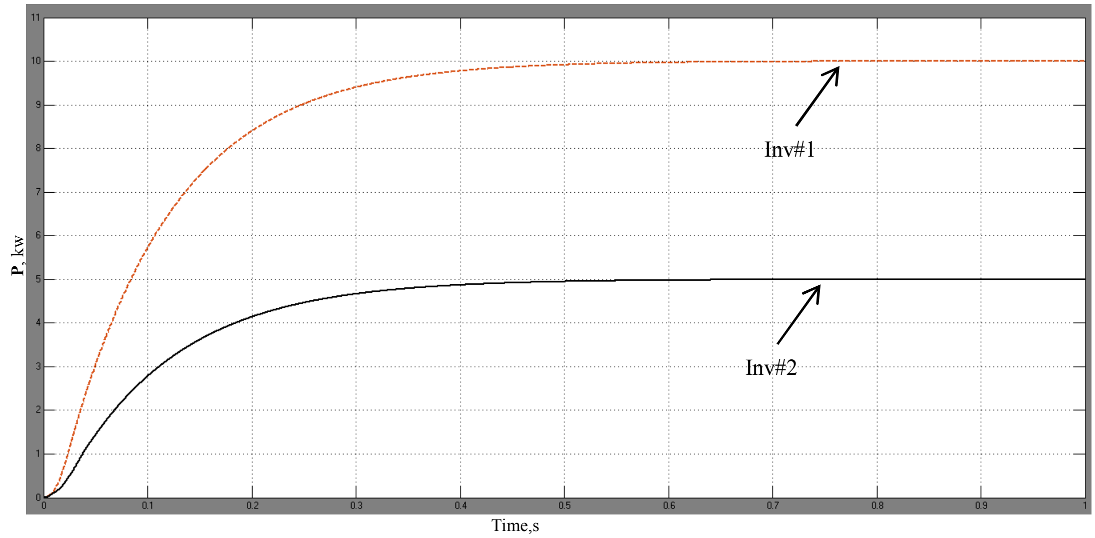


Figure 5.36: Active power sharing at grid connected mode

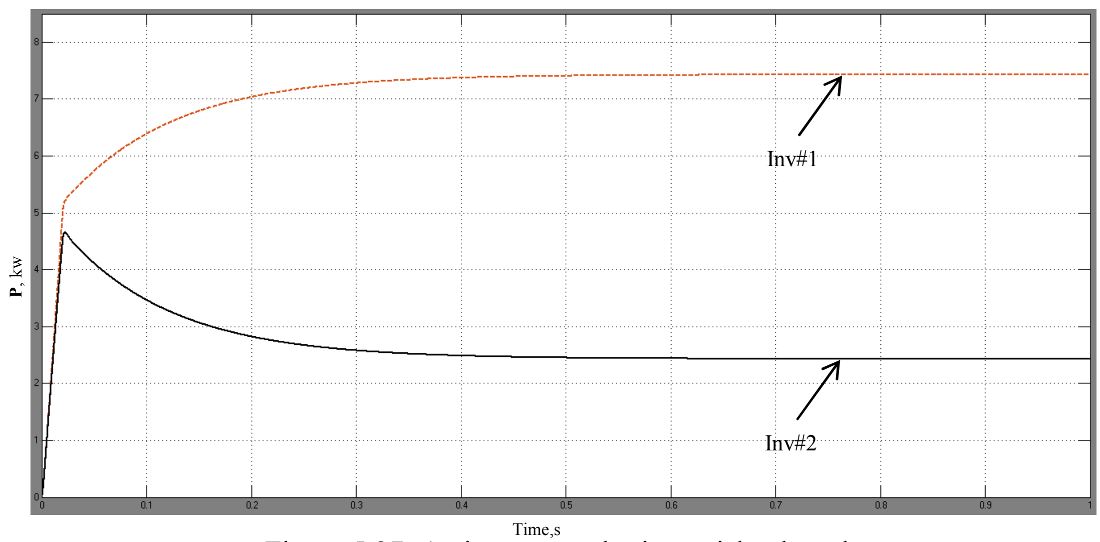


Figure 5.37: Active power sharing at island mode

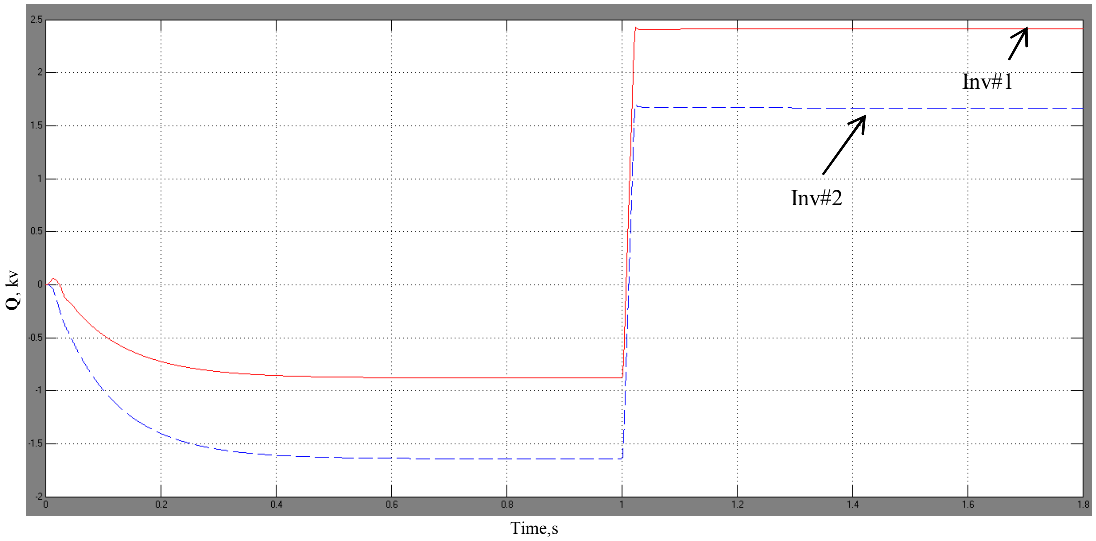


Figure 5.38: Reactive power sharing at transferring mode from grid connected to island mode

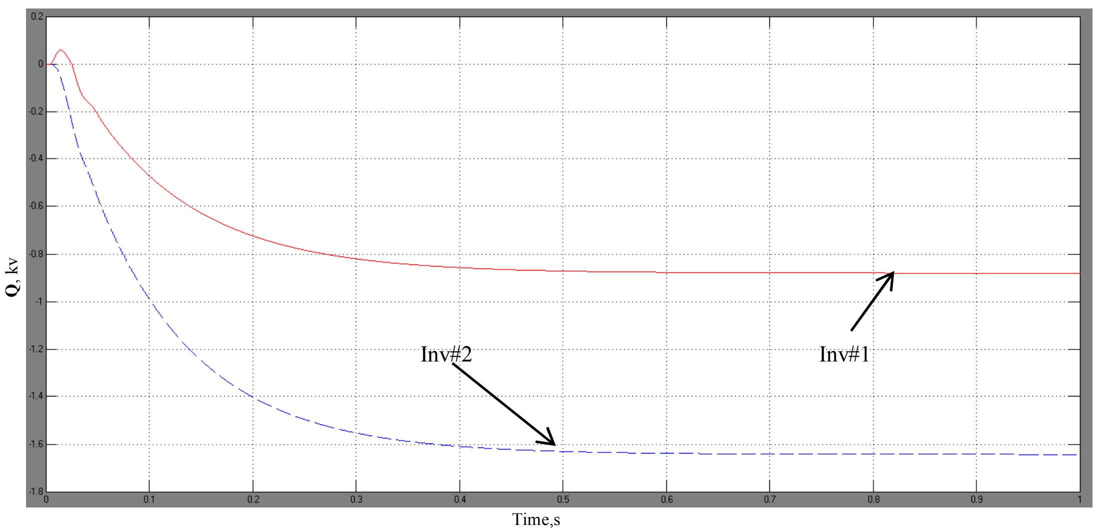


Figure 5.39: Reactive power sharing at grid connected mode

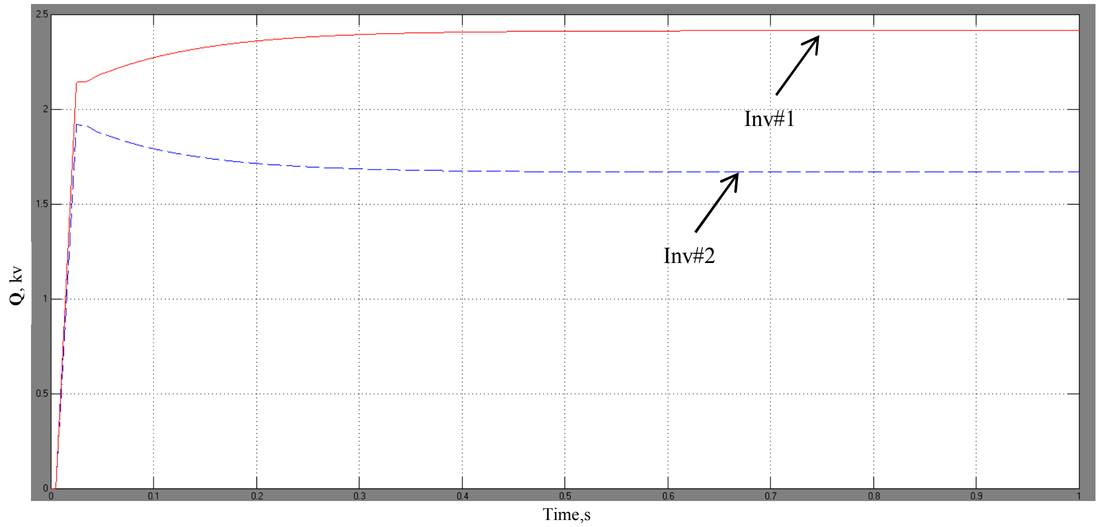


Figure 5.40: Reactive power sharing at island mode

5.7 Case study #6 of three parallel inverters with PID controller.

In this case study we modify the droop controller in case study #3 by adding PID controller with droop method to get more accurate active and reactive power sharing as shown in results below:

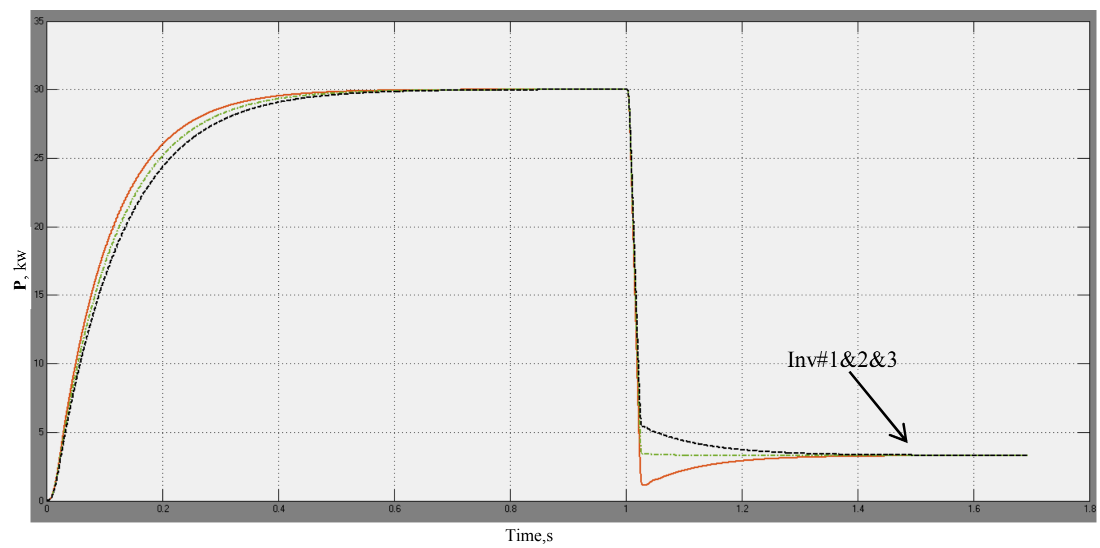


Figure 5.41: Active power sharing at transferring mode

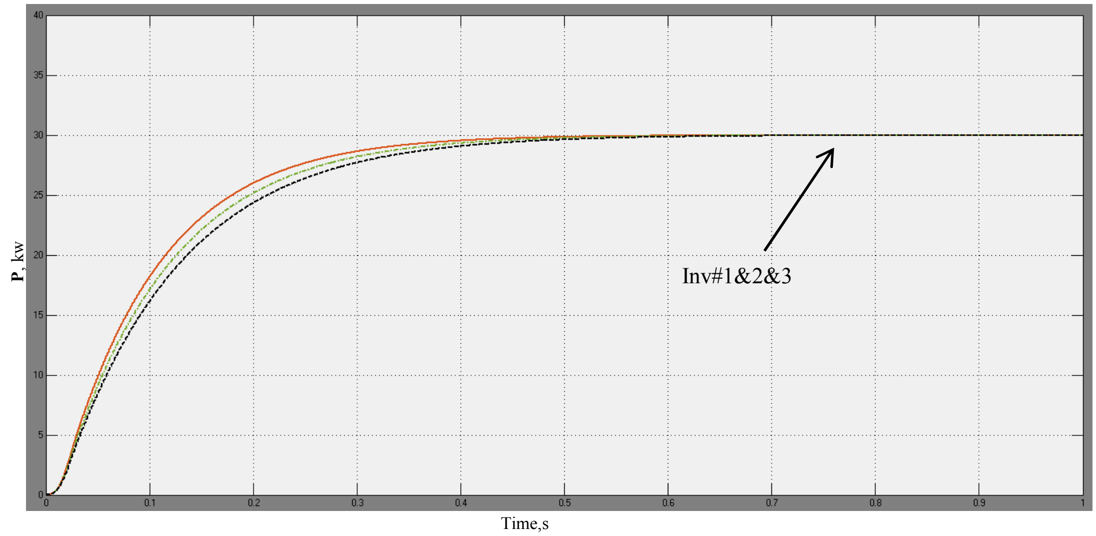


Figure 5.42: Active power sharing at grid connected mode

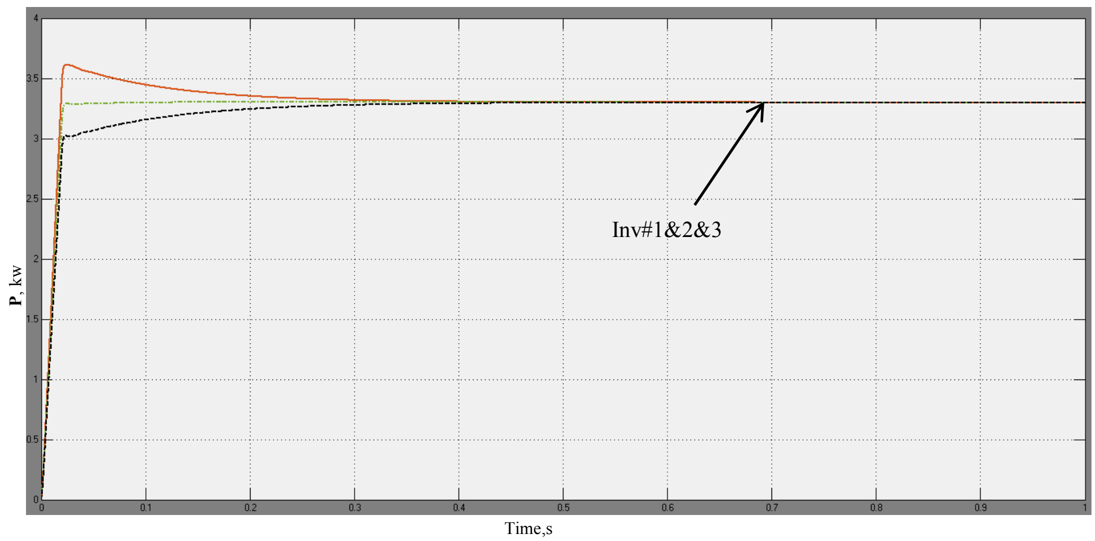


Figure 5.43: Active power sharing at island mode

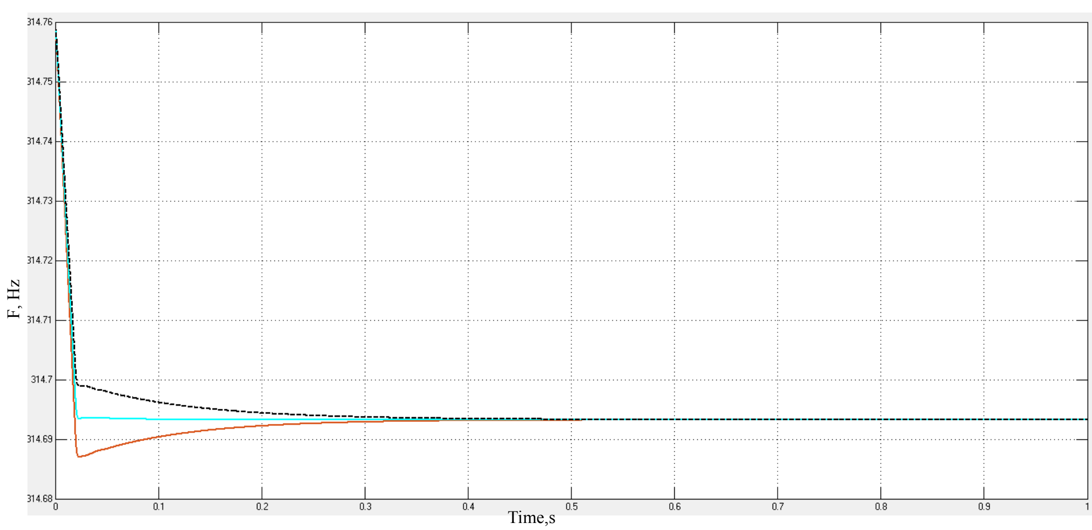


Figure 5.44: Frequency sharing at island mode

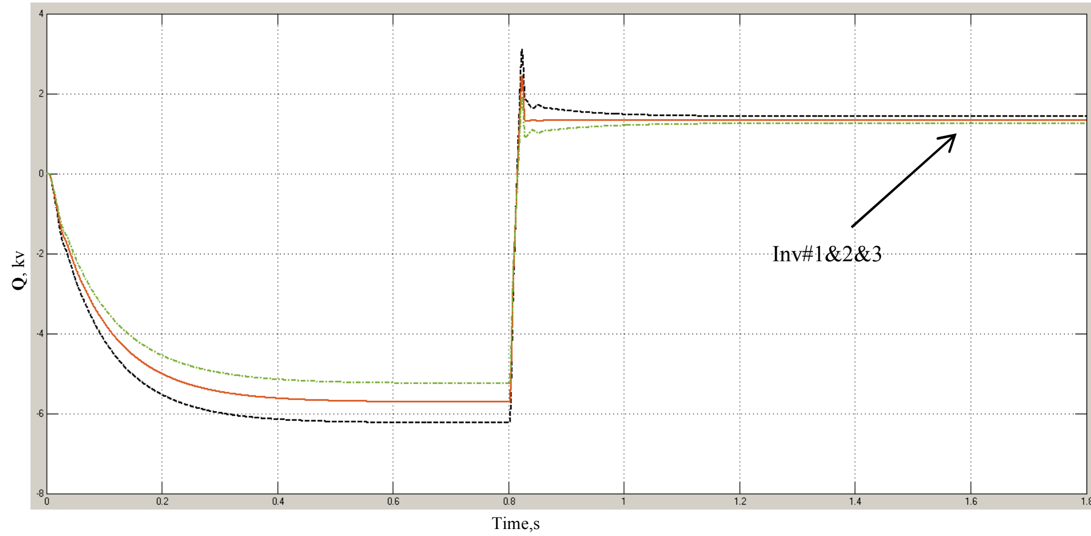


Figure 5.45: Reactive sharing at transferring mode

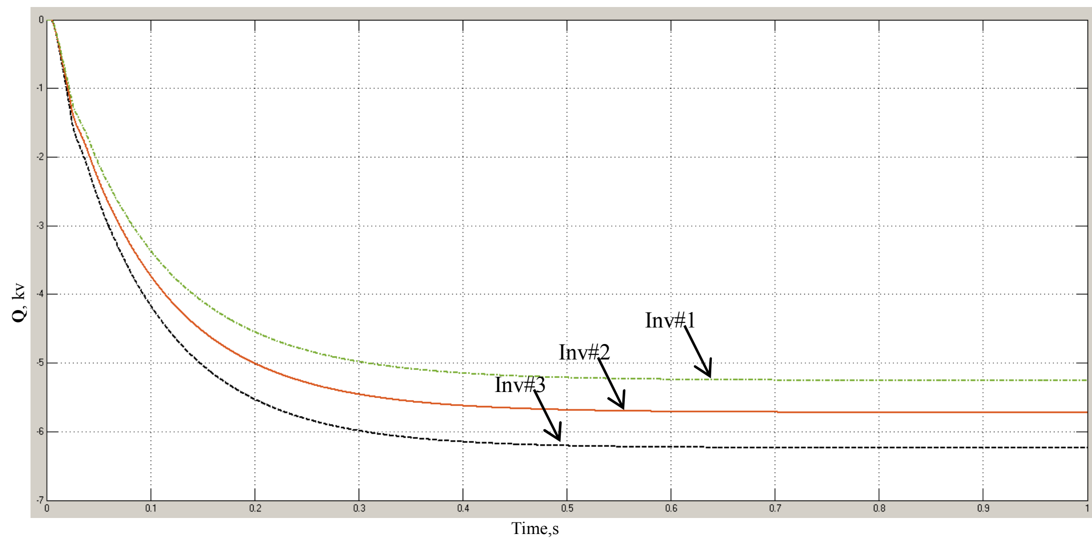


Figure 5.46: Reactive sharing at grid connected mode

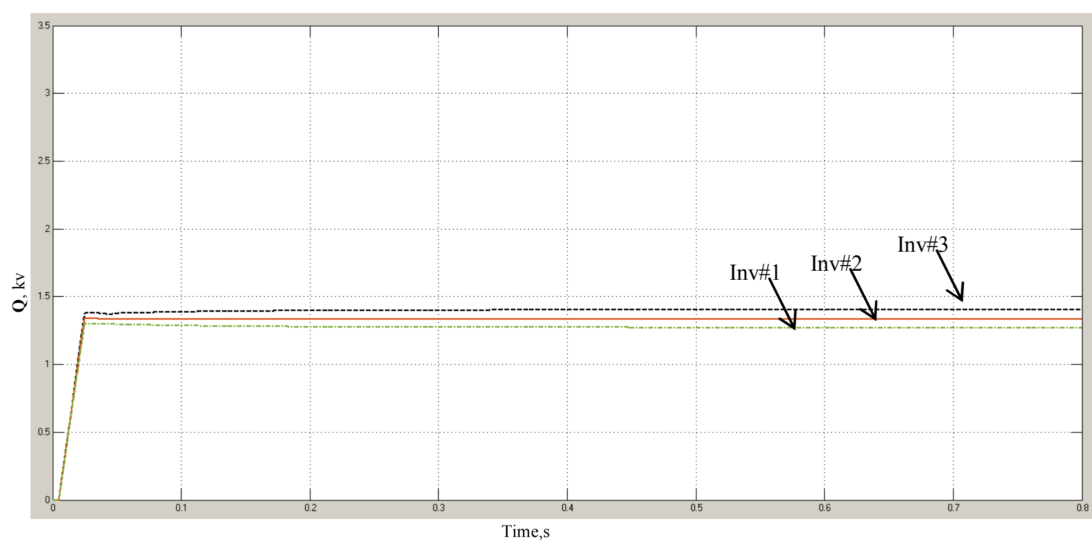


Figure 5.47: Reactive sharing at island mode

CHAPTER 6

CONCLUSION AND FUTURE WORKS

Finally in this chapter, the conclusions derived from this dissertation thesis are presented.

From the discussion in previous chapters, it can be seen that micro-grid is the future grid for power systems. Using micro-grid in distribution power systems will be let to integrate distributed energy resources such as (wind turbines, PV, fuel cells, etc.) in the grid. Integration these alternative sources will decrease the greenhouse gases from the atmosphere, reduce dependence on fossil fuels and interface remote villages with power grid more easily and reliability. Start to inject and use MG needs to solve problems resulting from power sharing on the inverters. So this thesis offers the best way to solve this problem and review the control strategies of parallel operation of DG inverters. From these Techniques droop control strategy are explained with using active power filters (APFs) for harmonic voltage and current compensation in design.

From the inverter control strategies it is found that active load sharing control techniques have some limitations. Due to intercommunication requirement between the inverters, control complexity is significant. Although active load sharing techniques for parallel operation of a fixed number of inverters can be better due to its robust control, expansion of capacity due to the supplemental load may not be easy. On the other hand, droop control seems better for most purposes. Research indicates that most efforts are being put into droop control techniques due to its capacity expansion flexibility, independent inverters and hot-swap facilities. Active and reactive power sharing of the distributed inverters operating in parallel has been explained. It has been assumed that there is no communication between the inverters. Each inverter has its own control unit, and these controllers share the active and reactive power demanded by the load in proportion with their rated powers. This system provides flexibility for the units or loads to be added to or removed from the network. Furthermore, this structure makes it possible to use inverters with different ratings together, without overloading them.

In this thesis the droop control is modified by using PID controller to give more accurate active and reactive power sharing and we achieved good active and reactive power sharing as reviewed in previous chapter. But we advise to use in future more solutions to modify droop control such as **Angle droop controller** and **External supplementary loops**. Today these techniques are taken a lot of attention from researchers to use them with droop control method and get more and more accurate power sharing on inverters.

The tables below conclude the features of power sharing by using droop controller and comparing these results with adding PID controller with droop method.

Table 6.1: Active power sharing and comparing the results between different case studies

Island Mode	***Case study# 1***	***Case study# 2***	***Case study# 3***	***Case study# 4***	***Case study# 5***	***Case study# 6***
P1(KW)	*4.95*	*7.4*	*3.33*	*5*	*7.5*	*3.33*
P2(KW)	*4.95*	*2.6*	*3.33*	*5*	*2.5*	*3.33*
P3(KW)	-	-	*3.33*	-	-	*3.33*
Grid-Mode	***Case study# 1***	***Case study# 2***	***Case study# 3***	***Case study# 4***	***Case study# 5***	***Case study# 6***
P1(KW)	*30*	*10*	*31*	*30*	*10*	*30*
P2(KW)	*30*	*5*	*29*	*30*	*5*	*30*
P3(KW)	-	-	*30*	-	-	*30*

Table 6.2: Comparison of reactive power results and other parameters between case studies

Island Mode	Case study# 1	Case study# 2	Case study# 3	Case study# 4	Case study# 5	Case study# 6
Q1(KW)	2	2.3	1.39	2	2.4	1.4
Q2(KW)	1.85	1.7	1.25	2	1.6	1.35
Q3(KW)	-	-	1.2	-	-	1.25
Overshoot % of P at transient response	50	40	46.6	0 (over-damped)	0 (over-damped)	0 (over-damped)
Ts of active power at grid-connected (s)	0.13	0.11	0.12	0.4	0.4	0.4
Ts of active power at Island mode (s)	0.05	0.09	0.05	0.01	0.01	0.01
Ts of reactive power at grid-connected(s)	0.13	0.12	0.13	0.3	0.3	0.3
Ts of reactive power at island Mode(s)	0.03	0.06	0.04	0.02	0.02	0.02

REFERENCES

[1] Mohd A., Ortjohann E., Morton D., Omari O.,(2010), "Review of control techniques for inverters parallel operation", Electric Power Systems Research, 80:1477-1487.

[2] Trends in photovoltaic applications, (2007), "Survey report of selected IEA countries between 1992 and 2006", Rep. IEA-No:16, Sweden.

[3] Vasquez, J.C., Guerrero, J.M., Miret, J., Castilla, M., de Vicuña, L.G., (2010). "Hierarchical Control of Intelligent Microgrids", Industrial Electronics Magazine,IEEE,4:23-29.

[4] Vandoorn, T.L., Renders, B., Meersman, B., Degroote, L., Vandevelde, L., (2010), "Reactive Power Sharing in an islanded microgrid", Universities Power Engineering Conference (UPEC), 1-6.

[5] Khadem S.K, Basu M, Conlon M.F., (2011), "Parallel operation of inverters and active power filters in distributed generation system—A review", Renewable and Sustainable Energy Reviews, 15:5155-5168.

[6] Lasseter, R.H., (2002), "MicroGrids," Power Engineering Society Winter Meeting, IEEE, 1:305-308.

[7] Lasseter, R.H., (2006), "Autonomous control of microgrids," Power Engineering Society General Meeting,. IEEE , 8:255-261.

[8] Gungor, V.C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C., Hancke, G.P., (2011), "Smart Grid Technologies: Communication Technologies and Standards", Industrial Informatics, IEEE Transactions, 7:529:539.

[9] Panajotovic, B., Jankovic, M., Odadzic, B., (2011), "ICT and smart grid," Telecommunication in Modern Satellite Cable and Broadcasting Services (TELSIKS), 1:118-121.

[10] Odadzic B., Panajotovic B. and Jankovic M., (2011), "Telecommunication Hybrid Power System in Smart Grid", InfoTeh Conference, Jahorina.

[11] Hartono, B.S., Budiyanto, Y., Setiabudy, R.,(2013), "Review of microgrid technology", QiR (Quality in Research), International Conference on , 5:127,132, 25-28.

[12] Driesen, J., Katiraei F., (2008),"Design for distributed energy resources," Power and Energy Magazine, IEEE , 6:30-40.

[13] Schwaegerl C.,(2009), “Advanced Architectures and Control Concepts for More Microgrids”, Report on the technical, social, economic, and environmental benefits provided by Microgrids on power system operation.

[14] Tsikalakis A., Hatziargyriou N., (2008), “Centralized Control for Optimizing Microgrids Operation”, IEEE Trans. on Energy Conversion, 23:241-248.

[15] Piagi, P., Lasseter R.H.,(2006),"Autonomous control of microgrids," Power Engineering Society General Meeting, IEEE, 4:255-231.

[16] Illindala M., Siddiqui A., Venkataramanan G., Marnay C., (2007), “Localized Aggregation of Diverse Energy Sources for Rural Electrification Using Microgrids”, Journal of Energy Engineering, 121-131 .

[17] Hartono B.S., Budiyanto Y., Setiabudy R.,(2013), "Review of microgrid technology", QiR (Quality in Research), International Conference,127,132, 25-28.

[18] Acevedo S.S., Molinas M.,(2011), "Power electronics modeling fidelity: Impact on stability estimate of micro-grid systems”, Innovative Smart Grid Technologies Asia (ISGT), 1-8, 13-16.

[19] Kaygusuz A., Keles C., Baykant Alagoz B., Karabiber A.,(2013), “Renewable energy integration for smart sites”, Energy and Buildings, 64:456-462.

[20] Alagoz B.B. , Kaygusuz A. , Karabiber A. ,(2012), “A user-mode distributed energy management architecture for smart grid applications”, Energy ,44:167–177.

[21] Arnold J., Achieving a smart energy ecosystem, Power Engineering International, http://www.powerengineeringint.com/articles/print/volume-18/issue 5/features/achieving-a-smart-energy-ecosystem.html, 01 May 2010.

[22] Farrell J., The Challenge of Reconciling a Centralized v. Decentralized Electricity System, http://www.ilsr.org/challenge-reconciling-centralized-v-decentralized-electricity-system. 17 October 2011.

[23] Energy Information Administration (EIA), International Energy Outlook 2014, http://www.eia.doe.gov/oiaf/ieo/world.html, 09 September 2014.

[24] Akorede M., Hizam H., Pouresmaeil E.,(2010), “Distributed energy resources and benefits to the environment”, Renewable and Sustainable Energy Reviews, 14: 724-734

[25] Capehart B., Distributed Energy Resources (DER), WBDG,a program of the national institute of building sciences, http://www.wbdg.org/resources/der.php#app, 23 June 2014.

[26] Ackermann T., Andersson G., Söder L.,(2001), “Distributed generation: a definition”, Electric Power Systems Research, 57: 195-204.

[27] Sharma D., Bartels R.,(1998), “Distributed electricity generation in competitive energy markets: a case study in Australia”, in: The Energy Journal Special issue: Distributed Resources: Toward a New Paradigm of the Electricity Business, The International Association for Energy Economics, Clevland, Ohio, 17–40 .

[28] Pepermans G., Driesen J. Haeseldonckx D., Belmans R., D'haeseleer W., (2005),"Distributed generation: definition, benefits and issues", Energy Policy, 33:787-798.

[29] El-Khattam W., Salama M.M.A,(2004), "Distributed generation technologies, definitions and benefits", Electric Power Systems Research, 71:119-128.

[30] Chandorkar MC, Divan DM, Adapa R.,(1993), "Control of parallel connected inverters in standalone ac supply systems", IEEE Trans Ind Appl ,29:136–43.

[31] Loh P. C., Newman M. J., Zmood D.N., and Holmes D.G.,(2003),"A comparative analisys of multiloop voltaje regulation strategies for single and three-phase ups systems", IEEE Trans. Ind. Electron, 18(5):1176–1185.

[32] Guerrero J. M., Vasquez J. C., Matas J., Sosa J. L., and de Vicuna L. G.,(2007), "Parallel operation of uninterruptible power supply systems in microgrids", In 12th Euro-pean Conference on Power Electronics and Applications (EPE'07), 1–9.

[33] Mastromauro R. Liserre A.,M., dell Aquila A., Guerrero J.M., and Vasquez J. C.,(2008)," Droop control of a multifunctional pv inverter", In IEEE International Symposium on Industrial Electronics (ISIE 08).

[34] Villeneuve P. L.,(2004),"Concerns generated by islanding", IEEE Power and Energy Magazine, 49–53, 49-53.

[35] Kawabata T. and Higashino S.,(1998), "Parallel operation of voltage source inverters", IEEE Trans. Ind. Applications, 24 (2):281–287.

[36] Chandorkar M. C. and Divan D. M.,(1993), "Control of parallel operating battery inverters in standalone ac supply system", IEEE Trans. Ind. Applications, 29:136–143.

[37] Barsali S., Ceraolo M., Pelachi P., and Polim D.,(2002), "Control techniques of dispersed generators to improve the continuity of electricity supply",In Proc. IEEE PES-Winter Meeting, 2:789–794.

[38] Vilathgamuwa D. M., Loh P.C., and Li Y.,(2006), "Protection of microgrids during utility voltage sags", IEEE Trans. Ind. Electron, 53:1427–1436.

[39] Zhang B., Wang D. W., Zhou K. L., and Wang Y.G.,(2008), "Linear phase lead com- pensation repetitive control of a cvcf pwm inverter" IEEE Trans. Ind. Electron, 55:1595–1602.

[40] Teodorescu R. and Blaabjerg F.,(2004), "Flexible control of small wind turbines with grid failure detection operating in stand-alone and grid-connected mode", IEEE Trans.Power Electron, 9:1323–1332 .

[41] Tuladhar A., Jin H., Unger T., and Mauch K.,(2000), "Control of parallel inverters in distributed ac power systems with consideration of line impedance effect", IEEE transactions on industrial electronics, 36(1):131–138.

[42] Wang C., Nehrir, M.H.,(2006), "Distributed Generation Applications of Fuel Cells", Power Systems Conference: Advanced Metering, Protection, Control, Communication, and Distributed Resources, 6:244,248, 14-17 .

[43] Laughton M.A.,(2002), "Fuel cells," Power Engineering Journal , 16(1): 37-47.

[44] Breeze P.,(2005), Fuel cells, In Power Generation Technologies, ISBN 9780750663137, Third Edition, Newnes, Oxford.

[45] Salameh Z., (2014) Chapter 2 - Photovoltaic, In Renewable Energy System Design, ISBN 9780123749918, Academic Press, Boston.

[46] Chaar L. El, lamont L.A., El Zein N.,(2011), "Review of photovoltaic technologies", Renewable and Sustainable Energy Reviews, 15: 2165-2175.

[47] Energy and Miniral Engineering, Energy in the changing world, www.e-education.psu.edu/egee401/content/p7_p5.html, 15 October 2012.

[48] Solar Magazine, Solar Server Online Portal to Solar Energy, www.solarserver.com/solarmagazin/solar-report_0509_e.html, 24 September 2009.

[49] Dixon S.L. and Hall C.A.,(2014), Chapter 10 - Wind Turbines, In Fluid Mechanics and Thermodynamics of Turbomachinery, ISBN 9780124159549 (Seventh Edition), Butterworth-Heinemann, Boston.

[50] Towler B.,(2014), Chapter 9 - Wind Energy, In The Future of Energy, ISBN 9780128010273, Academic Press, Boston.

[51] Soteris A., (2014), Chapter 13 - Wind Energy Systems, In Solar Energy Engineering, ISBN 9780123972705, (Second Edition, Academic Press, Boston.

[52] Layton J., (2014), How Stuff Works, How Wind Power Works, http://science.howstuffworks.com/environmental/green-science/wind power2.htm, 02 June 2014.

[53] Clark R., (2014), Chapter Three - Wind Turbine Components and Descriptions: Essential Components to Have a Productive, Reliable, and Safe Wind Machine, In Small Wind, ISBN 9780123859990, Academic Press, Boston.

[54] Dincer I., and Zamfirescu C.,(2014), Chapter 7 - Renewable-Energy-Based Power Generating Systems, In Advanced Power Generation Systems, ISBN 9780123838605, Elsevier, Boston.

[55] Breeze P.,(2014), Chapter 15 - Biomass-based Power Generation, In Power Generation Technologies, ISBN 9780080983301, (Second Edition), Newnes, Boston.

[56] Salameh Z., (2014), Chapter 5 - Emerging Renewable Energy Sources, In Renewable Energy System Design, ISBN 9780123749918, Academic Press, Boston.

[57] Scott W.G.,(1998), "Micro-Turbine Generators for Distribution Systems" IEEE Industry Applications Magazine,5:350-361.

[58] Salameh Z., (2014), Energy Storage, In Renewable Energy System Design, ISBN 9780123749918, Academic Press, Boston.

[59] Blaabjerg F., Chen Z., and Kjaer S. B., (2004),"Power electronics as efficient interface in dispersed power generation systems", IEEE Transaction on Power Electronics, 19(5): 1184-1194.

[60] McDowall J. A.,(2001), “Opportunities for electricity storage in distributed generation and renewables", in Proc. IEEE/PES Transmission and Distribution Conference and Exposition, 1165-1168.

[61] Green Prophet, Botobus: Istanbul public transit goes botanical and organic, http://www.greenprophet.com/2014/10/botobus-istanbul-public-transit-goes-botanical/#sthash.JgEiEgTL.dpuf, 05 October 2014.

[62] New Energy and Fuel, Energy Density and Power Density, http://newenergyandfuel.com/http:/newenergyandfuel/com/2009/03/20/the-ultracapacitor-competition-intensifies/energy-density-power-density/,17 March 2009.

[63] Bekiarov S, Emadi A,(2002), ”Uninterruptible power supplies: classification, operation, dynamics, and Control”, IEEE Trans. APEC2002, 1:10-14,597 – 604.

[64] José R., (2011), Inverters, In Power Electronics Handbook, ISBN 9780123820365, (Third Edition), Butterworth-Heinemann, Boston.

[65] Nayar C.V., Islam S.M., Dehbonei H., Tan K. and Sharma H., (2011), Power Electronics for Renewable Energy Sources, In Power Electronics Handbook ISBN 9780123820365, (Third Edition), Butterworth-Heinemann, Boston.

[66] Salam A. A., Mohamed A. and Hannan M. A.,(2008), “TECHNICAL CHALLENGES ON MICROGRID,” ARPN Journal of Engineering and Applied Sciences, Asian Research Publishing Network (ARPN) ,3(6):64-68.

[67] Govardhan, M.D.; Roy, R.,(2011), "Notice of Violation of IEEE Publication Principles A review on key issues of microgrid," Innovative Smart Grid Technologies - India (ISGT India), 2011 IEEE PES , 322(327): 1-3.

[68] Ezzt, M, Marei, M, Abdel-Rahman, M, Mansour, M.,(2007), “A hybrid strategy for distributed generators islanding detection”, In: IEEE power engineering society conference and exposition in Africa—PowerAfrica,5:1–7.

[69] Kunte, R, Gao, W.,(2008), “Comparison and review of islanding detection techniques for distributed energy resources”, In: 2008 40th North American power symposium, 1–8.

[70] Fayyad, Y.,(2010), “Neuro-wavelet based islanding detection technique”, In: IEEE electrical power & energy conference, 1–6.

[71] Timbus, A, Oudalov, A, Ho, C.,(2010), “Islanding detection in smart grids”, In: Energy conversion congress and exposition (ECCE),3631–3637.

[72] Khamis A., Shareef H., Bizkevelci E., Khatib T.,(2013),” A review of islanding detection techniques for renewable distributed generation systems”, Renewable and Sustainable Energy Reviews, 28:483-493.

[73] Li C., Cao C., Cao Y., Kuang Y., Zeng L., Fang B.,(2014), “A review of islanding detection methods for microgrid”, Renewable and Sustainable Energy Reviews, 35:211-220.

[74] Lasseter R. H.,(2002), “Microgrids,” in Proceedings of the IEEE Power Engineering Society Winter Meeting, 1:305–308.

[75] Feero W.E.,(2002), “Protection issues of the microgrid concept”, Consortium for Electric Reliability Technology Solutions. 2:233-245.

[76] Venkataramanan G, Illindala M.,(2002), “Microgrids and sensitive loads”. In: Power engineering society winter meeting, 1:27–31,315–22.

[77] Marnay C, Javier RF, Afzal SS.,(2001), “Shape of the microgrid”, In: Power engineering society winter meeting, 1:30-150.

[78] Parlak K. Ş., Özdemir M, Aydemir T.,(2009), “Active and reactive power sharing and frequency restoration in a distributed power system consisting of two UPS units”, International Journal of Electrical Power & Energy Systems, 31: 220-226.

[79] Ashdown B, Poulin J.,(1993), “Distributed power a solution for the 90s”, In: International telecommunications energy conference (INTELEC), 2:47–51.

[80] Shanxu D, Yu M., JK Y., Jian C.,(1999), “Parallel operation control technique ofvoltage source inverters in UPS. In: IEEE-PEDS’99, 2:7-883.

[81] Broeck H., Boeke U.,(1998), “A simple method for parallel operation of inverters”. In: Intelec. San Francisco, CA, 5:255-345.

[82] Lee C., Kim S., Kim C., Hong S., Yoo J., Kim S., ,(1998), “Parallel UPS with an instantaneous current sharing control”. In: IECON,73-568.

[83] Parlak, K.S.; Aydemir, M.T.; Ozdemir, M.,(2006), "Active and reactive power sharing in parallel operated inverters", Electrotechnical Conference, 2006. MELECON 2006. IEEE Mediterranean , 1052(1055): 16-19.

[84] Smart Grid Information Clearing House, Smart Grid Projects, http://www.sgiclearinghouse.org, 02 January 2012.

[85] Dimeas A.L.; Hatziargyriou, N.D.,(2005), "A MAS architecture for microgrids control", Intelligent Systems Application to Power Systems, 2005. Proceedings of the 13th International Conference, 5:6-10 .

[86] Dimeas A. L., Hatziargyriou N. D.,(2005),”Operation of a Multiagent System for Microgrid Control”, IEEE,3:12-25.

[87] Bergen AR. (1986), Power systems analysis, Englewood Cliffs, NJ: Prentice-Hall.

[88] Emadi A, Nasiri A, Bekiarov SB.,(2005), “Uninterruptible power supplies and active filters”, 1st ed. LLC: CRC press, 4:151-201.

[89] Ye Z, Boroyevich D, Choi J., Lee F.,(2000), “Control of circulating current in parallel three-phase boost rectifiers”, IEEE APEC, 4:506–12.

[90] Siri K, Lee C., Wu T.,(1992), “Current distribution control schemes for parallel connected converter modules Part II”, Central-limit control. IEEE Trans AerospElectron Syst , 28:841–51.

[91] Siri K., Lee C., Wu T.,(1992), “Current distribution control for parallel connected converters”, IEEE Transactions on Aerospace and Electronic Systems, 28 (3): 841–851.

[92] Shanxu D, Yu M, Jian X, Yong K, Jian C.,(1999), “Parallel operation control technique of voltage source inverters in UPS”, Power Electron Drive Syst Conf ,5:883–7.

[93] Tsai-Fu W, Yu-Kai C.,(2000), “3C strategy for inverters in parallel operation achieving an equal current distribution”, IEEE Trans Ind Elect ,7(2):273–81.

[94] Chandorkar MC, Divan DM, Adapa R.,(1993), “Control of parallel connected inverters in standalone ac supply systems”, IEEE Trans Ind Appl ,29:136–43.

[95] Guerrero JM, de Vicuna LG.,(2004), “A wireless controller to enhance dynamic performance of parallel inverters in distributed generation systems”, IEEE Trans Power Electron, 9(5):1205–13 .

[96] Skjellnes T., Skjellnes A., Norum L.,(2002), “Load sharing for parallel inverters without communication”, in: Nordic Workshop on Power and Industrial Electronics (Norpie 2002), Stockholm, Sweden, 3:145-166.

[97] Guerrero, J.M.; Garcia De Vicuna, L.; Matas, J.; Castilla, M.; Miret, J.,(2004), "A wireless controller to enhance dynamic performance of parallel inverters in distributed generation systems", Power Electronics, IEEE Transactions on , 19(5):1205,1213.

[98] Murphy Paul et al.,(2010), “Enabling Tomorrow’s electricity system: report of the Ontario Smart Grid forum”, Toronto, ON: Independent Electricity System Operator (IESO).

[99] Bayliss C.R. and Hardy B.J., (2012), Chapter 27 - Smart Grids, In Transmission and Distribution Electrical Engineering, ISBN 9780080969121, Fourth Edition, Newnes, Oxford.

[100] Höller J., Tsiatsis V., Mulligan C., Karnouskos S., Avesand S., and Boyle D., (2014), Chapter 12 - The Smart Grid, In From Machine-To-Machine to the Internet of Things, ISBN 9780124076846, Academic Press, Oxford.

[101] Knapp E., and Samani R., (2013), Chapter 1 - What is the Smart Grid?, In Applied Cyber Security and the Smart Grid, ISBN 9781597499989, Syngress, Boston.

CURRICULUM VITAE

PERSONAL INFORMATION

Name Surname	: Ahmed ISMAIL
Date of birth and place	: 08/12/1986 - UAE
Foreign Languages	: English – Arabic - Turkish
E-mail	: ahmed2022@gmail.com

EDUCATION

Degree	**Department**	**University**	**Date of Graduation**
Undergraduate	Electrical Engineering	Islamic University Of Gaza	2009
High School	Harun Rashid		2004

WORK EXPERIENCE

Year	**Corporation/Institute**	**Enrollment**
2010	Ministry of Communication and information technology	2010/ Communication Engineer
2009	Electrical Engineering Islamic University Of Gaza	Teaching Assistant

Projects

1. Cellular & Wireless sys in 3 rd & 4th G, UMTS Handover, Demo Simulation Using C++.

2. AM & FM low-range transceivers.

3. Speaker recognition using VQ method, in MATLAB

4. Design Lag, Lead, Lag-Lead, & PID controller By using MATLAB & 3d SCADA Virtual Reality.

AWARDS

1. Yurtdışı Türkler ve Akraba Topluluklar Başkanligi –YTB Scholarship