Impact of Powerformer on System Stability

Major Project Report

Submitted in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(Electrical Power Systems)

By

NAITIK PATEL

13**MEEE**30

DEPARTMENT OF ELECTRICAL ENGINEERING

INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

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Undertaking for Originality of the Work

I, **Naitik Patel** (**Roll.No.13MEEE30**), give undertaking that the Major Project entitled **"Impact of Powerformer on System Stability"** 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:

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Assistant Professor

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Certificate

This is to certify that the Major Project Report entitled **"Impact of Powerformer on System Stability"** submitted by **Naitik Patel (Roll No: 13MEEE30)** towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by him 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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Acknowledgement

Success of any work depends upon the dedication, sincerity and hard work. It also requires some ingredients such as motivation, encouragement and time.

First of all, I would like to thanks my project guide Prof. Gaurang Buch, whose keen interest and excellent knowledge base helped me to finalize the topic of the dissertation work. His constant support and interest in the subject equipped me with a great understanding of different aspects of the required architecture for the project work. He has shown keen interest in this dissertation work right from beginning and has been a great motivating factor in outlining the ow of my work.

My sincere thanks to Prof Dr.P.N.Tekwani, Head of Electrical Engineering Department and Prof Dr.S.C.Vora, P.G Co-ordinator, department of Electrical Engineering, Nirma University. I would like to thank all the other faculty members of Department of Electrical Engineering, Nirma University.

Finally, I would like to thanks my parents, family and all my friends who encouraged me and supported me throughout the project work.

Naitik Patel

13MEEE30

Abstract

Conventional high-voltage generators are designed with voltage levels rated to maximum of 30 kV. The power grids with voltages as high as 765 kV cannot be directly supplied from these generators. Power step-up transformers are used to transform the generated voltage to high transmission voltage level suitable for the interface with the transmission grid. These transformers impose significant drawbacks on the power plant as a whole reduction in efficiency, high maintenance costs, more space, less availability and an increased environmental impact. During the last century, a number of attempts were made at developing a high-voltage generator, the Powerformer that could be connected directly to the power grid, without step-up transformer. When XLPE-insulated cables were introduced in the 1960s there were some initial problems with their reliability, caused by poor control of the manufacturing processes. These problems have since been overcome and today's high-voltage XLPE-insulated cables have an impressive track record. Therefore, the development of the Powerformer is inherently linked to the reliability and the development of the XLPE insulated cables. The Powerformer has opened a new technological chapter in the generation and transmission of electrical energy. Scope of the project includes modeling and analysis of Powerformer during faults and its impact on stability of the power system.

Nomenclature

V_q .... q axis Stator voltage
V_d .... d axis Stator voltage
V_o .... origin axis Stator voltage
V_a .... three phase voltage
V_b .... three phase voltage
V_c .... three phase voltage
I_q .... q axis Stator Current
I_d .... d axis Stator Current
I_{kq} .... q axis damper winding Current
I_{kd} .... d axis damper winding Current
I_o .... origin axis Stator voltage
I_a .... three phase current
I_b .... three phase current
I_c .... three phase current
V_q .... q axis Stator voltage
V_q .... q axis Stator voltage
V_q .... q axis Stator voltage
P_{em} .... electromechanical power
T_{em} .... electromechanical Torque
T_{mech} .... mechanical Torque
T_{damp} .... damping Torque
ω_r .... rotational speed
ω_b .... base speed
L_{mq} .... q axis stator magnetizing inductance
L_{md} .... d axis stator magnetizing inductance
rs .... stator resistance
rf .... d axis field winding resistance
r_{kq} .... q axis damper winding resistance
r_{kd} .... d axis damper winding resistance

$rpkq$ .... q axis field winding resistance

$rpkd$ .... d axis field winding resistance

rpf .... field winding resistance

xls .... armature or stator winding leakage reactance

x_q .... q axis reactance

x_d .... d axis reactance

x_{kq} .... q axis damper winding reactance

x_{kd} .... d axis damper winding reactance

$xplkq$ .... q axis field winding reactance

$xplkd$ .... d axis field winding reactance

$xplf$ .... d axis field winding linkage reactance

xmQ .... q axis mutual flux linkage reactance

xmD .... d axis mutual flux linkage reactance

Ψ_q .... q axis flux linkage

Ψ_d .... d axis flux linkage

Ψ_o .... origin axis flux linkage

Ψ_{kq} .... q axis flux linkage damper winding

Ψ_{kd} .... d axis flux linkage damper winding

Ψ_{mq} .... q axis flux linkage magnetizing winding

Ψ_{md} .... d axis flux linkage magnetizing winding

E_f .... field winding voltage

Contents

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Chapter 1

Introduction

1.1 Powerformer Concept

Powerformer, although a new concept in the design of 3-phase AC generator, its rotor is same as that of conventional generator. The main difference in the design of conventional generator and Powerformer is located in the stator winding. The use of high voltage cable instead of conventional winding increases dielectric strength between phase and grounded body. It increases the generated voltage considerably. Its allows direct connection of Powerformer with high voltage network without using step up transformer[5]. This is illustrated in Figure 1.1, 1.2

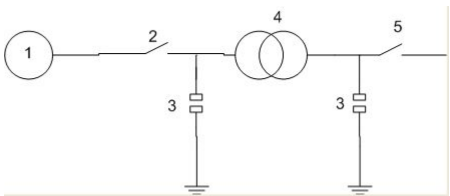

Figure 1.1: Single line diagram of conventional generator[5].

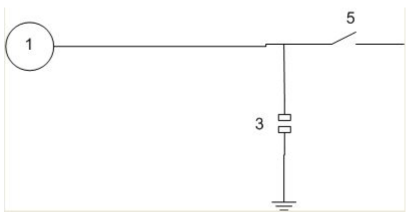

Figure 1.2: Single line diagram of Powerformer[5].

1. Generator
2. Generator and breaker
3. Surge arrester
4. Step up transformer
5. Circuit breaker

Figure 1.1, 1.2 Shows the typical arrangement of a conventional generator plant using step-up transformer(a), and using Powerformer (b). As Powerformer is able to generate at high voltage, it is able to give features of generator and step up transformer. So, use of Powerformer results in omission of step up transformer, low voltage bus and generator circuit breaker as shown in Figure 1.1, 1.2. As a consequence there is an increase of up to 1.5 percent of the total electrical power efficiency in comparison with the today's best designs, without using superconductive materials. Reactive power output and overload capability are also improved in Powerformer. These results into overall reduction in size and weight of the generator plants, which has a lesser impact on the environment. Use of Powerformer in generator plants calls for major changes in design, engineering, manufacturing and production of the complete plant. The new machine technology gives promising future possibility for both water and thermo power stations and electrical devices[5].

1.2 Powerformer Construction

1.2.1 Construction of stator winding in Powerformer

The magnetic circuit of Powerformer require certain change in winding design. The stator winding in Powerformer consists a power cable with solid insulation and two semiconducting layers, one surrounding the conductor and the other outside of the insulation used. XLPE cable is used as solid insulation in stator winding of Powerformer. It is successfully being used in under ground high voltage power lines since 1960s[5].(see Figure1.3) The cable are threaded through the stator slots, to form a winding which can produce the high voltage. The use of high voltage cables in Powerformer winding offers significant advantages over conventional designs. In conven-

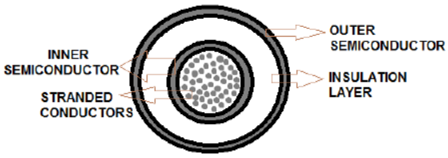

Figure 1.3: Cross section power cable used in the stator winding of Powerformer [5].

tional generator to favor maximizing the current loading in the machine, rectangular conductors are used in order to obtain a maximum packing density of copper for the stator windings. The non-uniform field distribution of the conductor shape with high field concentration of the circuit is shown in Figure1.4[5]. As previously discussed,

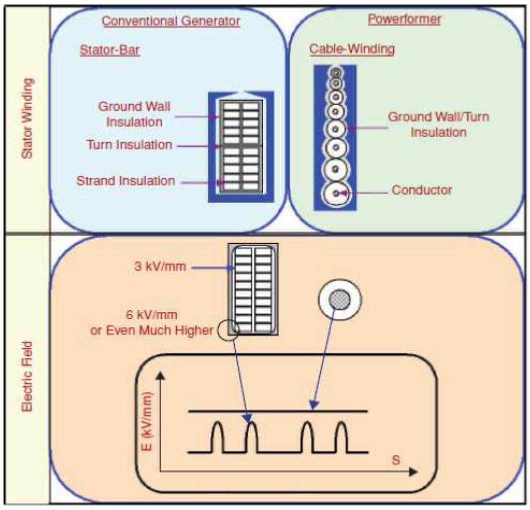

Figure 1.4: Stator bar of the conventional generator and stator cable winding of the Powerformer[5].

Powerformer winding consists of insulated high voltage power cables, it is similar to the commercial and standard power cables used in power distribution system. The cables in Powerformer do not have metallic sheath or a screen. The winding of Powerformer cable consists of stranded conductors, inner semi-conductive layer, a solid dielectric(XLPE) and an outer semi-conductive layer. The main purpose of the inner semi-conductive layer is to create a uniform electric field on the inner surface of the insulating layer while the outer semiconducting layer acts to limit the electric field within the insulator. The word semiconductor refers to a material have a relatively high resistivity, in this case which is XLPE doped with carbon. Such a semiconductor is, more specifically a resistive conductor. In stranded conductors there is a central wire surrounded by concentric layers of 12, 18, 24, 30, 36 and 42 wires also called as concentric-lay conductor. Each layer is applied with alternate directions of lay. The wire cross-section dimension are selected according to the prevailing system voltage and the maximum power of the generating unit. A conductor inserted into an electric machine is subjected to a higher magnetic flux leakage than a conductor in a transmission or distribution systems. The conductor of Powerformer is divided into mutually insulated strands to minimize additional losses due to magnetic leakage flux. The majority of the strands may be insulated at common electrical potential of the strands and the inner semi-conductive layer, one or more strands in the outermost layer may be non-insulated. The voltage induced in stator winding of Powerformer is gradually increased from the neutral point to the line terminal. Therefore the cable used in the stator winding is subjected to various electrical stresses along the length of the winding. In a Powerformer, a thinner insulation for the first few turns of the winding, and thereafter increasing the thickness of the insulation used. This is known as stepped insulation. A method of obtaining this is by using a predetermined number of different dimensions of cables per phase (i.e. a gradual increase of the insulation thickness). Stepped insulation allows better optimization of the volume of laminated stator core ensures that the tooth width is effectively constant along its length is independent of the radial expansion keeping the flux density is constant. Such field concentrations generates material stress and prevents the output voltage of the generator to be higher than 30 kV. Powerformer winding on the other hand from uniform electric field. That means the insulating material is evenly loaded and used in an optimal way. Powerformer cable for an electric field strength 10 kV/mm, which should be compared with the 3 kV/mm is designed to be able to manage today's generator windings (Figure 1.5). These characteristics increase the voltage generated with Powerformer windings fully insolated, which also minimizes the risk of partial discharges and internal two and three-phase fault[5]. The stator current in Powerformer is much lower than with conventional generators - With equal rating due to the high voltage generated, mechanical forces acting on the end winding are low. This allows the bracing system for the end winding as compared to the conventional generators can be simplified. High-voltage cable has a positive effect in terms of the

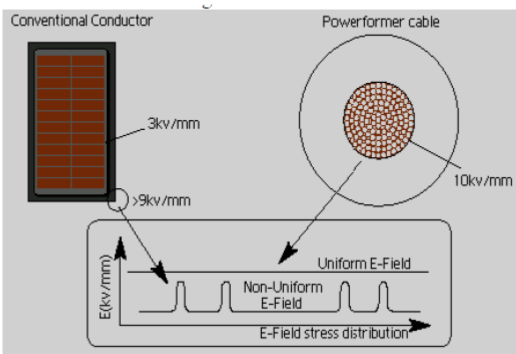

Figure 1.5: Powerformer cable in comparison with conventional rectangular conductors[5].

reliability of the generator. In comparison of the number of defects in high-voltage cables, statistics show that high-voltage lines have fewer faults. It is possible to use thin insulation for the first few turn, and then increasing thickness of insulation for subsequent turns. Such an arrangement called graded insulation, allows better utilization of the volume of the laminated core and the solid insulation. The entire cable sheath is connected to ground potential, so the electric field outside the cable is close to zero. Since the outer shell is at ground potential. There is no need for the control of the electric field. Thus field concentrations in the core are removed, in the coil-shaped end portions and in the transition region between them. The field of conventional generators have to be controlled at several points per turn. To reduce the cost of cable and to have ability of several output level in terminals, three types of standard XLPE cables are used 11, 33 and 63 kV in the stator slots of Powerformer. In each slot there are 12 XLPE cables in such a way that two of the first cables near rotor surface are 11 kV cable and the next four 33 kV cables are behind them and the last six cables are 63 kV [5]. It is clear that the neutral point of first conductors near

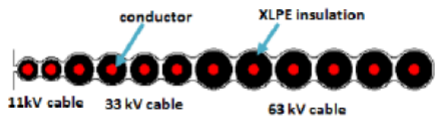

Figure 1.6: The proposed slot of Powerformer and the cables inside [5].

the slots (near rotor surface) and the terminals of the generator are in the vicinity of the cable at the end of the slot[5].

1.2.2 Stator design

The Powerformer is equipped with a conventional rotor. The stator of the Powerformer is constructed from a laminated core, built from electric plates. Teeth point in the outer portion towards the rotor(in the middle). The winding is located in the slots between teeth. The cross section of the slots in the direction of the rotor decreases, since each winding turn requires less cable insulation closer to the rotor. The cross-section of the winding cable is accounted by the stator slot design. Simultaneously, the teeth should be as wide as possible at each radial plane. This will reduce the losses in the machine and also the required excitation current. The stator teeth can be formed so that the radial width of the slot is substantially constant over its entire length. This balances the loading of the stator tooth. The winding can be described as a multi layer concentric winding, which means that the number of coil ends crossing each other is minimized. This feature allows simpler and faster threading of stator winding. Figure 1.7 (a) and (b) shows a sectional view of the Powerformer stator and the temperature distribution of stator slot, as a result of using a high-voltage cable in the stator winding corresponding to an increase of the output voltage to a decrease in the charging current in the machine for a given input power. Therefore in stator of Powerformer, lower current density leads to lower resistive losses in the machine. The outer semi conductive layer is connected to the earth cable. Thus the electric field outside the outer semiconducting layer in the vicinity of the coil end portion is zero. There is no need for controlling the electric field in the coil end region, as in the conventional generator. In the conventional generators, the field is to be controlled at several points per revolution. This eliminates field concentrations in the core, coil end portions and in transition between them. There is no risk for either partial or corona discharges in each region of the coil. The personal safety is increased substantially as the end winding region is at ground potential. Because of the lower currents and current densities, the current forces in Powerformers are considerably smaller than that for conventional generators. Another important aspect in the construction of a Powerformer is to minimize vibration of the cable. To achieve this goal and to ensure a good electrical contact between the cable and the laminated core, the cable is fixed in the slot. It is mounted on a triangular shaped silicon rubber tube, which is inserted between the cable and slot wall as the Figure 1.7 shows. The shape of the cross section of the rubber tube is adapted to necessary elastic deformation, allowing the fixation forces to be kept within certain limits. This limits the maximum force, reducing the deformation of the cable cross-section. A minimum force must be kept at low temperatures, to avoid the loss of contact between the cable and slot wall. However to avoid local deformation of the cable at the end-winding region due to vibrations and tension forces, the cables are separated by a rubber spacer[5]. Each

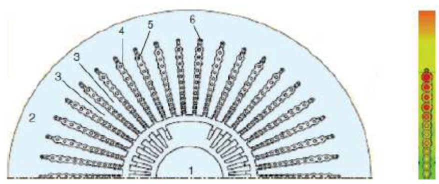

Figure 1.7: (a) Sectional view of the Powerformer stator: 1) rotor, 2) section of stator, 3) teeth, 4) slots, 5) main winding cable, and 6) auxiliary winding, (b)temperature distribution around a stator slot[5].

slot has circular holes at intervals to form narrow waists between the winding layers, as shown in figure1.8 below[5]. From the analysis and synthesis it was found that the

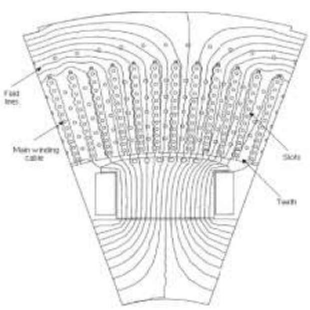

Figure 1.8: Section of the stator in Powerformer [5].

principal losses in Powerformer are associated with the laminated iron core. Therefore, the stator core in Powerformer is axially cooled by water pipes of XLPE. The water cooling is done at zero potential (in the core) and is completely separate from all E-fields[5].

1.3 Methodology

- Literature survey
- By replacing conventional machine and doing analysis with Powerformer
- Comparison of conventional machine and Powerformer
- Studying impact on system stability on power system

1.4 Literature Survey

For the better understanding of project literature survey plays a very important role. Literature survey consists of papers and books referred which gives fundamental knowledge of network observability.

- **Xiangning Lin, Qing Tian, Pei Liu, Lian Chen** [3] This paper entitled Investigation of internal fault modeling of Powerformer discusses a model of a 75 MVA and 150 kV synchronous machine (Powerformer), which can be used to simulate internal fault waveforms for power system protection studies. A method to calculate the inductance and its magnetic axis location of the faulty path is outlined. Comparisons are made between the simulated waveforms and recorded waveforms to verify the accuracy of the model.

- **Qing Tian** [9] This paper entitled Investigation of internal fault modeling of Powerformer Part I: The machine model discusses the set-up of a mathematical model of Powerformer, a new type of salient pole synchronous machine, for analyzing internal phase and ground faults in stator windings. The method employs a direct phase representation considering the cable capacitance.

- **Qing Tian** [10] This paper entitled Investigation of internal fault modeling of Powerformer Part II: The machine model discusses compared with experimental results for phase to phase fault in the stator windings of a 15 kW synchronous test generator as a single machine with no load and neutral grounding with a resistor.

- **Craig Aumuller, Member, and Tapan Kumar Saha, Senior Member IEEE** [4] The paper entitled investigating the impact of Powerformer on large scale system voltage stability, discusses transmission system to determine the potential impact of the Powerformer on the voltage stability of this system.

- **Surender Kumar Yellagoud, Naman Bhadula, Siddharth Sobti** [5] The paper entitled A Study of Powerformers and their impact on power system reliability and environment discussed, high volta generators are designed rated to maximum of 30 kV. The power grids with voltages as high as 1100 kV cannot be directly supplied from these generators, power step-up transformers are used to transform the generated voltage to high transmission voltage level suitable for the interface with the transmission grid.

- **Craig Anthony Aumuller, Member, IEEE, and Tapan Kumar Saha,Senior Member, IEEE** [11] The paper entitled Investigating the impact of Powerformer on voltage stability by dynamic simulation discussed overview of dynamic analysis carried out to determine the impact of the Powerformer on voltage stability. The unique aspects of the Powerformer will highlighted and the modeling of long-term dynamic elements, especially those pertinent to the study of the Powerformer will discussed.

1.5 Outline of Thesis

- **Chapter 1** To introduce the conventional generator device known as Powerformer and thereby the construction of Powerformer. The methodology and literature survey is also described.

- **Chapter 2** Gives a description of need of Powerformer and their advantage, disadvantage, environment impact and their reliability and impact on voltage stability are also discussed briefly.

- **Chapter 3** Includes modelling of synchronous generator, based on different dynamics equation of generator and modelling of Powerformer are discussed and shown their result.

- **Chapter 4** To give a brief introduction about power system stability. Voltage stability and load angle stability analysis was carried out and compared for following stability analysis was performed for fault condition and during sudden change of load. Powerformer connected with infinite bus. Wsccc 3 machine 9 bus system with Powerformer and conventional generator transformer.
- **Chapter 5** Includes conclusion and future scope.

Chapter 2

Need of Powerformer

The Powerformer is the innovative design, which allows it to generate electricity at much higher voltages than conventional equipment. This allows the electricity to be fed directly into the local power grid without using a step-up transformer and associated equipment. By reducing the size and number of components, the Powerformer increases reliability, lowers maintenance costs, cuts power losses and reduces overall life cycle costs by up to 30 percent. The Powerformer revolutionizes power generation by eliminating the need to attach a transformer to the generator. In a conventional system, electricity is generated at voltages that are too low to be efficiently transmitted through a power grid. This is overcome by attaching a step-up transformer and associated electrical equipment to the generator to lift the voltage into the 30 to 400 kV range. The Powerformer uses high-voltage cable technology to generate electricity at much higher voltages. The benefits of eliminating the step-up transformer include, life cycle cost (LCC) reduction of up to 30 percent. By reducing the size and number of components in the power plant, the Powerformer saves space, service and maintenance costs, reduces losses, and increases plant reliability. Environmental benefits: The Powerformer contains no oil, epoxy or other materials found in conventional generators that can create disposal problems. The Powerformer reduces power losses and there by increases overall energy efficiency. It can also be used to connect small energy sources, like wind or small-scale hydro plants, to larger power grids [6] .

2.1 Advantage

a. High efficiency

b. More reliable

c. Low losses

d. Low environment effect

2.2 Disadvantage

a. More expensive

2.3 Enviornmental Impact

A Life-Cycle Assessment (LCA) is a tool to create a complete picture of the environmental impact of a product or system, throughout their life from raw material extraction, production, recycling and finally give up for disposal. A lifetime of 30 years was assumed, the environmental impact expressed as Environmental Load Unit (ELU), a high impact on the environment is expressed as a high ELU number. Powerformer system has less environmental impact than a traditional system, in all its life stages, this is mainly because Powerformer has less energy loss. Powerformer is clean and safe, a conventional step-up transformer has several tones of oil. The handling of the oil-based insulation and cooling systems with the associated fire and leakage risks can be avoided, which gives a clean and safe power plant. Powerformer fully insulated winding minimizes the risk of PD, thus less danger of ozone production and environmentally friendly power plants. Finally, a majority of the material used in Powerformer be easily recycled after the dismantling of the machine[7].

2.4 Impact on Power System Reliability

Reliability is necessarily interdependent with business and higher investment in order to achieve a higher reliability or even to maintain the reliability of current and acceptable levels. Currently, the only approach to improve the reliability of systems without additional new capacity, either by reducing downtime by hiring additional personnel for repairs, or to extend up time by more sophisticated monitoring and maintenance techniques. These alternatives are now more likely than the combination of capital scarcity and uncertainty in demand and fuel costs are higher for the new equipment. In this context, in this section the effect of a new high-voltage generator is examined. This high voltage machine directly controls the high voltage side of the grid and has some additional features such as higher availability, more reactive power margin and additional short-term overload capacity. Studies have confirmed that they delay the system voltage sag by several seconds [5].

2.5 Impact on Voltage Stability

Voltage stability and voltage collapse issues have in recent years begun to pose a undesirable threat to the operational security of power systems. Recent collapses, have highlighted the importance of avoiding generator limiting in order to limit potential voltage instability. The particular importance of the stator current limitation and its contribution to the collapse of a system has also been highlighted. The focus of this paper is a new type of generator, the Powerformer which connects directly to the high voltage bus, and therefore, controls this high side buss voltage directly [4].

2.6 Summary

This chapter provides a description of need of Powerformer then also discuss to the advantage, disadvantage, environment impact their reliability and impact of voltage stability.

Chapter 3

Modeling of Powerformer

3.1 Simulation of Synchronous Generator

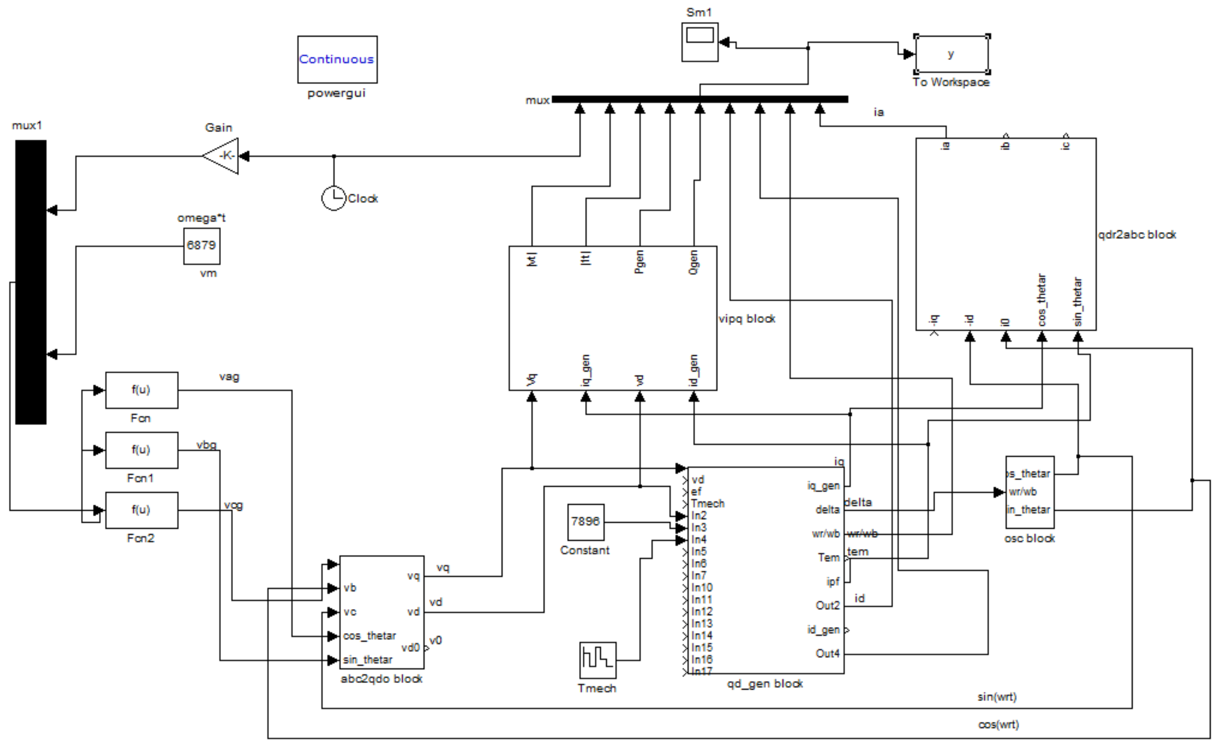

Figure 3.1: Simulation of synchronous generator

The block qd.gen contains the simulation of the generator proper in its rotor references frame. A close examination of the manner in which the rotor winding equations are implemented in the simulation will reveal that the addition of another rotor winding having a common magnetizing reactance with other winding of the same axis can done quite easily. The details of the rotor block are shown in Figure 3.1. In simulation, startup transients can also be minimized by temporarily setting the damping, however when desired steady-state condition is established, it should be reset correspond to the actual value before conducting the study. The transformation of the qdo rotor reference currents back to abc stator currents are performed inside the qdr2abc block. The details of the qdr2abc block are shown in figure shows the inside of the VIPQ block, in which the instantaneous magnitude of the stator voltage, stator current, and stator real and reactive power at the generator's terminal are computed. The parameter of synchronous generator are given in appendix [7].

$$\Psi_q = \omega b \int v_q - \frac{\omega r}{\omega b}\Psi_d + \frac{rs}{xls}(\Psi_{mq} - \Psi_q)dt \tag{3.1}$$

$$\Psi_d = \omega b \int v_d + \frac{\omega r}{\omega b}\Psi_q + \frac{rs}{xls}(\Psi_{md} - \Psi_d)dt \tag{3.2}$$

$$\Psi_o = \omega b \int (v_o - \frac{rs}{xls}\Psi_o)dt \tag{3.3}$$

$$\Psi'_{kq} = \frac{\omega b r'_{lkq}}{x'_{kq}} \int (\Psi_{mq} - \Psi'_{kq})dt \tag{3.4}$$

$$\Psi'_{kd} = \frac{\omega b r'_{lkd}}{x'_{kd}} \int (\Psi_{md} - \Psi'_{kd})dt \tag{3.5}$$

$$\Psi'_{f} = \frac{\omega b r'_{f}}{x_{md}} \int (\Psi_{mq} - \Psi'_{kq})dt \tag{3.6}$$

$$\Psi'_{f} = \frac{\omega b r'_{f}}{x_{md}} \int E_f + \frac{x_{md}}{x'_{lf}}(\Psi_{md} - \Psi'_{f})dt \tag{3.7}$$

Where,

$$\Psi'_f = \omega_b L_{mq}(i_q + i'_{kq}) \tag{3.8}$$

$$\Psi'_{mq} = \omega_b L_{mq}(i_q + i'_{kq}) \tag{3.9}$$

$$\Psi'_{md} = \omega_b L_{md}(i_d + i'_{kd} + i'_f) \tag{3.10}$$

$$E_f = x_{md}\frac{v'_f}{r'_f} \tag{3.11}$$

$$\Psi_q = x_{ls} i_q + \Psi_{mq} \tag{3.12}$$

$$\Psi_d = x_{ls} i_d + \Psi_{md} \tag{3.13}$$

$$\Psi_o = x_{ls} i_o \tag{3.14}$$

$$i_q = \frac{\Psi_q - \Psi_{mq}}{x_{ls}} \tag{3.15}$$

$$i_d = \frac{\Psi_d - \Psi_{md}}{x_{ls}} \tag{3.16}$$

$$i'_{kd} = \frac{\Psi'_{kd} - \Psi_{md}}{x'_{lkd}} \tag{3.17}$$

$$i'_{kq} = \frac{\Psi'_{kq} - \Psi_{mq}}{x'_{lkq}} \tag{3.18}$$

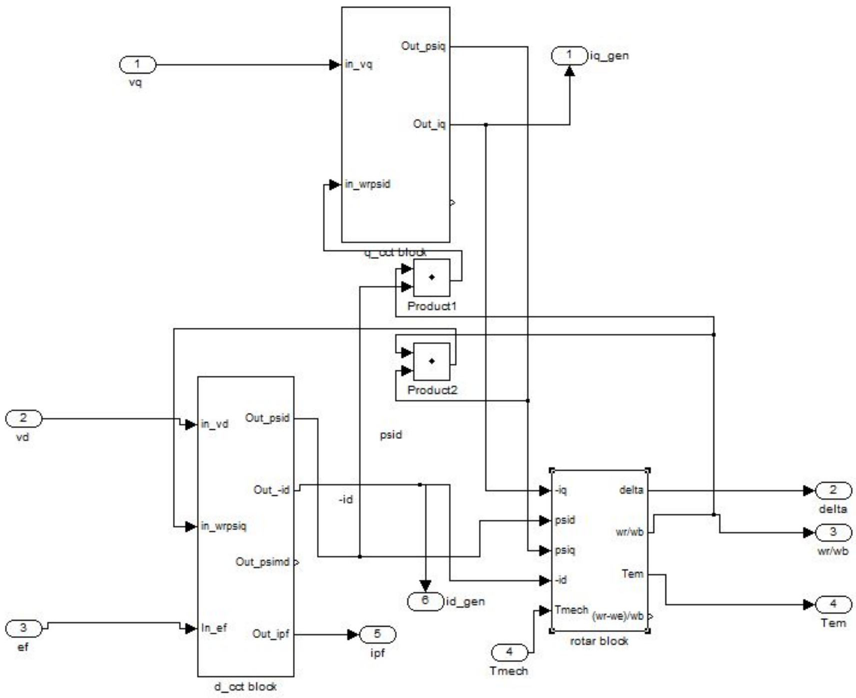

Figure 3.2: Simulation of qd Generator block

Torque expression by rotor block of synchronous generator is follow by,

$$T_{em} = \frac{3}{2}\frac{P}{2\omega_b}(\Psi_d i_q - \Psi_q i_d) \tag{3.19}$$

$$\omega_r(t) - \omega_e = \frac{P}{2J}\int (T_{em} + T_{mech} - T_{damp}) dtelect.rad/s \tag{3.20}$$

3.2 Simulation and Results of Synchronous Generator

The simulation of three phase voltage, source voltage and rotational speed is show in Figure 3.3, 3.4, 3.5 and 3.6.

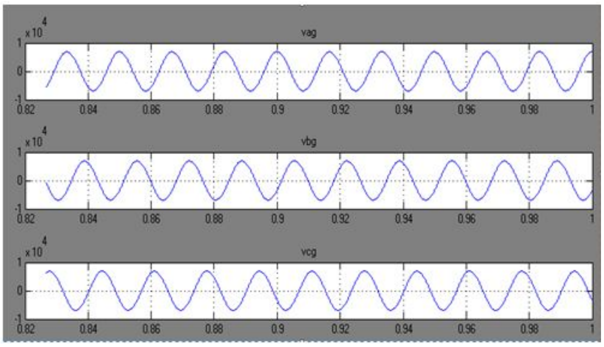

Figure 3.3: Waveform of 3 phase voltage

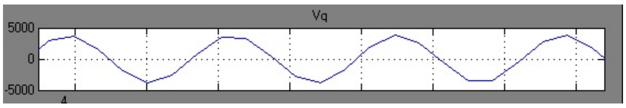

Figure 3.4: Waveform of source voltage

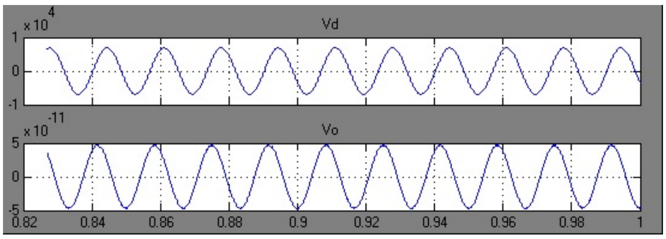

Figure 3.5: Waveform of source voltage

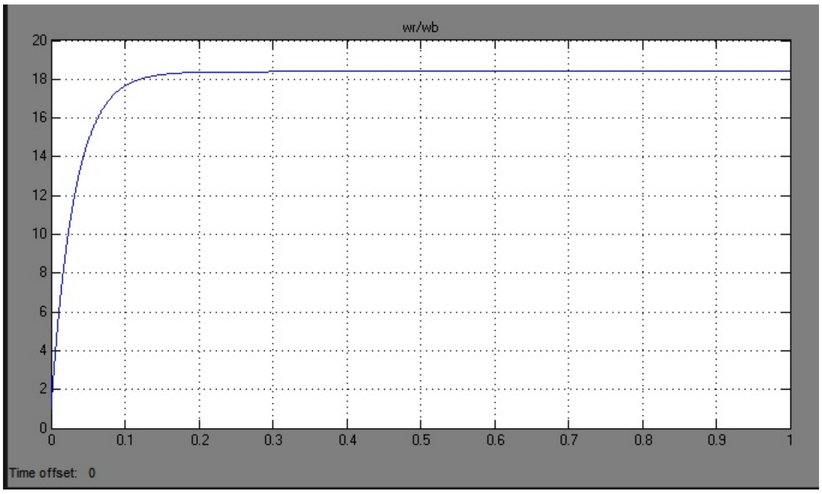

Figure 3.6: Waveform of rotational Speed

3.3 Modeling of Powerformer

As shown in figure 3.7, a Powerformer with a high reactance grounded is connected to an infinite bus bar through a short transmission line.

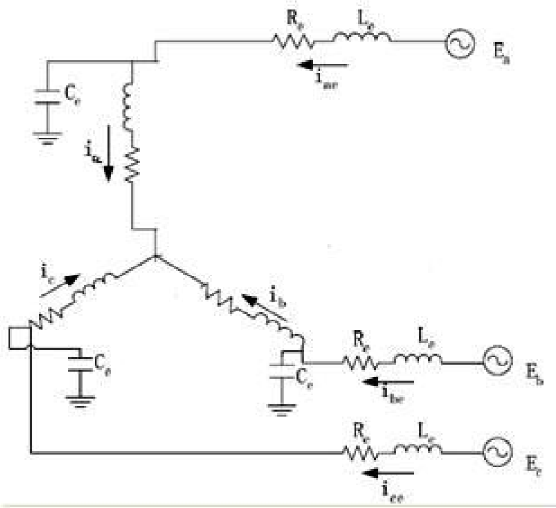

Figure 3.7: Equivalent circuit of powerformer by lumping capacitance at the terminal[3].

The terminal voltage of the Powerformer can be expressed as,

$$V_p + R_e I_{ae} + L_e \frac{d}{dt} i_{ae} - E_{bus} sin_{wt} = 0 \tag{3.21}$$

$$V_m = 0 \tag{3.22}$$

$$V_n = V_p \tag{3.23}$$

$$V_b + R_e I_{be} + L_e \frac{d}{dt} i_{be} - E_{bus} sin(wt - 2\prod/3) = 0 \tag{3.24}$$

$$V_c + R_e I_{ce} + L_e \frac{d}{dt} i_{ce} - E_{bus} sin(wt + 2\prod/3) = 0 \tag{3.25}$$

E_{bus} is the peak value of the phase voltage of the infinite bus, and i_{ae}, i_{be}, i_{ce} are three phase currents of the transmission line. The terminal node equation of the Powerformer can be expressed as follows. The parameter of Powerformer are given in appendix.

$$C_e \frac{d}{dt} V_p = i_{ae} - i_a \tag{3.26}$$

$$C_e \frac{d}{dt} V_b = i_{be} - i_b \tag{3.27}$$

$$C_e \frac{d}{dt} V_c = i_{ce} - i_c \tag{3.28}$$

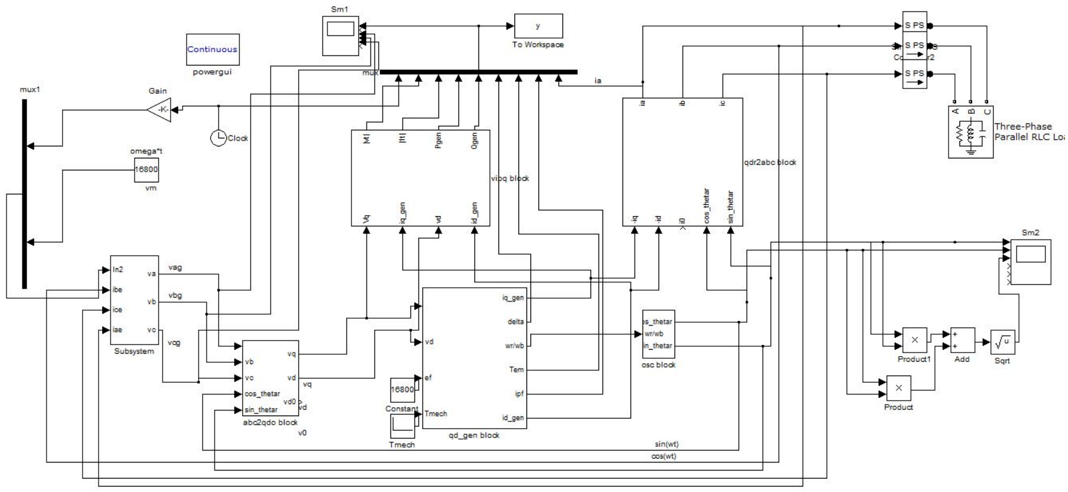

Figure 3.8: Simulation of Powerformer

The simulation of Powerformer is as shown in figure 3.8. The Powerformer subsystem shows in figure 3.9. In these subsystem equation of terminal voltage in the Powerformer and node equation of Powerformer.

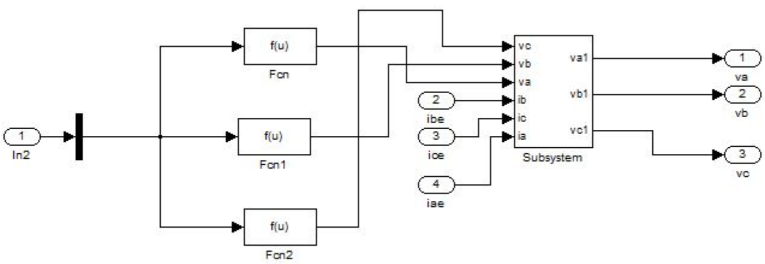

Figure 3.9: Simulation of Powerformer

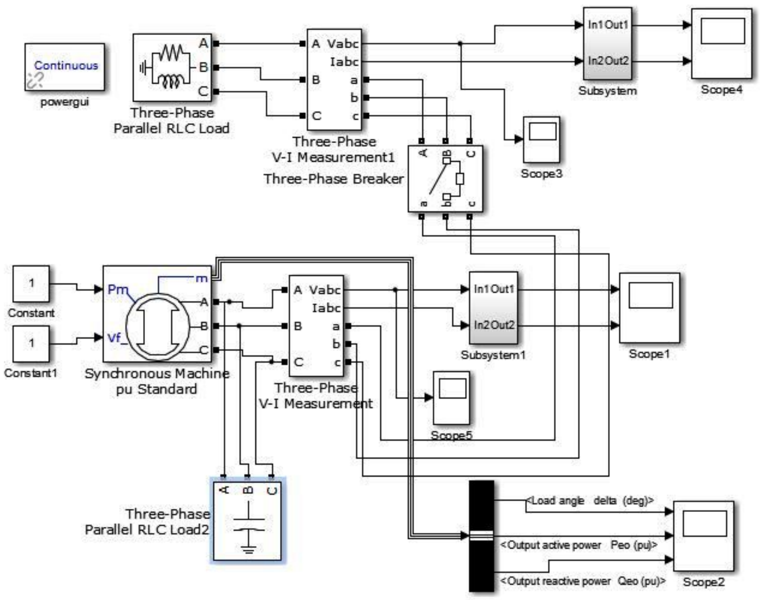

Figure 3.10: Simulation of Powerformer with lumped capacitance generator terminal

3.4 Simulation and Results of Powerformer

The simulation of three phase voltage, source voltage and rotational speed is show in figure 3.11, 3.12, 3.13, 3.14 and 3.15

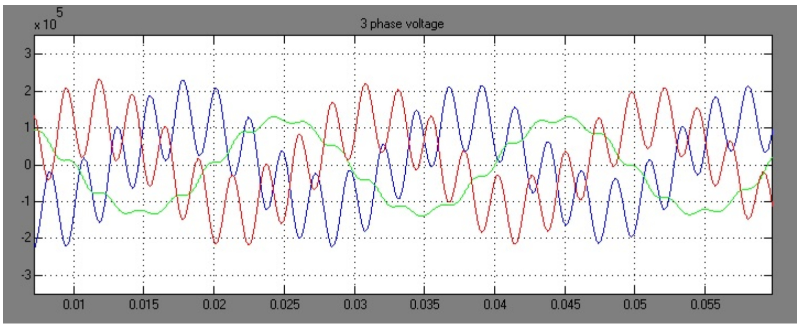

Figure 3.11: Waveform of 3 Phase Voltage

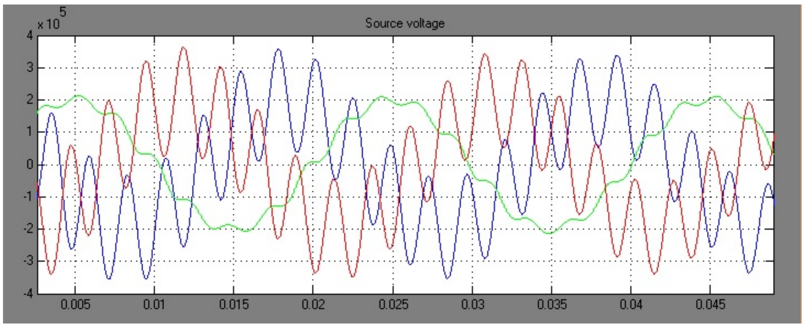

Figure 3.12: Waveform of source Voltage

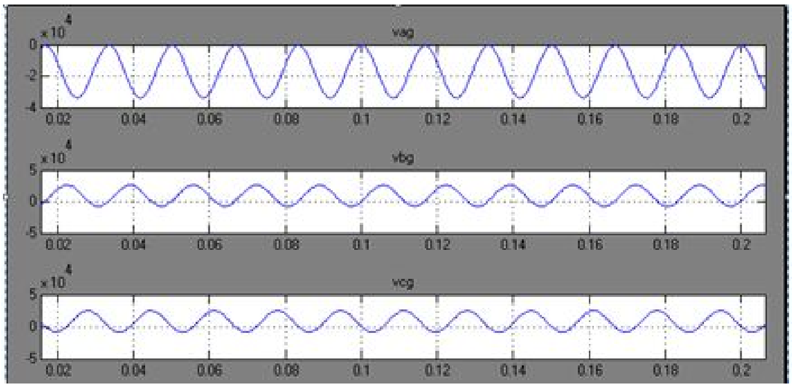

Figure 3.13: Waveform of 3 Phase Voltage

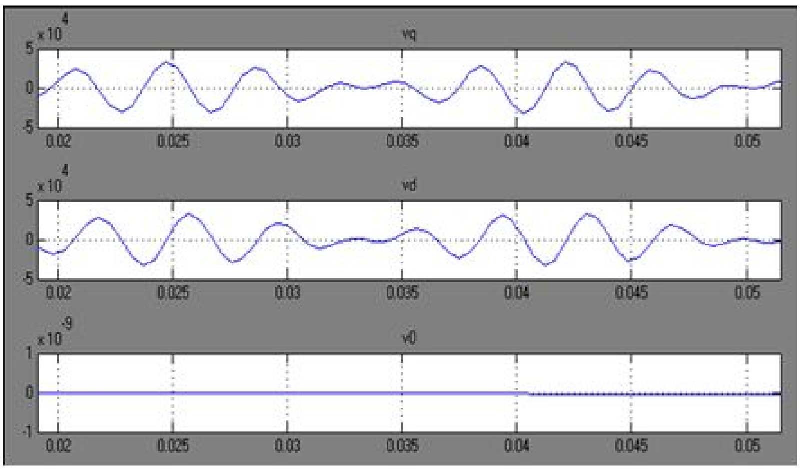

Figure 3.14: Waveform of source voltage

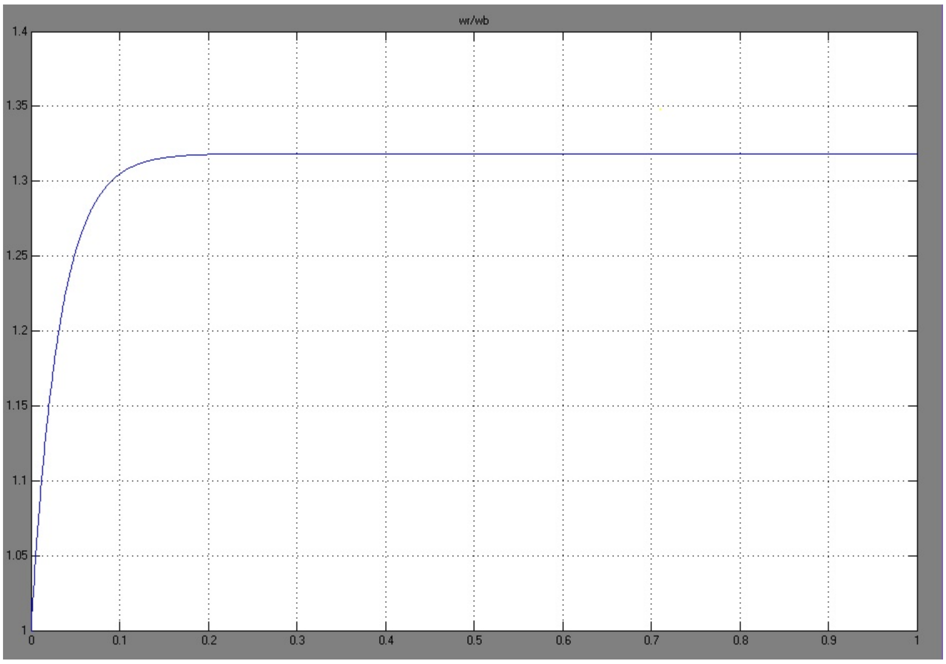

Figure 3.15: Waveform of rotational speed

3.5 Summary

The chapter is included to the modeling of synchronous generator different dynamics equation of generator and modeling of powerformer to the node equation are discussed and shown their result.

Chapter 4

Power System Stability Studies

Stability of a power system is its ability to return to normal or stable operating conditions after having been subjected to some form of disturbance. Conversely, instability means a condition denoting loss of synchronism or falling out of step. Furthermore, stability is the tendency of a power system to develop restoring forces equal to or greater than the disturbing force in order to maintain the state of equilibrium. The system is said to remain stable (to stay in synchronism), if the forces tending to hold machines in synchronism with one another are sufficient to overcome the disturbing forces. Stability is conducted at planning level when new generating and transmitting facilities are developed. The studies are needed in determining the relaying system needed, critical fault clearing time of circuit breaker, critical clearing angle, auto reclosing time, voltage level and transfer capability between system. When the power system loss stability, the machines will lose synchronization and it will no longer working at synchronous speed. This will lead to power, voltage and current to oscillate drastically. It can cause damage to the loads which receive electric supply from the instable system. The stability of a system refers to the ability of a system to return back to its steady state when subjected to a disturbance. Power is generated by synchronous generators that operate in synchronism with the rest of the system. A generator is synchronized with a bus when both of them have same frequency, voltage and phase sequence. Power system stability can be defined as the ability of the power system to return to steady state without losing synchronism. Usually power system stability is categorized by,

a. Steady state stability

b. Transient stability

c. Dynamic stability

4.1 Steady State Stability

Steady state stability is the ability of the system to develop restoring forces equal to or greater than the disturbing force and remain in equilibrium or synchronism after small and slow disturbances. Increase in load is a kind of disturbance. If increase in loading takes place gradually and in small steps and the system withstands this change and performs satisfactorily, then the system is said to be in steady state stability. Thus the study of steady state stability is basically concerned with the determination of upper limit of machines loading before losing synchronism, provided the loading is increased gradually at a slow rate. In practice, load change may not be gradual.

4.2 Transient Stability

Transient stability is the ability of the power system to maintain synchronism when subjected to a severe transient disturbance such as the occurrence of a fault, the sudden outage of a line or the sudden application or removal of loads. The resulting system response involves large excursions of generator rotor angles and is influenced by the nonlinear power angle relationship. Following such sudden disturbances in the power system, rotor angular differences, rotor speeds, and power transfer undergo fast changes whose magnitudes are dependent upon the severity of disturbances. For a large disturbance, changes in angular differences may be so large as to cause the machine to fall out of step. This type of instability is known as transient instability. Transient stability is a fast phenomenon, usually occurring within one second for a generator close to the cause of disturbance. The objective of the transient stability study is to ascertain whether the load angle returns to a steady value following the clearance of the disturbance. The transient instability phenomenon is a very fast one and occurs within one second or a fraction of it for generator close to location of disturbance.

4.3 Dynamic Stability

Small signal stability is the ability of the power system to maintain stability under continuous small disturbances also known as dynamic stability. These small disturbances occur due to random fluctuations in loads and generation levels. Furthermore this stability is the ability to regain synchronism with inclusion of automatic control devices such as automatic voltage regulator (AVR) and frequency controls. This is the extension of the steady state stability which takes a longer time to clear the disturbances.

4.4 Voltage Stability

Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition. The voltage deviations need to maintain within predetermined ranges. A voltage stability problem occurs in heavily stressed systems, which are associated with long transmission lines. Voltage stability depends on the active and reactive power balance between load and generation in the entire power system and the ability to maintain/restore this balance during normal and abnormal operation. The main contributor in voltage instability is the increase of reactive power requirements beyond the sustainable capacity of the available reactive power resources when some of the generators hit their field or armature current time-overload capability limits. A typical scenario of voltage instability is unbalance reactive power in the system resulting in extended reactive power transmission over long distances.

4.4.1 Infinite bus

Single machine connected to a large system through transmission lines. A general system configuration is shown in Figure 4.1. Because of the larger size of the system to which the machine is supplying power, there is no change in the voltage and frequency. Such a voltage source of constant voltage and constant frequency is called infinite bus. For given system condition, the magnitude of infinite bus voltage remain constant and machine is perturbed. As the steady state system conditions change, the magnitude of voltage may change, changed operating condition of the external network.

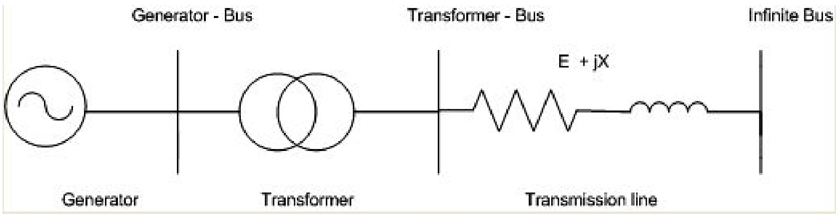

Figure 4.1: Single machine connected to infinite bus

4.4.2 Powerformer connected to infinite bus

Powerformer connected to infinite bus is show in Figure 4.1. Active power, reactive power and load angle show in Figure 4.2, 4.3, 4.4, 4.5, 4.6, 4.7.

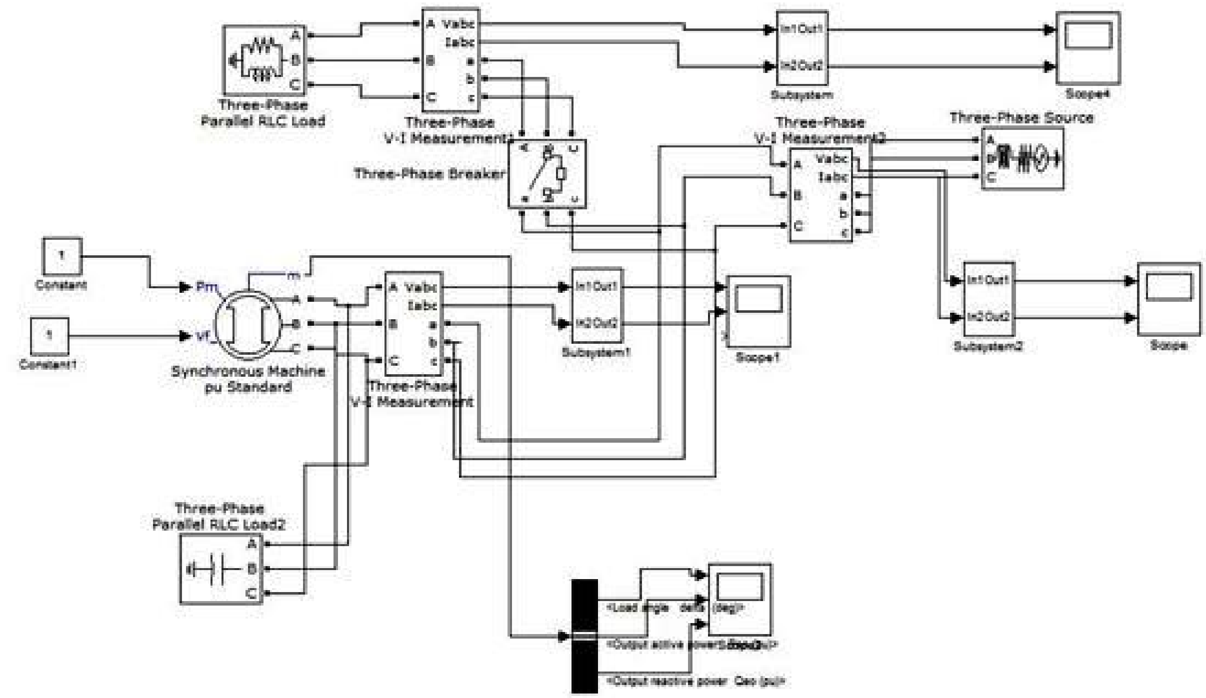

Figure 4.2: Powerformer connected to infinite bus

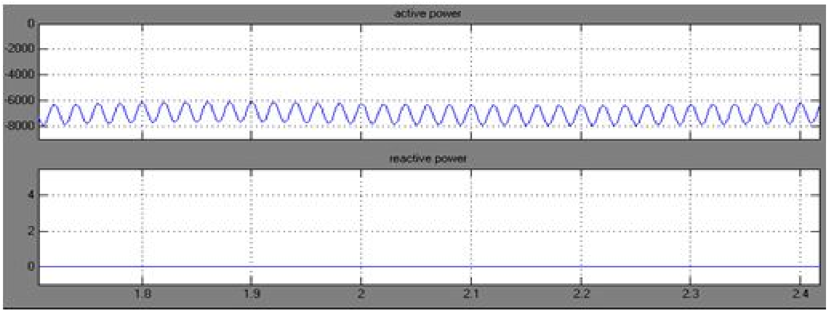

Figure 4.3: Waveform of active and reactive power parallel load

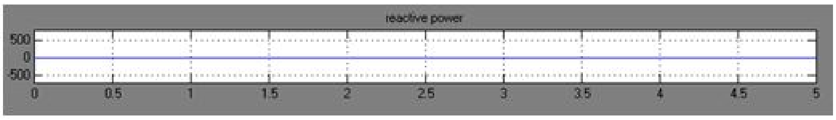

Figure 4.4: Waveform of active and reactive power parallel load

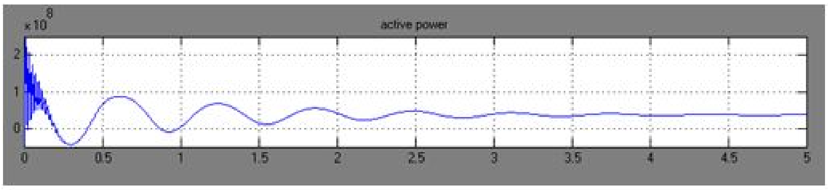

Figure 4.5: Waveform of active and reactive power connected to infinite bus

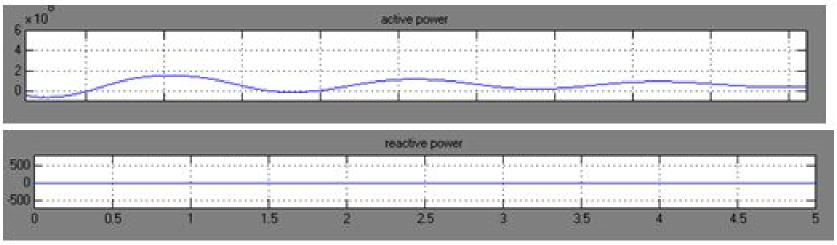

Figure 4.6: Waveform of active and reactive power connected to infinite bus

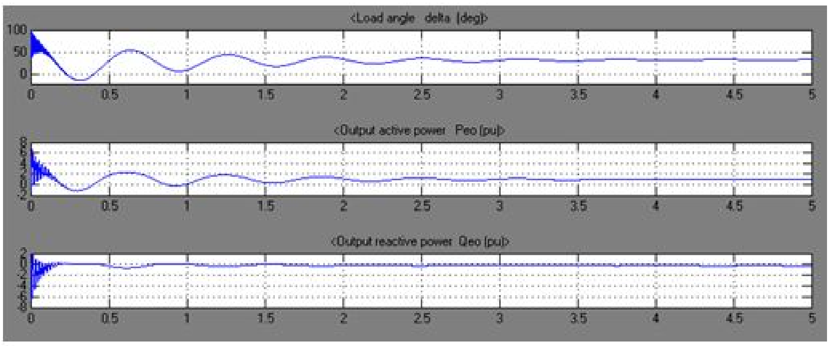

Figure 4.7: Waveform of load angle, active power, reactive power

4.5 Wscc 3 Machine 9 Bus System

For the stability analysis of the system, a standard model is desired to be chosen so that comparison of the result can be made. So, we have chosen the wsccc 3 machine 9 bus system. This system is to be analyzed under steady state conditions. A Base MVA is taken as 100 MVA and the system frequency is 50 Hz. In this system consists of three generator among which generator 1 is a swing bus, generator 2 and 3 are PV buses. The governor and excitation are used to in the system to take care of overall dynamics of the system. load 1, 2 and 3 are inductive load connected to the system. The parameter of wsccc 3 machine 9 bus system is given in appendix.

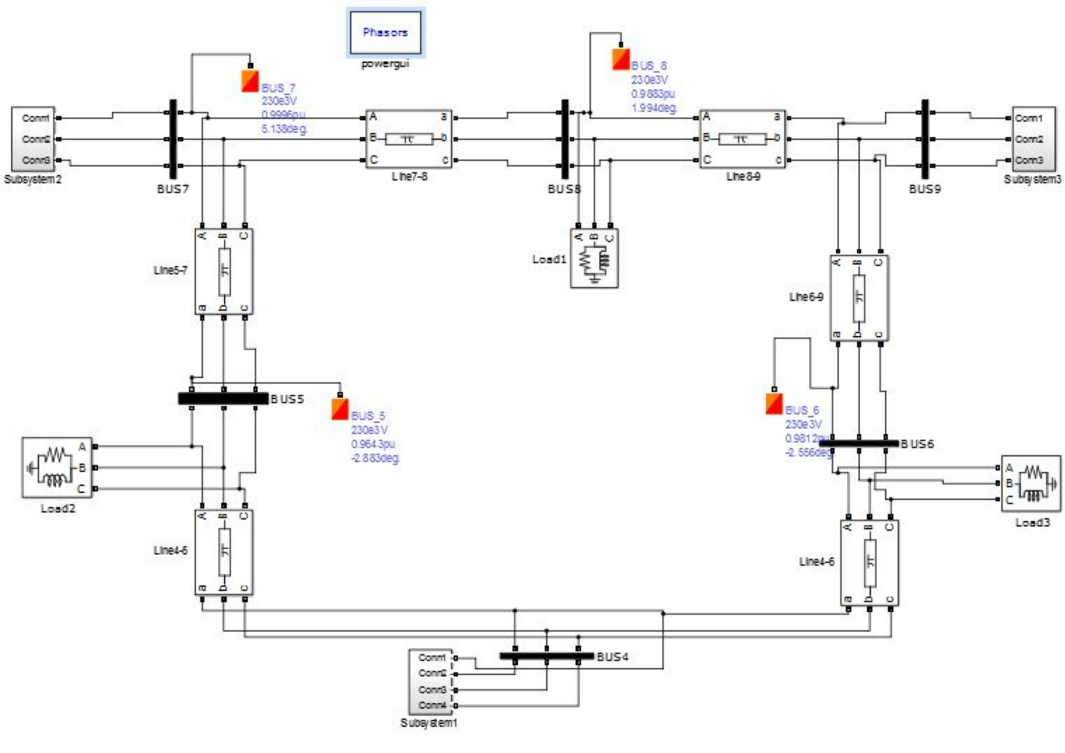

Figure 4.8: Wsccc 3 machine 9 bus system

The subsystem is shown in Figure 4.9 includes exciter and governor system in generator 1, 2, and 3. All three generator are steam generator. The type of governor used for this machine will be steam type. This machine is round rotor machine.

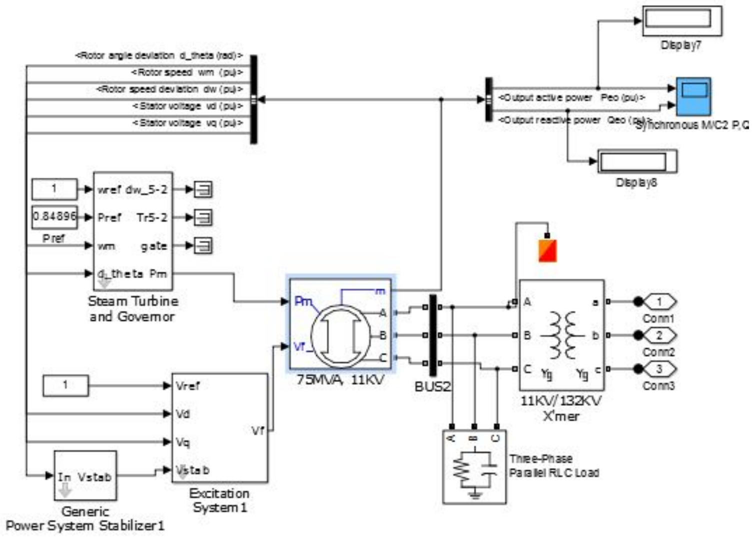

Figure 4.9: Excitation and governor system

4.6 Stability Analysis During Fault for Wsccc 3 Machine 9 Bus System Connected With Powerformer

Wsccc 3 machine 9 bus connected with powerformer during fault is shown in figure 4.10. In this model single phase to ground fault carried out. Fault is carried out to one of the transmission line voltage and load angle are measured.

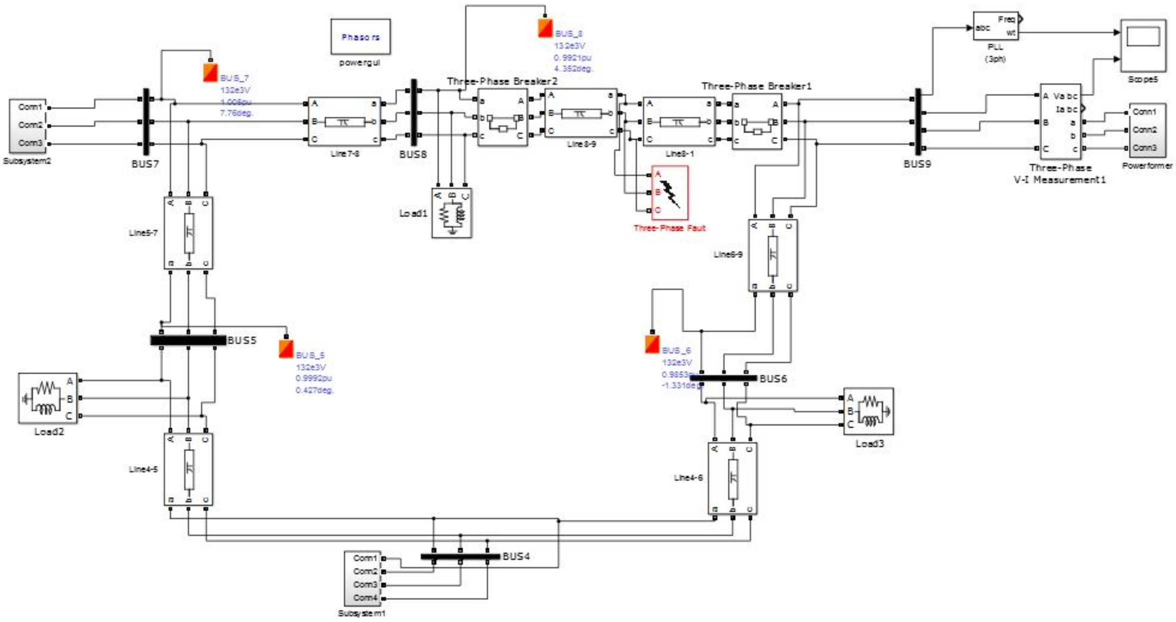

Figure 4.10: Excitation and governor system

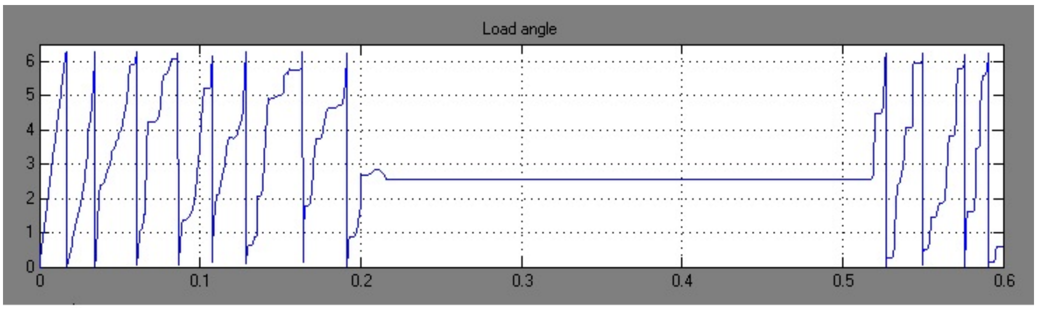

Figure 4.11: Waveform of load angle with fault analysis

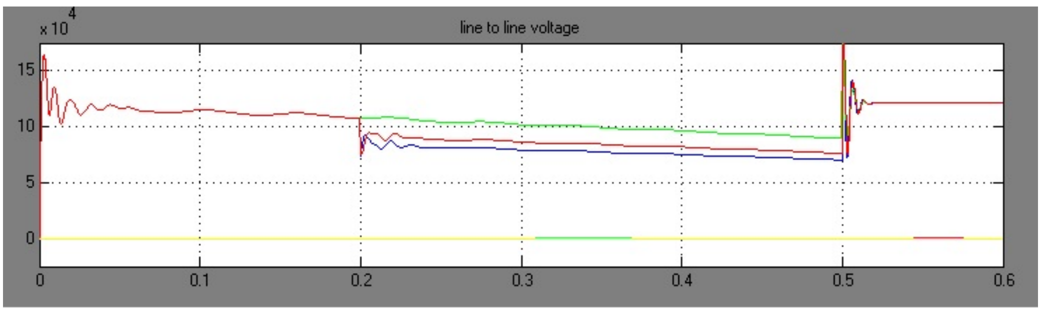

Figure 4.12: Waveform of line to line voltage with fault analysis

4.7 Stability Analysis During Fault for Wsccc 3 Machine 9 Bus System Connected Without Powerformer

Wsccc 3 machine 9 bus connected without powerformer during fault is shown in figure 4.13. In this model single phase to ground fault carried out. Fault is carried out to one of the transmission line and voltage and load angle are measured.

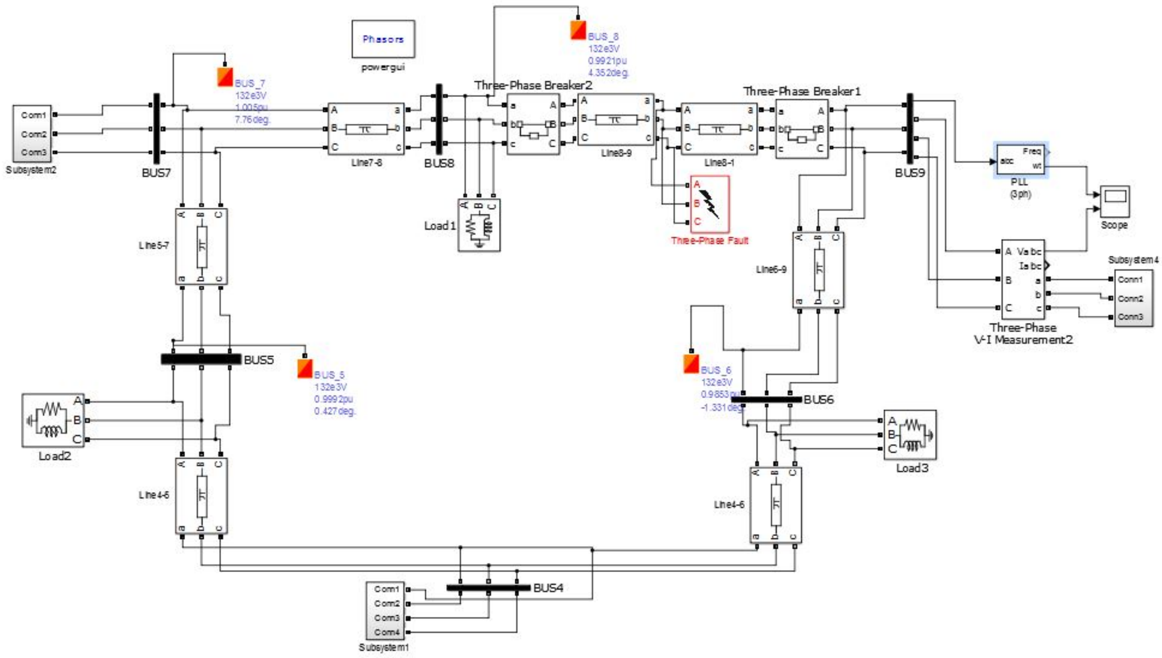

Figure 4.13: Excitation and governor system

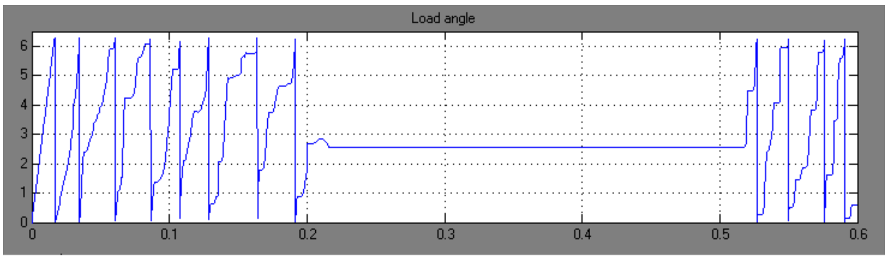

Figure 4.14: Waveform of load angle with fault analysis

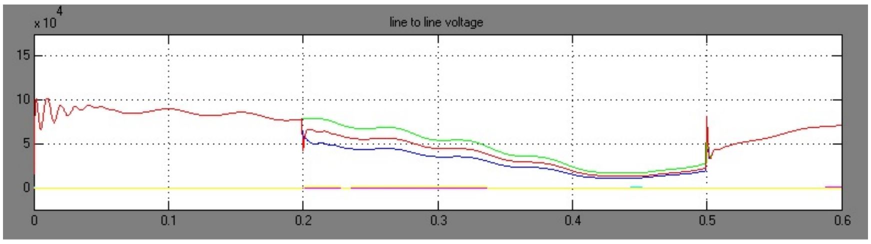

Figure 4.15: Waveform of line to line voltage with fault analysis

For doing the during fault analysis on Powerformer and synchronous machine, voltage and load angle are measured. So, we can find the voltage stability of the system. And, then results obtained with Powerformer and synchronous generator are compared.

4.8 Summary

This chapter provides to gives a brief introduction about power system stability. Voltage stability and load angle stability analysis was carried out and compared for following stability analysis was performed for fault condition and during sudden change of load. Powerformer connected with infinite bus. Wsccc 3 machine 9 bus system with Powerformer and conventional generator transformer.

Chapter 5

Conclusion and Future Scope

5.1 Conclusion

Modeling of synchronous generator and modeling of Powerformer has been studied. First synchronous generator model has been implemented and verified then it was modified for Powerformer modeling. Powerformer is also simulated by lumping the effect of stray capacitance at the terminal of synchronous generator. Then voltage stability and load angle stability analysis was carried out and compared for following stability analysis was performed for fault condition and during sudden change of load.
1. Powerformer connected with infinite bus.
2. Wsccc 3 machine 9 bus system with Powerformer.
3. Wsccc 3 machine 9 bus system with conventional generator transformer.

Following observation are found. In Powerformer, voltage and load angle are more stable then conventional generator.

5.2 Future Scope

Stability analysis can be carried out on all the buses of wsccc 3 machine 9 bus system for different condition of fault and for different variation in load conditions. Analysis can also be carried out on IEEE 14 bus system.

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Appendix

Parameter of Synchronous generator,

$$P_n = 75MVA \tag{5.1}$$

$$V_n = 132KV \tag{5.2}$$

$$F_n = 50Hz \tag{5.3}$$

$$X_d = 0.8425 \tag{5.4}$$

$$X_d' = 0.379 \tag{5.5}$$

$$X_d'' = 0.2707 \tag{5.6}$$

$$X_q = 0.5649 \tag{5.7}$$

$$X_q' = 0.3329 \tag{5.8}$$

$$X_q'' = 0.2505 \tag{5.9}$$

$$Xl = 0.084 \tag{5.10}$$

$$Tdo' = 5.615 \tag{5.11}$$

$$Tdo'' = 0.02200 \tag{5.12}$$

$$Tqo' = 0.10485 \tag{5.13}$$

$$R_s = 0.004 \tag{5.14}$$

Parameter of Powerformer,

$$\omega_b = 314 \tag{5.15}$$

$$rs = 0.04 \tag{5.16}$$

$$xls = 0.084 \tag{5.17}$$

$$xmQ = 0.021 \tag{5.18}$$

$$rpkq = 0.014 \tag{5.19}$$

$$xplkq = 0.0316 \tag{5.20}$$

$$rpf = 0.0065 \tag{5.21}$$

$$rpkd = 0.0062 \tag{5.22}$$

$$xmd = 1.54 \tag{5.23}$$

$$xplf = 0.092 \tag{5.24}$$

$$xplkd = 0.0478 \tag{5.25}$$

$$xmD = 0.022 \tag{5.26}$$

Wsccc 3 machine 9 bus system parameter,

Table 5.1: Load Data

Load connected to bus	P(MW)	Q(MW)
5	125	50
6	90	30
8	100	35

Table 5.2: Transmission line data per Km

Line between buses	R(ohm)	L(H)	C(F)
7-8	0.085	0.1909	1.976
8-9	0.0119	0.2673	2.7719
5-7	0.032	0.427	4.058
6-9	0.039	0.4509	4.748
4-5	0.010	0.2254	2.334
4-6	0.017	0.244	2.0955

Table 5.3: Exciter data

Parameters	Exciter 1	Exciter 2	Exciter 3
K_A	20	20	20
T_A sec	0.2	0.2	0.2
K_E	1	1	1
T_E sec	0.314	0.314	0.314
K_F	0.063	0.063	0.063
T_F sec	0.35	0.35	0.35