

T.C.
ISTANBUL AYDIN UNIVERSITY
INSTITUTE OF GRADUATE STUDIES



**CONTROL MICROGRID WITH RENEWABLE ENERGY SOURCE AND
MULTIPLE CONVERTERS**

THESIS

Shahbaz LATIF

Department of Electrical & Electronic Engineering
Electrical and Electronics Engineering Program

June, 2019

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Electrical and Electronics Engineering Program**

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June, 2019

DECLARATION

I hereby declare with respect that the study “Control Microgrid With Renewable Energy Source And Multiple Converters”, which I submitted as a Master thesis, is written without any assistance in violation of scientific ethics and traditions in all the processes from the Project phase to the conclusion of the thesis and that the works I have benefited are from those shown in the Bibliography.(.../.../20...)

Shahbaz LATIF

To God, who continues to guide me and give me strength throughout all challenges.

To my dear parents, who taught me to believe in myself.

To my good friends, who were there for me in the most difficult moments.

FOREWORD

First of all, I would like to express my endless gratitude to ALLAH for being who I am right now and helping me to find patience, strength with in myself to complete this thesis.

I would also like to thank my family not only for encouraging me to go abroad for Master's degree, but also for teaching me to chase my dream sand never give up. I can not express how grateful I am for having such a loving family that always believes in me. Moreover, my family is my source of inspiration and engine that helps me to improve and move on. I can not mention the patience and support that they showed with in this period of my life. Behind of any my success there is a hard work of my dear parents.

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June, 2020

Shahbaz LATIF
(Electrical & Electronics Engineer)

TABLE OF CONTENT

Page

FOREWORD	v
TABLE OF CONTENT	vi
ABBREVIATIONS	viii
LIST OF FIGURES	ix
LIST OF TABLES	x
ABSTRACT	xi
ÖZET	xii
1. LITERATURE REVIEW	1
1.1 PLUG and PLAY Power.....	1
1.2 Trends in micro-grid control	2
1.3 Real World micro-grids –An overview	2
1.4 Control and power management	3
1.5 Multiple input DC-DC converter	4
1.6 Power Quality Control inHybrid Micro-Grid system.....	5
1.7 Energy storage control in Renewable energy based Micro-Grid	6
2. MICRO-GRID	7
2.1 Modes of operation.....	8
2.1.1 Grid-connected Mode	8
2.2 Islanded mode operation	9
2.3 Classification of Micro Grid	9
2.3.1 AC coupled Micro-Grids	10
2.3.2 DC coupled Micro-Grids	10
2.3.3 Micro Grid control system	10
3. MICRO GRID PROTECTION SYSTEM	13
3.1 Factors considered while designing protection system	13
3.2 Methods of Protecting a MicroGrid	14
4. ENERGY STORAGE TECHNOLOGIES IN MICRO-GRIDS	16
4.1 Types of Storage Batteries	16
4.1.1 Lead Acid batteries	16
4.1.2 Lithium ion batteries.....	16
4.1.3 Sodium Ions battery.....	16
4.1.4 Flywheels	17
4.1.5 Super capacitor.....	17
4.2 Sizing of backup storage for Micro-Grids	18
5. MICRO GRID CONTROL TECHNIQUES	20
5.1 PQ control	20
5.2 V/f Control.....	21
5.3 Droop control	21
5.4 Economic dispatch for a micro- grid using renewable sources	22
6. METHODOLOGY	24
6.1 Tools and Techniques	24

6.1.1 Batteries as Energy Storage	25
6.1.2 Photovoltaic Cells.....	26
6.1.3 Wind Turbine	28
6.2 Control Philosophy	30
6.3 Proportional Integration Control	31
6.4 Modelling of micro grid using PI Controller	32
6.5 Simulation Result of PI Controller for Micro grid	34
6.6 PR Controller	35
6.7 Experimental modelling for PI and PR controller.....	36
6.8 Advantages of PR Controller over PI Controller	40
7. CONCLUSION	42
REFERENCES	43
RESUME.....	45

ABBREVIATIONS

CAN	: Control Area Network
CSU	: Current Sensing Unit
DC	: Direct Current
DFT	: Discrete Fourier Transform
DG	: Distributed Generator
DSP	: Digital Signal Processing
ESS	: Energy Storage System
FCL	: Fault Current Limiter
FESU	: Flywheel Energy Storage Unit
FHES	: Fuel Cell, Hydrogen Tank and Electrolyzer System
FPGA	: Field Programmable Gate Array
FQB	: Frequency Reactive Power Boost
IPEM	: Integrated Power Electronics Module
LC	: Local Control
MCC	: Micro Grid Control Center
MG	: Micro Grid
PCC	: Point of Common Coupling
PoC	: Point of Coupling
SKIIP	: SEMIKRON intelligent integrated power
SOC	: State of Charge
SSFCL	: Solid State Fault Current Limiter
SST	: Solid State Transformer
VPD	: Voltage Power Droop
VSC	: Voltage Source Converters

LIST OF FIGURES

Page

Figure 1.1: Proposed Hardware Interface (Hou et al., 2011)	1
Figure 1.2: Micro-Grid technologies(Barnes et al., 2007)	3
Figure 1.3: Micro-grid Phase Voltage Transient	4
Figure 1.4: Multiple input converter topology	5
Figure 1.5: Proposed Micro-Grid network.....	6
Figure 2.1: Micro-Grid concept.....	7
Figure 2.2: Transition between modes of operation	9
Figure 2.3: A CB on connection to Grid	11
Figure 5.1: PQ Control schematic	20
Figure 5.2: V/f control schematic	21
Figure 5.3: relationship between active power output and frequency	22
Figure 5.4: Relationship between reactive power output and voltage.....	22
Figure 6.1: Micro-Grid.....	24
Figure 6.2: Battery Bank Charging	25
Figure 6.3: Battery Bank Discharging	26
Figure 6.4: Photovoltaic Cells	26
Figure 6.5: Photovoltaic Cell Equivalent Circuit	27
Figure 6.6: PV Cells Modelling.....	28
Figure 6.7: Wind Turbine.....	29
Figure 6.8: Wind Turbine Modelling.....	29
Figure 6.9: Flow Chart	30
Figure 6.10: Simulink model of hybrid micro-grid	31
Figure 6.11: .1 at 100 KW: Voltage and Power from Utility to Load.....	37
Figure 6.12: .2 at Load of 100KW: Voltage, Current and Power from Solar grid to Load	37
Figure 6.13: .3 at Load of 100KW: Voltage, Current and Real Power at Load.....	38
Figure 6.14: For Load 100 KW and 5 KVAR: Voltage, Current, Real Power and Reactive Power from Utility to Load.....	38
Figure 6.15: For Load = 100 KW and 5 KVAR: Voltage, Current, Real Power and Reactive Power from Solar Grid to Load	39
Figure 6.16: Above fig shows voltage,, current, dc-link voltage and rotor speed of wind generator.....	39
Figure 6.17: For Load = 100 KW and 5 KVAR: Voltage, Current, Real Power and Reactive Power at Load	40

LIST OF TABLES

Page

Table 4:1: Characteristic Comparison Table.....	17
Table 4:2: Advantages and disadvantages of different storage types.....	18
Table 6.1: Comparison between THD Values.....	36
Table 6.2: Solar and Wind data	40

CONTROL MICROGRID WITH RENEWABLE ENERGY SOURCE AND MULTIPLE CONVERTERS

ABSTRACT

Micro-Grid technology is an emerging field and it is the interest area of researchers working specially on energy sectors. As our country is facing energy crises from many years and it is expected to reach severity level in future as the fuel prices are increasing. The single point of power generation cannot overcome the short fall currently facing the country. The industries for instance sugar and textile generating energy and exporting excessive energy to national grid.

These days, the main focus for power generation is to utilize renewable energy sources. There are solar parks and wind energy farm are being constructed and their numbers are increasing day by day which are no doubt the major sources for reducing energy crises in the country.

In this thesis, study on small scale power generation unit is being considered spread over a city to overcome energy crises. The terminology used for these small scale energy unit is Micro-grid. The problem with these micro-grid is that of synchronisation with the main grid that is when the main grid is off line, these micro-grid should be synchronised in such a way that they can export sufficient energy to the main grid.

This thesis addresses this issue by improving a control scheme for renewable energy resources and multiple convertors for energy storage system.

Keywords: *Micro-grid, renewable energy, Droop Control, Model Predictive control, multi agent system, islanded modes, Wind Turbine, Energy storage system, Photovoltaic cells.*

YABANCI DİL KAYGISININ ORTAOKUL ÖĞRENCİLERİ ÜZERİNDEKİ ETKİLERİ

ÖZET

Mikro-Şebeke teknolojisi gelişmekte olan bir alandır ve özellikle enerji sektörlerinde çalışan araştırmacıların ilgi alanıdır. Ülkemiz uzun yıllardan beri enerji krizleriyle karşı karşıya olduğu için yakıt fiyatları arttıkça gelecekte şiddet seviyesine ulaşması beklenmektedir. Elektrik üretimindeki tek nokta, şu anda ülkenin karşı karşıya olduğu kısa düşüşün üstesinden gelemez. Örneğin şeker üreten ve enerji üreten ve ulusal şebekeye aşırı enerji ihraç eden tekstil sektörleri.

Bugünlerde elektrik üretiminin ana odağı yenilenebilir enerji kaynaklarından faydalanmaktadır. Güneş parkları var ve rüzgar enerjisi çiftliği inşa ediliyor ve sayıları her geçen gün artıyor, bu da ülkedeki enerji krizlerini azaltmak için önemli kaynaklar.

Bu tezde, enerji krizlerinin üstesinden gelmek için küçük ölçekli enerji üretim birimi üzerine yapılan bir çalışma bir şehre yayılmış olarak değerlendirilmektedir. Bu küçük ölçekli enerji birimi için kullanılan terminoloji Mikro şebekedir. Bu mikro şebekedeki sorun, ana şebeke kapalı olduğunda ana şebekeyle senkronizasyondur, bu mikro şebeke ana şebekeye yeterli enerji verebilecek şekilde senkronize edilmelidir.

Bu tez, yenilenebilir enerji kaynakları için bir kontrol şemasını ve enerji depolama sistemi için çoklu dönüştürücüler geliştirerek bu sorunu ele almaktadır.

Anahtar Kelimeler: *Kaygı, yabancı dil kaygısı, engel, yenmek, strateji*

1. LITERATURE REVIEW

1.1 PLUG and PLAY Power

This paper presents a new hierarchical approach for power electronics based interface between distributed energy resources and grid. The author primarily focusses on improvement in voltage stabilization, optimization of power flow and improved in voltage stability. To achieve this author proposes (Hou, Hu, &Hui, 2011)

Paper demonstrates a simulation of a 3-phase grid connected converter for lithium battery energy storage system model, and integrates a SKIIP based on IPEM. The controller for implementation of IPEM is made using DSP and FPGA with different communication interfaces.(Hou et al., 2011)

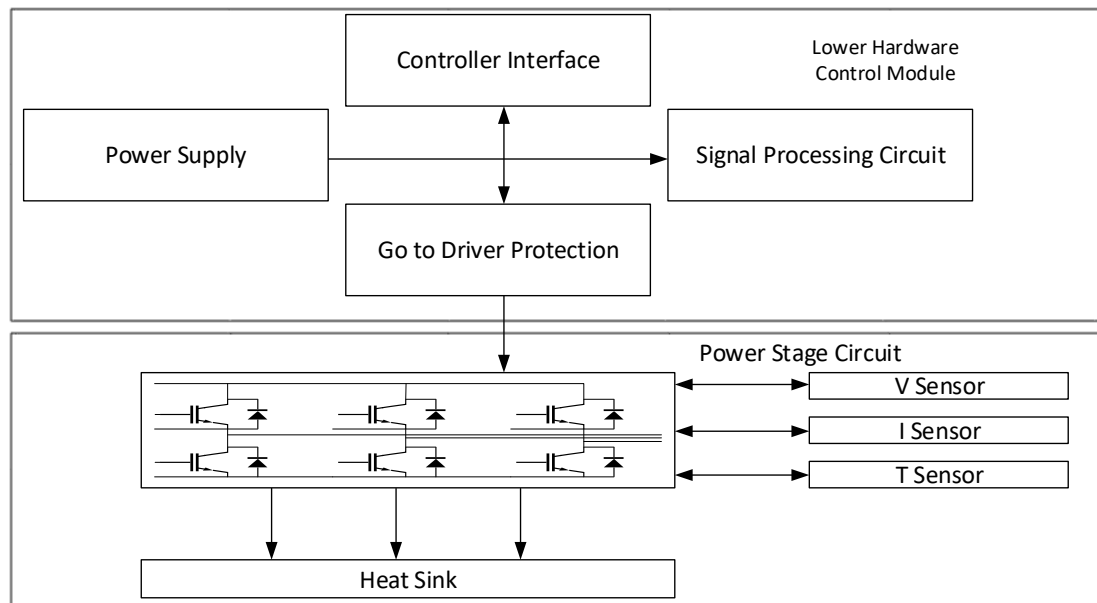


Figure1.1: Proposed Hardware Interface (Hou et al., 2011)

Experimental results shown in this paper show improved flexibility and processing rate because of FPGA and DSP's plus envisions a plug and play power electronic interface for micro-grid control.

1.2 Trends in micro-grid control

This paper thoroughly reviews different trends of micro-grid control and major challenges in it. After peer review authors compare and place different control techniques under different levels, namely -primary, secondary & tertiary where former two levels deals with operation of micro-grid while tertiary level is associated with coordinated operation of micro-grid and host-grid. The paper focusses on mostly control techniques of primary and secondary levels e.g Droop Control, Model Predictive control and Multi-agent systems etc.(Olivares et al., 2014)

Paper weighs on ESS as key-technology for intermittent renewable source integration but also highlights that resource management challenge with it, other than that issue like low inertia of power-electronic interfaced units, low voltage grid's lower X/R ratio, uncertainty of generation output etc. With some issues addressed while other proposed techniques are yet to be tested (Olivares et al., 2014)

1.3 Real World micro-grids –An overview

This paper again is review paper that not only compares various micro-grid structures and highlights the operation control techniques used or proposed for micro-grid structures that are already operational or to be soon operationalized, around the globe.(Barnes et al., 2007)

The paper sheds light on various micro-grid projects and tries to establish the fact that how this has become a 'buzz-word' for various enhanced micro-generation system's types. The author sheds light on how all of these systems somehow have a virtual or physical prime-mover arrangement and its effectiveness with reference to its location near point-of-coupling. Behavior of PoC and how modern day micro-grids are less reliant on it. Authors try to present the real world projects as hard demonstrators of their findings which makes paper quite effective (Barnes et al., 2007)

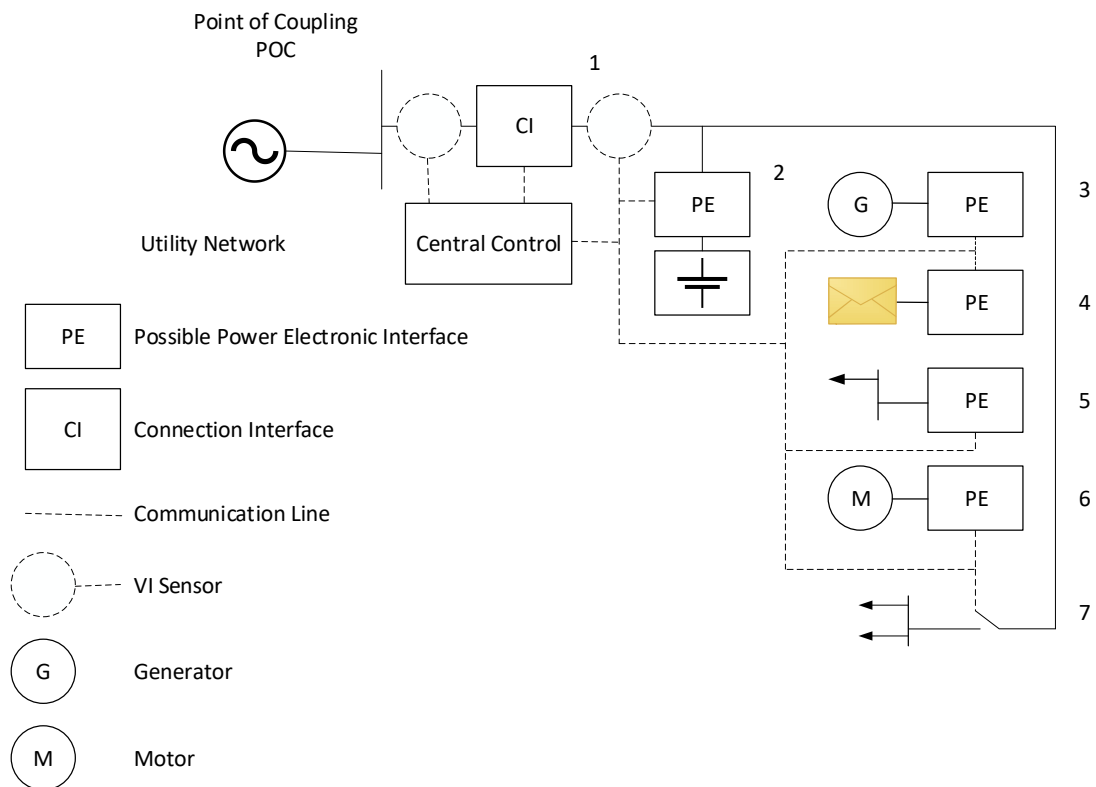


Figure 1.2: Micro-Grid technologies (Barnes et al., 2007)

1.4 Control and power management

This paper suggests a controlling scheme for parallel operation of voltage source converters fed micro-grid in parallel using voltage and frequency boost techniques VPD/FQB. (Sao & Lehn, 2008)

The paper presents a way of controlling options in both grid controlled and islanded modes using multiple voltage source converters with *dq-frame* current controls and standard inductor interfaces to operate in parallel. The technique also enables frequency and voltage regulation, inherent over current protection of VSC in islanded mode. Joint voltage regulation and frequency regulation is achieved by drooping voltage and frequency references VPD/FQB controller against *d-axis* and *q-axis* of corresponding VSC.

The test result shows following voltage and frequency transients and imply that VPD/FQB control schemes are robust islanding transients. (Sao & Lehn, 2008)

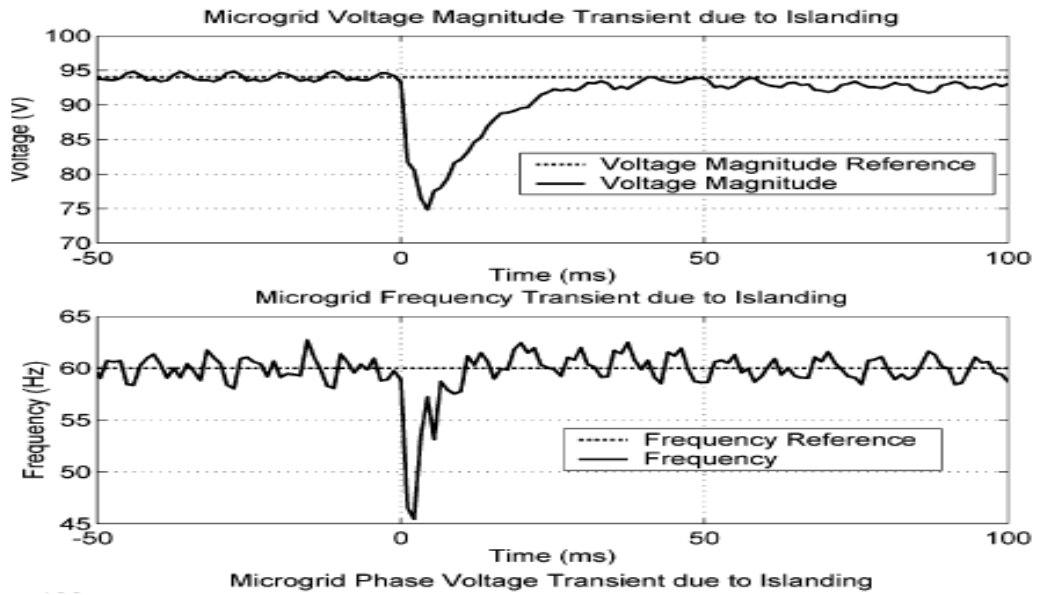


Figure 1.3: Micro-grid Phase Voltage Transient

1.5 Multiple input DC-DC converter

This paper comprehensively suggests an application oriented micro-grid i.e. a telecom power plant based upon modular architecture. Paper explains why such system would be cost effective and also conceptualizes the required architecture and not just that but also sheds light on other similar researches carried out. (Kwasinski & Krein, 2005)

The paper suggests that a micro-grid architecture fed through multiple input dc-dc converters is scalable and cost effective.

The suggested topology of converters and rectifiers as shown below can help create highly flexible plant that can be configured based on power budget. (Kwasinski & Krein, 2005)

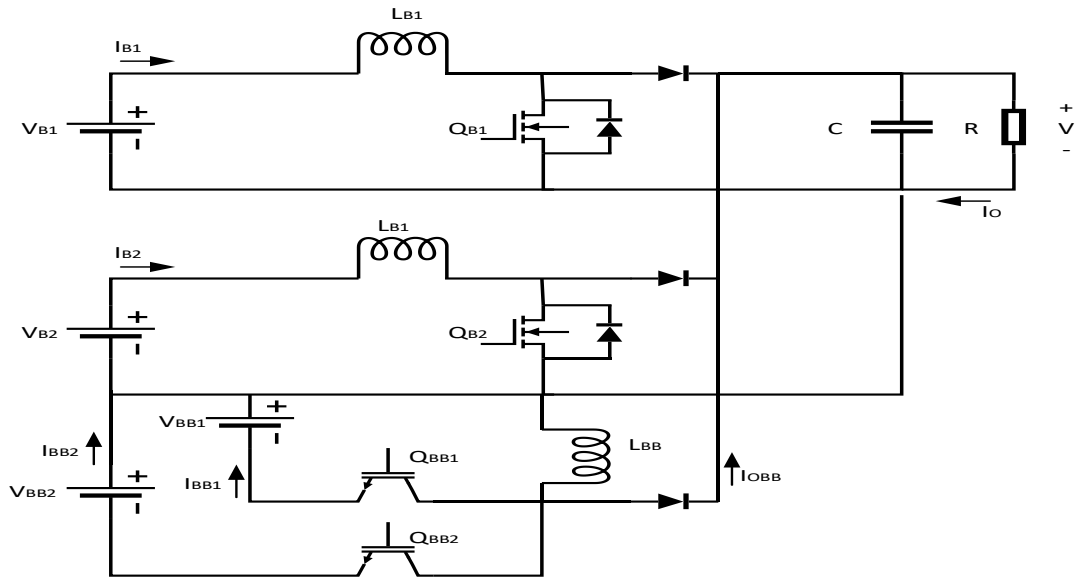


Figure 1.4: Multiple input converter topology

Starting cost saving is achieved by reduced energy storage capacity and support facilities which is further complemented by 150V dc as primary distribution voltage. With the help of bi-directional converters, the energy storage devices are connected to 150v dc bus.

1.6 Power Quality Control in Hybrid Micro-Grid system

Stability and power quality of micro-grid can be affected with different kinds of power sources. This paper focusses on a technique where combining micro-turbine and fuel cell, Hydrogen tank and Electrolyzer system Hybrid System (FHES) to enhance micro-grid system's ability to address power quality issue of frequency fluctuation. (Li, Song, & Han, 2007) Effective utilization of load controllable electrolyzers system can significantly improve power quality for frequency. The paper also discusses that PI compensator can be used to compensate power changes at Micro-grid system and tie line. With experimental results paper also deduces that by applying smaller T_{es} (Time constant for ES) to control ES load rapidly can be effective in upgrading operation capability of handling frequency fluctuation. (Li et al., 2007) The micro-grid system based on pc control and monitoring, through CAN communication system, comprising of a micro turbine to supply base load, an electrolyzer to create Hydrogen,

hydrogen storage tank ,renewable energy based generators and proton exchange membrane fuel cell is envisioned. (Li et al., 2007)

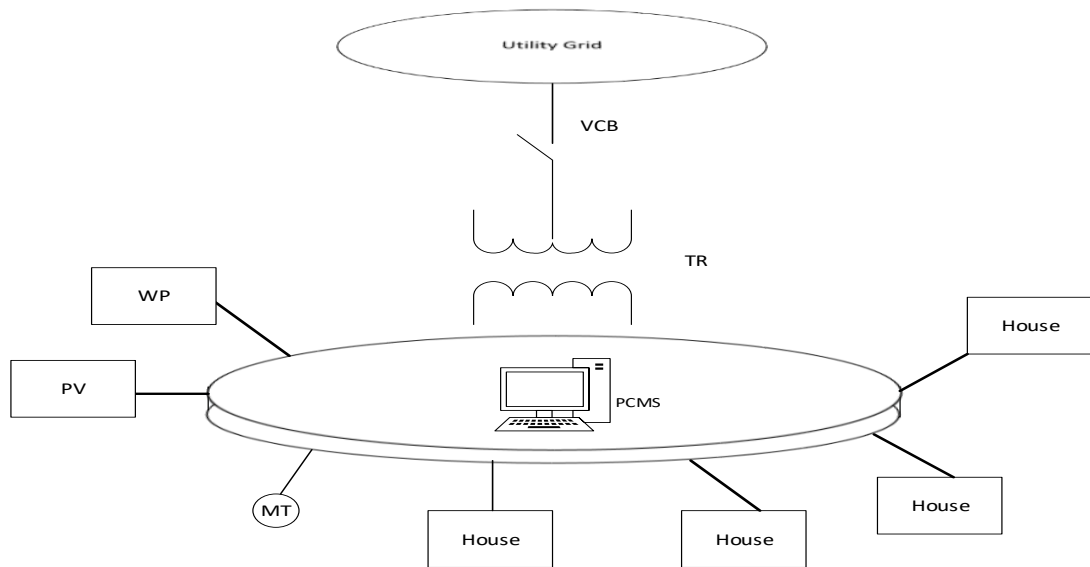


Figure1.5:Proposed Micro-Grid network

1.7 Energy storage control in Renewable energy based Micro-Grid

This paper deals with the role of Energy storage in Renewable sources based micro-grid and also identifies the works that has been done in this regard. The paper gives reference to a micro grid project funded to test the control techniques and energy storage in renewable micro-grids.(Tang & Qi, 2012)

The paper highlights how Distributed Energy Resources have become so important and an enhanced micro-grid, the only viable solution that can work in islanded, grid-tied modes & also smoothly transits between two modes. The paper focusses on how renewable energy based micro-grids can have black start support, stable control support and improved power quality (such as DC voltage offset, frequency distortion and harmonics etc.)(Tang & Qi, 2012)

2. MICRO-GRID

Traditional definition of micro-grid may vary but with introduction of new trends in energy storage and control techniques the micro-grid can be defined as combination of Distributed Generation systems, a group of loads and Energy storage systems(ESSs) using various control techniques to supply uninterrupted electricity with respect to a *Common Coupling Point* connection with host Grid at distribution level

(Kalpesh C. Soni&Belim, 2015) Such isolated micro-grids have also been existed in past in remote areas where host power system distribution could 'not reach, fulfilling needs of a local community. With integration of renewable energy sources, the roads to heavy investment in micro-grids have been opened specially after introduction of smart grids. But in order to successfully integrate renewable energy sources with micro-grid, researchers have to overcome a lot of challenges.(Olivares et al., 2014)

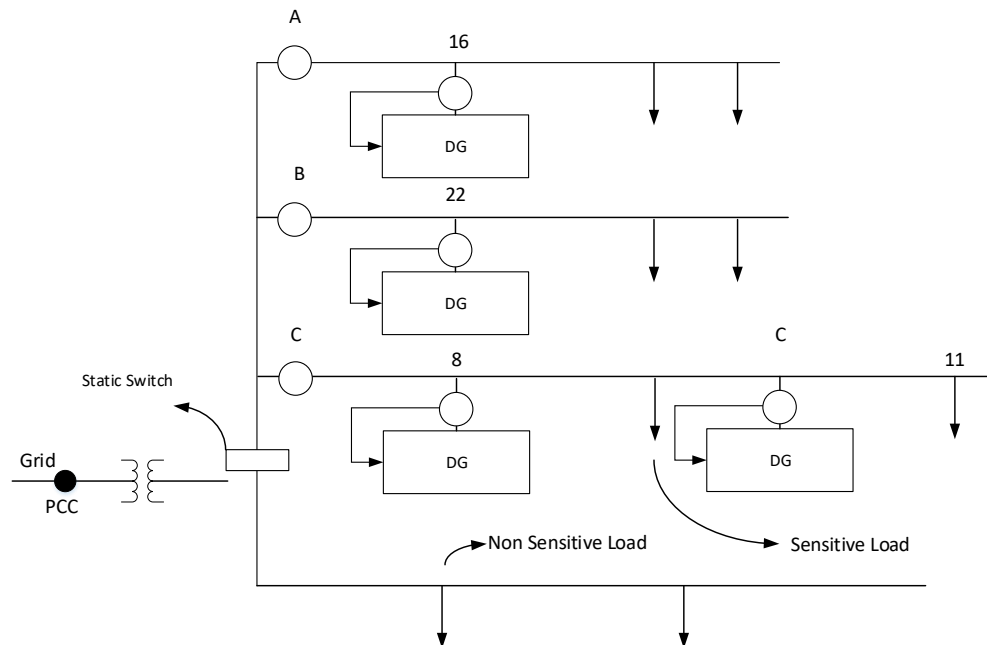


Figure2.1: Micro-Grid concept

The distributed Generation (DG) close to the load reduces dependency upon Centralized Power System from the view-point that new technology reduces line losses, infrastructure costs, load shedding , congestion of network and also allows one to be consumer and producer at the same time , saving many from heavy bills of utility companies, thanks to renewable resources like Wind and Solar.(Yeshalem& Khan, 2018)

2.1 Modes of operation

Micro-grid works in two modes of operation

- *Grid connected mode*
- *Islanded mode*

2.1.1 Grid-connected Mode

This mode of operation may be defined as micro-grid connected to host power network at point of common coupling and exchanges power with it. When load is more than distributed generation, micro-grid inhales power from main distribution network and in other case injects excess power to main grid. The distribution network dispatch layer connects with centralized control layer of micro-grid at and share amount of power exchange at PCC to dispatch centre in order to regulate distributed generation output, energy storage and load in order to balance active & reactive power, and micro-grid status (connected/disconnected) (Ahmed, Amin, Aftab, & Ahmed, 2015; Yeshalem& Khan, 2018)

This type of arrangement is aimed at increasing energy efficiency and load shifting with the help of energy storage's charge & discharge and by time-of-use tariff. (Ahmed et al., 2015; Augustine, Suresh, Moghe, & Sheikh, 2012).

Under this arrangement, micro-grid can be considered as controllable load w.r.t main grid where it manages power factor under uniform power factor and is not allowed to manage grid voltage. With the help of reactive output of Distributed Generation and regulation of reactive power compensation equipment it somewhat manages bus voltages within it.(Ahmed et al., 2015; Augustine et al., 2012; Yeshalem& Khan, 2018)

2.2 Islanded mode operation

As micro-grid separates from main grid its transits into islanded mode in order to supply uninterrupted power to various loads. This means that DGs, ESs and loads of micro-grid will operate independently. If changes in DG system's output or fluctuation of load occurs and is beyond the capacity of ES to compensate then voltages and system frequency may drop which results in load shedding. It is also possible that in above given circumstances that system voltage and frequency may rise instead of dropping, if such case occurs output of some DG's will be limited until things return to normalcy. In case if dispatchable DG's produced output is maximum, and the SOC of ES is below lower limit, load shedding of unimportant loads can occur. Various control techniques are employed to control frequency deviation and inertia of system like *droop-control method*.

(Ahmed et al., 2015; Tang & Qi, 2012; Yeshalem & Khan, 2018).

Transition between modes of operation is itself a very deep topic and is beyond the scope of this thesis but a few control techniques will be discussed later.

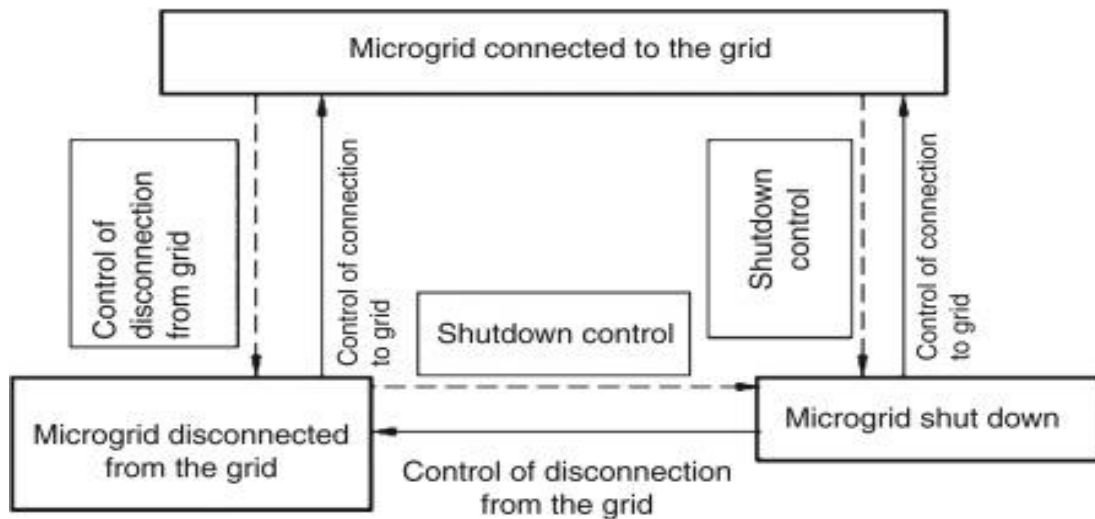


Figure 2.2: Transition between modes of operation

2.3 Classification of Micro Grid

The classification of micro grid are as under

- AC Coupled Micro-Grid
- DC Coupled Micro-Grid

2.3.1 AC coupled Micro-Grids

In a centralized ac coupled micro-grid all power producing elements are linked to AC bus either directly or with the help of AC-AC converters, in order to get a certain coupling technology. to control the flow of energy master inverters are employed.

In ac coupled de-centralized micro-grid , technology is not linked with a bus bit rather directly with the load energy resources may not be available at same location thus power generating components can be installed anywhere resources are available. But its control system is very complex as compared to centralized grid(Yeshalem& Khan, 2018)

2.3.2 DC coupled Micro-Grids

In such type of configuration all energy sources are linked to DC bus before being linked with AC bus with the help of converter, if required AC load is provided using inverter. A charge controller is used to avoid deep discharge and over-charge .Disadvantage of such configuration is low conversion efficiency.(Yeshalem& Khan, 2018)

2.3.3 Micro Grid control system

Micro Grid control system must be paced at different multiple levels of the system and must enable persistent communication between different control units in order to cope up with continuously variable output of distributed generators and load demand changes with time. Head of this hierarchical control system is a dedicated micro grid central controller installed at medium/low voltage substation, manages micro grid and supervisory control, integrated it with main grid and also communicated between network operators. (Yeshalem& Khan, 2018)Transition between grid connected and islanding mode is done via a central switch which also enables synchronization between both power systems.

Switch interconnection technology in a micro grid uses Digital signal processor technology and is provided with relevant communication devices, coherent with IEEE 1574 Standard Network Interconnection. Below given figure is a schematic of circuit breakers on connection to grid.(Hartono &Setiabudy, 2013; Yeshalem& Khan, 2018)

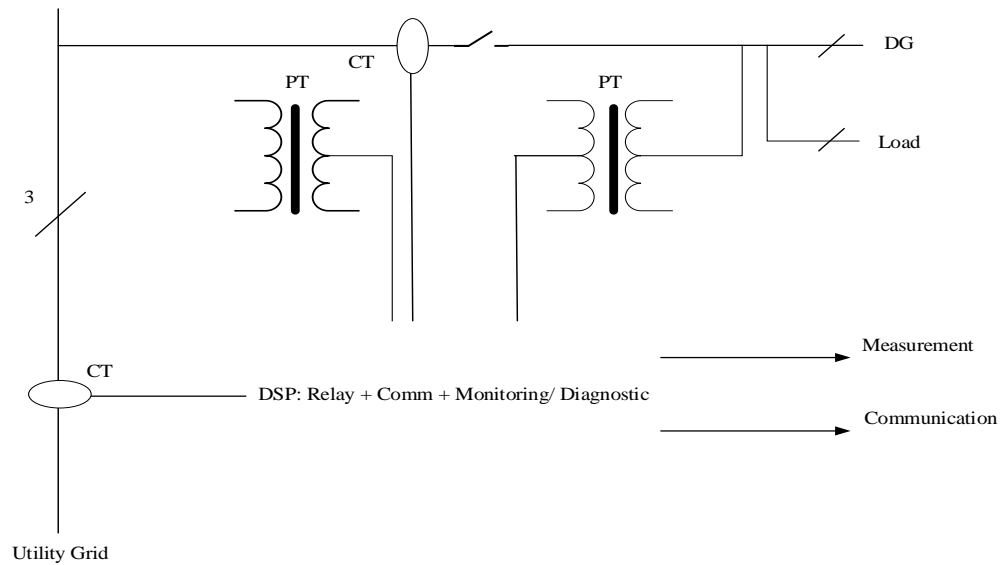


Figure2.3: A CB on connection to Grid

Control system of a micro-grid is designed in such a way so as to cater its steady state and dynamic characteristics. Micro Grid has inbuilt unbalanced load due to one phase loads, and the supply of power comes from uncontrolled sources such as Solar. Large role of energy storage systems and accommodation of connection and disconnection mechanism to manage operational expenses. For certain types of loads, MGs require service preference and power quality initially. To address these type of issues micro grid control system has to be different from that of a conventional power system.(Hartono &Setiabudy, 2013).

Micro grid Control Centre (MCC) determines power output from each Local Control, on the basis of input production capacity owned by each *Local Control (LC)*. MCC predicts, upon these inputs and operating policy, needs and production plus also infrastructure condition consideration of other microgrid. It also determines LC operations which includes setting LC production capacity,

amount of loads to be served and market price for energy optimization of LC.(Hartono &Setiabudy, 2013)

3. MICRO GRID PROTECTION SYSTEM

Although renewable micro-grids are an effective replacement to fossil fuel based production, but there are a lot of challenges while maintaining micro grid protection system because of its dynamic nature and modes of operation (connected or islanded). Various factor are considered while designing a micro gird protection system and various techniques can be employed.

3.1 Factors considered while designing protection system

Below discussed are a few important factors considered while designing a protection system.

Type of Grid is a crucial factor in protection system, whether a grid is AC coupled or DC coupled or mixed coupled. Type of loads, network and converters used as well as different type of distributed generators have different outputs and accordingly loads , therefore type of grid plays an important part .As for bus protection differential protection is preferred for both type of grids. Main difficulty is with D.C grids because of lacks of experience, therefore one has to pin on AC options available that can be implied to DC grids also keeping in mind the rating differences for both type of operations. Different type of fuses , switches and circuit breakers are used for protection but the problem arises in case of DC where time constant is great and circuit breakers operate with delay so dedicated electronic switch based circuit breakers are used for DC Micro Grids.(Ahmed et al., 2015; Hosseini, Abyaneh, Sadeghi, Razavi, &Nasiri, 2016; Meng et al., 2017).

Topology of MG also comes into play, whether it's looped or meshed topology, because this affects direction and magnitude of fault currents and hence protection plan for upstream and downstream branches is changed accordingly.

Types of Distributed Generation units also are important in this situation. DG units can be categorized as synchronous, asynchronous and Inverter-Interfaced

DG and in order to observe response each must be modelled, and each modelling of each DG unit is done using different parameters by researchers. These models help us in calculating amount of fault current produced by each of these DG units, their sources impact on operation time of protective devices (over current relays) etc. Electromagnetic characteristics of IIDGs is dependent on topology and controller for converters.(Hosseini et al., 2016; Xiao, Wang, Setyawan, & Xu, 2015).

Communication infrastructures, methods of data acquisition and time delays also play an integral part in MGs. Standard protocols for substation automation are used like IEC 61850. Communication infrastructure may be classified into three categories like *local area based, wide area measurement and hybrid scheme*. Communication links can be wired or wireless or both. Supervisory remote control unit, Phasor measurement units and protective devices, which are usually set adjacent to fault locations, are informed and various fault identification techniques are used. Time delay affects the speed of communication which in turn affects protection system. Delays are usually related to delay of current and voltage transducers, data processing time, DFT window size, data size of PMUs output, data concentrators and transitions data. Keeping all delays in mind suitable communication guide and mode is chosen.(Hosseini et al., 2016)

3.2 Methods of Protecting a MicroGrid

Changing of protective devices and adjustment of settings is also widely proposed means of protection. Like replacement of non-directional relay with directional one, which suit bi-directional flow of power, changing of settings of protective devices (re-configuration of constraint causing relays) each time a new DG unit is added or topology of network is modified. Relay's overcurrent curves can be changed in order to avoid synchronization problem plus use of microprocessor based re-closers is envisioned to have more options as per the status of DG (connected or disconnected). Researchers also have proposed inclusion of re-closer as a replacement of fuses, in the branch where DG is added, plus a relay in the branch where DG unit is connected to network, this helps in avoiding fuse meltdown during transient fault occurrences.

1. Other researches carve out idea of disconnecting DG unit from network quickly with help of switches (like GTO's), until network returns to its prior state. This pre-emptive measure is taken by Current Sensing Unit (CSU) which calculates network currents in order to detect any potential fault, usually taking more than seven cycles in order to avoid any fault identification mistake. This method avoids change of protection devices or their settings and is also a low cost solution. Once the fault is removed the DG can be reconnected to the network.
2. Another proposed and efficient way of protection is using fault current limiter to limit short circuit current. Best located in the branch where DG is installed in series with it, FCL is impedance that is zero under normal condition and increases proportionally thus limiting the short circuit current also significantly reducing operation time of over current relay. Solid state fault current limiter SSFCL's and also hybrid FCL are proposed which have multiple paths and are composed of power semiconductor elements, current limiting impedance and mechanical switches and breakers. RL feed-forward and flux charge model feedback algorithms are also suggested for protection.
3. Another suggested method is use of smart solid state transformer to protect micro grid. Method pins on primary voltage of bus which is connected to SST, remains constant even until power rating of SST is greater than its maximum power. Under normal circumstances primary voltage of SST must never be less than 0.9pu. If it falls under 0.8pu it can be predicted that a fault has occurred and this would result in separation of SST from the network and supply of power from DGs and energy storages in secondary of SST. (Hosseini et al., 2016)

4. ENERGY STORAGE TECHNOLOGIES IN MICRO-GRIDS.

With increase in demand of micro grids, there has been a sharp rise in the demand for efficient energy storage systems, esp. Distributed energy storage systems recently. Various researches are under study, as scope of my thesis I will shed light on most used storage technologies that can be classified as electro-chemical, chemical, mechanical, thermal and electrical systems.(Augustine et al., 2012; Gao, 2015; Kamel, Donahue, &Dankworth, 2014; Tang & Qi, 2012)

4.1 Types of Storage Batteries

There are following types of Batteries used in the micro-grid system

4.1.1 Lead Acid batteries

Based upon electro-chemical reaction between anode and cathode, and made of spongy lead cathode, lead dioxide anode and Sulphuric acid as electrolyte, rechargeable lead acid batteries are widely used as energy storage means because of their high efficiency, low cost, and good surge capability with ability tolerate deep discharge cycles varying for different types. However its energy to volume ratio is debatable.(Gao, 2015)

4.1.2 Lithium ion batteries

Three layered lithium ion batteries also make a good share in batteries market. Due to its light weight, good power density and quick response behaviour, and low self-discharge rate they are highly preferred for small electronic devices. It operates in way that resembles a capacitor and are quite expensive (Gao, 2015; Tang & Qi, 2012)

4.1.3 Sodium Ions battery

With installed capacity of 250MW sodium sulphur batteries are also under development mode for micro-grids. Main advantages are high efficiency, high

power density and large battery lifetime (around 10 years).however operational cost is main constraint.(Gao, 2015; Tang & Qi, 2012)

4.1.4 Flywheels

Flywheel energy storages unit (FESU) is a moveable weighted disk that can store kinetic energy. In order to counter gravity the disk is made in such a way that it is perpendicular to the rotor. They act as generators and can be charged with help of motors when required. It has high power density, long life span and high conversion efficiency. Modern day flywheels can reach up to 16,000 rpm amounting capacity to 25kWH.They have low maintenance cost supported by short response time. (Gao, 2015; Tang & Qi, 2012)

4.1.5 Super capacitor

Made up of stack of single cells , connected in series, packed and immersed into electrolytic solution forming a double-layered charge distribution and an insulator as separator , super-capacitor has a storage capacity of 20-1000 times that of normal capacitor , and a high power density and conversion rate .A super-capacitor is made up of numerous capacitors arranged in series or parallel.(Gao, 2015; Tang & Qi, 2012)

Table4:1: CharactersticComparision Table

Type	Energy Density	Power Density	Response Time	Continuous Discharge Time	Cycling Time
Flywheel	5–30	400–1500	< 1s	1s–15min	Above 20,000 times
Compressed Air	30–60	–	1–10mins	Above 1-24Hr	Above 100,000 times
Lead Acid	30–50	75–300	<10s	1s-10 hr	2000 times
Lithium-Ion	75–200	150–300	<10s	1s-10 hr	<10,000 times
Sodium Suffer	100–250	100–250	<10s	1s-10 hr	2500-6000 times
Super Capacitor	5–10	5–10	<1s	1ms-1 hr	100,000 times
Superconducting Magnet	1–10	1–10	<5ms	1ms-1hr	100,000 times

Table4:2: Advantages and disadvantages of different storage types

Type	Advantage	Disadvantage
Flywheel	High Power Density and quick response time	Low Energy Density
Compressed Air	Large Capacity, Long Continuous Discharge Time	Limited Location, Slow response
Lead Acid	High Capacity so High Energy Density	Low power Density, low cycling times
Lithium-Ion	High Energy Density	Small capacity hard for lager application
Sodium Suffer	High Energy Density	Need high temperature in working process
Super Capacitor	High Power Density and quick response time	Low energy density, expensive
Superconducting Magnet	High Power Density and quick response time, High Cycling Time	Low energy density, expensive, magnetic pollution to the environment

4.2 Sizing of backup storage for Micro-Grids

Reliable and effective backup storage for critical loads is very important element in micro grids. Therefore Sizing of backup storage is needs to be carefully chalked out. The backup can be in form of fuel cell or electrical energy storage, when deciding size of storage power rating on basis of load and energy rating on basis of time period is considered.in developing a way to size backup storage consider below given parameters(Mitra, 2010)

S_F = primary supply failure event

L = critical loads power failure experience event

R = random variable representing downtime of primary supply

t_A = for how long can storage unit support critical load in case of failure

$f_{R(t)}$ = probability density function of R

Now suppose a power failure occurs for period longer than t_A , the probability can be stated as

$$\Rightarrow P\{L\} = P\{\{R > t_A\} \cap S_F\}$$

$$\begin{aligned}
&= P\{R > t_A | S_F\} P\{S_F\} \\
&= \left(\int_{t_A}^{\infty} f_R(r) dr \right) P\{S_F\} \tag{4.1}
\end{aligned}$$

Now $\alpha = 1 - A_1 / 1 - A_0$, where α is *unavailability ratio*

From above both equations it can be derived that

$$\Rightarrow \int_{t_A}^{\infty} f_R(r) dr = \alpha \tag{4.2}$$

Which implies to the relation from which required energy storage can be calculated. (Mitra, 2010; Tang & Qi, 2012)

5. MICRO GRID CONTROL TECHNIQUES

For reliable grid operation and smooth function various control techniques are used but 3 main techniques are *PQ control V/f control and droop control*.

5.1 PQ control

The main objective of this type of control method is that when frequency and voltage deviation occur within a certain limit, the micro source's active and reactive power should remain constant, and in order to achieve that both must be firstly de-coupled. Since this method cannot control voltage and frequency therefore an extra distributed generator is required to regulate both. In grid –tied mode, main power grid is responsible for regulation of voltage and frequency of micro- grid. (Gao, 2015; Olivares et al., 2014)

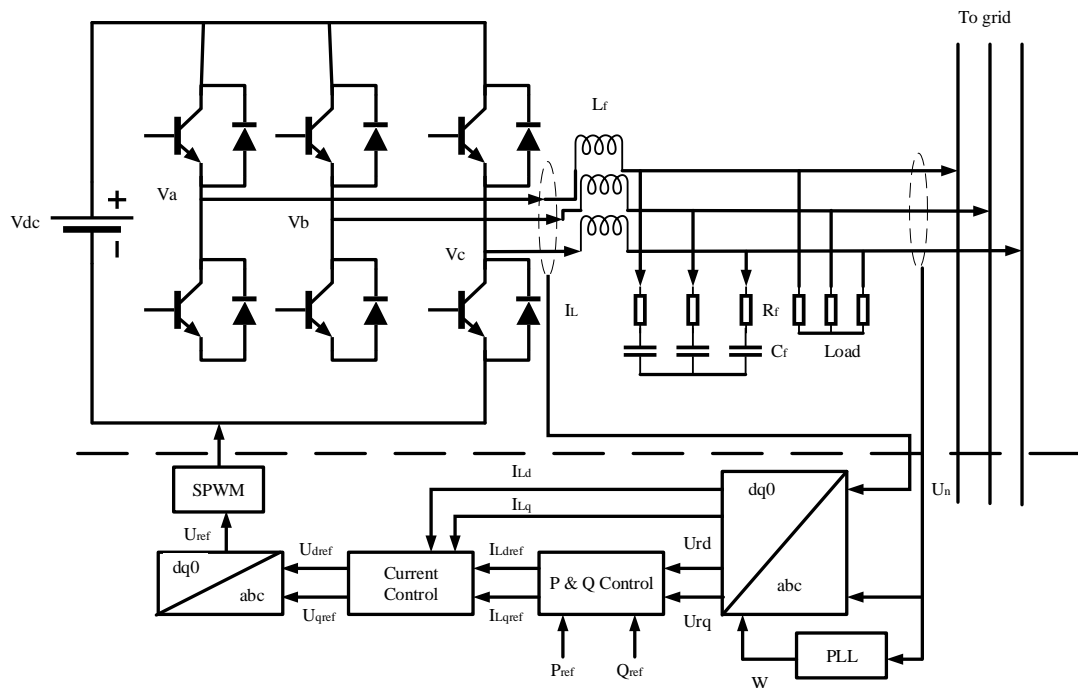


Figure 5.1: PQ Control schematic

5.2 V/f Control

Purpose of this type of control technique is to regulate frequency and voltage magnitudes irrespective of actual active and reactive power outputs of micro-sources. Frequency and voltage controllers regulate active and reactive power respectively in order to achieve given reference values of voltage and frequencies. It's quite common technique in islanded mode.(Gao, 2015)

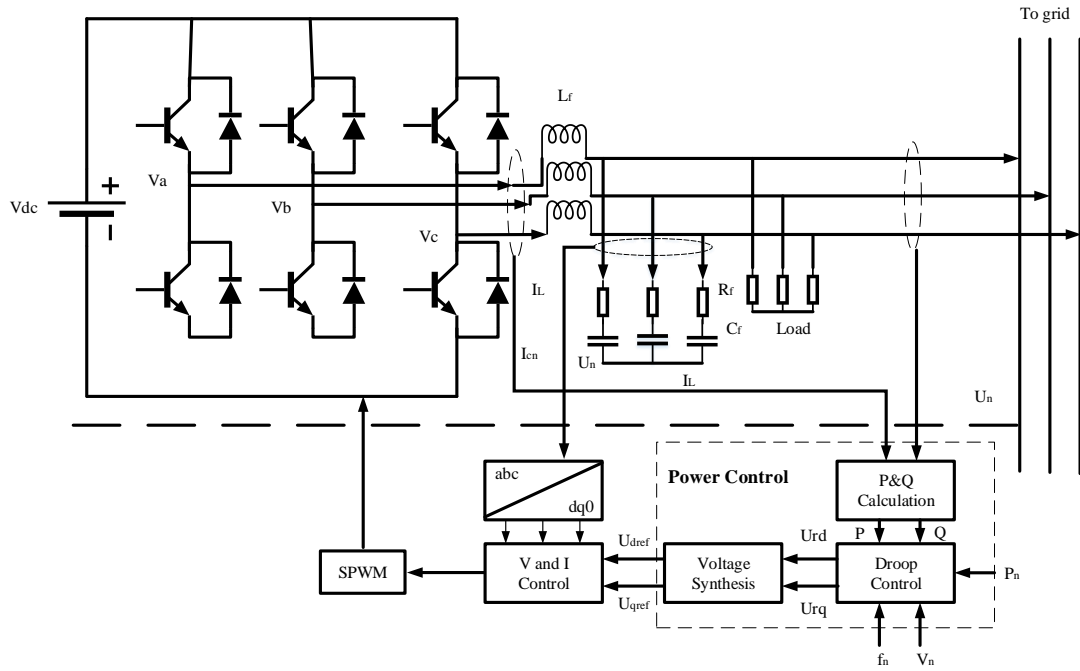


Figure 5.2: V/f control schematic

5.3 Droop control

With changing load all the time, in a micro-grid, the generators also keep on changing power output depending upon frequency deviations. This relationship can be mathematically described by the given below equation:

$$\Delta P = P_2 - P_1 = S_P (f_1 - f_2) \quad (5.1)$$

where ΔP is power change in output.

& S_P = reciprocal of slope of curve, determined by each characteristic of DG.

While system voltage control can be carried out by adjusting reactive power output of micro sources.(Olivares et al., 2014)

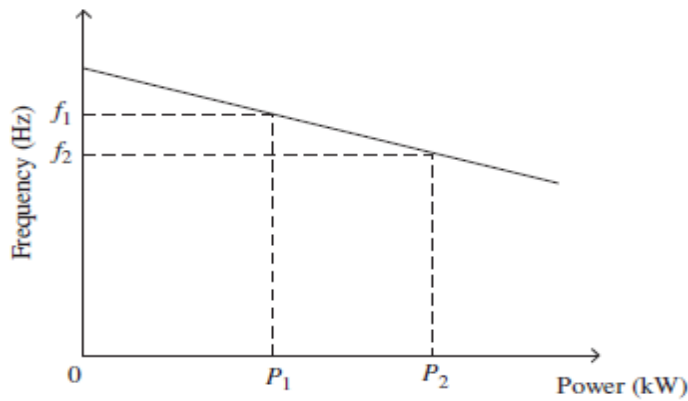


Figure5.3: relationship between active power output and frequency

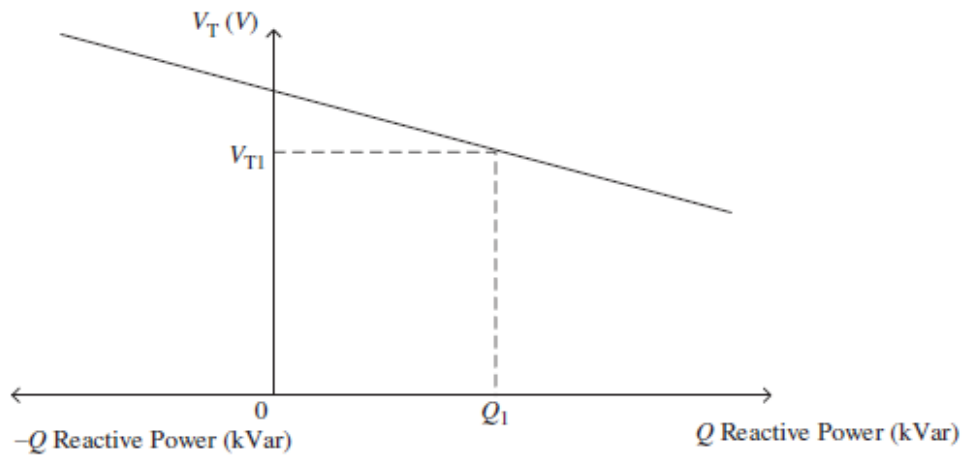


Figure5.4: Relationship between reactive power output and voltage

5.4 Economic dispatch for a micro- grid using renewable sources

Energy Economics is also a term kept in mind whenever a generation plant is setup. Same applies for micro-grid as it is used by a number of customers to meet their energy supply demand, and that depends upon cost/kwH of electricity supplied. For analysing dispatch rate an isolated grid with solar and wind can be considered. Resources maintenance cost, investment cost and generation cost functions can be modelled. Due to intermittent nature of energy created by renewable source they are highly dynamic and thus cannot be considered as

dispatch able. In formulation of Economic Dispatch these sources are considered as negative loads with a limited prediction accuracy. A micro-grid can be considered with combined heat and power, two conventional generators, wind and solar generations. Different combination of simulation with certain fixed parameters can be simulated in Matlab to obtain different results.

With inclusion of all five generators and no renewable energy credits, the total generation cost is higher since the investment cost for solar is higher. {Yeshalem, 2018 #60} (Ahmed et al., 2015; Augustine et al., 2012)

With no intermittent source included (solar or wind), but only CHP and conventional generators included does not give any profit or loss for micro-grid but makes system highly reliable because of absence of any intermittent resource.

With only wind included, but not solar, along with other generation means the overall system cost reduces since wind has moderate investment cost. Now again consider case with all sources included but along with credits for solar which include federal tax subsidy and tax rebated we can make solar profitable reducing overall generation cost. (Augustine et al., 2012)

6. METHODOLOGY

In this chapter, analyses of micro-grid components will be discussed. Matlab/Simulink has been used for analysis of this study to support proposed hardware

6.1 Tools and Techniques

A micro-grid consists of different energy sources. These sources of energy are integrated to a common DC Bus bar. Power electronic circuits are being used as interfaces between sources and Main grid, Load and energy storage unit as mentioned in the figure 5. The main objective of micro-grid is that during short fall, it meet the demand of the load. The analysis require different sources of energy and for the analysis point of view, three sources of energy are used as show as under:

- Energy Storage
- Photovoltaic Cells
- Wind Turbines

These sources are connected through a common bus bar through which Main grid, Load and Energy storage system are connected. {Alzahrani, 2017} This is depicted in the figure 6.1

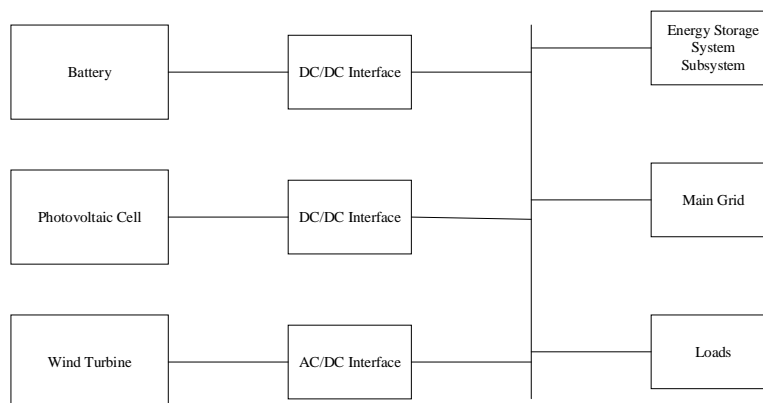


Figure6.1: Micro-Grid

6.1.1 Batteries as Energy Storage

In micro-grid, very important factor comes when there is a short fall and that why energy storage plays a significant role. Its optimum stability and synchronise operation with other sources of energy is achieved by positioning of energy storage system between load and renewable sources. {Alzahrani, 2017} The capacity of energy storage is calculated by considering the short fall from main grid. The formula for capacity of energy storage is as under:

$$B_{size} = \frac{E_{Load} \times Days_{off}}{DOD_{Max} \times \eta_{temp}} \quad (6.1)$$

Where

E_{Load} is load in Ampere/ Hour during short fall, $Days_{off}$ is number of days of short fall, DOD_{Max} is maximum depth of discharge of the battery η_{temp} is temperature correction factor. {Alzahrani, 2017}

The implementation of battery bank charging and discharging as energy storage in Matlab/Simulink has been carried out which is depicted in following figure 6.2 and figure 6.3

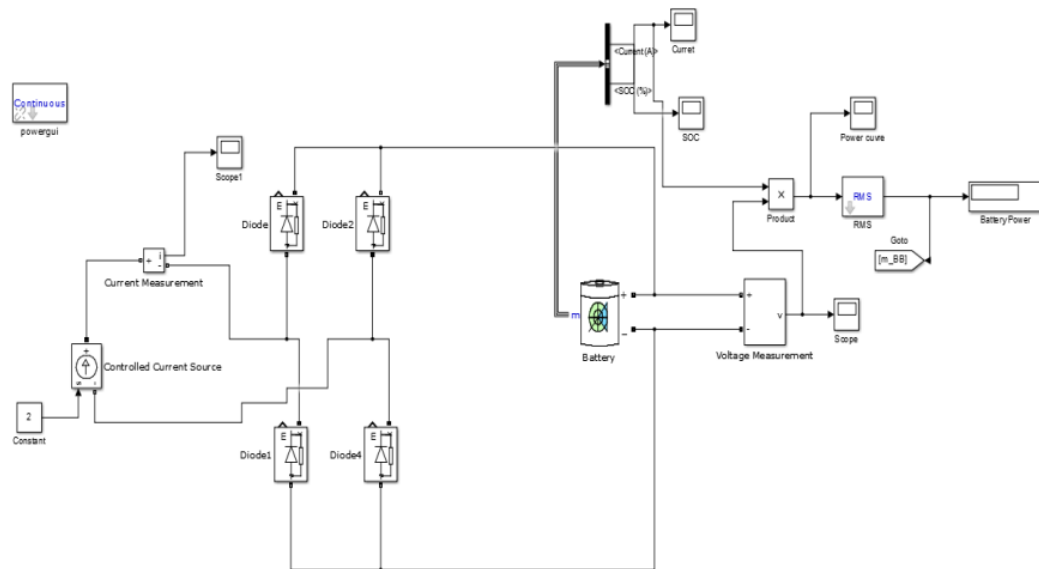


Figure 6.2: Battery Bank Charging

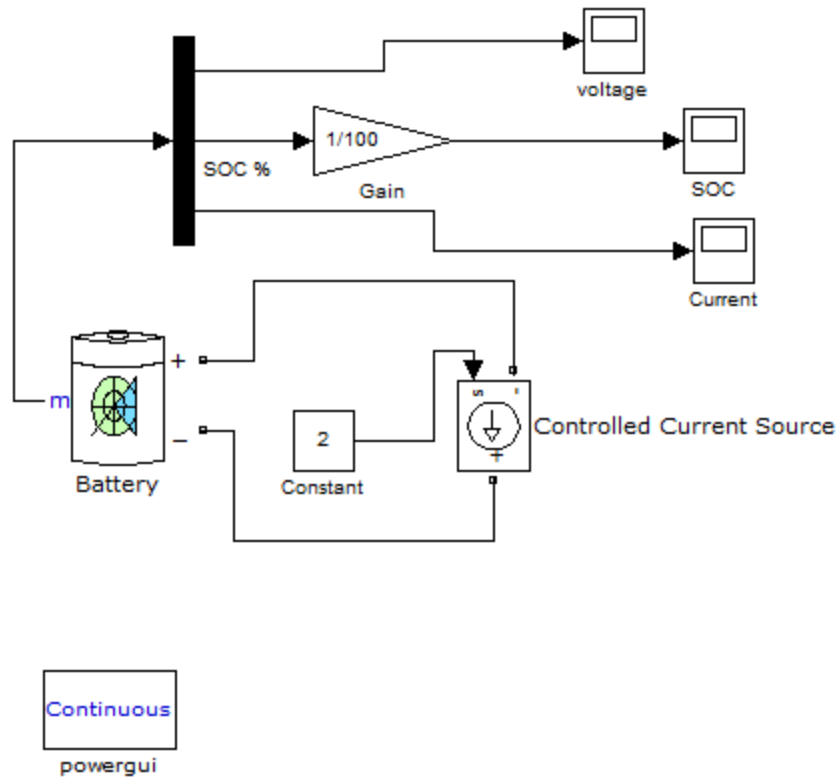


Figure6.3: Battery Bank Discharging

6.1.2 Photovoltaic Cells

It is used to convert the sunlight into electricity directly and that is why it is used very frequently in micro-grid. The DC voltage as an output is fed to the inverter and AC power supply is given to the load through inverter. It is the most prevalent and inexpensive energy source in the world. {Alzahrani, 2017}



Figure6.4: Photovoltaic Cells

The irradiance is an instantaneous measurement of solar power over some area and its unit is watt per square meter which is calculated by the formula as under:

$$I_T = I_b R_b + I_d R_d + (I_b + I_d) R_r \quad (6.2)$$

Where I_b and I_d are normal and diffused solar irradiance respectively while R_b And R_d are tilt factor of difused and reflected part of solar irradiance. The hourly generation of Photovoltaic cells can be calculated by using the following formula:

$$P_{sj} = \eta_r \eta_{pc} + \gamma_d A_{PV} I_{Tj} \left(1 - K \left(\left(T_a + \frac{I_{T,NOCT}}{NOCT - T_{a,NOCT}} I_T \right) - I_T \right) \right) \quad (6.3)$$

Where η_r and η_{pc} are reference and smoothing power efficiency of module respectively, γ_d is the factor of density of a cell in module, K is the temperature coefficient of array A_{PV} is area of photovoltaic cell, T_a is the instantaneous ambient temperature, $NOCT$ Normal operating temperature of cell. {Alzahrani, 2017} The equivalent circuit of PV cell is depicted in the figure 6.5

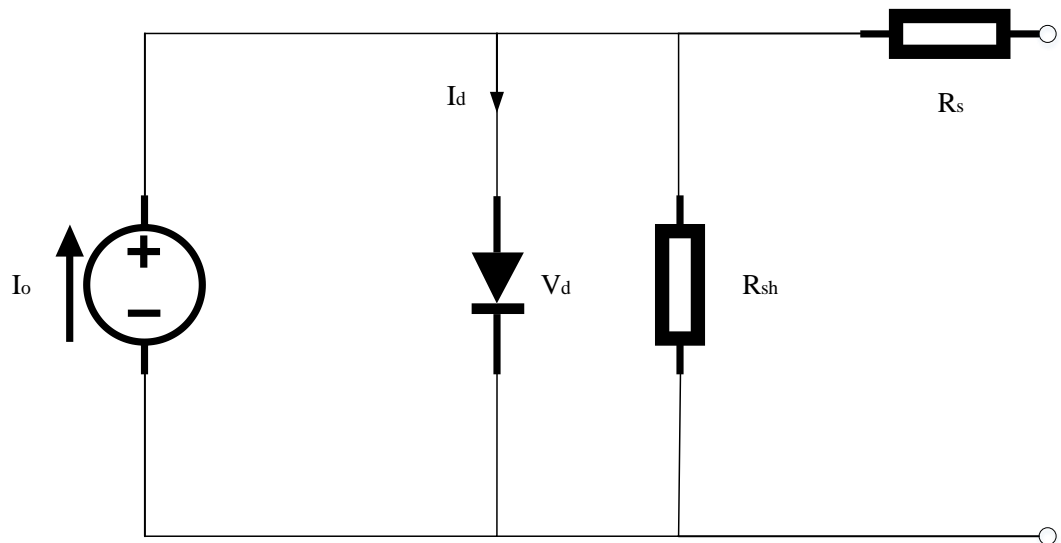


Figure6.5: Photovoltaic Cell Equivalent Circuit

There is photocurrent source. A diode is connected in parallel with photocurrent source and there is shunt resistor with series resistor. This circuit is built into Matlabs/Simulink to verify its nonlinear behaviour of I-V and P-V output characteristics of PV module. It is shown in figure 6.6

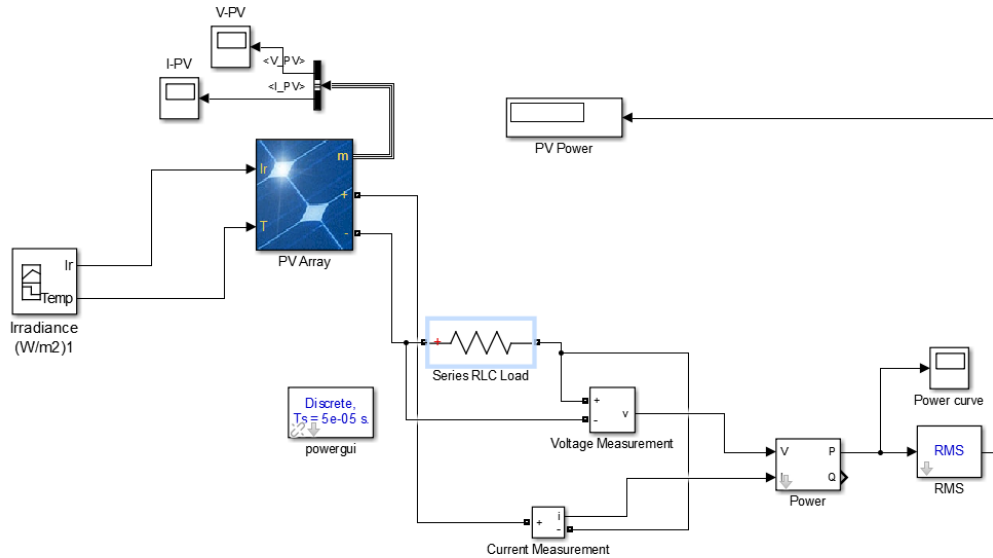


Figure 6.6: PV Cells Modelling

6.1.3 Wind Turbine

Energy extraction from wind is done with the help of blades in wind turbine, though the action of aerodynamic forces acting upon them. Rotation of drive shaft, connected with the blades, produces variable AC. This variable AC is converted into DC and then back into AC at a specific frequency. Irregular earth's surface and unequal heating up of earth's atmosphere by sun, causes changing pressure in different zones of earth which in turn leads to flow of air from high pressure zones to low pressure ones. The power generated by a wind turbine is shown in Equation (vii). {Grant, 2018}

Since power generated is proportional to the cube of wind speed therefore wind turbines are preferred to be kept in region where average annual wind speeds are high. If wind speeds are too high pitch control can be applied where the angle of the blades are adjusted to reduce the speed of the blades. {Grant, 2018}

The Simulink diagram of a wind turbine is shown in Figure 6.7 which is based on Equation (vii).

$$P_m = \frac{1}{2} \cdot \rho \cdot A \cdot C_p(\lambda, \beta) \cdot V^3 \omega \quad (6.4)$$

The Betz limits states that the power factor coefficient has a limit of 59.7%. The tip speedratio is the relative speed of the rotor and the wind speed. The pitch angle is the relative angle between the rotor and its axis. {Grant, 2018}



Figure6.7: Wind Turbine

The Simulink model of a wind turbine equation is shown in figure 6.8

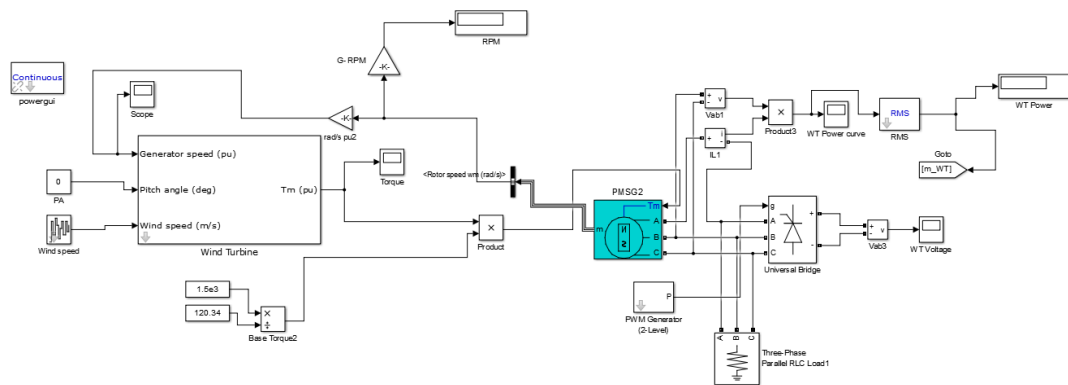


Figure6.8: Wind Turbine Modelling

6.2 Control Philosophy

There are various method of controlling micro-gird but in this thesis the control strategy for operation of micro-grid is built by considering two modes of operation which are as under:

- On Grid System
- Off Grid System

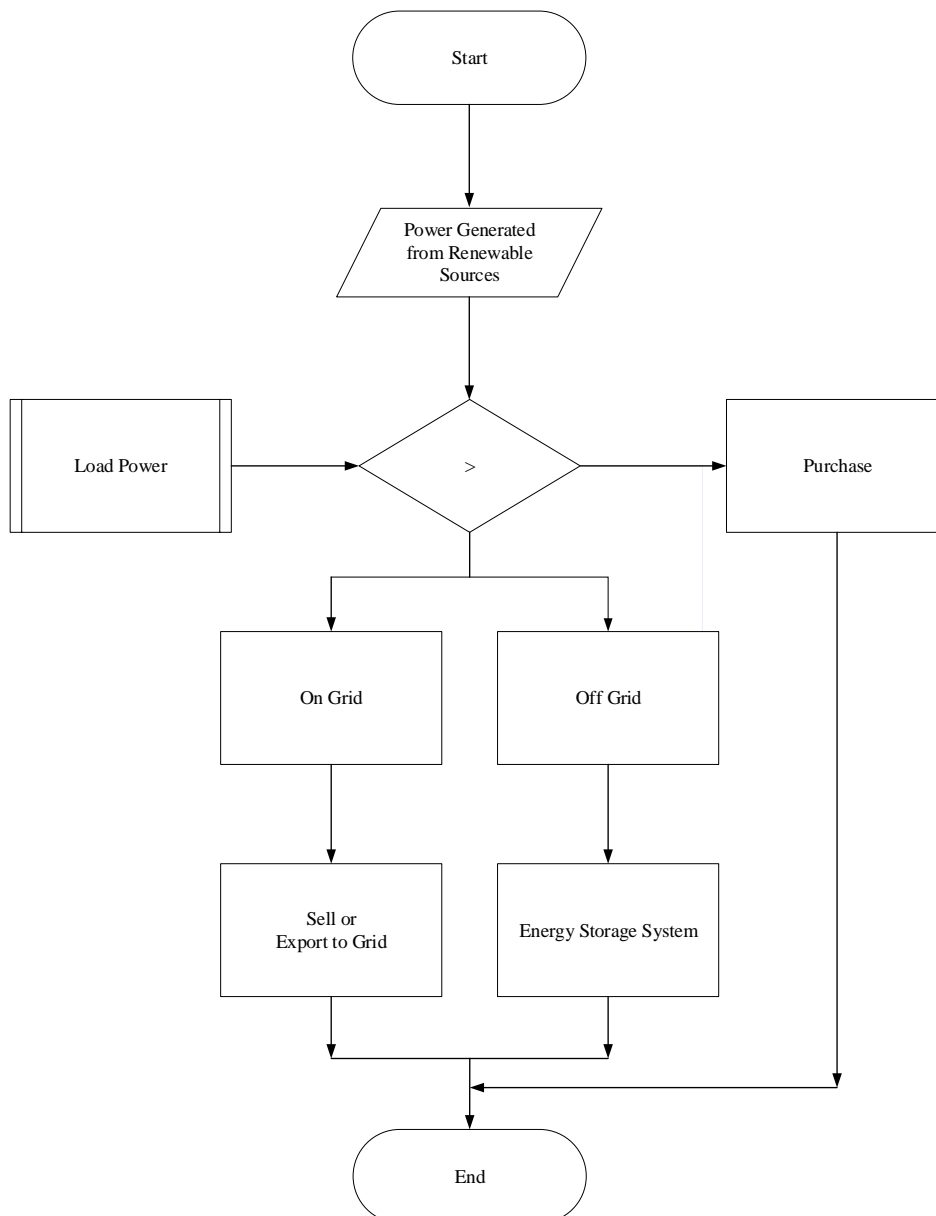


Figure6.9: Flow Chart

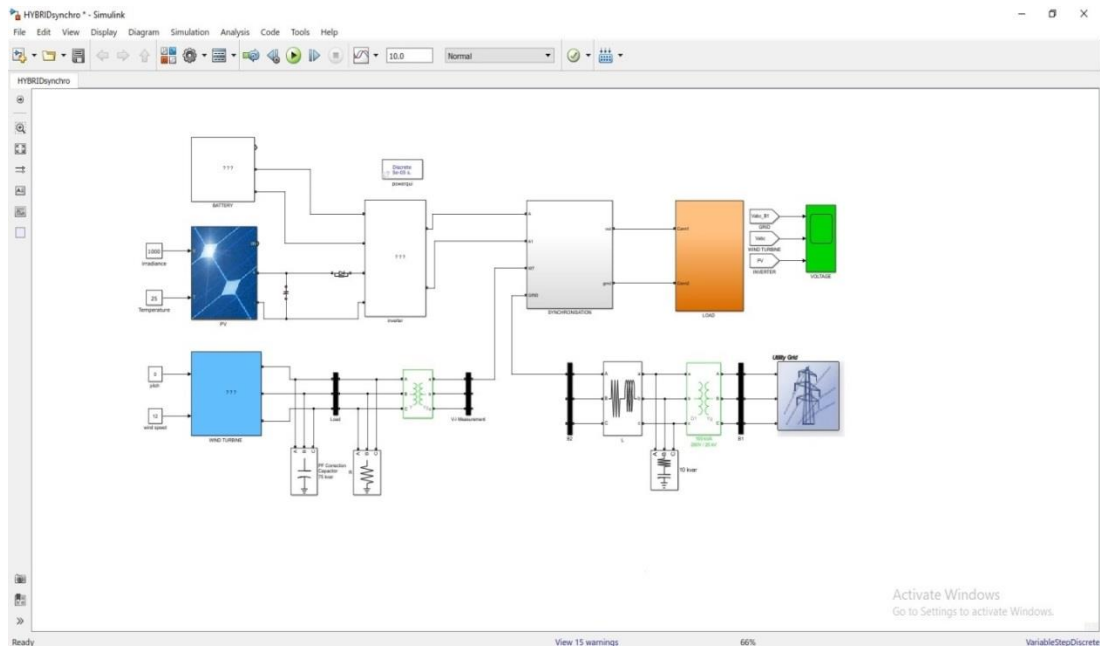


Figure 6.10: Simulink model of hybrid micro-grid

In this paper a comparison of different controller techniques used in the micro-grid is discussed to control the off/on grid. Proportional Integration that is PI controller is discussed first and Proportional control used in micro grid is discussed latter and finally comparison of these techniques will be discussed.

6.3 Proportional Integration Control

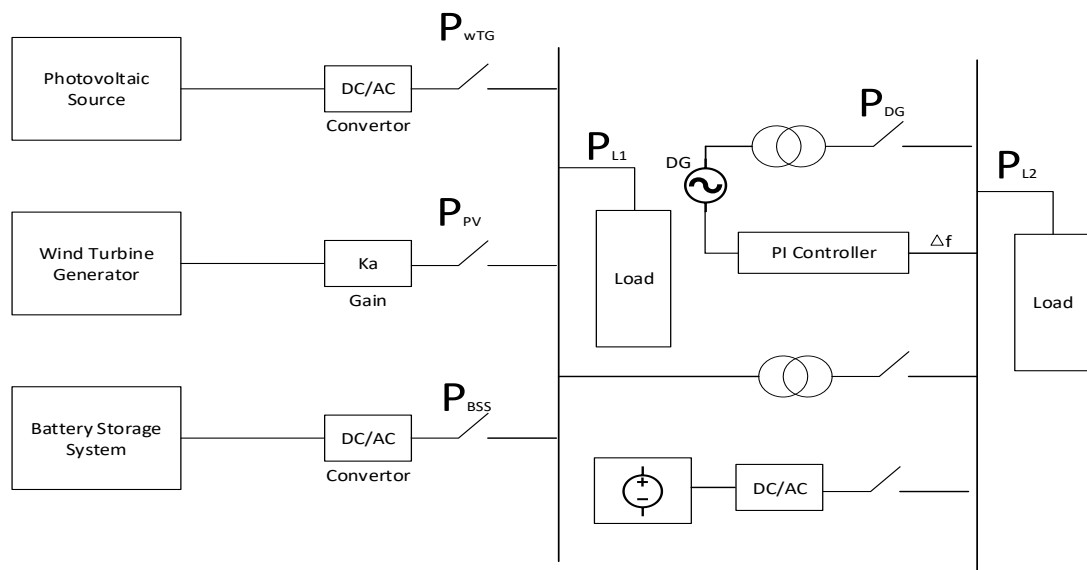
As in electrical power generation, there are different type of energy sources that is why this system becomes complicated. The Microgrid is in trend is increasing due to installation of small power plant of solar, wind, hydro etc. The fluctuation in output power is a major issue of renewable energy plant and introduce many technical issues likes' frequency divergence, voltage instability, harmonic etc. on grid side. It is the requirement to maintain the output synchronised with main grid and reduces fluctuation from the output.

The optimum performance of micro grid is achieved by three control frame work which are central, single and decentralized control. In central frame work, all data type of load and generating sources in the micro grid are collected. The control is on the generating units in single control while in decentralised control local controller is used for each distributed generating units local control signal are used in this method.

The complicated micro grid system is controlled by a controller which handle multiple complicated problems. It is the requirement of the controller that it must be intelligent, easily optimise the problem and give a produces a high accurate response in small period of time. In past, a compensation methods, and droop control methods were used but it was not as accurate as PI controller so it is not used.

6.4 Modelling of micro grid using PI Controller

There are two ways of modelling of micro grid control technique. It can be achieved in connected and disconnected mode. Some studies shows that micro grid in disconnected mode is preferred as compare to the connected mode. Number of parameter are required to model the micro grid control. Parameters of different micro sources for instance wind generator, storage system, PV sources are studied before modelling of isolated micro grid. Circuit breakers are used shown in figure, to protect the system from disturbance.



Generating Units	Rated Power (kW)
Solar Panel	30
Wind Generator	100
Battery Storage System	45

The table shows the rated power of different generating units and storage

Applied Load	Power (kW)
Primary Load	180
Secondary Load	170

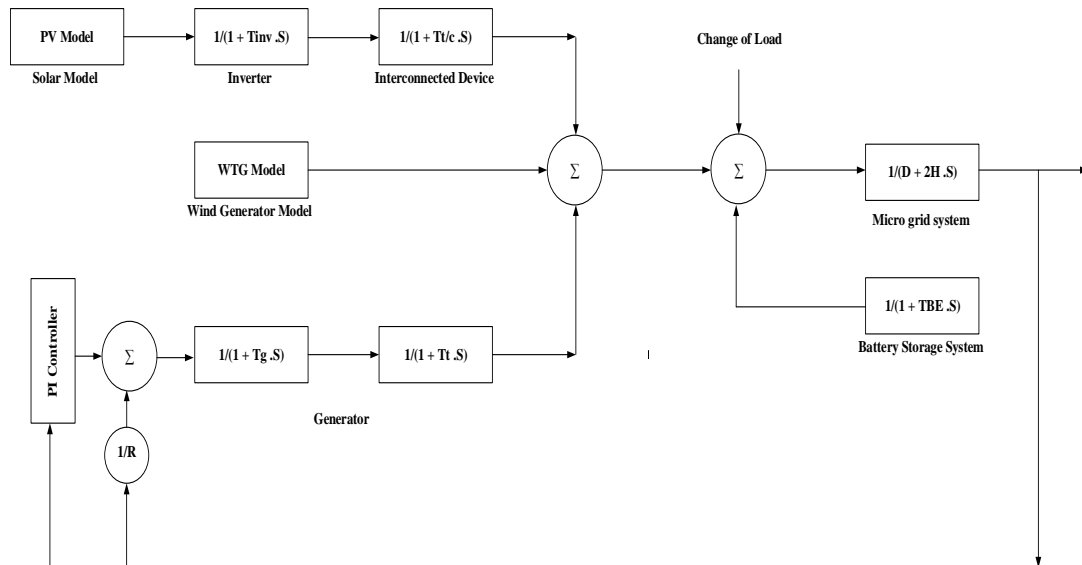
system.

The table shows the applied load and their power consumption. The modelling of micro grid is carried out in mat lab so parameters values are necessary for the frequency response model of the micro grid these values are given in the table.

Parameter	Value (pu)
$T_s (s)$	0.42
$T_g (s)$	0.081
$T_{\frac{1}{c}}(s)$	0.004
$T_{FE} (s)$	0.1
$T_{BE} (s)$	0.12
$T_{inv} (s)$	0.04
$2H (pu/s)$	0.166
$R (Hz/pu)$	3
$D (pu/Hz)$	0.0156

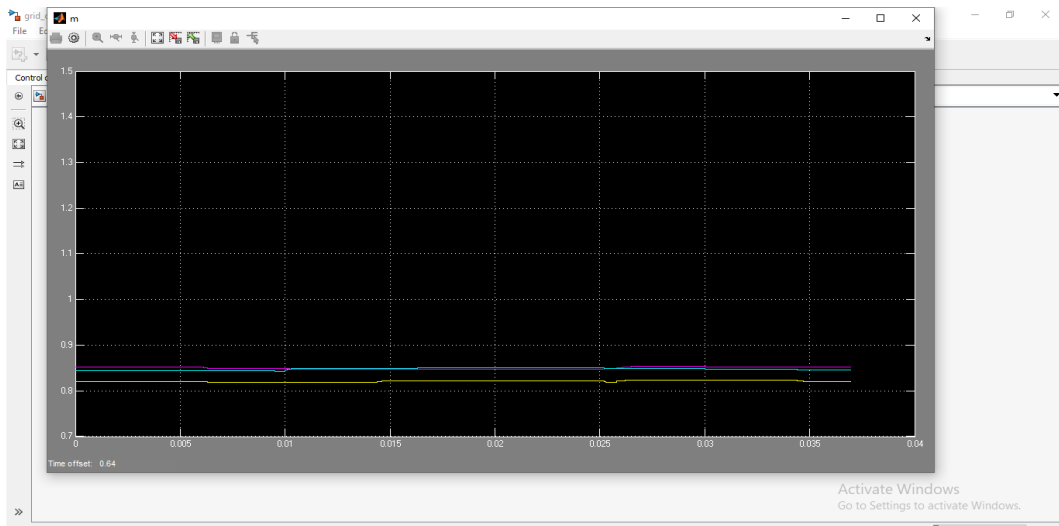
The tuning of PI controller is very critical and important and in the industrial system online tuning system is required to tune the parameters of PI controller. But in this paper, Ziegler Nichols method is used for tuning PI controller. The values of K_p and K_i are 4.0956 and 21.85 respectively. A model of micro grid in

isolated condition is very useful for study/ analysis of frequency response model of the system.

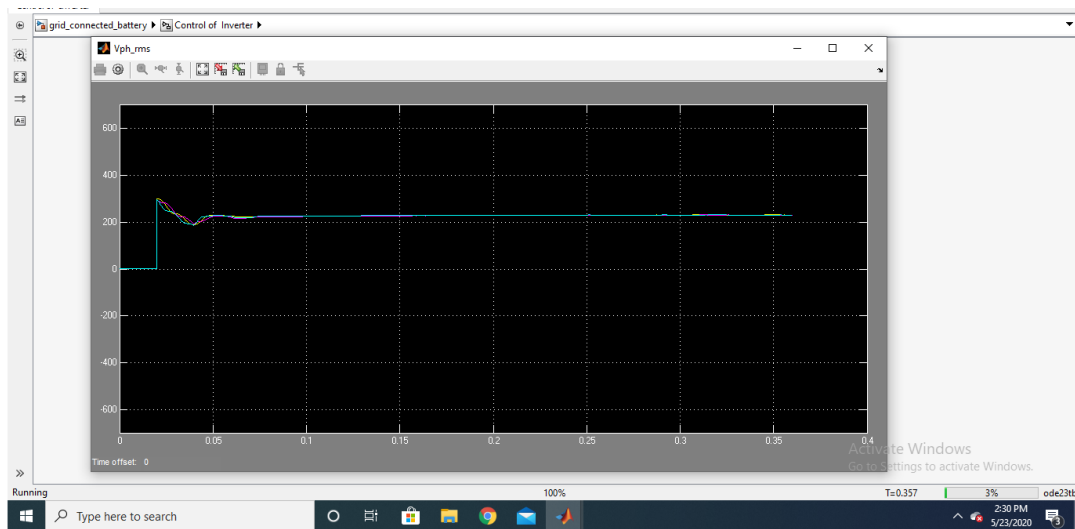


6.5 Simulation Result of PI Controller for Micro grid

There is one of the method used to control the frequency which is droop control method and area control. The PI controller is also used which is regulated and tuned based on certain points called pre-specified operating points. The optimal solution can be achieved by using PI controller. A good controller is controls the sudden changes in the feedback and controls the spikes or variation in the system. A micro grid system is tuned to get the values of K_p the is proportional gain and K_i integral action which are required such that frequency can be restored and for the easily elimination of frequency variations. A suitable amount of fluctuation in the load and variation in the power generation is used to provide a condition for analysis. A secondary controller is used to complete the control action or frequency control of the Microgrid. The figure shows the normal operating condition and at the starting point. Its need to tune by using Ziegler Nichols method.



The simulation of the micro grid model, the gain of PI controller is adjusted. The simulation results optimization capability of the controller. First, it is assumed that in the Micro grid model, the load disturbance is around 220 pu. And it gets stable at 200 pu.



6.6 PR Controller

The Proportional Resonant controller design in discrete domain for regulating active and reactive power output for three phase AC micro grid system. It is not only reducing the steady state error but also synchronised d-q transformation in three phase system. The Voltage Sourced Converter is required to configure which operate as a current source through an interface L-filter. The Power is

controlled by inverter indirectly. The analysis of PR controller is carried out in discrete domain forward and backward since in continuous domain its observation cannot be directly applied.

6.7 Experimental modelling for PI and PR controller

The experimental modelling for analysis of PI and PR controller is carried out using MATLAB/Simulink. A micro grid of 100KW consists of PV source connected to the main grid is developed. The compensator for PI and PR controller are implemented for the inverters output current regulation. The simulation required parameters which are as in the table.

Table 6.1: Comparison between THD Values

Parameters	PI Controller	PR Controller
Current	0.0855	0.0642
Voltage	0.0651	0.0441

The table shows the THD of current and voltage for PR controller is significantly less than that of PI controller. The simulation has been done for micro-grid at different types of loads for instance, pure resistive load and reactive loads with resistive load. The simulation results are shown in figures. The PR controller achieves accurately the required load of 100 KW + 75 KVAR as compared to PI controller which achieves at 90 KW + 71 KVAR which is shown in the figure.

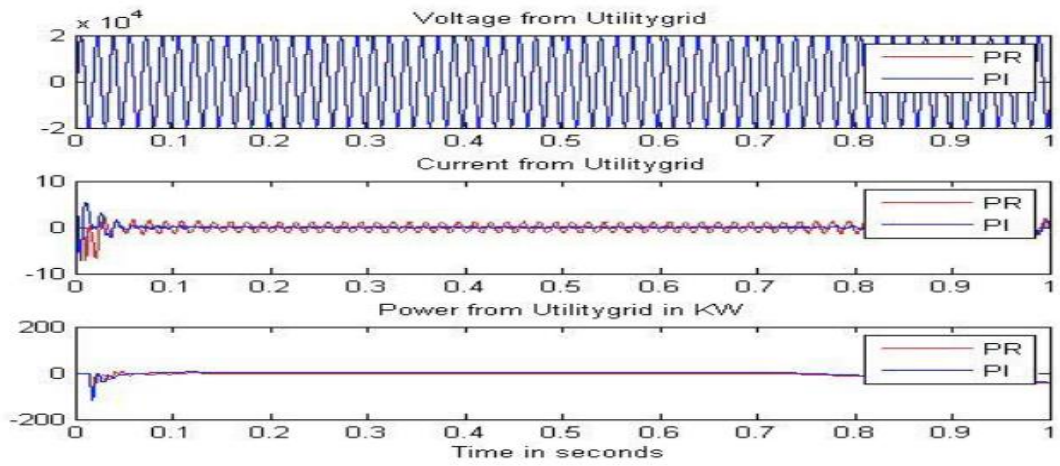


Figure 6.11: 1 at 100 KW: Voltage and Power from Utility to Load

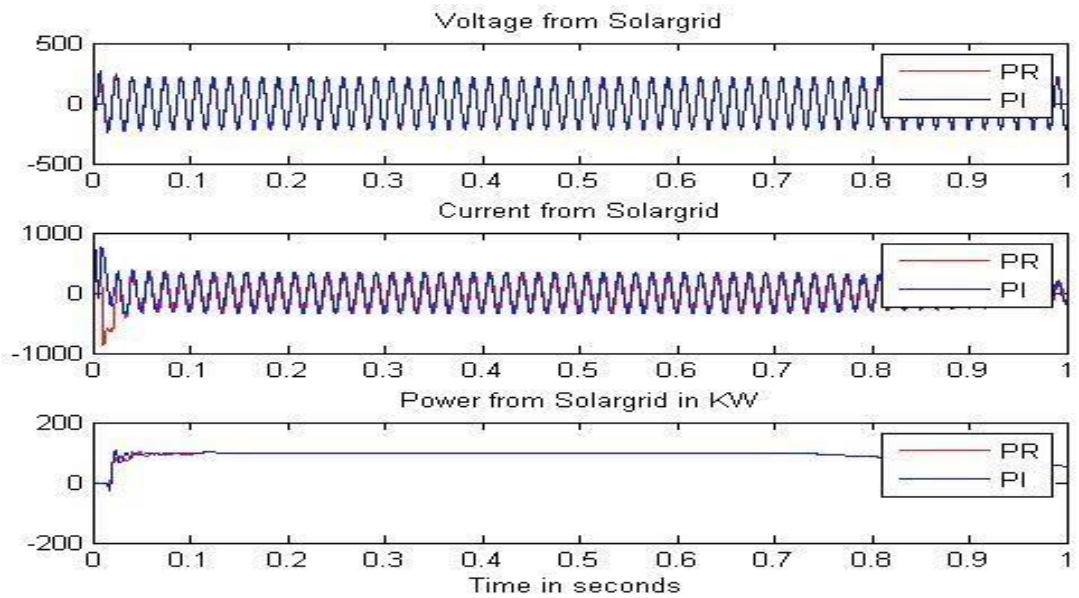


Figure 6.12: 2 at Load of 100KW: Voltage, Current and Power from Solar grid to Load

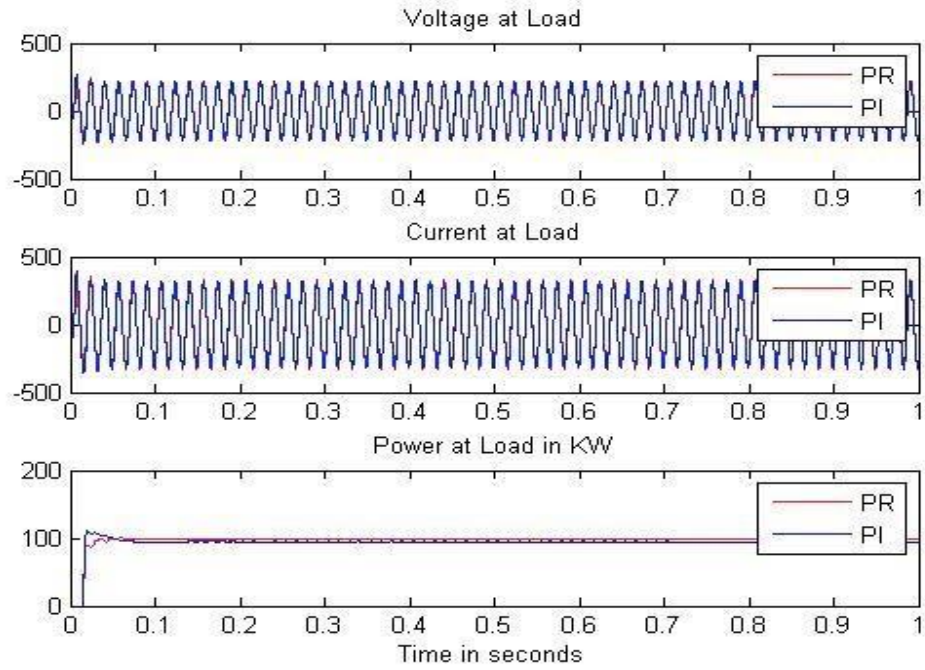


Figure 6.13: .3 at Load of 100KW: Voltage, Current and Real Power at Load

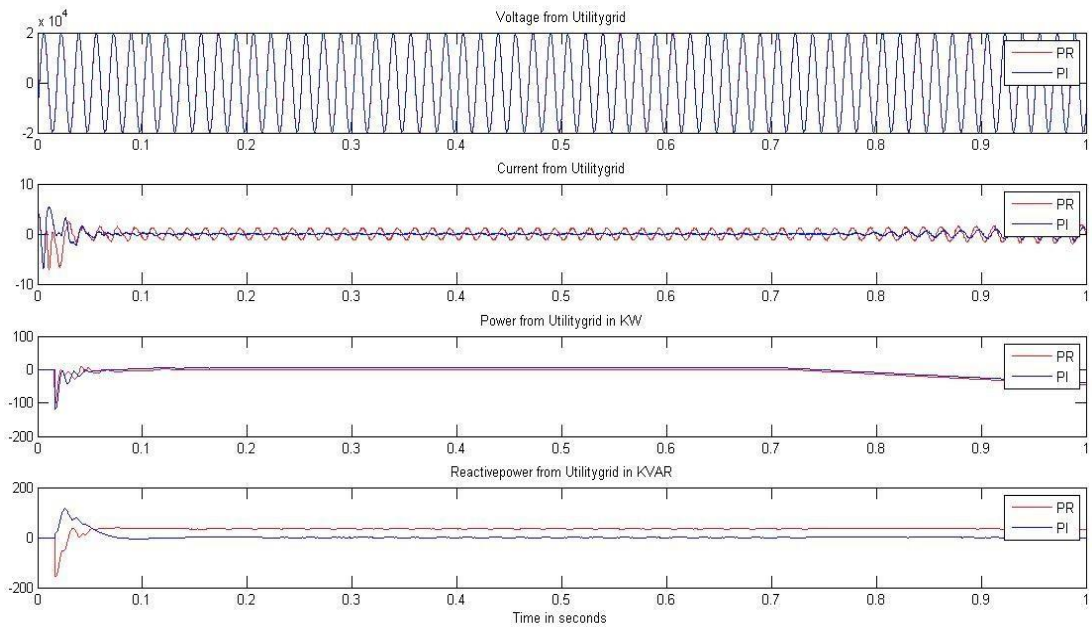


Figure 6.14: For Load 100 KW and 5 KVAR: Voltage, Current, Real Power and Reactive Power from Utility to Load

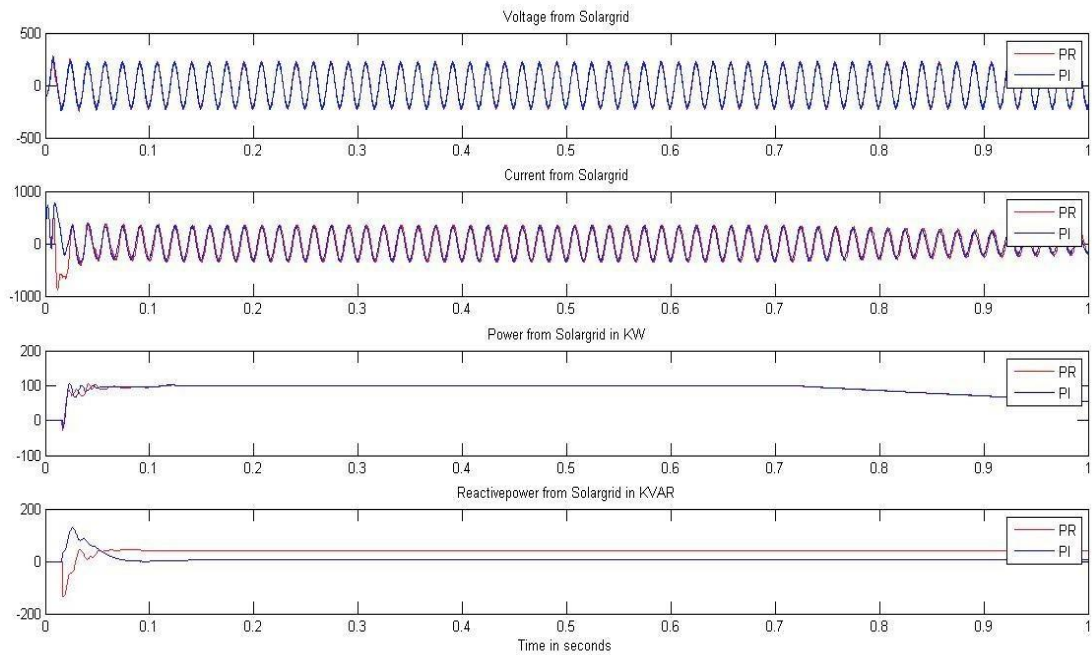


Figure 6.15: For Load = 100 KW and 5 KVAR: Voltage, Current, Real Power and Reactive Power from Solar Grid to Load

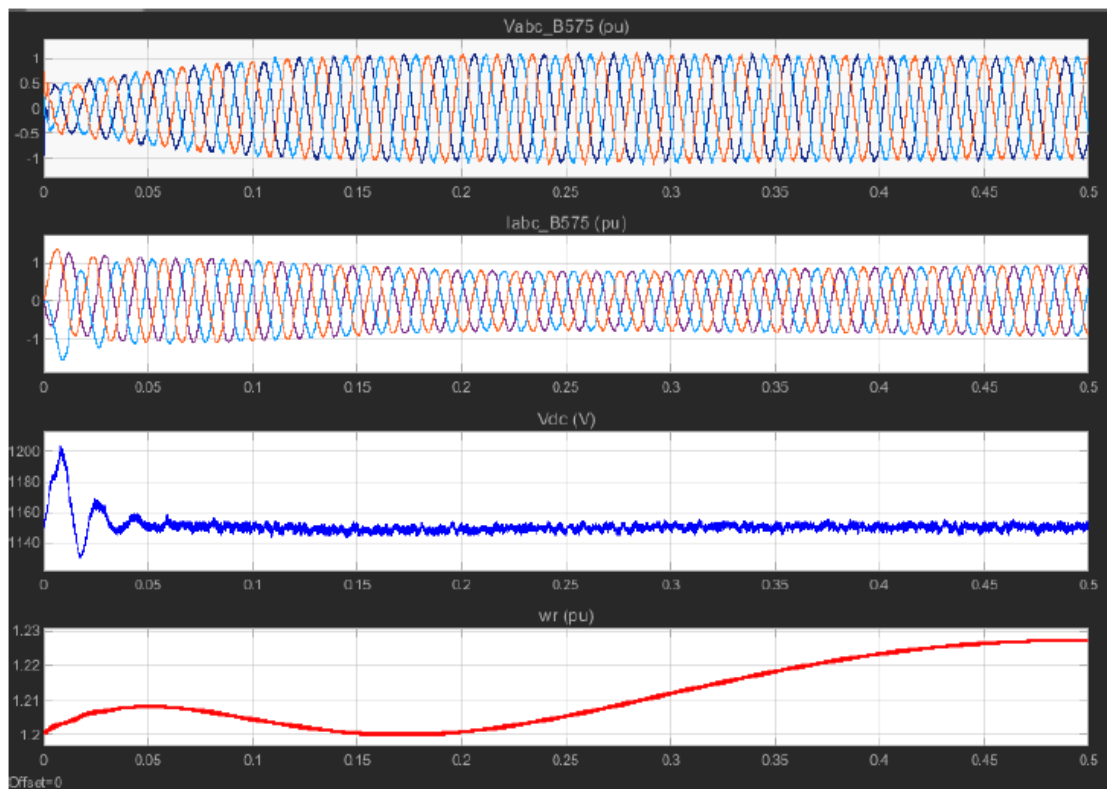


Figure 6.16: Above fig shows voltage,, current, dc-link voltage and rotor speed of wind generator

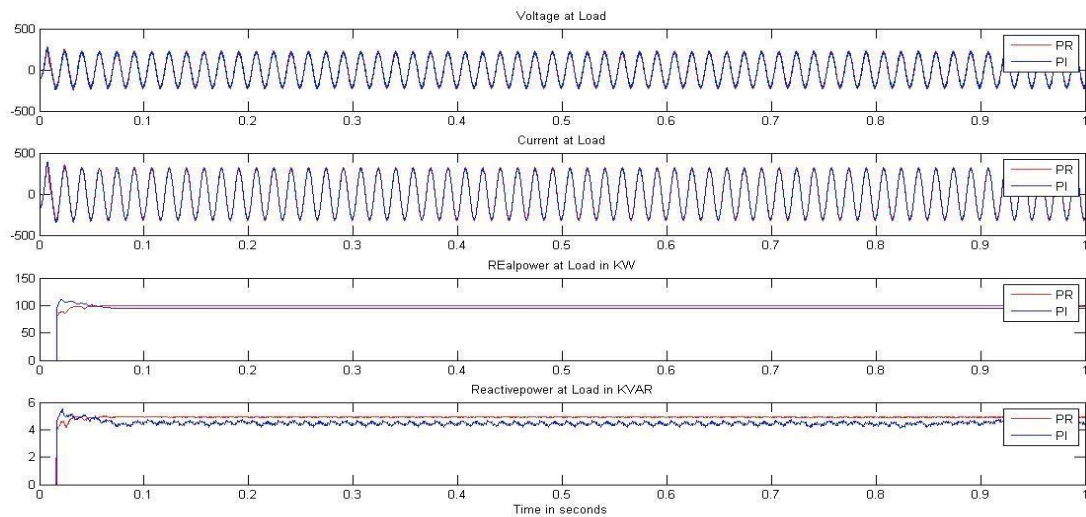


Figure 6.17:For Load = 100 KW and 5 KVAR: Voltage, Current, Real Power and Reactive Power at Load

Table 6.2: Solar and Wind data

SOLAR ARRAY + CONVERTER		WIND PLANT	
OUTPUT		OUTPUT	
V	200 V	V	200 V
I	19.4 A	I	4 A
P	3880W	P	800 W
Input power from sun = 10000 watts		BLADE LENGTH 9 m	
Overall plant efficiency (3880/10000)		Wind speed 12m/s	
= 38.8%			

6.8 Advantages of PR Controller over PI Controller

The grid which are connected to PV Inverter systems are very famous and number of such systems connected to main grid are increasing with the passage of time. The major drawbacks of these systems are due to harmonics generated through power electronic devices. Therefore, the quality of power generated from these sources is much poor or reduced. The Proportional Integral

controller is not used because it generated error as it go along with reference of sinusoidal wave. Since Integral term is the main cause for producing this steady state error. Hence, there is requirement of the grid voltage as feed forward term which helps the controller to try the steady state at fast rate and obtain a good dynamic response. This is the drawback of PI controller and it leads to development of PR controller. [7]

7. CONCLUSION

Micro-Grid (MG) system that is based on renewable power generation units is presented in this paper. The proposed system has been designed to operate in two operational modes; islanded & grid connected. The system performance is investigated using a simulation based on Matlab/Simulink software package. A control coordinator and monitoring system is also included to monitor micro-grid system state and decide the necessary control action for an operational mode. The system design took into consideration cost reduction through using a single 3-phase inverter instead of three one-phase inverters. Moreover, transformer has been eliminated to supply power to its local loads. It is intended that this work will be the base for the developing more sophisticated Micro-Grid designs.

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RESUME

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