Power Quality Issues and Analysis due to High Penetration of REG's into Power Grid

Major Project Report

Submitted in partial fulfillment of the Requirements

for the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(Electrical Power Systems)

By

SANDHYA RAJPUT

13MEEE20

DEPARTMENT OF ELECTRICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

MAY 2015

Power Quality Issues and Analysis due to High Penetration of REG's into Power Grid

Major Project Report

Submitted in partial fulfillment of the Requirements

for the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(**Electrical Power Systems**)

By

SANDHYA RAJPUT

13**MEEE**20

DEPARTMENT OF ELECTRICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

MAY 2015

Undertaking for Originality of the Work

I, **Rajput Sandhya Mangal Sinh (Roll.No.13MEEE20)**, give undertaking that the Major Project entitled **"Power Quality Issues and Analysis due to High Penetration of REG's into Power Grid"** submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Electrical Power Systems of 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.

Signature of Student
Date :-
Place :- Ahmedabad

Endorsed by:

Project Guide
Prof. C.R.Mehta
Assistant Professor
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

Certificate

This is to certify that the Major Project Report(Part-1) entitled **"Power Quality Issues and Analysis due to high penetration of REG's into Power Grid"** submitted by **Ms. Rajput Sandhya (13MEEE20)** towards the partial fulfillment of the requirements for Semester-IV of Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by him/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.

Date:

Project Guide
Prof. C.R.Mehta
Assistant Professor
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

Head of Department
Department of Electrical Engineering
Institute of Technology
Nirma University
Ahmedabad

Director
Institute of Technology
Nirma University
Ahmedabad

Acknowledgement

Achieving something in life always requires guidance and support of individuals and I have been blessed to have had the opportunity to work with such individuals during my term here.

This project consumed huge amount of work, research and dedication which was only possible with support and encouragement of such stalwarts in their respective fields and I would like to take up this opportunity to thank all of them. First and foremost, Prof.C.R.Mehta, Assistant Professor, Electrical Engineering Department, Institute of Technology, Nirma University for his superior knowledge and experience, motivation and co operation. His way of doing work with such nuance and detail has taught me a lot and would always help me going forward in my personal as well as professional life.

My sincere thanks to Dr.S.C.Vora, P.G Co-ordinator(EPS), Department of Electrical Engineering, Prof.Dr.P.N.Tekwani, HOD EE Department and Dr.K.Kotecha, Director, Institute of Technology, Nirma University. I would like to thank all the other faculty members of the Department of Electrical Engineering, Nirma University.

I express my gratitude toward my family and my class fellows for their kind co operation, support and encouragement which helped me in completion of this project.

Sandhya M. Rajput

13MEEE20

Abstract

Due to fast development of industries global power demand is increasing day by day. There is a large gap between power supply and load demand. Furthermore due to environmental and economical issues with fossil fuels it is required to introduce renewable energy sources into existing power system as an alternative to meet the demand.

Wind energy and PV solar generation are the most promising energy sources amongst all the RE sources which are free from green house gas emissions, and having potential to meet the energy demand as they are abundantly available in nature which encourages interest worldwide. But due to uncertainty of wind and solar, integration of these RE sources doesn't come without challenges. This involvement of REG's into the power system changes behavior of power flow, characteristics of power quality(such as voltage fluctuation, harmonics, inrush current, power fluctuation, low power factor and reactive power management). In addition new equipments are very sensitive to power deviation and disturbances, hence the assessment of power quality issues due to penetration of renewable is of a great concern today.

This thesis includes importance of power quality, various power quality issues, their cause and effects by considering wind as a energy source. For the purpose of analysis WSCC 3 machine 9 bus system is taken as a reference and it is implemented with the help of MATLAB software.The system is simulated under normal condition and after integrating wind farm inplace of one of the synchronous generator.

Abbreviations

RE .... Renewable Energy
REG .... Renewable Energy Generation
WTG .... Wind Turbine Generator
SCIG .... Squirrel Cage Induction Generator
DFIG .... Doubly Fed Induction Generator
PMSG .... permanent magnet Synchronous Generator
RSC .... Rotor side convertor
IGBT .... Insulated gate bipolar transistor

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Due to fastest growth in industries global power demand is increasing day by day. It is expected to be nearly double in next twenty years. There is a large gap between power supply and load demand. In addition due to the instability in the price of fossil fuels, limited supply and environmental issues renewable energy sources such as wind and solar generation are increasingly used as a fuel in many parts of the world as an alternative energy source. Renewable Energy sources can provide energy security such as transportation of diesel, natural gas, or coal is not involved. But the use of RE sources is again a challenging task. High penetration of intermittent wind and solar power will impact on technical issues, operational issues, power quality, reliability, protection, load management, grid interconnection and maintaining grid code. It also adds to the complexity of the system.

From different RE sources, especially wind is the most promising source of energy because it is free from greenhouse gas emissions, abundant in nature and having ability to meet energy demand promotes the interests of Worldwide. Since last decade there have been drastic improvements in wind generation Technology, so it is becoming an imperative source of energy. Advantage of Wind energy is being taken in many parts of the world, but the fortitude of wind energy potential depends on the meteorological aspects of wind energy capacity, wind velocity and direction and also solar irradiation.

Wind energy is materialized as the fastest growing energy technology. The total cumulative installed capacity of wind energy in the world by 2000 was 17, 400 MW, while in 2013 the cumulative installed capacity is 3, 18, 138MW as shown in fig1.1. Annual installed wind capacity in 2000 was only 3, 760 MW; with rapid growth, annual installed capacity in 2013 was 45, 769 MW as shown in fig1.2. .

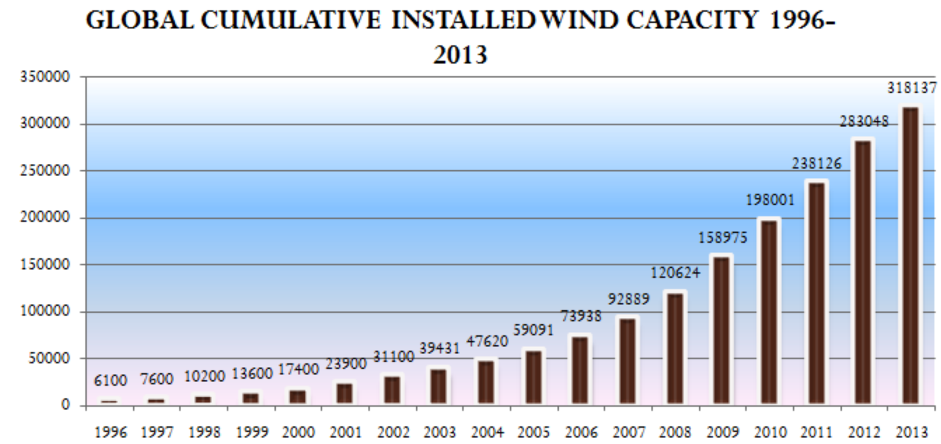

Figure 1.1: [Global Cumulative Installed Capacity]

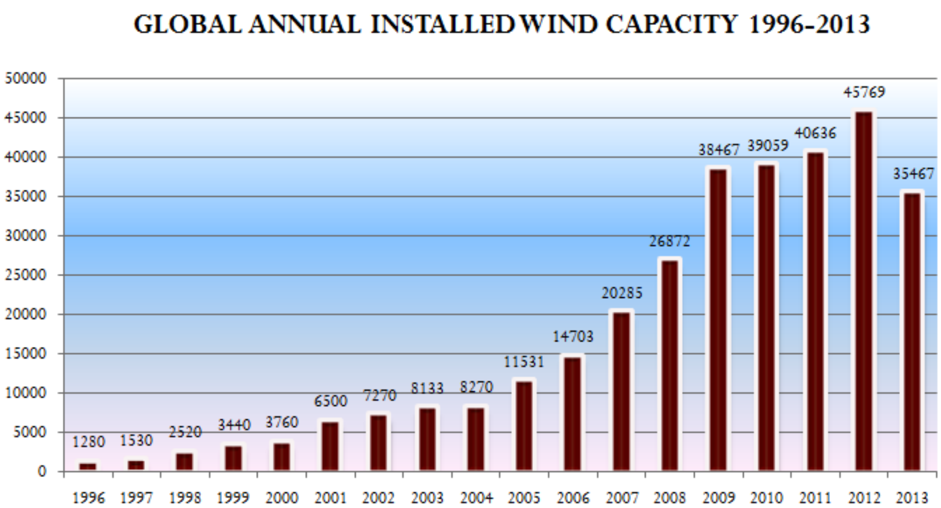

Figure 1.2: [Global Annual Installed Capacity]

1.1 Problem Identification

Electrical Power Quality is the measure of any deviation from the nominal values of that electrical parameter in magnitude and frequency. The term"Power Quality" is used to define the most important aspect of the electricity supply. It covers various types of issues of electricity supply and power system disturbances. This is a utility oriented factor and subjective to many objectives with various constraints. In the view of power system engineer it focuses on the broad perspective of quality, economy, stability, reliability,security and safety.

Due to intermittent nature of wind resources, the wind farm generates fluctuating electric power. These fluctuations have a negative impact on stability and power quality in electric power system. These impacts are increases as level of penetration is increases.

Wind energy has no significant effect up to small share up to 5% to 10% but it will create a problems when it increase to 20% to 25% of total demand. Situation is critical in weak grid. Large scale integration of DG units in the distribution grid not only affects the grid planning but also affect the operation of the distribution grid in following aspects of power quality[2].

- Power quality
- Variation in system voltage
- Fault level
- Protection system

1.2 Scope of Work

The scope of project work is to analyze the performance of renewable energy source(wind energy) integrating with conventional grid

- Study of convectional WSCC 3 machine 9 bus system .
- Study of power system with wind integration.
- Study and list out the problems with integration of wind energy source.
- Analysis and comparison of system with standard system.
- Proposing possible solution for listed issues.

1.3 Methodology

- Literature survey.
- Simulation study of standard test system for integration of renewable.
- Analysis of simulation results.
- Selection of suitable wind technology.
- Analyze effect on power quality with wind energy source.
- Suggest possible solution.

1.4 Thesis Overview

- **Chapter 1** The chapter includes introduction of the topic, identification of the problem and categorized different power quality issues. It also mentions scope of project work and proposed methodology.

- **Chapter 2** The chapter is about literature survey carried out for the project.

- **Chapter 3** The chapter is about importance of power quality, describing various PQ issues and their causes, effects on power system parameters. Describe different wind technologies, their relative advantages and disadvantage. Behavior of each type in different conditions.

- **Chapter 4** The chapter includes description of the system taken for simulation as per references.

- **Chapter 5** The chapter is about simulation of test system and discussion of results obtained. Comparison of results obtained under different condition and with normal system.

- **Chapter 6** The chapter includes conclusion and future scope.

Chapter 2

literature Survey

For the better understanding of project literature survey plays a very important role. Literature Survey consists of papers referred which provide basic knowledge of different renewable technics and their effect on conventional system.

- **R.C.Dugan** A book entitled "Electrical Power Systems Quality " gives information about power quality definition and its importance. It define various power quality terms. How it affects power system, equipment and economy involved[1].

- **Earnest Joshua,Wizelius Tore** A book entitled "Wind Power Plant And Projects Development" discusses about history of wind technology. Various type of wind turbine generators, their design and operating Characteristics. Their advantages, disadvantage. Why wind is behaving differently with conventional system. Technical and operational issues arises due to penetration wind into transmission and distribution network[2].

- **G.M. Shafiullah A.B.M.ShawkatAli,PeterWolfs .** The paper entitled "Potential challenges of integrating large-scale wind energy into the power grid" discusses the requirement for use of RE as an alternative source of energy and different impact of REG's specially wind on various technical, economical, environmental aspects and also with conventional grid[6].

- **Kishor V. Bhadane, Dr.M.S. Ballal)** The paper entitled "Investigation for Causes of Poor Power Quality in Grid Connected Wind Energy" discusses reasons of poor power quality with wind generation, its effect on economy involved with utility and end consumers[5].

- **Qiang Fu, Luis F. Montoya, Ashish Solanki, Student Member, IEEE, Vijay Bhavaraju, Member, IEEE** The paper entitled "Microgrid Generation Capacity Design With Renewables and Energy Storage Addressing Power Quality and Surety" discussed potential of renewable sources for energy surety and security. They model a microgrid with and without grid configuration and analyse the response of RE sources with storage devices[8].

- **Masoud Farhoodnea, Azah Mohamed, Hussain Shareef** The paper entitled " Power quality impacts of high-penetration electric vehicle stations and renewable energy-based generators on power distribution systems" discussed the effect of renewables is increases with increasing level of penetration. High level of renewables into system distort the parameters of system.They carried out their analysis on IEEE 38 bus system with different level of RE integration and listed various power quality issues[7].

Chapter 3

Power Quality Issues & Different RE Technologies

3.1 Importance Of Power Quality

The Quality of Electric Power has become a huge concern for the Electric Utilities as well as for the End-Users. The connotation ”Power Quality” has turn out as the most important exhortation in the Power Industry over the last three decades. The chief reasons for this huge concern can be categorized as

- New-generation load equipments are based on microprocessor-based controls. These power electronic devices are more responsive to power quality deviations than were used in the past[1].
- Now a days it is necessary to increase overall power system efficiency which consequences into use of high-efficiency adjustable-speed motor drives .For power factor improvement and reduce losses use of capacitors. Use of such devices ensuing in increasing harmonic levels on power systems. So, people are concerned about the long term impact of these devices on power system[1].

- Power consumers have an increased attentiveness of power quality issues. Customers are becoming better informed about such issues as disruption, sags, and switching transients and this is coercing utilities to improve the quality of power supplied[1].

- Majority of the things are now interrelated into a network and thus integrated processes mean that the failure of any component can results into complete loss of product or restart of whole process[1].

3.2 Different Power Quality Issues

Renewable energy sources have of late been recognized as efficient and alternative sources of power that have potential to provide sustainable and clean energy. Despite these being efficient generators, use of large hybrid renewable systems to power grids can cause several operational glitches for distribution networks. The severity of these glitches directly depends on the type of applied REG technology, level of penetration, and location of the installation. Power quality issues with REG can be categories as per following

- Inrush current
- Protection issues
- Sags and Swell in voltage
- Flicker
- O/P power fluctuation
- Harmonic
- Reactive power
- Dynamic stability
- System balances

3.2.1 Inrush Current

Due to the small unavoidable dissimilarity of voltage between grid and REG system a unidirectional transient inrush current flow between the REGs and the utility system at the time of switching. This current will disintegrate at an exponential rate. Due to this inrush current short term voltage sag is experienced at the nearby buses, thermal stress of the power components, or false tripping of the protective instruments. The relentlessness and time period of the formed inrush current depends on various system constraints such as system impedance, magnitude and sign of the flux linkage, and nonlinear magnetic saturation characteristic of the coupling transformer [8].

3.2.2 Protection

Protection issues in REGs are take place at the time of fault and unintentional islanding in particular parts of a utility system. During such condition, REGs may feed the loads or a portion of the system even after disconnection of the network from the utility grid. The installation of REGs can also increase fault levels and make issues severe related to protection coordination and isolation[8].

3.2.3 Sags and Swells In Voltage

REGs like solar PV systems are usually made to operate at near unity power factor to optimize use of solar energy. Therefore, these type systems injects active power only into the power system.Because of this the flow of reactive power in the system is being changed, and neighboring buses may experience under/overvoltage problems due to lack of it[8].

3.2.4 Flickers

Flickers are created due to inrush associated with energization of the stator of Induction generator[8].

3.2.5 Output Power Fluctuation

Output of renewable is variable in nature which create several operational problems. Power variations are generally take place in the interconnected RE systems such as wind and solar due to continues variations in wind speed or solar irradiance. Power fluctuations could results into overloading or underloading, undesirable voltage fluctuations, and voltage flickers[8].

3.2.6 Harmonics

Now a days harmonic distortion is said to be a serious power quality issue. It is because of the use of power electronic devices such as inverters and controller in REG systems. Harmonic distortion will increases the possibilities of parallel and series resonances, excessive heating in capacitor banks and transformers, neutral over current, and malfunctioning of protective instruments[8].

3.2.7 Reactive Power

Reactive power consumption by induction generators is a common problem which affects the grid stability and power quality. High amount of reactive power is being required by induction generator. Reactive power demand will increase as the amount of active power generation is increases.Due to these variation in active and reactive power the voltage at pcc will vary.So, it is obligatory to provide reactive power locally and as close as possible to the demand levels[8].

3.3 Different Types Of WTG Technology

As compared to other renewable technologies wind turbine technology proffer less expensive, eco-friendly and preservation free operation. Main advantages of WTGs can be summarized as following.

- It saves considerable money on service bills. Consumers will not suffers from power scarcity or outage[4].
- it provide environment friendly and proficient energy at comparatively low price ,specially in the area where reach of power grid is difficult with difficult geological features[4].
- The installation can be easily undone without leaving any undesirable effects at the site . It does not vulneraries values of the property/buildings[4].
- It requires less maintenance for turbine .So, no need for employing operating or maintenance personnel like other conventional turbine based power system. It means less maintenance less operating cost[4].
- It offers home made electrical energy and off grid living, which is not possible with other technologies[4].

WTGs used presently fall in any one of the following four categories.

3.3.1 Type A Fixed Speed Induction Generator

This type of WTGs were invented in 1980s and are working on a squirrel cage induction generator (SCIG) principle. They can marginally vary their speed up to 1-2% of rated value. It means they are almost "fixed speed" type generators, thus their power output fluctuates as wind speed changes. Reactive power consumption is one of the major issue with this generators. large static capacitor banks were used to provide sufficient compensation.Modal configuration is shown in fig.3.1.[15]

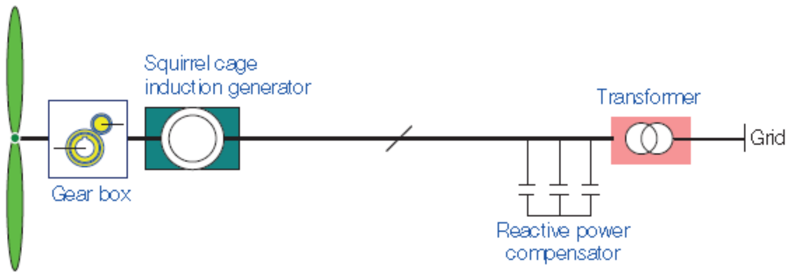

Figure 3.1: Topology of a fixed speed induction generator

3.3.2 Type B - Variable-Slip Induction Generator

This type of WTGs were invented in between 1980-1990.These generators are equipped with a wound rotor type induction generator (WRIG). In these WTGs power electronic devices are used to control the magnitude of rotor current.Type B generators can vary their speed up to 10% of their nominal rated speed. With the capability of handling speed variation power quality is improve and the mechanical loading of the turbine components is reduces. These generators are also equipped with an active pitch control system and reactive power compensators.[7].Modal configuration for this type is shown in fig.3.2.[15]

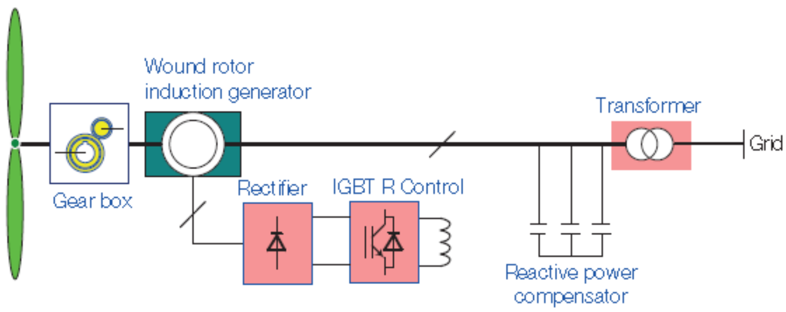

Figure 3.2: Topology of a variable-slip induction generator

3.3.3 Type C Doubly Fed Induction Generator(DFIG)

It is the most accepted wind turbine technology used at present. It combines the advantages of both type A and B having advancement in power electronics used. The rotor winding of DFIG is allied to the grid via a back-to-back insulated gate bipolar transistor (IGBT) power converter .So, it is possible to control both the amount and frequency of the rotor current. Stator winding is connected directly to the grid. 40% portion of the power output fed into the grid through convertor and remaining is directly goes into the grid. This WTG is designed in such way that it can handel speed variations up to 40% up and down to the rated value ,hence make the best use of wind energy. Providing decoupled control of active and reactive power by convertor, flexible voltage control without additional reactive power compensation, fast voltage recovery and voltage ride-through is enabled. Pitch control is also included to maximize energy capture from wind. Modal configuration is shown in fig.3.3.[15]

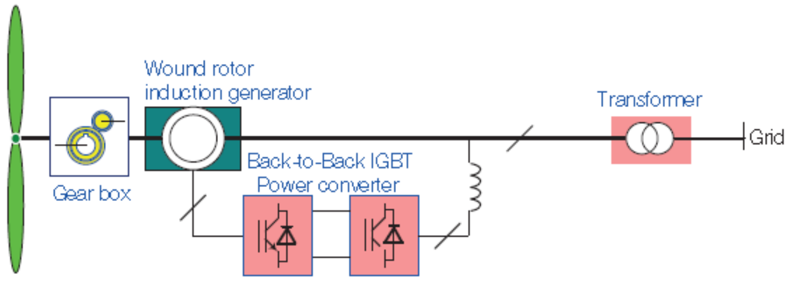

Figure 3.3: Topology of a doubly fed induction generator

3.3.4 Type D Full Power Conversion

The stator of this type of wind turbine is connected to the grid through a full power back-to-back IGBT power converter. So, all the power generated feed into the grid via the converter. The generator of this WTG cab be a synchronous generator with wound rotors, a SCIG, or a permanent magnet type generator .It may or may not be include the gear box. It can also be direct driven type . It has comparable characteristics with type C. it can be completely decoupled from the grid. It can provide wider range of speed variation as well as reactive power and voltage control capability. In addition, its output current can be modulated to zero hence, it limits short circuit current level contribution to the system.[7].Modal configuration is shown in fig.3.4.[15]

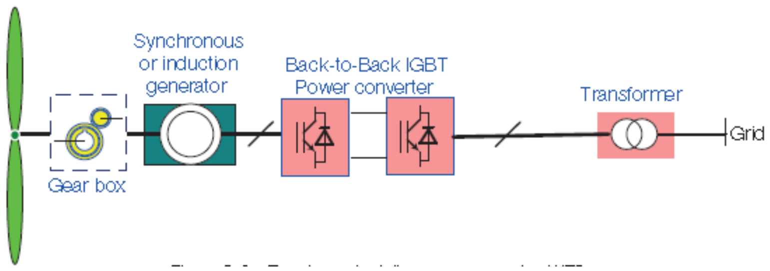

Figure 3.4: Topology of a full-power conversion WTG

Chapter 4

System Description

For the project analysis it is necessary to select a proper system for which data is available so a comparison can be made. For this purpose well known WSCC (Western System Coordinated Council) 9 bus test system is refereed. System parameters are taken as per given in reference[3]. The system comprises 3 synchronous generators at bus 1, 2 and 3. Generator 1 is a swing generator with 247.5 MVA 16.5KV rating. Generator 2 is of 192MVA 18KV capacity at bus 2 and generator 3 is having 128MVA 13.8KV capacity at bus 3 is connected. Three load of 125MW 50Mvar at bus 5, 100MW 35Mvar at bus 8 and 90MW 30Mvar at bus 6 respectively. Loads are considered as a static load. System is implemented in MATLAB(simulink). System base is 100 MVA and frequency is 60 Hz System diagram is shown in fig.4.1.

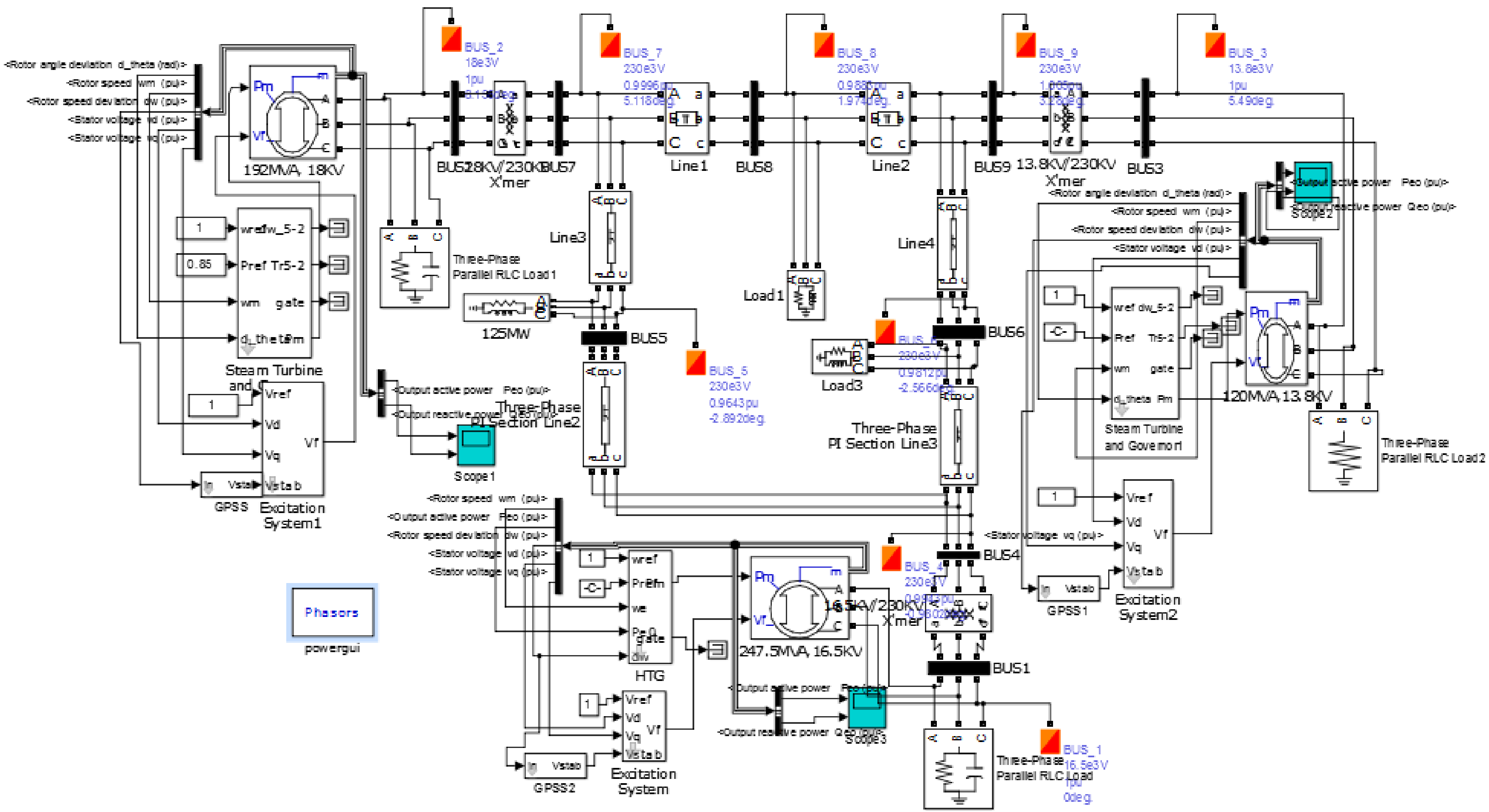

Figure 4.1: WSCC 9 Bus system

Chapter 5

Simulations and Results

First the system is simulated for normal condition so as to obtain load flow under steady state. From the simulation results it is observed that system is stabilized after 8 sec. After obtaining steady state, wind farm (of same capacity as synchronous generator) is integrated at bus 3 via step up transformer. (all values are in p.u on 100 MVA base). System was simulated in PSAT and in MATLAB(simulink) but,the results shown here are based on simulation done in MATLAB(simulik). Output of standard system under normal condition is shown in fig.5.1 fig.5.2 and fig.5.3.Load flow obtained under normal condition is shown in fig.5.5. Obtained results are fairly matches with with the references[3].

Fig.5.1 shows output of generator 1, which comprises active power, reactive power and generater rotor's mechanical speed. All values shown are in pu.

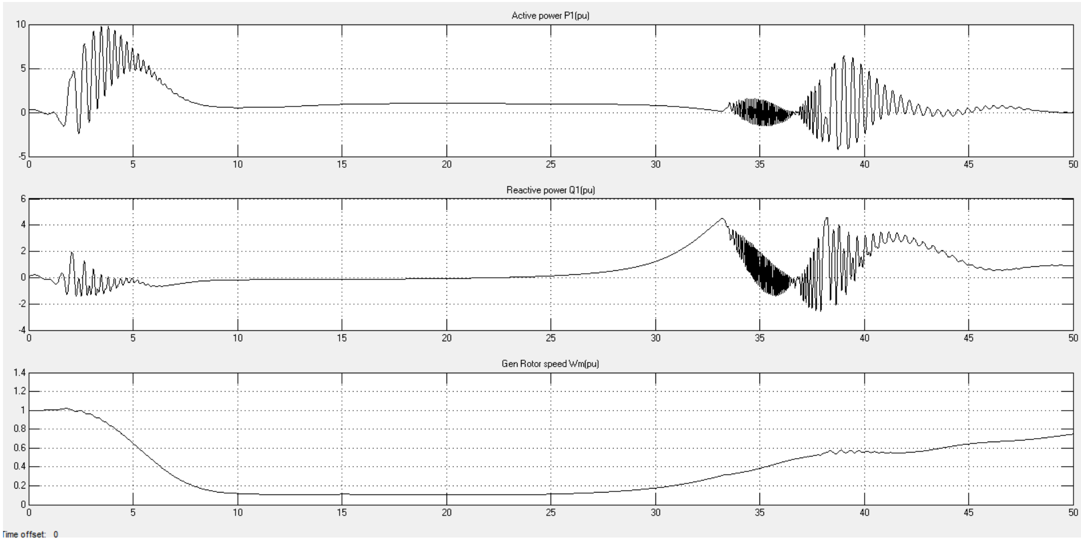

Figure 5.1: O/P of gen 1

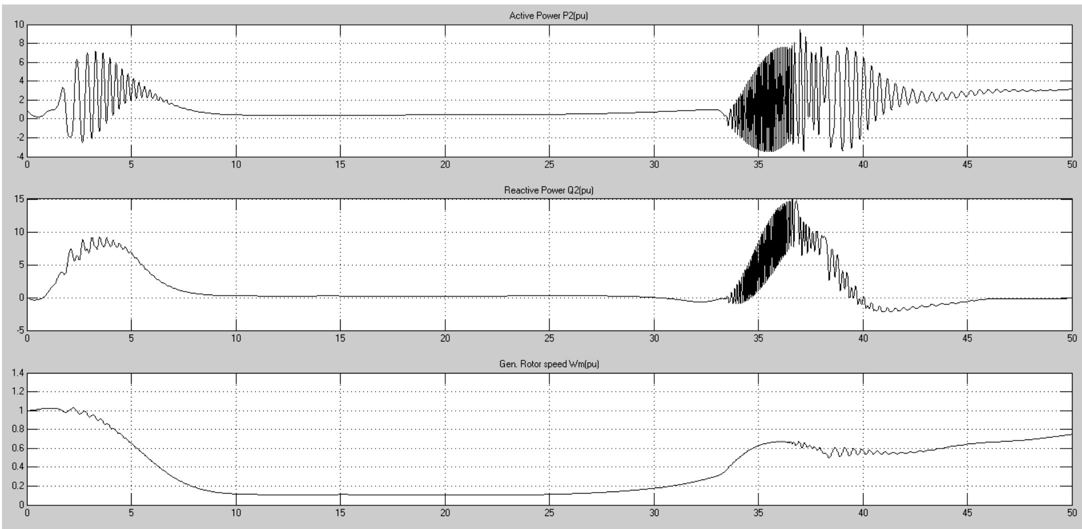

Figure 5.2: O/P of gen 2

Above fig.5.2 shows active power, reactive power and rotor speed of generater 2 in pu.

Fig.5.3 below shows output results of generator 3 contains active power, reactive power and rotor speed in pu.

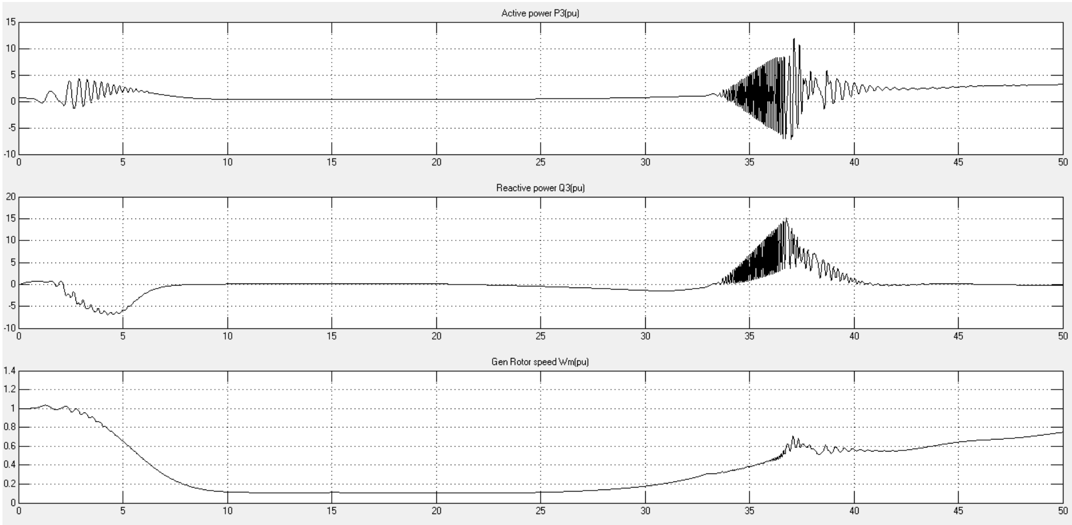

Figure 5.3: O/P of gen 3

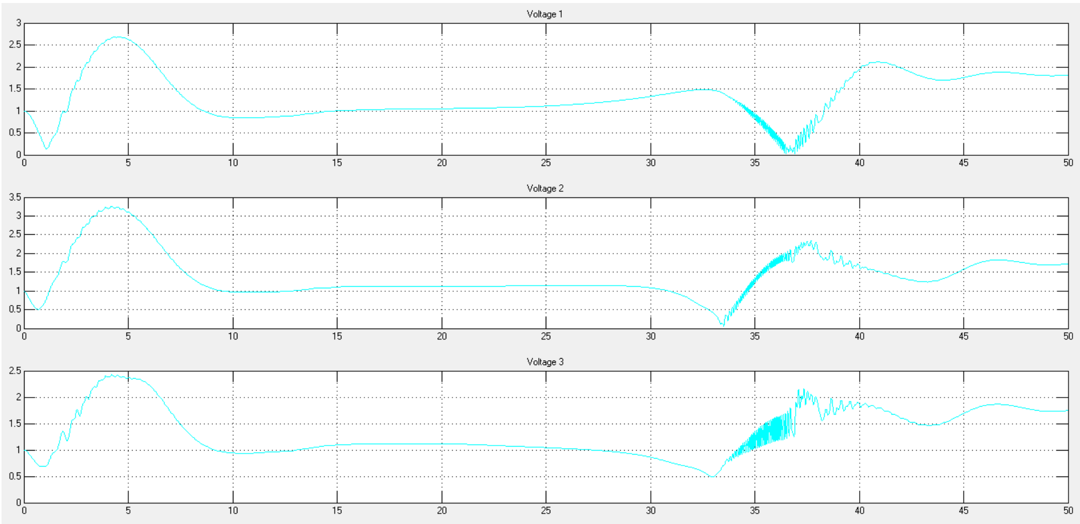

Figure 5.4: O/P voltage gen 1, 2, 3

Fig.5.4 shows voltage at bus 1, 2 and 3.

Table I: Comparison of active power with standard WSCC system

Bus No.	Active Power(MW)	Obtained Values
Bus 1	**71.6**	72.95
Bus 2	**163**	163.2
Bus 3	**85**	85
Bus 4	-	-
Bus 5	**125**	125
Bus 6	**90**	90
Bus 7	-	-
Bus 8	**100**	100
Bus 9	-	-

Table II: Comparison of reactive power with standard WSCC system

Bus No.	Reactive Power(MVAr)	Obtained Value
Bus 1	**27**	25.21
Bus 2	**6.7**	5.92
Bus 3	**-10.9**	-8.17
Bus 4	-	-
Bus 5	**50**	50
Bus 6	**30**	30
Bus 7	-	-
Bus 8	**35**	35
Bus 9	-	-

Table III: Comparison of voltage with standard WSCC system

Bus No.	Voltage(pu)	Obtained Value
Bus 1	**1.04**	1
Bus 2	**1.025**	1
Bus 3	**1.025**	1
Bus 4	**1.026**	0.99
Bus 5	**0.996**	0.96
Bus 6	**1.013**	0.98
Bus 7	**1.026**	1
Bus 8	**1.016**	0.99
Bus 9	**1.032**	1

Simulation results are compare with standard results given in the reference[5]. From above table it is observed that obtained results are almost matches with the standard. Bold values indicating reference values.

5.1 Wind Farm Model

For analysis on power quality due to wind penetration wind farm is integrated by replacing generater 3. Wind farm consisting 60 DFIGs each with 1.5MW capacity so,total installed capacity is 100MVA, 90MW. DFIG is wound rotor type induction generator in which rotor is connected through RSC convertor and stator is directly connected with grid hence, it is called as doubly fed induction generator.Power electronic convertor is back to back type IGBT convertor. Output voltage at PCC is 575V which is fed into system via stepup transformer(575V/13.8KV). Fig.5.6 shows 9 bus system after integration of wind farm at bus 3.For simulation Wind speed is constant at 14m/s after 13 sec. Cut in speed is 5m/s. At 5 sec wind speed is start increasing at speed of 1m/s.

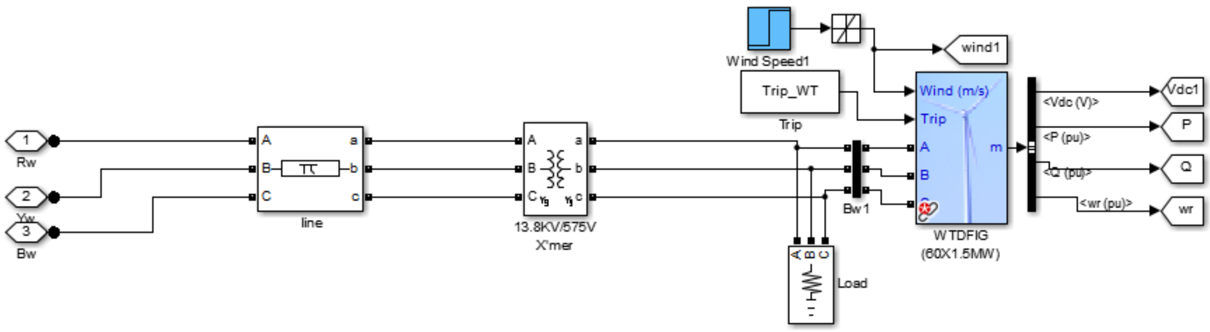

Figure 5.5: Wind Farm with 60X1.5MW

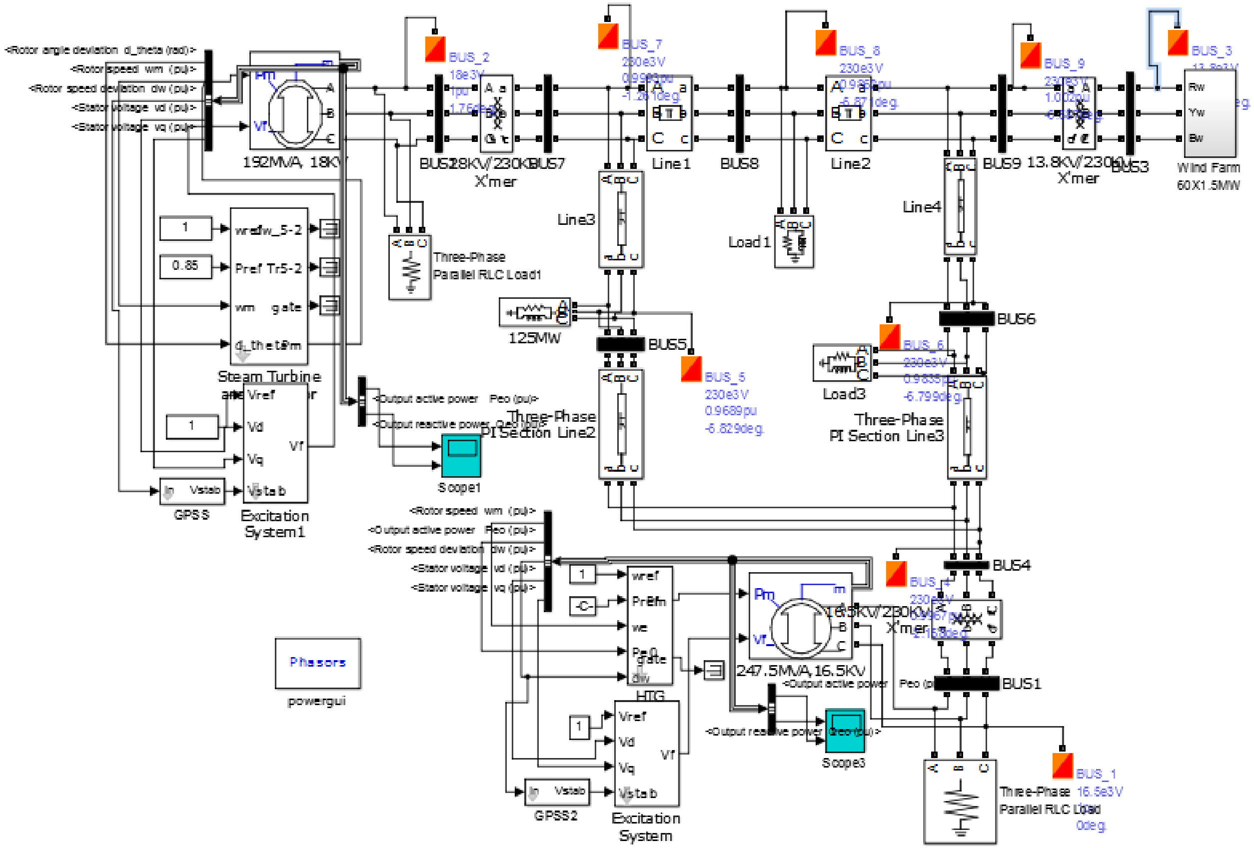

Figure 5.6: WSCC with Wind Farm integrated at bus 3

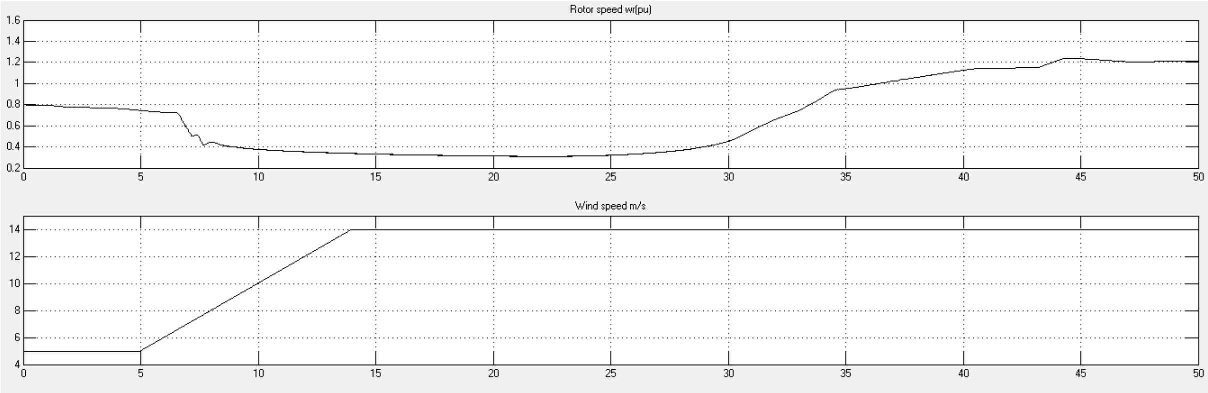

Figure 5.7: WTGs Rotor speed(pu) and wind speed(m/s) of wind generater

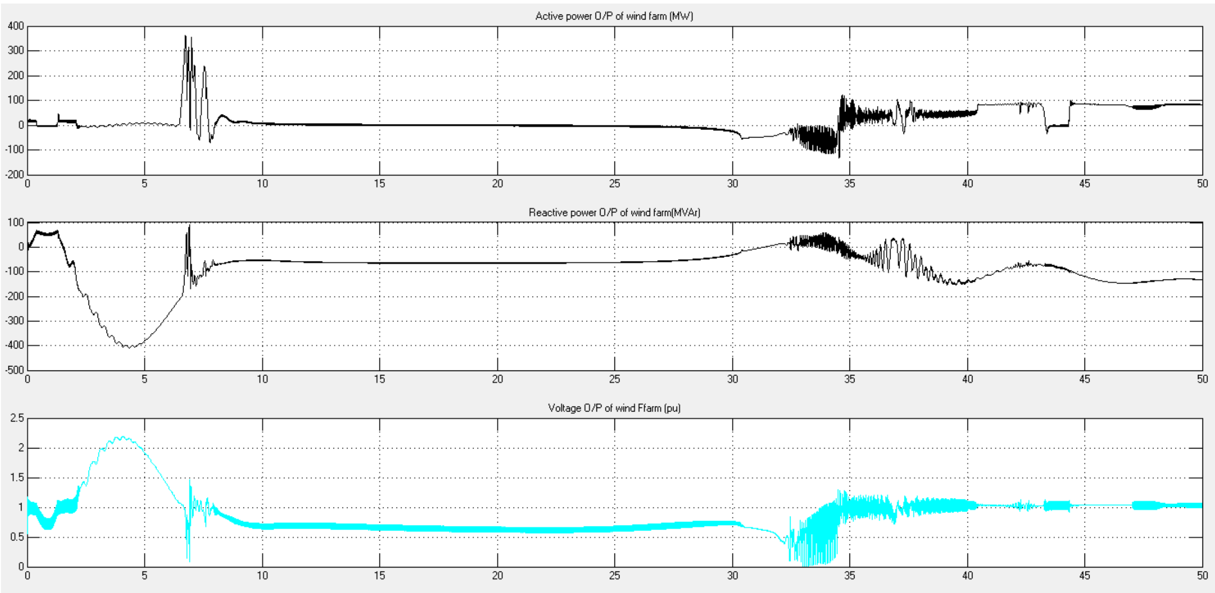

Figure 5.8: Active Power(MW), Reactive Power(MVAr) and voltage(pu) O/P of wind Farm

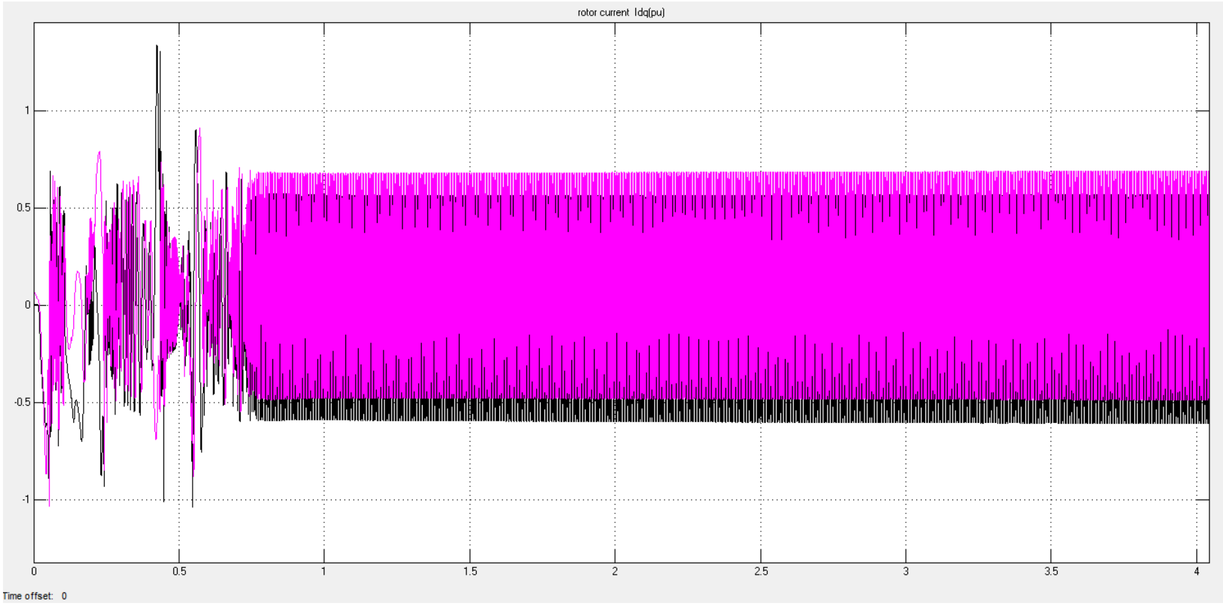

Figure 5.9: Rotor current of wind turbine

Fig.5.9 shows rotor current of one wind turbine in pu.It shows direct axis and quadrature axis component of rotor current.

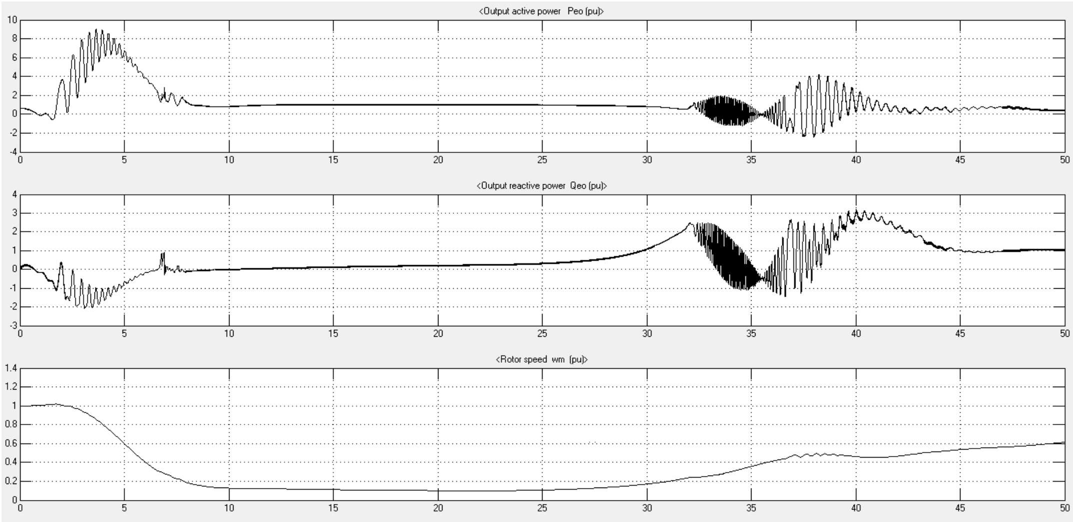

Figure 5.10: Active power(pu), Reactive Power(pu) and Rotor speed Wm(pu) of Gen 1 after integrating wind

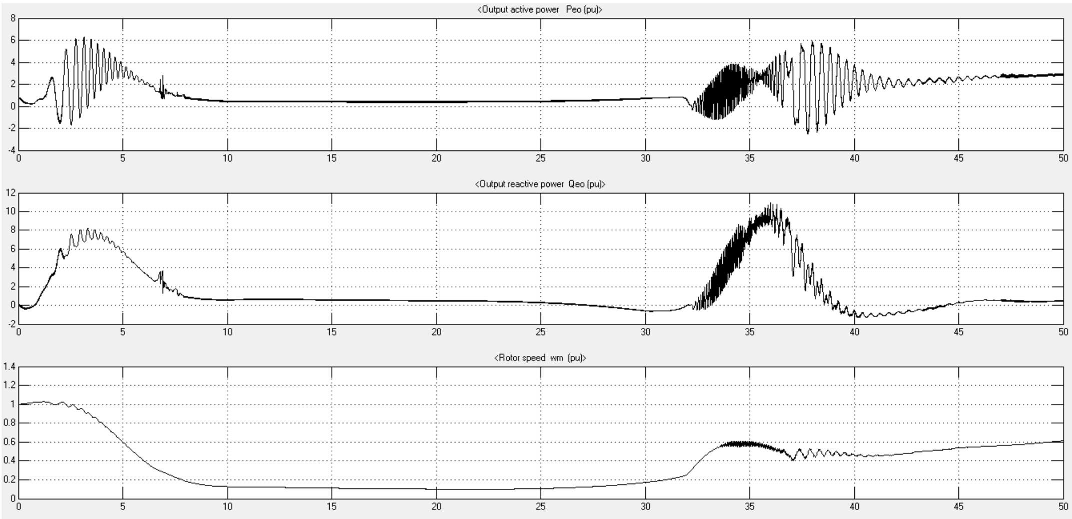

Figure 5.11: Active power(pu), Reactive Power(pu) and Rotor speed Wm(pu) of Gen 2 after integrating wind

Comparative analysis of voltage profile after integrating wind farm is shown in table 1. in which Con.I stand for normal condition and Con.II refers to after integrating wind at bus 3.

Table IV: Voltge at all buses

Sr.No	Bus No.	Con.I	Con.II
1	Bus 1	1.04	1.0
2	Bus 2	1.025	1.0
3	Bus 3	1.0	0.6
4	Bus 4	0.98	0.57
5	Bus 5	0.96	0.45
6	Bus 6	0.98	0.45
7	Bus 7	1.0	0.51
8	Bus 8	0.99	0.42
9	Bus 9	1.0	0.44

From above it is observed that after integrating wind voltage is reduce at bus 3, 8 and bus 9.

Chapter 6

Conclusion And Future Scope

6.1 Conclusion

Due to increasing power demand it is necessary to include renewable energy sources into existing power system. Among all renewable wind is highly exploited source of energy.But use of wind introduce several issues.

- Standard WSCC 9 bus test system is simulated in MATLAB. Load flow results are fairly matches with reference.
- Wind farm with equivalent capacity of one of the synchronous generator is introduced.
- Voltage and power profile is observed at point of common coupling.
- Due to wind generation reactive power demand is increases and due to that voltage dip is experienced at nearby bus.

6.2 Future Scope

Detailed analysis for the possible solution of the issues raised here can be carried on actual wind farm system. It is observed that active and reactive power output are directly proportional to direct, quadrature component of rotor current by keeping stator flux constant. So by controlling respective component of rotor current active and reactive power can be controlled.

References

[1] R.C Dugan, "Electrical Power System quality" Second edition New York Mc-Grew Hill Publication.

[2] Earnest Joshua, Wizelius Tore "Wind Power Plant And Projects Development" Prentice-Hall of India Publication.

[3] P.M.Anderson A.A.Fouad, "Power System Control and Stability" WILEY INDIA EDITION ,IEEE Press

[4] A.R.Jha, "Wind Turbine Technology" special Indian Edition ,CRC Press

[5] Kishor V. Bhadane, Dr. M. S. Ballal, Dr. R. M. Moharil, "Investigation for Causes of Poor Power Quality in Grid Connected Wind Energy- A Review".

[6] G.M. Shafiullah n, AmanullahM.T.,A.B.M.ShawkatAli,Peter Wolfs ," Potential challenges of integrating large-scale wind energy into the power gridA review", Renewable and Sustainable Energy Reviews VOL.20 pp.306–321 January 2013.

[7] Masoud Farhoodnea Azah Mohamed, Hussain Shareef, Hadi Zayandehroodi, "Power quality impacts of high-penetration electric vehicle stations and renewable energy-based generators on power distribution systems", Measurement VOL.46, pp.2423–2434 May 2013

[8] Qiang Fu, Luis F. Montoya, Ashish Solanki, Student Member, IEEE, AdelNasiri, Senior Member, IEEE, Vijay Bhavaraju, Member, IEEE, T. Abdallah, and David C. Yu, Senior Member, IEEE, "Microgrid Generation Capacity Design With Renewables and Energy Storage Addressing Power Quality and Surety", IEEE Transcation on Smart Grid, VOL. 3, No. 4 December 2012.

[9] Sharad W. Mohoda , Sudesh M. Hatwara, Mohan V. Awareb, "Grid Support with Variable Speed Wind Energy System and Battery Storage for Power Quality", Energy Procedia, VOL.12, pp.1032–1041 September 2011.

[10] Jair Urbanetz , Priscila Braun , Ricardo Rther, "Power quality analysis of grid-connected solar photovoltaic generators in Brazil",Energy Conversion and Management VOL.64, pp.8–14 September 2012.

[11] Mathilde Drouineau, Nadia Maizi , Vincent Mazauric ,"Impacts of intermittent sources on the quality of power supply: The key role of reliability indicators", *Applied Energy* VOl. 116 pp.333-343 December 2013.

[12] Er. Mamatha Sandhu, Dr.Tilak Thakur, "Issues, Challenges, Causes, Impacts and Utilization of Renewable Energy Sources - Grid Integration ",Int. Journal of Engineering Research and Applications VOL. 4 ISSUE. 3(version 1), pp.636-646 March 2014

[13] Anca D. Hansen, Pod Srensen, Lorand Janosi, John Bech" Wind farm modelling for power quality",Industrial Electronics Society VOL.1 pp.1959-1964 December 2001

[14] Jie Zhang, Wenjun Yan, Qiang Yang, Zhejing Bao, and Ruixiang Sun "Power quality measurement and analysis of offshore wind farm based on PSCAD/EMTDC models", International Conference on Advanced Computational Intelligence , pp. 371-375, October 2013

[15] "Grid integration of large-capacity Renewable Energy sources and use of large-capacity Electrical Energy Storage", October 2012

Appendix A

Appendix A

Table I: WSCC 9 bus generator data

Generator	1	2	3
Rated MVA	247.7	192	128
KV	16.6	18	13.8
PF	1	0.85	0.85
Speed	180rpm	3600rpm	3600rpm
Xd	0.1460	0.8958	1.3125
X'd	0.0608	0.1198	0.1183
Xq	0.0969	0.8645	1.2578
x'q	0.0969	0.1969	0.25
Xl(leakage)	0.0336	0.521	0.0742
T'do	8.96	6.00	5.89
T'qo	0	0.535	0.600
H(sec)	23.64	6.4	3.01

Table II: Exciter data

Parameter	Exciter 1	Exciter 2	Exciter 3
Ka	20	20	20
Ta(sec)	0.2	0.2	0.2
Ke	1	1	1
Te	0.314	0.314	0.314
Kf	0.063	0.063	0.063
Tf	0.35	0.35	0.35

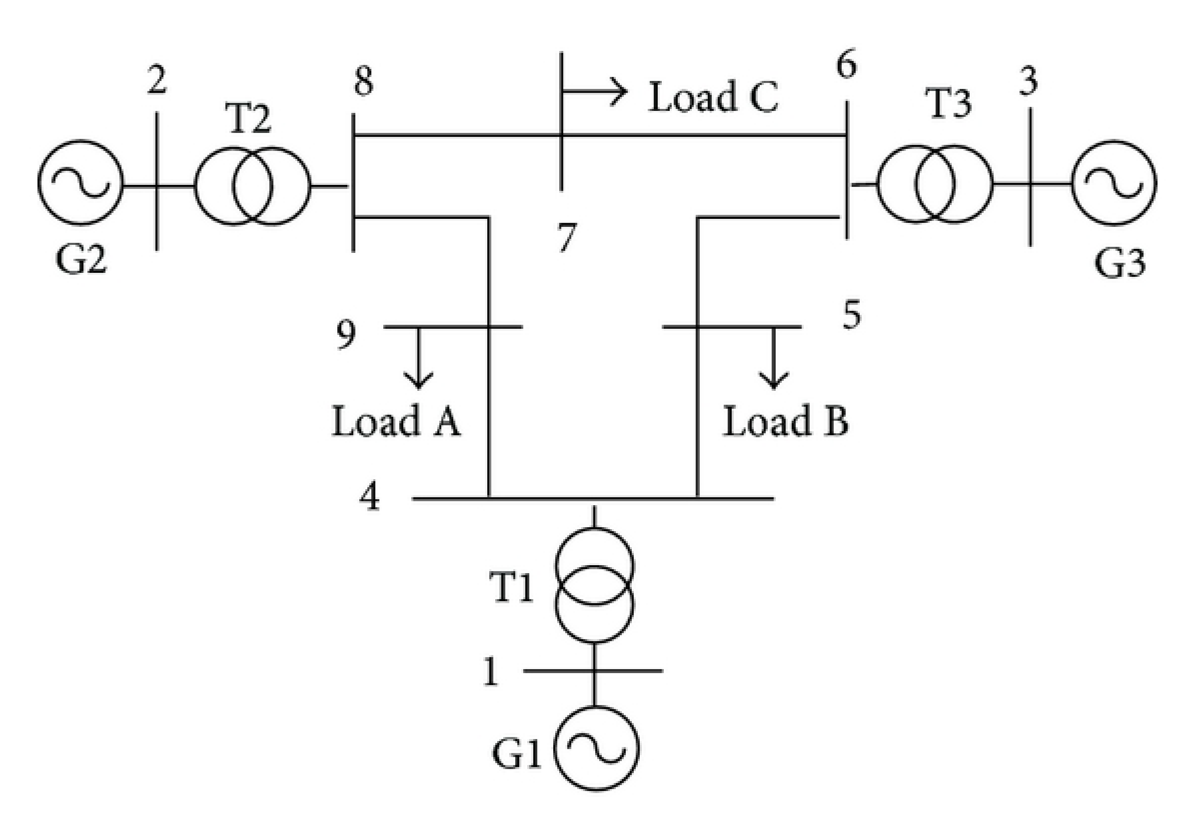

Figure A.1: Single line diagram of WSCC 9 bus system