Reactive Power Assessment Including Renewable Energy Sources

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the

Degree of

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IN

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(Electrical Power Systems)

By

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I, **Avani Patel(Roll No:12MEEE21)**,give undertaking that the Major Project entitled **"Reactive Power Assessment Including Renewable Energy Sources"** submitted by me,towards the partial fulfillment of the requirement for the degree of Master of Technology in Electrical Power System,Electrical Engineering,under Institute of Technology, Nirma University,Ahmedabad is the original work carried out by me and I give assurance that no attempt of plagiarism has been made.I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere,it will result in severe disciplinary action.

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CERTIFICATE

This is to certify that the Major Project Report entitled **"Reactive Power Assessment Including Renewable Energy Sources"** submitted by **Ms. Avani T. Patel (Roll No: 12MEEE21)** towards the partial fulfillment of the requirements for the award of degree in Master of Technology(Electrical Engineering)in the field of Electrical Power System of Nirma University is the record of work carried out by her under our supervision and guidance.The work submitted has in our opinion reached a level required for being accepted for examination.The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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ABSTRACT

The interest in renewable energy sources has increased significantly due to environmental issues and fossil fuel's elevated cost.Fossil fuel consumption increases the emissions of carbon dioxide and global warming. The perspective of global warming suppression and sustainable energy development, recently renewable energy such as wind generation and photovoltaic generation (PV) are getting attention world wide. Therefore,usage of renewable energy in the form of distributed generators (DGs) has increased rapidly. However, DG using renewable energy is influenced by the weather. Therefore, maintaining the voltage in the distribution to a statutory range becomes difficult. In addition, conventional distribution systems have been constructed without consideration of DG connections.Consequently, certain problems e.g. reactive power support, active power transmission, line loadings etc. emerge as a new problem as opposed to conventional case. If large amount of DGs using renewable energy are installed to a distribution network, voltage deviations and fluctuations based on output power fluctuation of DGs will become a significant problem.So the reactive power in the grid is needed to keep the external(grid) voltage at the desired value. The correction of deviation of the external voltage from the nominal require the supply of the reactive power to the grid. The needed amount depends on the current value of the active power supply. It should be recognized that system voltage level affects a generating plants ability to deliver reactive power to the grid and the power systems requirement for reactive support.The task is to assess reactive power in a considered system due to DG penetration and provide suggestions to maintain voltage support mechanism.

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Abbreviation

DG .... Distrubuted Generation
PV .... photo-voltaic
WSCC .... Western System Coordinating Council
RES .... Renewable Energy Sources
DFIG .... Doulbly-Fed Induction Generator
WRIG .... Wound Rotor Induction Generator
SCIG .... Squirrel Cage Induction Generator
PMSG .... Permanent Magnet Synchronous Generator
STC .... Standard Test Condition
MPPT .... Maximum Power Point Tracking
PWM .... Pulse Width Modulation
PI .... Proportional Integral
IGBT .... Insulated Gate Bipolar Transistor

Chapter 1

Introduction

1.1 Background

Despite renewable sources unpredictable power generation and installations of DG facilities have become significant options to provide electric energy. Recently, electric energy sector emphasized the importance of using renewable resources as a clean supply of electric energy. Most of these DG facilities were based on either wind power or solar irradiance, both of them are unpredictable and intermittent power resources[10].A major concern about renewable DG resources are the possible impacts of their outputs intermittency on the system operation. In distribution systems, the random output of renewable DG units may affect one or more of the given: quality of supply voltage,Active power and reactive power.

There has been a very large effort to understand reactive power and voltage control issues in power systems in last many years.The electricity world is facing a significant change due to regulatory, social and environmental issues, as well as technological development. In particular, a system approach able to manage intermittent energy supply from distributed power plants,leading to a steady supply of electricity is necessary. Similar control structures have been developed also for the voltage control, although their presence in operation is less frequent. Due to the increasing share of RES i.e photovoltaic plants and wind farms, intelligent grid management has become an even more important requirement for efficiently balancing production and consumption.Moreover,RES generation makes power flows in the grid to be more difficult to be predicted and controlled. In such a scenario, power flows management turns out to be a key factor for integrating scattered and decentralized RES production into the grid.

1.2 Literature Survay

The most important part of any studies is to understand the given concepts and the importance of the topic.This is achieved by survey of specious literature available.This section describes about some important papers to understand the concept of distributed generation in case of renewable energy sources and their impact on power system.

N.K. Roy,H. R. Pota - [1] In this paper methodology of a placement for distributed generator (DG) based on newly defined term reactive powe and gives simulation results showing the sensitivity of the location of renewable energy based DG on voltage profile of the system. Then a suitable location is identified for two principal types DG, i. e.,wind and solar.It is found that induction type wind generator reduces the system stability and solar energy based DG enhances the stability margin of the system compared to the base case. To reduce the possibility of voltage collapse, it is essential to increase the Q loadability of the system. So, strong buses are a good choice for wind generator installation and weak buses are a good choice for solar installation.

Asish Ranjan, S. Prabhakar Karthikeyan- [2]: In this paper Various DG technologies are being integrated into power systems to provide alternatives to energy sources and to improve reliability of the system. Power Evacuation from these remotely located DGs remains a major concern for the power utilities these days. The main cause of concern regarding evacuation is consumption of reactive power for excitation by Induction Generators (IG) used in wind power production which affects the power system in variety of ways. This paper deals with the issues related to reactive power consumption by Induction Generators during power evacuation. Induction generator based wind turbine model using matlab/simulink is simulated and its impact on the grid is observed.Wind farm model and simulations are carried out to study the various impacts it has on the grid and nearby wind turbines during islanding and system event on 3-phase to ground fault.

Suman Nath, Somnath Rana- [3]: In this paper design and test a power system of 14.9 KVA capacity, operating at 440V, 20m/s base wind speed, induction generator based-wind energy system via.MATLAB simulation is given. The different components of a wind energy system namely the wind turbine, generator, controller system, rectifier-inverter, battery, load and other equipments including transformers, grid etc.This paper includes design of generator model,wind turbine model,load model and rectifier model.

Wang Shuo, Liu Di, Xu Yonghai- [4]: This paper established a modular simulation model of MW-level grid-connected PV power station in PSCAD/EMTDC. Both theoretical and simulation analysis show that the MW-level PV power station will indeed exercise a great influence on voltage deviation of distribution networks. Along with increasing of PV capacity, voltage deviation will be increase. This paper puts forward a reactive power control method of PV power station based on synchronous PI current control.This method can achieve the regulation of power grid voltage by controlling reactive power.

A. Ellis, R. Nelson, E. Von Engeln, R. Walling, Fellow- [5]:In this paper capability of wind and solar plants are discuss for voltage regulation . It also examines the deficiencies in existing standards and provides recommendations to improve upon existing requirements in order to clearly define the role of variable generation in providing voltage support to the bulk electric grid. It should be recognized that system voltage level affects a generating plants ability to deliver reactive power to the grid and the power systems requirement for reactive support. A reduced requirement to inject reactive power into the power system when the Point of interconnection voltage is significantly above nominal and a reduced requirement to absorb reactive power when the point of interconnection voltage is significantly below nominal should be considered.

A. Tapia, G. Tapia, J. X. Ostolaza, J.R. Saenz- [6]: In this paper dynamic performance of the developed model has been simulated using the MATLAB SIMULINK package and the simulation results have been compared to the results obtained from the dynamic performance of a real wind farm located in Navarra (North of Spain). Active/reactive power regulation possibility can become very important in the decision making process for the generator-type that has to be implemented in each wind farm. The main problem described in this paper is the modelling of a complete wind farm, because different wind speeds can cause different rotor angular speeds and consequently, production of different amounts of active/reactive power on each generator.

Abdulrehman Kalbat- [7]: This paper discuss about grid tied PV system that is prepared in PSCAD.Grid-tied PV model which consist PV array,DC link capacitor,DC-DC buck converter,Inverter,Filter and grid.Use of every component given in detail.Total harmonic distortion analysis on the inverter output current using PSCAD block.It also analyze the effect of variable atmospheric condition(temprature and irradiation)on the performance of given PV model.

Liu Hai-jun,Wang Li-guo-[8]:Detail analysis of modelling method of PV array,maximum power point tracking in single stage grid-connected PV system given in this paper.The model designed under PSCAD/EMTDC environment.The simulation results show the characteristics of PV array and the output power.

1.3 Problem Identification

Distributing generation resources throughout the power system can have a beneficial effect if the generation has the ability to supply reactive power. Without this ability of performance,distribution system can be degraded.Reactive power (VAR) is required to maintain the voltage to deliver active power (watts) through transmission lines.When there is not enough reactive power, the voltage sags and it is not possible to push the power demanded by loads through the lines.Various types of distributed energy resources equipment are used to maintain voltages throughout the transmission system.Voltage control in an electrical power system is important for proper operation for electrical power equipment to prevent damage such as overheating of generators and motors, to reduce transmission losses and to maintain the ability of the system to withstand and prevent voltage collapse[17]The continous increase on the penetration levels of RES in power systems has lead to changes on design,control and operation of electrical network.

Because of these problems, the issue of power quality delivered to the end consumers is, more than ever, an object of great concern.So there is a need to observe reactive power in different types of DG sources in power system.

1.4 Objective and Scope of the Project

The objective of this project work is to assesing the RES impact on the system i.e active power,reactive power,voltage profile etc,and where the requirement of compensation in the case of different types of renewable sources, which can help in better operation of power system. This report discusses various distributed generation resources connected inplace of one generator in WSCC 3- machine, 9-bus system (available in literature[16] [9]). To achieve the objective, the scope of the project work can be proposed up to the assessment of reactive power including renewable sources. Also, power and voltage of a system are supposed to be recorded for analysis purpose. To achieve the objective of this project,the scope of the work is outlined as:

- Develop a standardized model of WSCC 3-machine,9-bus system in PSCAD or any other softwar and to observe load flow analysis under steady state condition for conventional case.

- Observe active power,reactive power,voltage results at each bus in steady state condition and after creation of fault at any bus in conventional case.
- Implementation of specific model in PSCAD i.e wind farm(SCIG wind turbine) or PV array,Connect this model into grid in place of any one machine which is given into the WSCC system.
- By the examine of simulation results we need to suggest that where it is required to connect capacitor bank for improving the assessed reactive power and voltage profile.

1.5 Outline of Thesis

The work carried out in the third phase is segregated into four chapters.

- **Chapter 1** introduces the need of carrying out assessment of reactive power and the motivation behind the project. It also includes review of literature studied, problem identication and scope of work.
- **Chapter 2** gives the present scenario and discusses concept of distributed generation.Various ways in which a distributed generation problem is explained. The need and benefits of using DGs is covered.
- **Chapter 3** describes wind generation technolgy,turbine power calculation and different wind model component description in detail.
- **Chapter 4** gives the detail about photovoltaic generation and their model description in detail.
- **Chapter 5** includes the work carried out.Simulation results of test system under different conditions are given.
- **Chapter 6** gives the conclusions of the study are summarized and followed by some ideas on future work

Chapter 2

Distributed Generation

2.1 Introduction

Traditionally, electrical power generation and distribution are purely a state owned utility. However, in order to keep up with the growing demand, many states are deregulating the electrical energy system. This trend is not without its own challenges.Distributed resources may be defined as generating resources other than central generating stations that is placed close to load being served, usually at customer site. It serves as an alternative to or enhancement of the traditional electric power system. The commonly used distributed resources are wind power, photo voltaic, hydro power.

2.2 Advantage of Distributed Generation

Wind turbines produce electricity by using the power of the wind to drive an electrical generator. Wind passes over the blades, generating lift and exerting a turning force. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox increases the rotational speed to that which is appropriate for the generator, which uses magnetic fields to convert the rotational energy into electrical energy. The power output goes to a transformer, which converts the electricity from the generator.In fact, many utilities around the world already have a significant penetration of DG in their system. But there are many issues to be taken into account with the DG.

a. Flexibility - DG resources can be located at numerous locations within a utility's service area. This aspect of DG equipment provides a utility tremendous flexibility to match generation resources to system needs.

b. Improved Reliability - DG facilities can improve grid reliability by placing additional generation capacity closer to the load, thereby minimizing impacts from transmission and distribution system disturbances, and reducing peak-period congestion on the local grid. Further more, multiple units at a site can increase reliability by dispersing the capacity across several units instead of a single large central plant.

c. Reduce loading of T and D system - By locating generating units on the low-voltage bus of existing distribution substations, DG will reduce loadings on substation power transformers during peak hours, thereby extending the useful life of this equipment and deferring planned substation upgrades.

d. Improve power quality and voltage profile of the system[11]

2.3 Technical Challenges Facing Distributed Generation

Distributed Generation (DG) is not without problems. DG faces a series of integration challenges, but one of the more significant overall problems is that the electrical distribution and transmission infrastructure has been designed in a configuration where few high power generation stations that are often distant from their consumers, push electrical power onto the many smaller consumers. DG systems are often smaller systems that are that are locally integrated into the low voltage distribution system.Adding DG to the existing electric power distribution system can lead to a reduction of protection reliability, system stability and quality of the power to the customers[12].Depending on the amount of DG connected and the strength of the utility power system, the issues are Voltage Regulation and Losses, Voltage Flicker.

2.4 Summary

This chapter describe Disributed resources used in DG. when they are introduce on system what challenges facing on system and their advantage.Detail study of wind turbine carried out in next chapter.

Chapter 3

Wind Generation

3.1 Introduction

Now-a-days global warming is the most burning issue found in many of the climate summit. Many researchers, scientists are working their own relevant areas to reduce the Effective mitigation of climate effect due to global warming by using different techniques. The electricity system is viewed as being easier to transfer to low-carbon energy sources than more challenging sectors of the economy such as surface and air transport . Hence the use of cost-effective and reliable low carbon electricity generation sources is becoming an important objective of energy policy in many countries. This is only possible by utilizing renewable sources as the key sources for the generation of electricity.The survey conveys that, over the past few decades wind energy has shown the fastest rate of growth of any form of electricity generation.The produced electrical power from wind has significantly increased in last years.For that reason todays wind turbines,which are centralised in wind park,have a significant influence on the power production.The merge of several wind turbines into bigger units in windfarms for increasing the production from wind energy.

This chapter discusses detail about the Wind generation, different types of wind turbine technology used to achieve fastest growth in the world market. The basic concepts of the turbines, maximum power extractable from wind, characteristics of wind turbine are also the part of this chapter. A laymans concept states that wind energy system means it is the combination of turbines, generators, the mediator power electronic converters and the brain called controller.

3.2 Induction Generator

Typically small renewable energy power plant mostly on induction generator because they are widely and commercially available and very inexpensive.It is also very easy to operate them in parallel with large power system.It is mostly suitable for hydro and wind power plant.Most of the fixed speed wind turbines employ squirrel-cage induction machines,for which models are radily available in most of power system modelling software.The in built induction machine model in PSCAD/EMTDC was used in the simulation.

3.3 Wind turbines

Wind turbines produce electricity by using the power of the wind to drive an electrical generator. Wind passes over the blades, generating lift and exerting a turning force. The rotating blades turn a shaft inside the nacelle, which goes into a gearbox. The gearbox increases the rotational speed to that which is appropriate for the generator, which uses magnetic fields to convert the rotational energy into electrical energy. The power output goes to a transformer, which converts the electricity from the generator.There is a huge range of possible wind turbine configuration.Most commonly wind turbines are sorted into the two major categories of "fixed speed turbine" and "variable speed turbine".There is a large range of topologies classified further in detail.

3.4 Wind turbines Technology

There are a large number of choices of topologies available to the designer of a wind turbine. However, commercial designs for electricity generation have now converged to three-bladed upwind turbines with horizontal axis. The largest machines are now tend to operate at variable speed and the smaller, simpler turbines are of fixed speed. For any fixed speed system the turbulence of the wind will result in power variations, affecting the power quality of the grid. on the other side, in any variable-speed wind turbine, power electronic equipments are used to control the generator, and therefore it is possible to control the rotor speed. Thus the power fluctuations caused by wind variations can be absorbed by changing the rotor speed and thus power variations originating from the wind conversion can be reduced. So, the power quality impact caused by the wind turbine can be improved compared to a fixed-speed turbine.

3.4.1 Fixed speed wind turbine(Type A)

Fixed-speed wind turbines are electrically fairly simple devices consisting of an aerodynamic rotor driving a low-speed shaft, a gearbox, a high-speed shaft and an induction (sometimes known as asynchronous) generator.It is directly connected to the grid. From the electrical system viewpoint they are perhaps best considered as large fan drives with torque applied to the low-speed shaft from the wind flow.It consists of a squirrel-cage induction generator coupled to the power system through a turbine transformer. The generator operating slip changes slightly as the operating power level changes and the rotational speed is therefore not entirely constant. However, because the operating slip variation is generally less than 1

3.4.2 Variable speed wind turbine

During the past few years the variable-speed wind turbine has become the dominant type among the installed wind turbines. Variable-speed wind turbines are designed to achieve maximum aerodynamic efficiency over a wide range of wind speeds.The

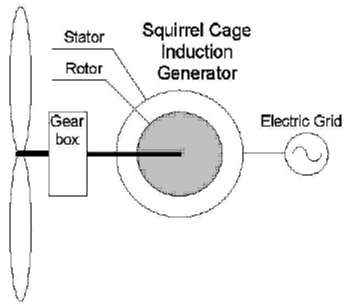


Figure 3.1: Type A (SCIG)generator configuration.

electrical system of a variable-speed wind turbine is more complicated than that of a fixed-speed wind turbine. It is typically equipped with an induction or synchronous generator and connected to the grid through a power converter.The power converter controls the generator speed; that is, the power fluctuations caused by wind variations are absorbed mainly by changes in the rotor generator speed and consequently in the wind turbine rotor speed. The advantages of variable-speed wind turbines are an increased energy capture, improved power quality and reduced mechanical stress on the wind turbine. Most common variable speed wind turbine configurations are as follows.

a. Limited variable speed(Type B).

b. Variable speed with partial scale frequency converter (Type C).

c. Variable speed with full scale frequency converter (Type D).

3.4.3 Type B wind turbine

This configuration corresponds to the limited variable speed wind turbine with variable generator rotor resistance. It uses a wound rotor induction generator (WRIG) and has been used by the Danish manufacturer Vestas since mid nineties. The generator is directly connected to the grid. A capacitor bank performs the reactive power compensation. A smoother grid connection is achieved by using a soft-starter. The unique feature of this concept is that it has a variable additional rotor resistance, which can be changed by an optically controlled converter mounted on the rotor shaft. Thus, the total rotor resistance is controllable. This optical coupling eliminates the need for costly slip rings that need brushes and maintenance. The rotor resistance can be changed and thus controls the slip. This way, the power output in the system is controlled. The range of the dynamic speed control depends on the size of the variable rotor resistance. Typically, the speed range is 0 to10

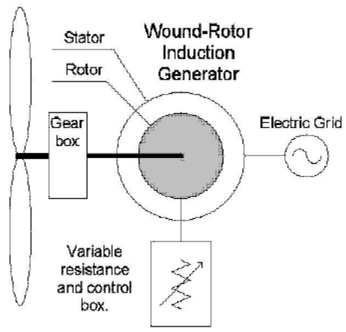


Figure 3.2: Type B (WRIG)generator configuration.

3.4.4 Type C wind turbine

This configuration is known as DFIG based wind turbine. It corresponds to the limited variable speed wind turbine having a WRIG and partial scale frequency converter (rated at approximately 30). The partial scale frequency converter performs the reactive power compensation and the smoother grid connection. It has a wider range of dynamic speed control compared with that of Type B wind turbine, depending on the size of the frequency converter. Typically, the speed range comprises synchronous speed -40

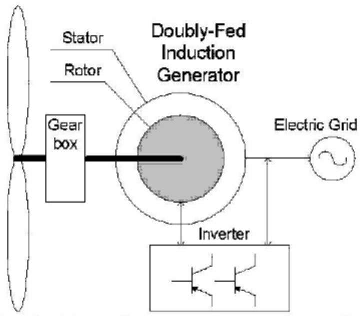


Figure 3.3: Type C (DFIG)generatorconfiguration.

3.4.5 Type D wind turbine

This configuration corresponds to the full variable speed wind turbine, with the generator connected to the grid through a full-scale frequency converter. The frequency converter performs the reactive power compensation and the smoother grid connection. The generator can be excited electrically (WRSG/WRIG) or by a permanent magnet (PMSG). Some full variable-speed wind turbine systems have no gearbox. In these cases, a direct driven multi pole generator with a large diameter is used. The wind turbine companies Enercon, Made and Lagerwey are examples of manufacturers using this configuration. The schematic configuration is shown in Fig.3.4

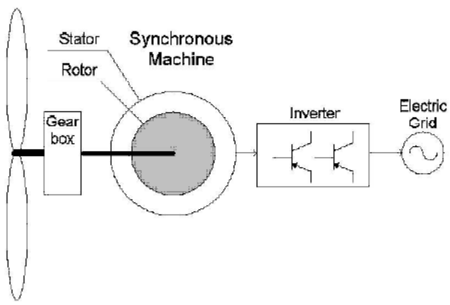


Figure 3.4: Type D (PMSG)generator configuration.

3.5 Power Output From Turbine

The kinetic energy given in terms of air of mass m,flowing at speed u in the x direction is

$$U = 1/2mu^2 = 1/2(\rho Ax)u^2 \qquad Joules \tag{3.1}$$

Where

A=Cross-sectional area in m^2

ρ=Air density in kg/m^3

x=Thickness of the mass in m

As air moving with side x moving with speed u and the opposite side fixed at the origin,so the kinetic energy increasing uniformly with x,because the mass is increasing uniformly[15].

The power in the wind,P_w,is the time derivative of the kinetic energy:

$$P_w = dU/dt = 1/2\rho Au^2 dx/dt = 1/2\rho Au^3 \qquad W \tag{3.2}$$

From the equation as the power being supplied at the origin to cause the energy of the parcel to increase according to Eq.3.1.Wind power varies with wind speed.

The power fraction extracted from the power in the wind by a practical wind turbine is usually given by the symbol C_p,coefficient of performance.Using this notation the actual mechanical power output can be written as

$$P_m = C_p(\rho Au^3) = C_p P_w \qquad W \tag{3.3}$$

The coefficient of performance is not a constant,but varies with the wind speed,the rotational speed of the turbine and turbine blade parameters like pitchangle.The Darrieus turbines operate with fixed pitch while the large horizontal axis turbines normally have variable pitch. The pitch is varied to hold Cp at its largest possible value up to the rated speed u_R of the turbine, and then it is varied to reduce Cp while

P_w continues to increase with wind speed, in order to maintain the output power at its rated value P_{mR}.

A variation of C_p versus u is shown in Fig. for the MOD-2 wind turbine[14].The turbine starts producing power at a hub height wind speed of 6.3 m/s (14 mi/h) and a C_p of about 0.28. A maximum C_p of 0.41, defined as C_{p_m}, occurs at 9 m/s (20 mi/h). Designing the blades to have a maximum coefficient of performance below the rated wind speed helps to maximize the energy production of the turbine.

The rated wind speed for the MOD-2 is 12.3 m/s (27.5 mi/h) at hub height.C_p has dropped to about 0.36 at this wind speed. The coefficient of performance at rated wind speed can be defined as C_{p_R}. Two curves for Cp are shown in Fig.3.5 for wind speeds above the rated wind speed, the upper curve showing the capability of the rotor and the lower curve showing Cp under actual operating conditions. The turbine is shut down at 20 m/s (45 mi/h) to prevent damage from such high winds, and the actual Cp is well under 0.1 when this wind speed is reached.

When the rotational speed is changed, r_{ω_m} changes. This in turn changes at a given wind speed. It is often convenient for design purposes to have a single curve forC_p, from which the effects of changing either rotational speed or wind speed can be determined. This means that the rotational speed and wind speed must somehow be combined into a single variable before such a single curve can be drawn[15].The *tipspeedratio* is a measure of how efficient the blades are relative to wind condition.Ideal TSR is between 6-8 for typical 3-blades WTs.In this range most possible power is being extracted from the wind. This $tipspeedratio(TSR)$ is defined as

$$TSR = Bladetipspeed(T)/Windspeed \tag{3.4}$$

The main shaft speed in rpm depends on the tip speed and the diameter of the swept ares of the blades.

$$rpm = (T * 60)/(D * \pi) \tag{3.5}$$

Where

T=Blade tip speed in m/s

D=Diameter of swept area in m

3.6 Wind Model Component

In PSCAD, component available for Wind model is given as

- Wind Source component
- Wind Turbine component
- Wind Governor

3.6.1 Wind Source

This component can be found in" Master Library/Machines".

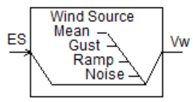


Figure 3.5: Wind Source Component

Table I: I/O for wind source component

I/O	Definition	Description
Es	Input External Value	An external value created by the user can be added to the value internally generated.
Vw	Output	Wind speed in m/s.

For wind turbine,three following wind characteristics are important:

- The mean wind speed: The rated characteristics are determined according to the mean wind speed.The mean wind speed is approximately 13m/s.
- The cut-in speed: At speeds higher than the cut in speed,mechanical brakes are released in order to let the turbine turn.In general,the cut-in speed is equal to 4m/s.
- The cut-out speed: At speeds higher than the cut-out speed,the turbine rotation is stopped in order not to damage the blades of the turbine.In general,the cut-out speed is approximately 25m/s.

3.6.2 Wind Turbine component

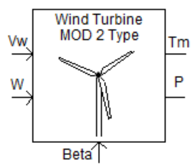


Figure 3.6: Wind Turbine Component

Table II: I/O for wind turbine component

I/O	Definition	Description
W	Input	Mechanical rotation speed of the turbine(rad/s)
Beta	Input	Angle of the blades(deg)
Vw	Input	Wind speed in (m/s)
Tm	Output	Torque of the turbine(p.u)
P	Output	Power of the turbine(p.u)

3.6.3 Wind Turbine Governor component

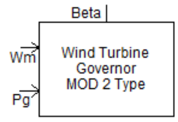


Figure 3.7: Wind Turbine Governor Component

Table III: I/O for wind governor

I/O	Definition	Description
Wm	Input	Mechanical rotation speed of the turbine(rad/s)
Pg	Input	Output power of the turbine(p.u)
Beta	Output	Angle of the blades(deg)

3.7 Summary

This chapter briefly discusses various types of windturbine topology.The calculation method of wind turbine ratings.The importance of turbine parameter and component description is highlighted in the latter part of this chapter.Simulation and results carried out in next chapter.

Chapter 4

Photovoltaic Generation

4.1 Introduction

Solar energy is one type of renewable energy and most available non-conventional type of energy on earth. Solar energy is directly converting into electricity by use of solar photo-voltaic cells without the involvement of any mechanical generators. Solar cells are the devices used to convert sunlight to electricity by the use of photovoltaic effect.

4.2 Solar Photovoltaic Technology

PV cells are made of semiconductor materials like silicon. For PV cells, a thin semiconductor wafer is treated to form an electric field, which is positive on one side and negative on the other. When energy of light strikes the solar cell, electrons are tapped loose from the atoms in the semiconductor material, and If electrical conductors are attached to the positive and negative sides, making an electrical circuit, the electrons can be captured in the form of an electric current called, electricity. This electricity can be used to drive a load. A PV cell can either be shaped circular or square in construction.PV cell electrical equivalent circuit model is in [21].This model shows current source anti parallel with a diode, a series resistance and a shunt resistance.When the cell is exposed to light dc current I_g generated and it varies linearly with solar irradiance.The current I_d through the antiparallel diode is largely responsible for producing the I-V characteristics. Solar cells are usually very small, and each can be capable of generating a few watts of electricity. They are normally pooled into modules of some cells. These modules are then assembled into PV arrays up to several meters on a side. These flat-plate PV arrays can be mounted facing south at a fixed angle, or they can be made to follow sun by mounting on a tracking device, allowing them to capture more sunlight. For utility-scale electricity generating applications, numbers of arrays are interconnected to form a single, large system. PV arrays are generally considered as an expensive choice compared to existing utility fossil fuel generated electricity [13].

4.3 PV Modelling In PSCAD

The latest version of PSCAD default master library contains PV model and maximum power point tracking component.It was developed by Dr.A.D.Rajapakse from the university of Manitoba,canada and it implements behavior of equation based on temperature and irradiance inputs.The default parameters of the individual PV cell which were used in the simulation.The amount of power generate depends on the operating point on the I-V curve.MPPT device is required to keep the system operating at the knee of I-V curve with the change in weather and temperature.

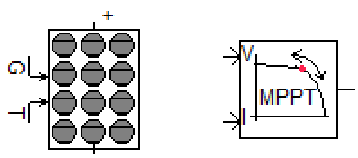


Figure 4.1: PV Module components available in PSCAD

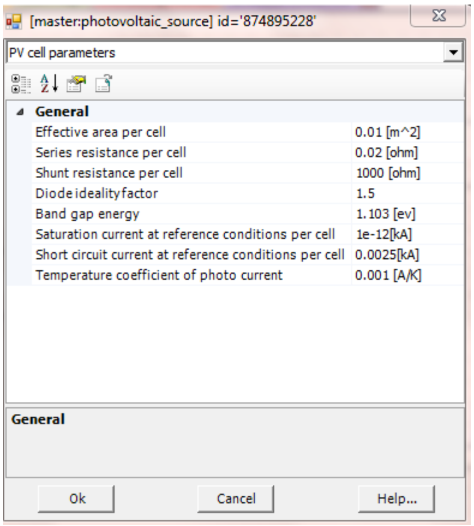


Figure 4.2: PV Cell Default Parameters in PSCAD

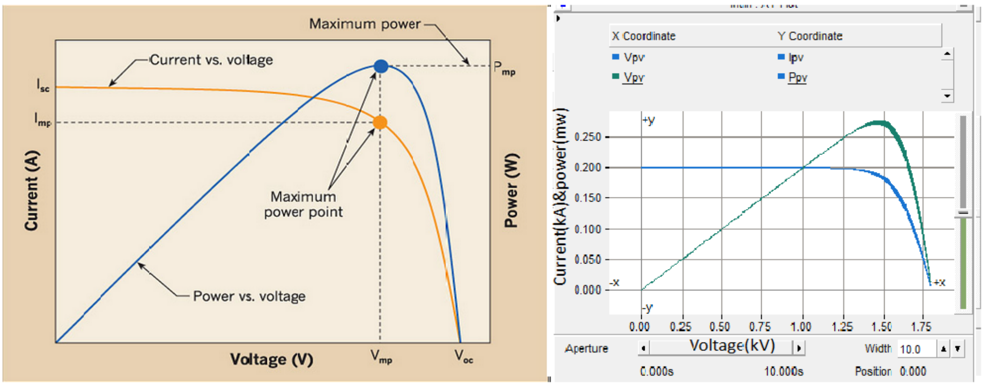


Figure 4.3: (a)PV Module I-V and Power Characteristics (b)PV Module I-V and power characteristics of simulation

The PV array configuration used in simulation,one can change the number of cells in a module in Parallel or series cofiguration as well as can change the PV array with series or parallel connect PV modules as needed.The MPPT model has option to run with either the IC(Incremental Conductance) or P & O(Perturb and observe) algorithms. It requires the entry of the arrays open circuit voltage(Voc),short circuit current(Isc) and a starting initial value.The algorithm used in this model is based on the Incremental Conductance(IC)method.Fig 4.3(a) indicate ideal characteristics and Fig(b) indicate actual simulation characteristics of PV module.In Fig 4.3 (b) short circuit current is 0.2kA,open circuit voltage nearly 1.78kV and maximum power is 0.258mw at voltage 1.5kV.

4.4 Summary

This chapter describe about photovoltaic generation technology and their use and implementation in software.The simulation of pv given in next chapter.

Chapter 5

Simulation Results

5.1 Description of WSCC 3-machine,9-bus System

To carry out this analysis, it is required to choose an appropriate system data which is available to have comparison of results.In this case for simulation of a popular Western System Coordinating Council(WSCC) 3 generator, 9 bus system is preferred.This system available in reference[16].

This system is simulated using PSAT as well as PSCAD/EMTDC sofware.The discussion in the report is based on the outcome in PSCAD.The parameters are based on the details given in reference[16].The base MVA is 100MVA and frequency is 60 Hz. PSCAD required the load flow data as inputs to all the machines. The loadflow data is taken from the reference[16] [9].Using the correct load flow data the system is run under steadystate.Steady state representation of the system can be seen from the Fig.5.1.

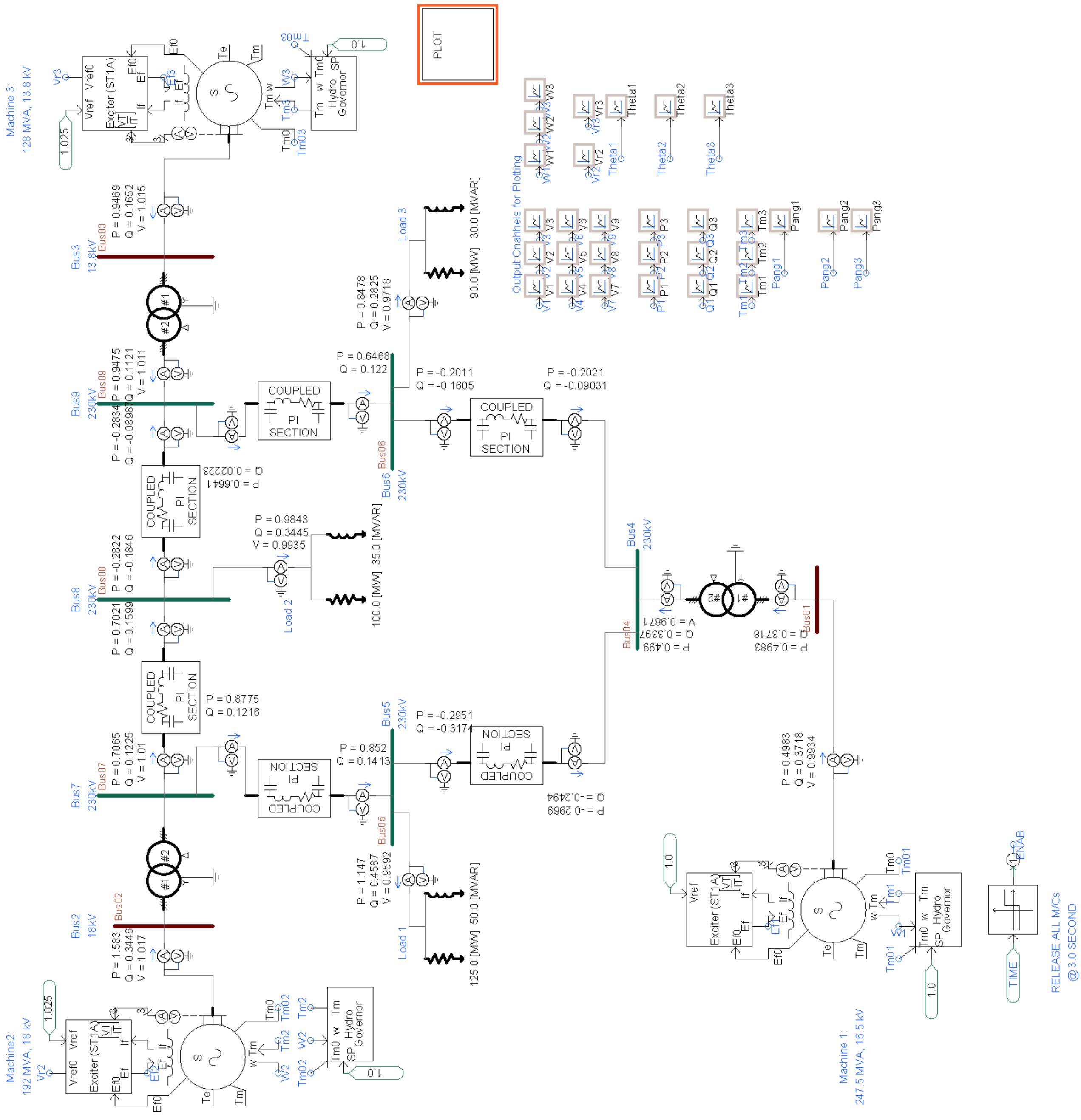


Figure 5.1: WSCC 3 machine power system steady-state representation in PSCAD

5.2 Simulation Results

5.2.1 Simulation under a steady-state Condition:

As mentioned earlier,the system is first run to steady-state.To analyze the power and voltage of the system in the case where renewable sources introduce in this system,simulation is performed.The values of incoming and outgoing real and reactive power at each node is in balance and all the loads are correctly supplied.

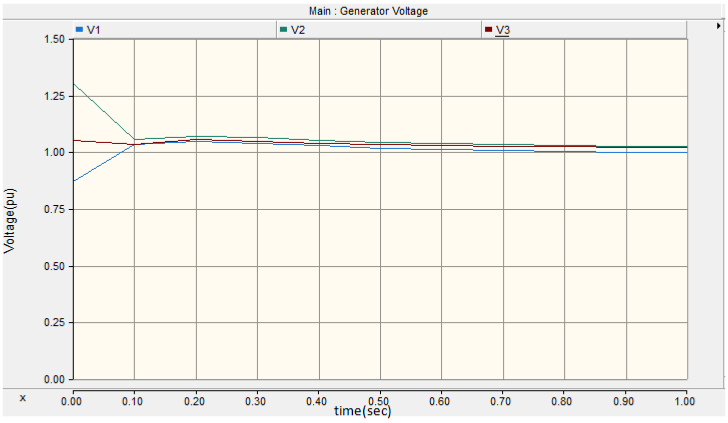


Figure 5.2: Voltage of Gen:1:2:3 in steadystate condition(pu)

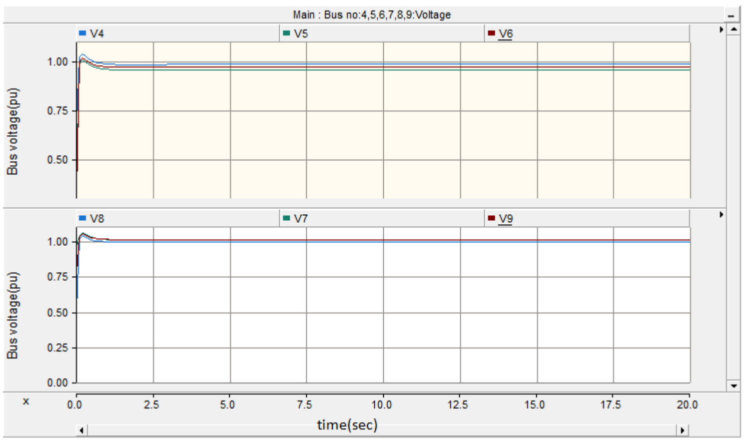


Figure 5.3: Voltage of (a)Bus:4,5,6 (b) Bus:7,8,9 in steadystate condition(pu)

Observations and interpretations from results are enlisted as follows:

- Active power,Reactive power,voltage at each bus and speed of all three machines in Fig.5.25.35.4 are almost nearly equal to data given in reference.The frequency of system is 60 Hz.

- It can be seen from results a stable value is achieved after almost 0.5 sec.

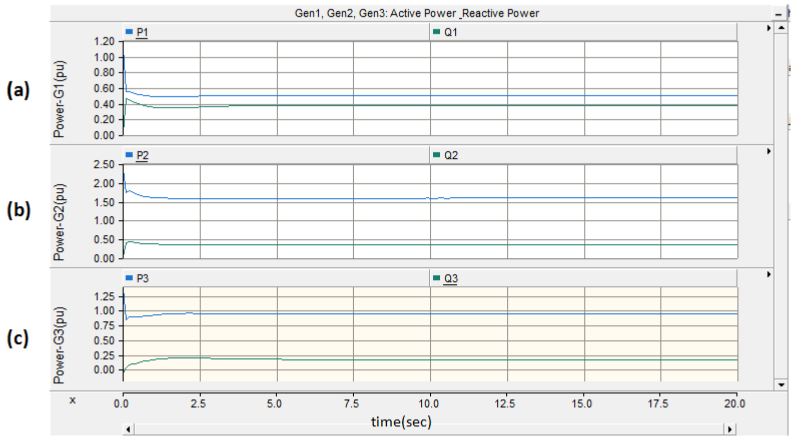


Figure 5.4: Active and reactive power of Gen:1:2:3(pu)

5.2.2 Simulation perform under Fault Condition:

The WSCC system is simulated by creating three phase fault at bus 8,given in Fig 5.5.The fault is enabled using a timed logic block which is available in PSCAD.The fault occurs at 3sec and for a duration of 0.3 sec.

Observations and interpretations from results are enlisted as follows:

- Under this condition power result ,speed of all generators and voltage at each buses are taken as measurements.

- It can be seen from Fig 5.6 fault is cleared within 0.3 sec of application,voltage value regain at nearly 9sec after clearence.

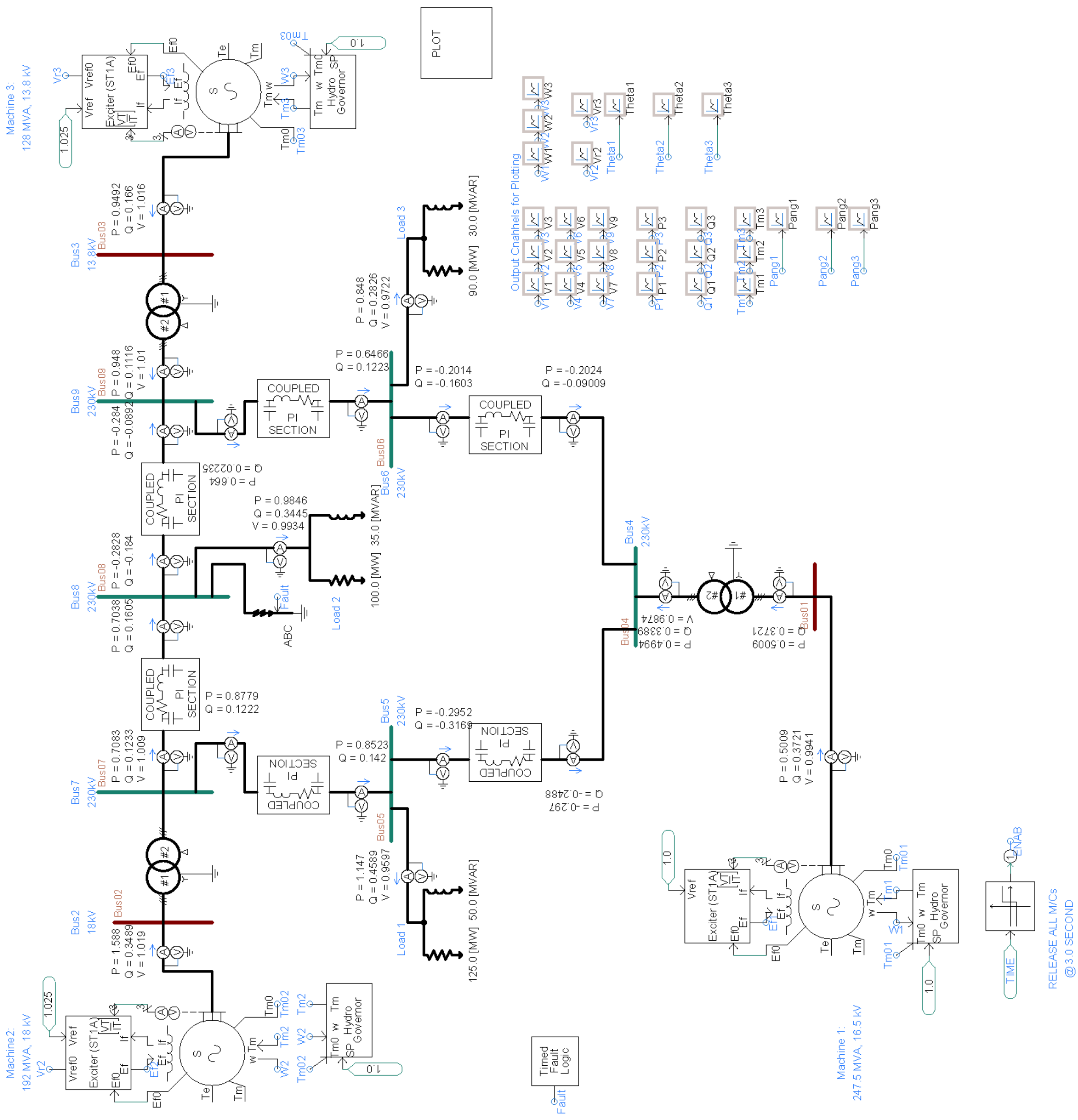


Figure 5.5: Fault representation of system in PSCAD

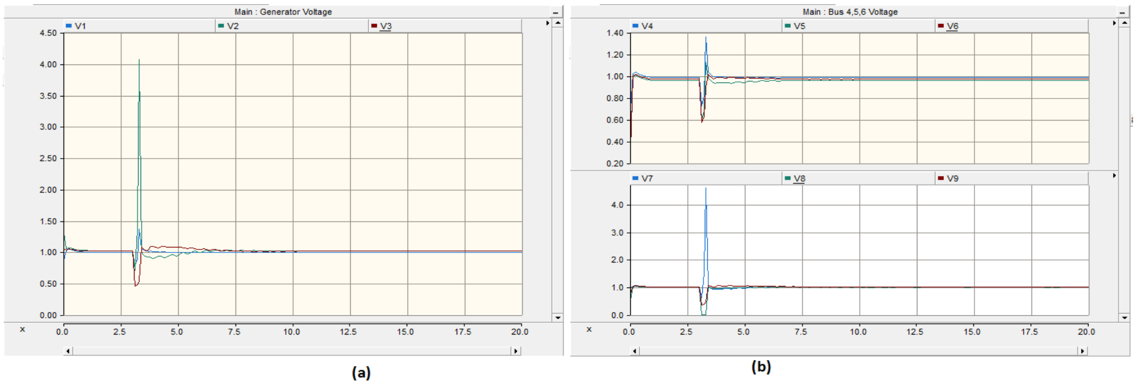


Figure 5.6: (a)Gen:1,2,3:voltage9pu) (b)Bus:4,5,6,7,8,9:voltage(pu) at fault condition

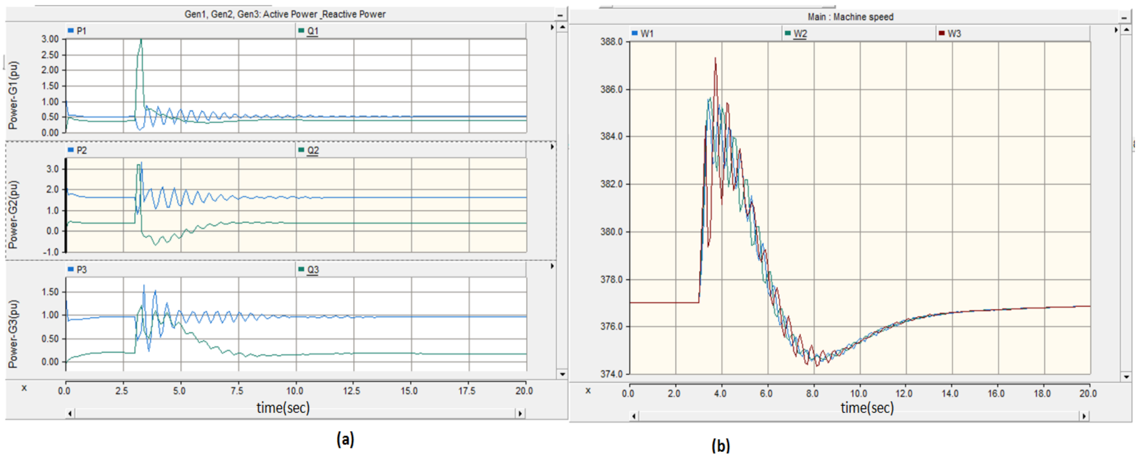


Figure 5.7: (a)Gen:1:2:3 active and reactive power after create a fault(pu) (b)Gen:1,2,3 speed(rad)

It can be seen from Fig5.7 (a)power regain its value after 10sec. From speed measurements in Fig 5.7(b)there is initially a dip at fault occurence value.The stable value is achieved after almost 7sec.Thus a stable value is achieved depending on the system dynamics based on generation and load connected.

5.2.3 Simulation results of the Windfarm Connected System:

Here,one renewable source i.e Wind farm connected in the same system in place of any one generator as mention earlier.In this Fig5.10 nine machine coherently parallel connected at bus-3 by removing one generator.One wind turbine generator model out of nine is given in Fig.5.11.

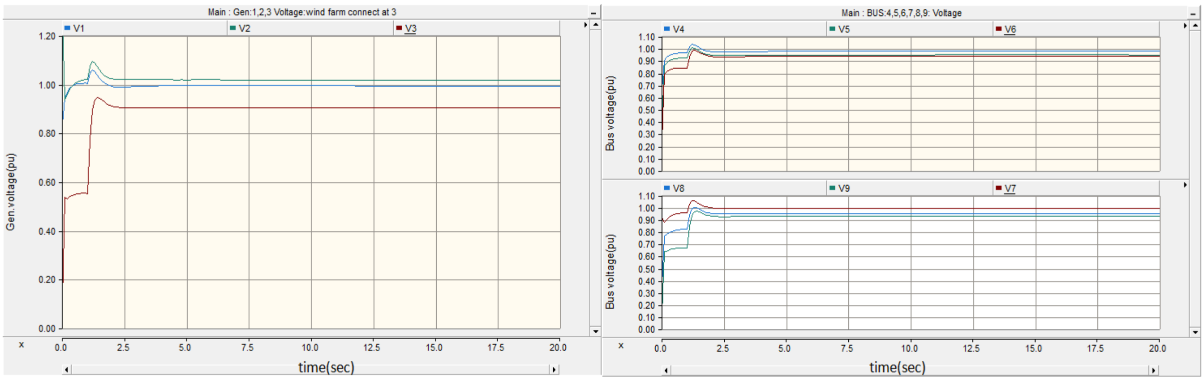


Figure 5.8: voltage at all Buses(pu) when windfarm connected at Bus 3

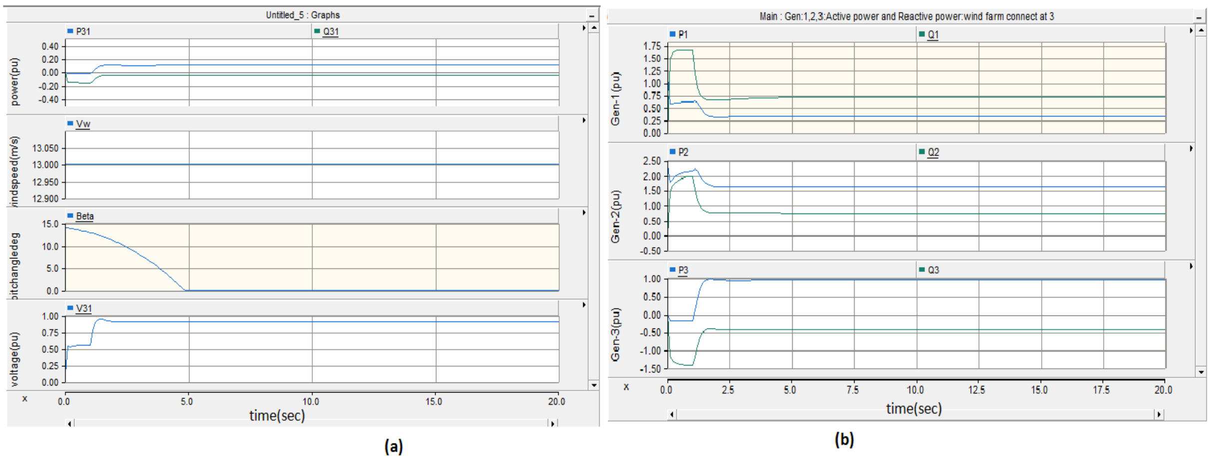


Figure 5.9: (a)Active and Reactive power,wind speed,pitch angle and voltage of one windturbine out of nine(b)Active and Reactive power(pu) of G1,G2 when wind farm connect at Bus3

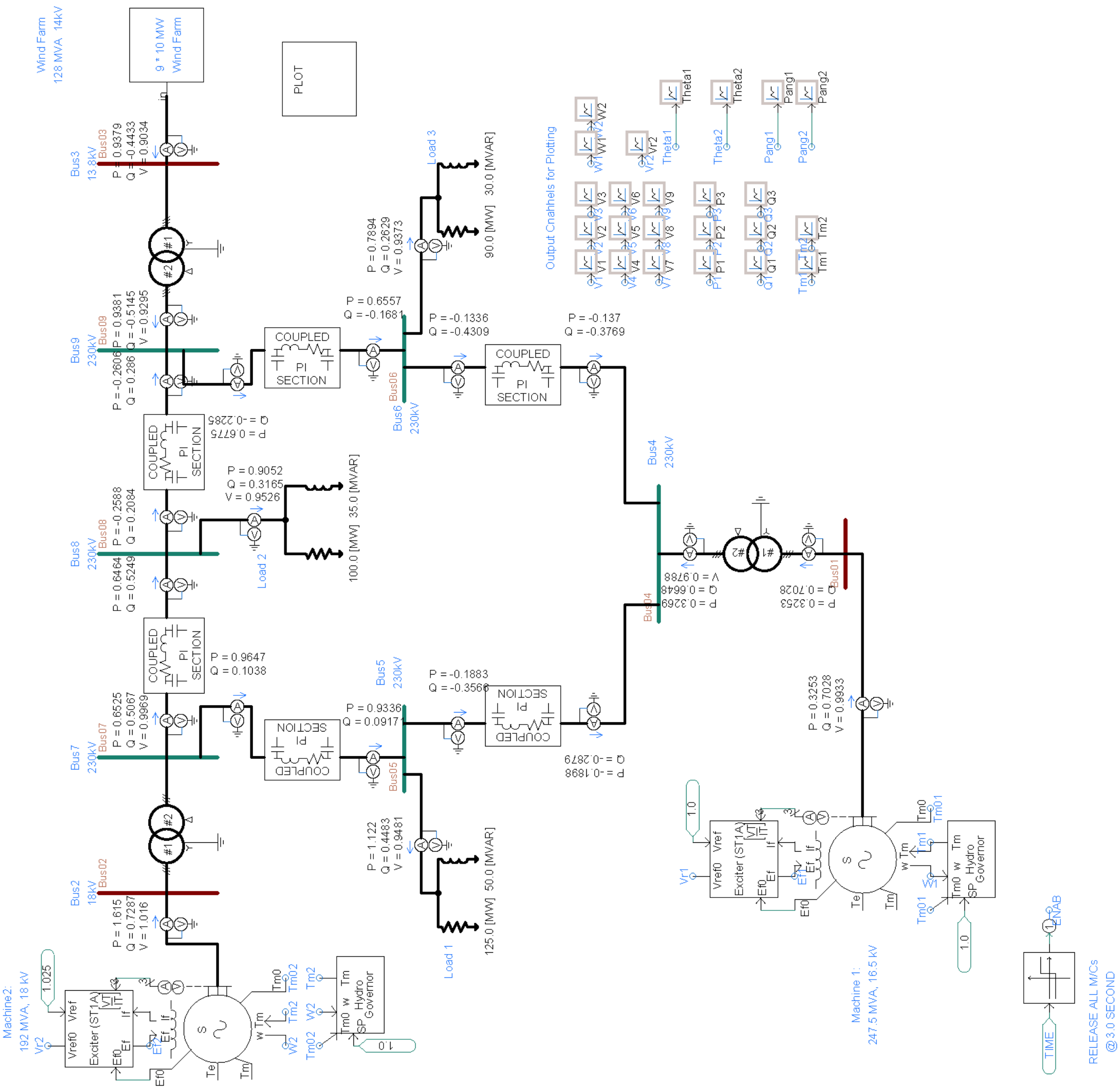


Figure 5.10: WSCC 3 machine power system representation when windfarm connect at Bus3

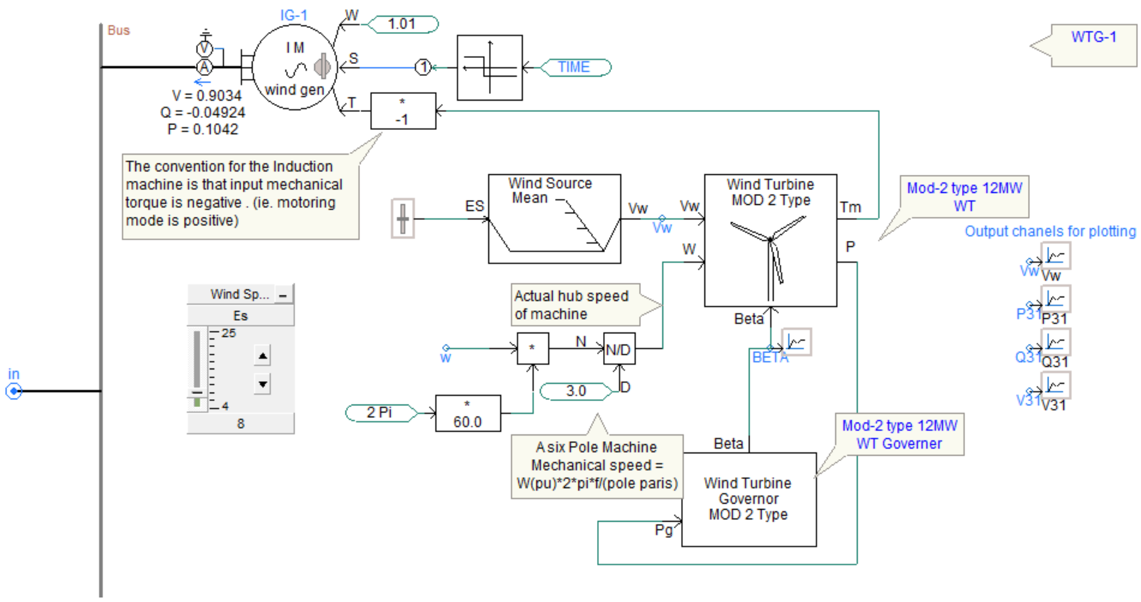


Figure 5.11: One wind turbine generator model out of nine

Observations and interpretations from results are enlisted as follows: Wind turbine data, blade diameter,swept area and turbine power are calculated as per the equation mentioned in the previous chapter.All this values are given in appendix.In this system 9.6MW*9 wind turbine Induction Generators are connected in parallel as per Fig5.11.This subsystem is directly connected to the grid at Bus3.Wind turbine generator and governor parameters are calculated as per chapter 3.Wind speed is 13m/s constant. Under this condition,power and voltage of all buses are taken as measurement.

- It can be seen from simulation perform after wind farm connected at bus 3 inplace of one generator,there are voltage dip of 0.9034 from 1.015 pu in Fig**??**.
- From Fig.5.9 some voltage dip of 0,9295 from 1.011 pu occure also at bus 9. It is just because wind farm connect at bus 3.
- There is a requirement of voltage control at bus 3 and bus 9.30MVAR is required to connect at bus 3 to regain its voltage level.

5.3 Power and Voltage Results of System

Table I: Active Power,Reactive Power and Voltage At Each Bus on both condition ***Case A :Steady-state representation of WSCC system, Case B : Wind farm connected into the system***

Case	**Active Power**		**ReactivevPower**		**Voltage**	
	A	B	A	B	A	B
Bus-1	0.4983	0.3253	0.3718	0.7028	0.9934	0.9933
Bus-2	1.583	1.615	0.3446	0.7287	1.017	1.016
Bus-3	0.9469	0.9379	0.1652	-0.4433	1.015	0.9034
Bus-4	0.499	0.3269	0.3397	0.6648	0.9871	0.9788
Bus-5	0.852	0.9336	0.1413	0.0917	0.9592	0.9481
Bus-6	0.6468	0.7894	0.122	0.2629	0.9718	0.9373
Bus-7	1.583	1.61	0.2441	0.6105	1.01	0.9969
Bus-8	0.7021	0.9052	0.1599	0.3165	0.9935	0.9526
Bus-9	0.9469	0.9381	0.1121	-0.5145	1.011	0.9295

The table is indicate both the results of WSCC system in steadystate condition and WSCC system with WindFarm connect in place of Generator 3.In first case synchronous generator 1,2 and 3 are connected at Bus 1,2and 3 respectively.Gen1 is taken as swing.Loads are connected at Bus 5,6 and 8.In second case Windturbine induction generator is directly connected to the grid at Bus3 inplace of one synchronous generator. From the table we can see that the voltage dip at Bus3,Bus 8 and Bus 9 and Bus3 reactive power is very less according to stady state result.

5.4 Grid-tied Photovoltaic System Model in PSCAD

The grid connected PV system design in PSCAD as per reference [7]and it mainly consists of PV array model which is connected to the DC-DC converter through DC link capacitor,three phase inverter,AC filter through 14kV Utility grid equivalent model.By using the default values, the final output recieving in grid is 260 kilo-watt for the total 400 modules.

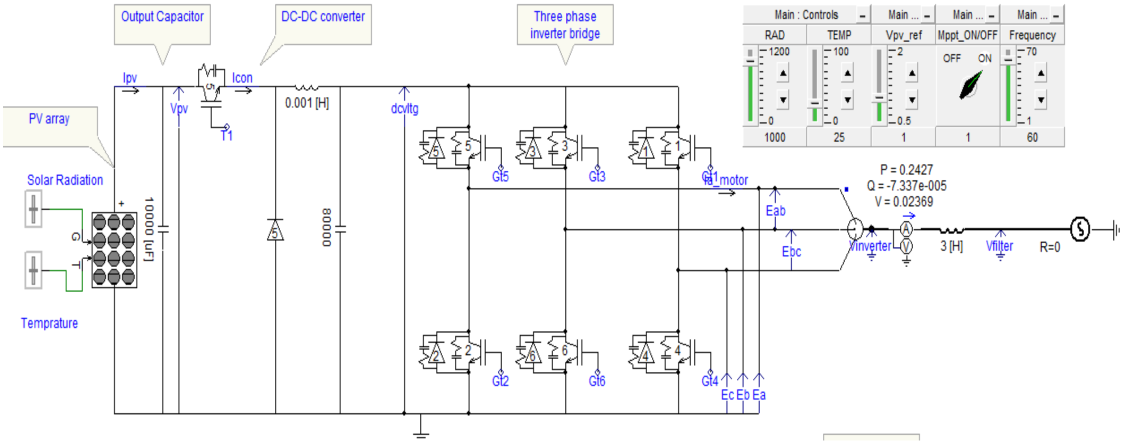


Figure 5.12: Grid tied PV system in PSCAD

PV array parameters	PV array name (optional)	PVarray1
	No. of modules connected in series / array	20
	No. of module strings in parallel / array	20
	No. of cells connected in series / module	108
	No. of cell strings in parallel / module	4
	Reference irradiation (W/m^2)	1000
	Reference cell temperature (^oC)	25
PV cell parameters	Effective area / cell (m^2)	0.01
	Series resistance / cell (Ω)	0.02
	Shunt resistance / cell (Ω)	1000
	Diode ideality factor	1.5
	Band gap energy (eV)	1.103
	Saturation current at reference conditions / cell (A)	$1e^{-9}$
	Short circuit current at reference conditions / cell (A)	2.5
	Temperature coefficient of photo current (A/K)	0.001
Monitoring	Photo current / module (A)	-
	Internal diode current / module (A)	-
	Internal diode voltage / module (V)	-
	Internal power loss / module (W)	-
	Output power / module (W)	-
	PV array output current (A)	Iarray
	PV array output voltage (V)	Varray

Figure 5.13: Parameter of PV module in PSCAD model

The effect of varying the input irradiation and temperature on short circuit and open circuit voltage repectively as shown in Fig. 5.12. Increase in irradiation which increased the short circuit current.The system is performed on standard test condition(STC).STC are condition under which a module is typically tested in a laboratory under an irradiation intensity of 1000 W/m^2,cell/module temperature of 25+/-2$degree$ C. The DC link is use for minimizes the ripple of PV source current by using a large capacitor.It is assumed in determining the size of DC link capacitor that the output current will be a ripple free.

5.4.1 DC-DC Converter Control

This converter is use for step down the input voltage(buck converter) or step up the voltage(boost converter)DC-DC converter is used for maximum power point tracking by controlling the voltage across the dc link capacitor and PV array [7].In Fig.5.14 buck converter was used that consist of PWM circuit.This is achieved by creating a reference voltage and then supplied to a PI controller which create switching signals that force the voltage accross the pv array to follow the reference voltage.The PWM signal was generated by using a comparator which has the duty cycle signal at port A and triangular wave at port B which ranges from 0 to 1.When Ais greater than B output of comparator set to 1 otherwise 0.

5.4.2 Firing Pulse Generation

The switching signals of the 6 IGBT switches of 3-inverter bridge shown in Fig.5.14.Three sinusoidal wave with 60 Hz frequency and phase shift equal of some angle with additional shifting of -120 and 120 degree.Comparator compare sin wave and triangular wave with magnitude ranges -1 to 1.Signal Gt1,Gt3 and Gt5 were generated by setting the output of the comparator to 1 when Modulating wave is greater than the triangular wave.The switching signals Gt4,Gt6 and Gt2 were generated by inverting1,3 and 5 signal.

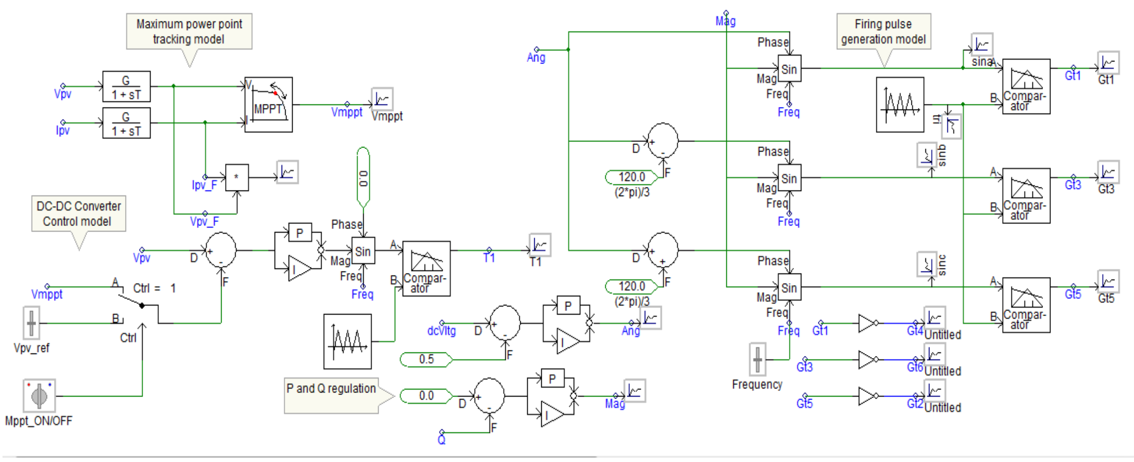


Figure 5.14: DC-DC converter control model and Firing pulse generation model

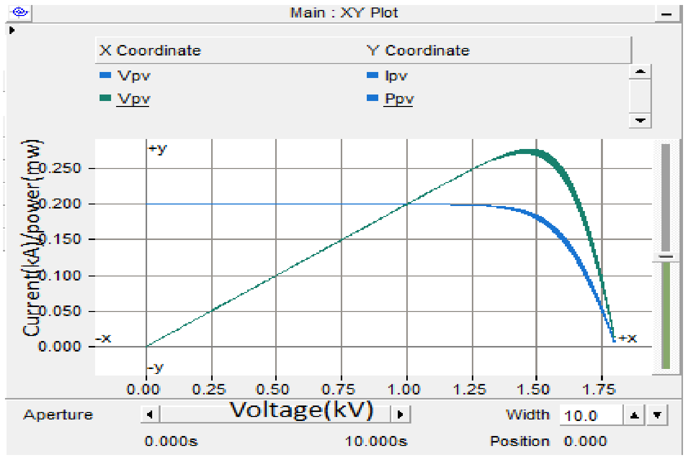
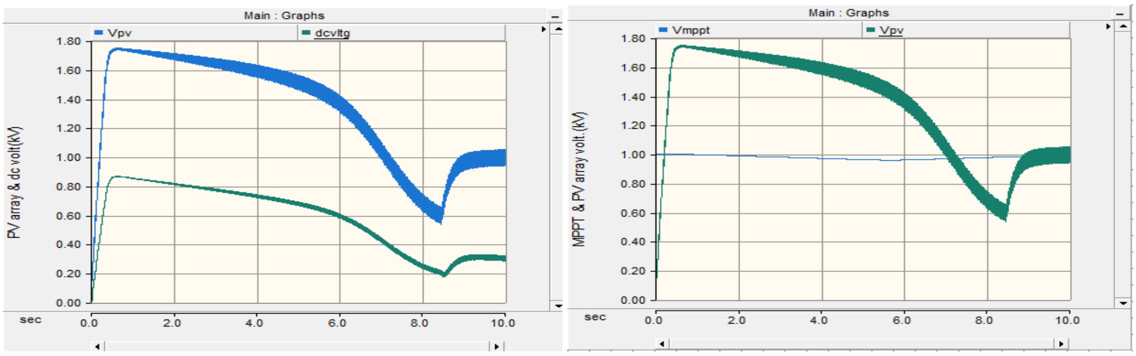


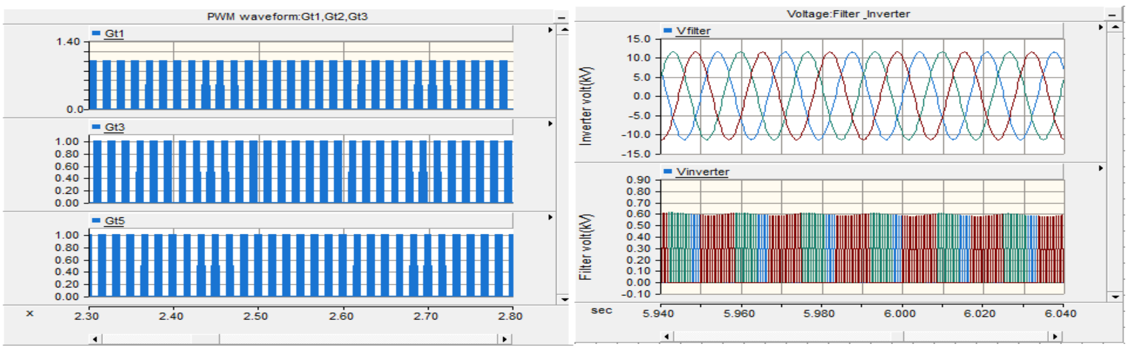
Figure 5.15: I-V and PV curve of PVarray

Observation and interpretations from results are enlisted as follows: After performing this simulation, the different outcome shown in Fig. 5.16.It indicates that pv array voltage is nearly 1.8kV and dc voltage around 0.84kv after buck converter connection at temperature 25degree,irradiation 1000 W/m^2.Fig. 5.16 (b) is the pv output voltage to track reference voltage (Vmppt) to operate at MPP.In Fig.5.17 indicating PWM generation of signal Gt1,Gt3,Gt5 very with 0-1.Filter voltage and inverter voltage waveform given in (b) which is not a perfect sinusoidal.



(a) (b)

Figure 5.16: (a)PV array voltage and DC voltage(kV) (b)MPPT voltage with PV array voltage(kV)



(a) (b)

Figure 5.17: (a)PWM generation:Gt1,Gt2,Gt3 (b) Filter voltage and Inverter voltage(kV)

5.5 summary

This chapter shows the results obtained from simulation of multi-machine test system.It also provides the model of windfarm connected WSCC system and small scale gridtied pv simulation results,and their interpretation.

Chapter 6

Conclusion and Future Work

Traditionally,the electrical grid has been designed for integreting the various types of conventional system.Therefor any emerging technology like wind or solar energy,some problems are bound to arise because of their special way of generating electrical power.

From the examination of literature available,the higher wind/solar power penetration,the larger impact on wind power quality and irradiation and temperature effect on the system wide level.Thus the requirement of it can be concluded that impact of renewable sources are major concern about their operation.The aim of the project work carried out is to study system performance with conventional and nonconventional case.

The following sections summarise the main conclusion getting from the results presented in this thesis and future work that were not addressed in this piece of work due to time limitations and implementation complexity.

6.1 Conclusion

A 3-generator,9-bus system is prefered for the project work and the simulation carried out on the system provides measurements.This measurement are obtained as to simulate the data available in steady state condition.After developing the wind farm and connecting it at any one bus inplace of one generator, it is observed that on the inclusion of renewable source,the effect of reactive power on the system is severe and demands for reactive power compensation devices at various buses. One such case of reactive power requirement is presented using wind farm as a renewable source.

For a case of solar as renewable, a grid tied model for small penetration level is designed which may be extended for higher However, at present the behaviour of the model is not as accurate as expected and hence a further modification in the model is required.

This thesis highlights the issues that when wind energy or solar penetration increase,more demands will be placed on the system for better voltage control,more output,fault-right-through capability,better reactive control and dynamic voltage support for system reliable operation.

6.2 Future Work

As an extension for this work,Develope the model of different types of generators and conneting to a WSCC system. In chapter-5,results based on solar system are presented.Due to certain implementation difficulties and time constraints,expected behaviour of the system are not accurate.So in future,work can be done on this to modify the model for accurate results.

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Appendix A

All Machine Data for Windfarm

Table I: Turbine Data

Turbine rated power	12 MW
Rotor diameter	168 m
Hub hight	110 m
No. of blades	3(MOD-2 type)
Cut-in wind speed	4 m/s
Cut-out wind speed	25 m/s
Rated wind speed	13 m/s
Rotor speed	12 rpm
Rotor swept area	22385 m^2

Table II: Generator Data

Rated MVA	11.76 MVA
Rated voltage	14 kV line-to-line
No.of pole	6
Rated Frequency	60 Hz