CHAPTER ONE

INTRODUCTION

1.1 General concept

Induction generators were used from the beginning of the 20th century until they were abandoned and almost disappeared in the 1960s. With the dramatic increase in petroleum prices in the 1970s, the induction generator returned to the scene. With such high-energy costs, rational use and conservation implemented by many process of heat recovery and other similar forms became important goals. By the end of 1980s, wider distribution of population over the planet, as improved transportation and communication enabled people to move away from large urban concentration, and growing concern with the environment led to demand by many isolated communities for their own power plants. In 1990s, ideas such as distributed generation began to be discussed in the media and in the research centers.

Much emphasis has been placed on the induction machine as the electromechanical energy converter in such generation schemes. Low and medium power self excited induction generators are ideally suited for non-conventional energy systems such as wind electric generators, micro- hydro power stations, etc. in rural areas, where large wind resources are available, stand-alone wind turbine driven induction generators can meet the local requirements such as heating, lighting, pumping, etc.

The increasing concern to the environment and fast depleting conventional resources have motivated the researches towards rationalizing the use of conventional energy resources and exploring the non-conventional energy resources to meet the ever-increasing energy demand. A number of renewable energy sources like small hydro, wind, solar, industrial waste, geothermal, etc. are explored. Since small hydro and wind energy sources are available in plenty, their utilization is felt quite promising to accomplish the future energy requirements. Harnessing mini-hydro and wind energy for electric power generation is an area of research interest and at present, the emphasis is being given to the cost-effective utilization of these energy resources for equality and reliable power supply. Induction generation is often used in wind turbines and some micro hydro installations due to their ability to produce useful power at varying speeds [1].

Usually, synchronous generators are being used for power generation but induction generators are increasingly being used these days because of their relative advantageous features over conventional synchronous generators. Induction generators require an external supply to produce a rotating magnetic flux. The external reactive supply can be supplied from the electrical grid or from the externally connected capacitor bank, once it starts producing power. Induction generators are mechanically and electrically simpler than other generator types. Induction generators are rugged in construction, requiring no brushes or commentators, low cost and low maintenance, operational simplicity, self-protection against faults, good dynamic response, and capability to generate power at varying speed. These features facilitates the induction generator operation in stand-alone/isolated mode to supply far flung and remote areas where extension of grid is not economically viable, in conjunction with the synchronous generator to fulfill the increased local power requirement, and in grid-connected mode to supplement the real power demand to the grid by integrating power from resources located at different sites.

A detailed study of the performance of the induction generator during steady-state and transient condition is important for the optimum utilization. The steady-state performance is important for ensuring good quality power and assessing the suitability of the configuration for a particular application, while the transient condition performance helps in determining the insulation strength, suitability of winding, shaft strength, value of capacitor, and devising the protection strategy. [2, 3]

1.2 Statement of Problem

Self-Excited Induction Generator usually connected to a wind turbine (variable speed), in this project self-excited induction generator is connected to hydro turbine to study the performance of the system and to extract the power.

1.3 Objective

The aims of this thesis are:-

1) To present the complete modelling and simulation of hydro turbine which drive self-excited squirrel-cage induction generator .
2) Control of the system during the steady state and transient period.

1.4 Methodology/Approach

1. In this project the mathematical model of hydro turbine based on self-excited induction generator will be derived, three-phase capacitor bank is connected across the stator terminals of induction generator.
2. The modelling and simulation methodology will be proved using Matlab/Simulink software.

1.5 Scope of the thesis

This thesis contains five chapters.

The First Chapter provides a brief introduction of the work, the contribution of the thesis and the outline of the thesis.

The Second Chapter presents a brief literature review of the SEIG system and an overview of established nonlinear computer models for induction machines.

Chapter three gives the dynamic and mathematical models of induction machine, and also model of governor, PID and hydro turbine.

In Chapter four the Matlab/simulink software is used to simulate the behavior of the SEIG system when feeding resistive loads. The dynamic model of the system is completed by incorporating a capacitor bank connected to the stator terminals into the model which is needed to provide reactive power to both the generator and the load. The behavior of the SEIG model is then examined when feeding a purely resistive load connected to the stator terminals. The results from the simulation are analyzed and used to demonstrate the performance of the SEIG system.

Chapter five presents the conclusions and discussions of the thesis and suggestions for future work.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Due to an increase in greenhouse gas emission more attention is being given now to renewable energy and moreover rapid depletion of conventional fossil fuels and environmental concern have result in extensive use for electrical power generation.

The inability of the power utilities to supply isolated users has resulted in the development of stand-alone power generation system. Distributed and stand-alone power generation are receiving greater attention due to the cost and complexity of grid systems with related to transmission losses [4]. With increase d emphasis on renewable energy technologies hydro, wind and biomass is being explored out of which small hydro and wind remains the most competitive. Since the location of these systems is in remote areas these systems must be reliable, robust, economical and manageable by the local people [5]. For the above requirements the induction generations is the most suitable. It has several advantages over the synchronous machines. The development in power electronics and control devices has also removed the drawback of induction generators regarding voltage and frequency control [6]. Two main problems arise in stand-alone systems based on micro-hydro and wind concerning frequency regulation. First the mechanical power delivered by the turbines can vary, especially in wind farms. Second, the loads supplied are variable by nature, so an active power balance should be achieved rapidly. From the efficiency point of view turbine governor seems an appropriate solution because by maintaining the produced power in range with the demanded one eliminates the produced power in range with the demanded one eliminates the need for an additional circuit in the system. But, such a configuration is expensive and inefficient for low-power applications (few tens of KW) [5]. As the mechanical constants are high, the regulating process is slow and the overall cost is significant. Also, the system's response under suddenly load switching is poor, resulting in voltage sags and frequency deviations. Using a load controller is better option, which feeds a dump load, enabling the total power supplied by the generator to match the sum between the consumer's loads and dump load. As the active power balance is achieved, the frequency is satisfactory regulated [8].

In the literature, starting in the early nineteenth century, it is well known that a three-phase induction machine can be made to work as a self- excited induction generator (SEIG) [9, 10]. In an isolated application a three-phase induction generator operates in the self-excited mode by connecting three AC capacitors to the stator terminals [9, 11], or using a converter and a single DC link capacitor [12]. The normal connection of a SEIG is that the three exciting capacitor are connected across the stator terminals and there is no electrical connection between rotor and stator and rotor windings. However, in the literature a SEIG with electrical connection between rotor and stator windings is also reported [13].

2.2. Hydro Power Generation

Hydropower is a renewable energy source where power is derived from the energy of water moving from higher to lower elevations. It is a proven, mature, predictable and cost-competitive technology. The mechanical power of falling water is an old tool used for various services from the time of the Greeks more than 2000 years ago. The world's first hydraulic station of 12.5kw was commissioned on 30 September 1882 on Fox River at the Vulcan street plant in

Appleton, Wisconsin, USA. Though the primary role of hydropower in global energy supply today is in providing centralized electricity generation, hydropower plants also operate in isolation and supply independent systems, often in rural and remote areas of the world. [7].

2.2.1. Potential Resource

The annual global technical potential for hydropower generation is 14,576 TWH, with a corresponding estimated total capacity potential of 3,721 GW-hour). Undeveloped capacity ranges from about 47% in Europe to 92% in Africa, indicating large and well-distributed opportunities for hydropower development worldwide. Asia and latin America have the largest technical potentials and the largest undeveloped resources. Africa has highest portion of total potential that is still undeveloped.

It is noteworthy that the total installed capacities of hydropower in north America, Latin America, Europe and Asia are of the same order of magnitude and, in Africa and Australasia/Oceania, an order of magnitude less, Africa due to underdevelopment and Australasia/Oceania because of size, climate and topography. The global average capacity factor for hydropower plants is 44%. Capacity factor can be indicative of how hydropower is employed in the energy mix (e.g peaking versus base-load generation) or water availability, or can be an opportunity for increased generation through equipment upgrades and operational optimization.

2.2.2. Technology and applications

Hydropower projects are usually designed to suit particular needs and specific site conditions, and are classified by project type, head (I,e. the vertical height of water above the turbine) or purpose (single- or multi-purpose). Size categories (installed capacity) are based on national definitions and differ worldwide due to varying policies. There is no immediate, direct link between installed capacity as a classification criterion and general properties common to all hydropower plants (HPPs) above or below that MW limit. All in all, classification according to size, while both common and administratively simple, is to a degree arbitrary: general concepts like small or large hydropower are not technically or scientifically rigorous indicators of impacts, economics or characteristics. It may be more useful to evaluate a hydropower project on its sustainability or economic performance thus setting out more realistic indicators. The cumulative relative environmental and social impacts of large versus small hydropower development remain unclear and context dependent.

Hydropower plants come in three main project types : Run-of-river (RoR), storage and pumped storage. RoR HPPs have small intake basins with no storage capacity. Power production therefore follows the hydrological cycle of the watershed. For RoR HPPs the generation varies as water availability changes and thus they may be operated as variable in small streams or as based-load power plants in large rivers. Large-scale PoP HPPs may have some limited ability to regulate water, flow and if they operate in cascades in unison with storage hydropower in upstream reaches, they may contribute to the overall regulating and balancing ability of a fleet of HPPs. A fourth category, in stream (hydrokinetic) technology, is less mature and functions like PoP without any regulation.

Hydropower projects with a reservoir (storage hydropower) deliver a broad range of energy services such as base load, peak, and energy storage, and act as a regulator for other sources. In addition they often deliver services that go beyond the energy sector, including flood control, water supply, navigation, tourism and irrigation. Pumped storage plants store water as a source for electricity generation. By reversing the flow of water, electrical energy can be produced on demand, with a very fast response time. Pumped storage is the largest-capacity form of grid energy storage now available.

2.3 Induction Generator

An induction generator is a type of electrical generator that is mechanically and electrically similar to and induction motor. Induction generators produce electrical power when their shaft is rotated faster than the synchronous speed of the equivalent induction motor. Induction generators are often used in wind turbines and some micro hydro installations due to their ability to produce useful power at varying speeds. Induction generators are mechanically and electrically simpler than other generator types.

To excite the generator, external reactive supply can be supplied from the electrical grid or from the externally connected capacitor bank, once it starts producing power. The rotating magnetic flux from the stator induces currents in the rotor, which also produces a magnetic field. If the rotor rotates slower than the rate of the rotating flux, the machine acts like an induction motor. If the rotor rotates faster, it acts like a generator, producing power at the synchronous frequency [14].

In stand-alone induction generators, the magnetizing flux is established by a capacitor bank connected to the machine and in case of grid connected, it draws magnetizing current from the grid. It is mostly suitable for wind generating stations as in this case speed is always a variable factor.

2.3.1 Advantages and disadvantages of induction generator

Several types of generators are available. The right choice of generator depends on a wide range of factors related to the primary source, the type of load, and the speed of the turbine, among others.

i. ***Advantages*** :

- Simple and robust construction.
- Run independently.
- Inexpensive as compared to the conventional synchronous generator.
- Minimal maintenance.
- Inherent overload protection.
- Stand-alone applications, no fixed frequency.
- Less material cost because of the use of electromagnets rather than permanent magnets.

ii. ***Disadvantages :***

- Requires significant reactive energy.
- Poor power factor.
- Poor voltage and frequency regulation.

Therefore, the wider acceptance of the SEIG is dependent on the methodology to be adopted to overcome the poor voltage and frequency regulation, its capability to handle dynamic loading, and its performance under unbalanced conditions [7].

The induction generator can also be operated in parallel with synchronous generator to supplement the increased local power demand. The configuration may exploit the advantages of both the machines, i.e. improved power factor from the synchronous generator and low power generation cost from the induction generator.

The dynamic performance of the configuration with load controller should be thoroughly investigated to assess the feasibility of dispensing costly governors.

2.3.2. Classification of Induction Generators

The induction generators can be classified into three:

1. Classification on the basis of their rotor construction:

The induction generator basis of rotor construction is classified as:

i. Squirrel cage induction generator

For the squirrel cage type induction generator, the rotor winding consists of un-insulated conductions, in the form of copper and aluminum bars embedded in the semi closed slots. These solid bars are short circuited at both ends by end rings of the same material. Without the rotor core, the rotor bars and end rings look like the cage of a squirrel. The rotor bars from a uniformly distributed winding in the rotor slots.

ii. Wound rotor induction generator

In the wound rotor type induction generator, the rotor slots accommodate and insulated distributed winding similar to that used on the stator. The wound rotor type of induction generator costs more and requires increased maintenance [1].

2. Classification on the basis of their excitement process :

The induction generator basis of excitement process is classified as:

i. Grid connected induction generator

The grid-connected induction generator (GCIG) takes the reactive power from the grid, and generates real power via slip control when driven above the synchronous speed, so it is called grid connected induction generator. It is also called autonomous system. Figure 2.1 shows a grid connected induction generator. The operation is relatively simple as voltage and frequency are governed by the grid voltage and grid frequency respectively [1].

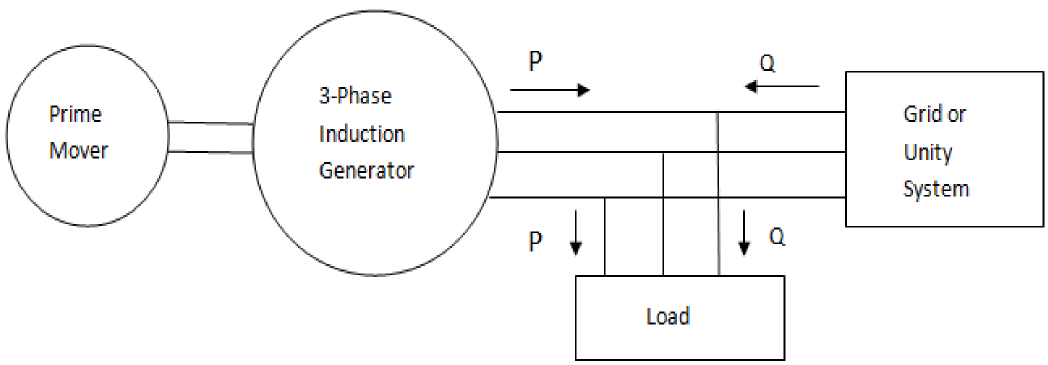


Figure 2.1: Grid connected induction generator

ii. Self-Excited Induction Generator (SEIG)

The self excited induction generator takes the power for excitation process from a capacitor bank, connected across the stator terminals of the induction generator. This capacitor bank also supplies the reactive power to the load.

Figure 2.2 shows a self-excited induction generator.

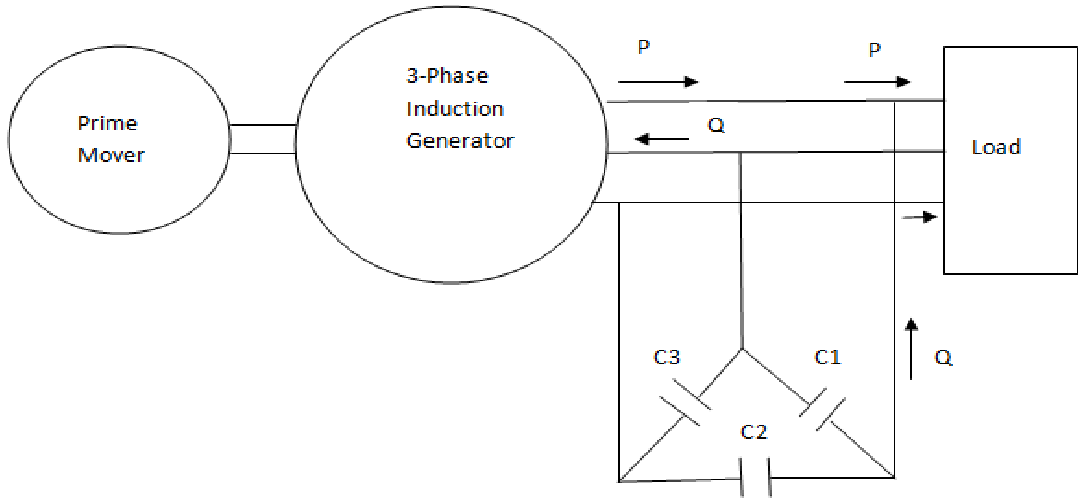


Figure 2.2: Self-excited induction generator

The excitation capacitance serves a dual purpose for stand-alone induction generator: first ringing with the machine induction in a negatively damped, resonant circuit to build up the terminal voltage from zero only the permanent magnetism of the machine, and the correcting the power factor of the machine by supplying the generator reactive power [1-3, 7, 13].

The main drawback of using the per-phase steady state equivalent circuit model is that it cannot be used to solve transient dynamics because the model was derived from the steady state conditions of the induction machine. The per-phase equivalent circuit of SEIG is shown in Figure 2.3:

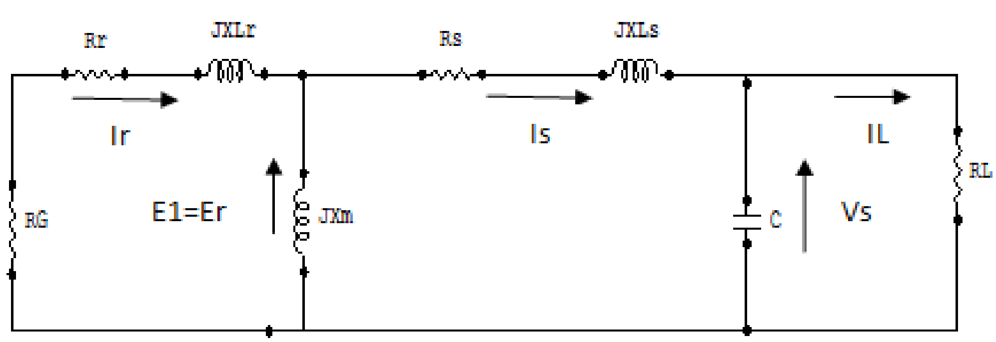


Figure 2.3: Per-phase equivalent circuit of the stand-alone induction generator.

In figure 2.3, R_L is resistive load connected to stator terminals of the SEIG. C represents the per-phase value of the excitation capacitance connected to the stator terminals of SEIG.

$I_s = I_C + I_L$………………………………………………………….. (2.1)

I_C Being the capacitive current leads the stator terminal voltage by 90° and I_L is in phase with V_s.

The no-load current is given by

$I_0 = I_m + I_{CL}$………………………. …………………………………..(2.2)

Where I_m is the magnetization current and I_{CL} is the core loss current.

Again $I_s = I_0 + I_r$……………………………………………………..(2.3)

E_1 Leads Ψ_r by 90° and in phase with I_{CL}.

Stator terminal voltage is given by

$V_s = E_1 + I_s(R_s + jX_{ls})$………………………………………………..(2.4)

On the rotor side, slip being negative

$E_2 = -sE_1 = I_r(R_r - jsX_{lr})$…………………………………………… (2.5)

Figure 2.4 illustrates the phasor diagram of SEIG when it is connected to a resistive load.

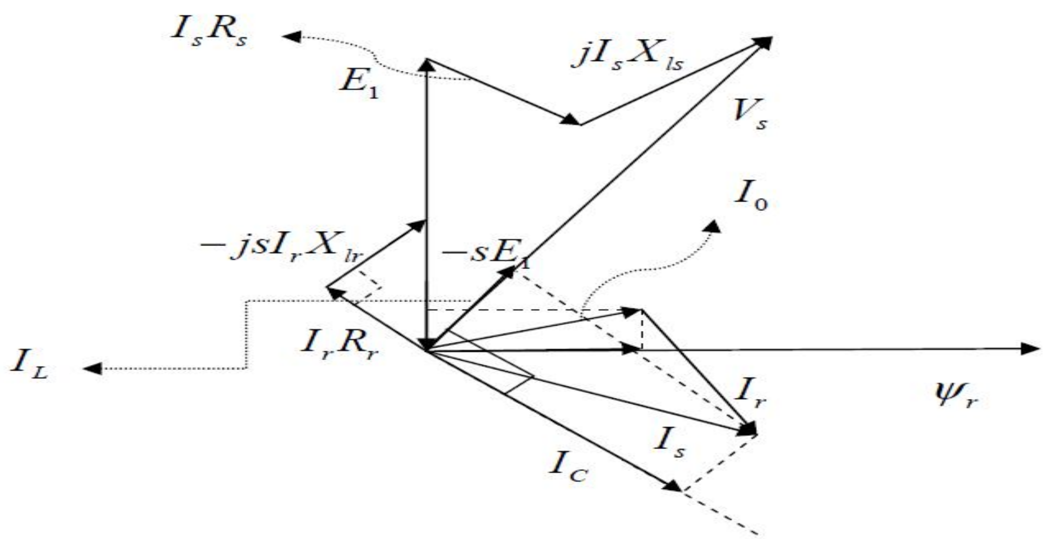


Figure 2.4: Phasor diagram of SEIG with resistive load

3. **Classification on the basis of prime movers used, and their locations**

   The induction generator basis of prime movers and its location is classified as:

   i. Constant-speed constant frequency (CSCF)

In this scheme, the prime mover speed is held constant by continuously adjusting the blade pitch. An induction generator can operate on an infinite bus bar at a slip of 1% to 5% above the synchronous speed. Induction generators are simpler than synchronous generators. They are easier to operate, control, and maintain, do not have any synchronous problems, and economical [15].

   ii. Variable-speed constant frequency(VSCF)

Variable speed constant frequency (VSCF) energy conversion schemes generally use synchronous or wound rotor induction machines to obtain constant frequency power generation, even in presence of prime mover speed fluctuations [6]. Further, on account of its simplicity, ease of implementation, and low cost, the self-excited induction generator finds wide application in power generation using non-conventional energy sources such as wind. The variable-speed operation of wind electric system yields higher output for both low and high wind speeds. This results in higher annual energy yields per rated installed capacity. Both horizontal and vertical axis wind turbines exhibit this gain under variable speed operation. There are two poplar schemes to obtain constant frequency output from variable speed as discussed. [15, 16].

iii. Variable-speed variable frequency (VSVF)

This scheme is the only one known where the generator gives more than its rated power without being overheated. Since the proposed concept is to be used for heating purposes, a constant voltage and a constant frequency is irrelevant. Thus, the model will be of interest for frequency and voltage insensitive applications especially in remote areas. With variable prime mover speed, the performance of synchronous generators can be affected. For variable speed corresponding to the changing derived speed, SEIG can be conveniently used for resistive heating loads [2,3].

2.4 Phenomena of Self Excitation

When the induction machine is driven by a prime mover, the residual magnetism in the iron core of the magnetic circuit of the machine induce EMF in the stator windings at a frequency proportional to the rotor speed. This EMF is applied to the capacitors connected to the stator terminals and causes leading current to flow in the stator winding, and hence a magnetizing flux in the machine is established. Thus the self excitation process is initiated and the machine is then called SEIG and is capable to operate as a generator in isolation. Once the machine is loaded, the magnitude of the steady-state voltage generated is determined by the non-linearity of the magnetizing characteristics, the value of capacitance, speed, machine parameters, and terminal load. As the load and speed of SEIG around any operating point changes, the demand for lag VAR to the machine to maintain constant AC voltage across its terminals also changes.

2.5. Application of Induction Generator

Induction generators, generally, have the application in the wind, solar and micro hydro power plants to generator power for various critical situations as given below. [17]

Electrification of far flung areas:

- Remote family.
- Village community.
- Small agriculture applications.
- Lighting and heating loads.

For feeding critical locations:

- Library
- Computer center.
- Hospitals.
- Telephone exchange.
- Cinema Hall.
- Auditorium.
- Marketing complex.

As a portable source of power supply:

- Decorative lighting.
- Lighting for projects and constructional site.

CHAPTER THREE

MATHEMATICAL MODEL

3.1. Introduction

The equations of the three phase squirrel cage induction generator were developed from principles. The windings of the induction generator may be represented diagrammatically as shown in figure 3.1, and in the first instance it is assumed that both ends of each of the stator and rotor phase windings are accessible. There are then six voltage equations, and each of the six voltages depends upon all of the six currents. The impedance matrix therefore consists of 36 non- zero terms. To simplify the presentation of these equations the phase transformation C1 is used to transform the three phase windings to two phase windings, and the commutator transformation C2 is used to transform the two phase windings to commutator windings.

3.2. Mathematical Equations

Figure 3.1 shows the three phase winding in the stator and rotor of induction generator.

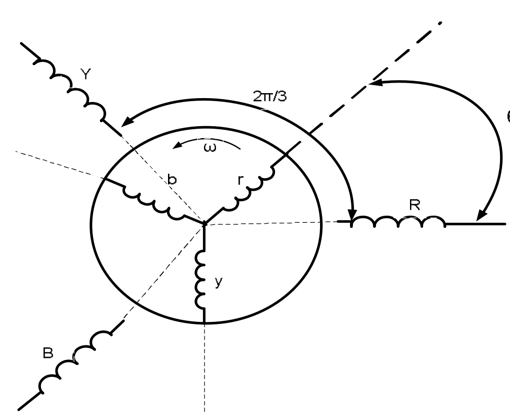


Figure 3.1: The three phase winding of induction generator

From figure 3.1 stator voltage equations are:

$$V_R = R_S I_R + \frac{d\lambda_R}{dt} \quad \text{……} \quad (3.1)$$

$$V_Y = R_S I_Y + \frac{d\lambda_Y}{dt} \quad \text{……} \quad (3.2)$$

$$V_B = R_S I_B + \frac{d\lambda_B}{dt} \quad \text{……} \quad (3.3)$$

And rotor voltage equations are:

$$V_r = R_r I_r + \frac{d\lambda_r}{dt} \quad \text{……} \quad (3.4)$$

$$V_y = R_r I_y + \frac{d\lambda_y}{dt} \quad \text{……} \quad (3.5)$$

$$V_b = R_r I_b + \frac{d\lambda_b}{dt} \quad \text{……} \quad (3.6)$$

Where $\lambda's$ are flux linkages, R_s and R_r are stator and rotor phase resistances, R,Y and B represent stator winding while r,y, and b represent rotor windings.

Flux linkages of the stator and the rotor windings can be written in terms of the winding inductances and the currents [4]. The effects of hysteresis and eddy currents are ignored and teeth and slot effects are neglected. Next, it is assumed that the IM is balanced and the saturation reduces all the component fluxes in a particular region of the machine and related with each winding by the same proportional. Also, the fundamental and thirds harmonic components of the mutual inductances are assumed to be the general characteristic for IM's [15].Equation 3.7 shows the relation between stator and rotor of induction generator.

$$[V]=\begin{bmatrix} v_R \\ v_Y \\ v_B \\ v_r \\ v_y \\ v_b \end{bmatrix} \quad \text{and} \quad [I]=\begin{bmatrix} i_R \\ i_Y \\ i_B \\ i_r \\ i_y \\ i_b \end{bmatrix},$$

$$[Z] = \begin{bmatrix} R_S+\hat{L}_S P & P\widehat{M_S} & P\widehat{M_S} & \hat{M}pCOS\theta+\widehat{M_3}pCOS3\theta & \hat{M}pCOS\theta_2+\widehat{M_3}pCOS3\theta & \hat{M}pCOS\theta_3+\widehat{M_3}pCOS3\theta \\ P\widehat{M_S} & R_S+\hat{L}_S P & P\widehat{M_S} & \hat{M}pCOS\theta_2+\widehat{M_3}pCOS3\theta & \hat{M}pCOS\theta_3+\widehat{M_3}pCOS3\theta & \hat{M}pCOS\theta+\widehat{M_3}pCOS3\theta \\ P\widehat{M_S} & P\widehat{M_S} & R_S+\hat{L}_S P & \hat{M}pCOS\theta_3+\widehat{M_3}pCOS3\theta & \hat{M}pCOS\theta+\widehat{M_3}pCOS3\theta & \hat{M}pCOS\theta_2+\widehat{M_3}pCOS3\theta \\ \hat{M}pCOS\theta+\widehat{M_3}pCOS3\theta & \hat{M}pCOS\theta_2+\widehat{M_3}pCOS3\theta & \hat{M}pCOS\theta_3+\widehat{M_3}pCOS3\theta & R_r+\hat{L}_r P & P\widehat{M_r} & P\widehat{M_r} \\ \hat{M}pCOS\theta_2+\widehat{M_3}pCOS3\theta & \hat{M}pCOS\theta_3+\widehat{M_3}pCOS3\theta & \hat{M}pCOS\theta+\widehat{M_3}pCOS3\theta & P\widehat{M_r} & R_r+\hat{L}_r P & P\widehat{M_r} \\ \hat{M}pCOS\theta_3+\widehat{M_3}pCOS3\theta & \hat{M}pCOS\theta+\widehat{M_3}pCOS3\theta & \hat{M}pCOS\theta_2+\widehat{M_3}pCOS3\theta & P\widehat{M_r} & P\widehat{M_r} & R_r+\hat{L}_r P \end{bmatrix}$$

…………………………………...(3.7)

Where:

$\theta_2 = \theta - 2\pi/3$, $\theta_3 = \theta + 2\pi/3$

R_S = is the stator resistance.

R_r= is the rotor resistance.

$\hat{L}_S =$ is the stator self inductance .

$\hat{L}_r =$ is the rotor self inductance .

$\widehat{M_S}$ = is mutual inductance between stator phases.

$\widehat{M_r}$= is mutual inductance between rotor phases.

$\hat{M}$, $\widehat{M_3}$= are the fundamental and third harmonic components of the inductance between stator and corresponding rotor phases windings at θ =0.

The transformation of the 3-phase induction machine to two phase machine is done by using the phase transformation matrix C_1 , and it is convenient to derive the general form of the transformed impedance matrix at this point the complete transformation in compound form is:

$$C_1 = \sqrt{\frac{2}{3}} \begin{Vmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{Vmatrix}$$

In compact form:

The system impedance matrix is $[Z] = \begin{vmatrix} Z_{SS} & Z_{Sr} \\ Z_{rS} & Z_{rr} \end{vmatrix}$

The transformation matrix is $C = \begin{vmatrix} C_1 & 0 \\ 0 & C_1 \end{vmatrix}$

So:

$$\grave{Z} = C_{1t}\, ZC_1$$

Where:

$\grave{Z}$= is transferred impedance.

C_{1t}= transpose of phase transformation.

The new transformed impedance $[\grave{Z}] = \begin{vmatrix} C_{1t} & 0 \\ 0 & C_{1t} \end{vmatrix} \begin{vmatrix} Z_{SS} & Z_{Sr} \\ Z_{rS} & Z_{rr} \end{vmatrix} \begin{vmatrix} C_1 & 0 \\ 0 & C_1 \end{vmatrix}$

$$= \begin{vmatrix} C_{1t} Z_{SS} C_1 & C_{1t} Z_{Sr} C_1 \\ C_{1t} Z_{rS} C_1 & C_{1t} Z_{rr} C_1 \end{vmatrix}$$

i. Stator /Stator Impedance

From equation (3.7) the impedance of stator to stator may written as follow:

$$Z_{SS}=\begin{bmatrix} R_S+\hat{L}_S P & P\widehat{M_S} & P\widehat{M_S} \\ P\widehat{M_S} & R_S+\hat{L}_S P & P\widehat{M_S} \\ P\widehat{M_S} & P\widehat{M_S} & R_S+\hat{L}_S P \end{bmatrix}$$

Where:

Z_{SS}= is stator to stator impedance.

$$Z'_{SS} = C_{1t} Z_{SS} C_1 =$$

$$\sqrt{\frac{2}{3}}\left\|\begin{matrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{matrix}\right\| \begin{bmatrix} R_S+\hat{L}_S P & P\widehat{M_S} & P\widehat{M_S} \\ P\widehat{M_S} & R_S+\hat{L}_S P & P\widehat{M_S} \\ P\widehat{M_S} & P\widehat{M_S} & R_S+\hat{L}_S P \end{bmatrix} \sqrt{\frac{2}{3}}\left\|\begin{matrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{matrix}\right\| =$$

$$Z'_{SS} = \left\|\begin{matrix} R_S+L_{S0}P & 0 & 0 \\ 0 & R_S+L_S P & 0 \\ 0 & 0 & R_S+L_S P \end{matrix}\right\| \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.8)$$

Where:

$$L_{S0} = \hat{L}_S + 2\widehat{M}_S \quad , \quad L_S = \hat{L}_S - \widehat{M}_S$$

ii. Rotor /Stator Impedance

The mutual inductance between the stator and rotor are the keystone of induction motor performance. The nine elements of Z_{Sr} may be measured quite easily. Each stator phase in turn is energized and the three rotor phase voltages are measured in each case. The coefficients of mutual inductance naturally vary with rotor position for the particular case of the two phases.

From the experimental results, the complete impedance matrix may be written as equation (3.9):

$$Z_{rs} = \begin{bmatrix} \hat{M}pCOS\Theta & \hat{M}pCOS\Theta_2 & \hat{M}pCOS\Theta \\ \hat{M}pCOS\Theta_2 & \hat{M}pCOS\Theta_3 & \hat{M}pCOS\Theta_3 \\ \hat{M}pCOS\Theta_3 & \hat{M}pCOS\Theta & \hat{M}pCOS\Theta_2 \end{bmatrix} \quad \text{.......................................} \quad (3.9)$$

$$Z'_{rs} = C_{1t} Z_{rS} C_1$$

Where:

Z_{rs}= is rotor to stator impedance.

$$Z_{rS}C_1 = \begin{bmatrix} \hat{M}pCOS\Theta & \hat{M}pCOS\Theta_2 & \hat{M}pCOS\Theta \\ \hat{M}pCOS\Theta_2 & \hat{M}pCOS\Theta_3 & \hat{M}pCOS\Theta_3 \\ \hat{M}pCOS\Theta_3 & \hat{M}pCOS\Theta & \hat{M}pCOS\Theta_2 \end{bmatrix} \sqrt{\frac{2}{3}} \begin{Vmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{Vmatrix}$$

$$= \sqrt{\frac{2}{3}} \begin{bmatrix} 0 & \hat{M}pCOS\Theta & \hat{M}pCOS\Theta \\ 0 & \hat{M}pCOS\Theta_2 & \hat{M}pCOS\Theta_2 \\ 0 & \hat{M}pCOS\Theta_3 & \hat{M}pCOS\Theta_3 \end{bmatrix}$$

Since it is easy to show that

$$COS\Theta + COS\Theta_2 + COS\Theta_3 = 0$$

$$COS\Theta_3 - COS\Theta_2 = \sqrt{3}Sin\Theta$$

$$COS\Theta - COS\Theta_3 = \sqrt{3}Sin\Theta_2$$

$$COS\Theta_2 - COS\Theta = \sqrt{3}Sin\Theta_3$$

To complete the transformation there is

$$Z'_{rs} = C_{1t} Z_{SS} C_1$$

$$\sqrt{\frac{2}{3}} \begin{Vmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{Vmatrix} \sqrt{\frac{2}{3}} \begin{bmatrix} 0 & \hat{M}pCOS\Theta & \hat{M}pCOS\Theta \\ 0 & \hat{M}pCOS\Theta_2 & \hat{M}pCOS\Theta_2 \\ 0 & \hat{M}pCOS\Theta_3 & \hat{M}pCOS\Theta_3 \end{bmatrix}$$

$$Z'_{rs} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & \widehat{M}pCOS\Theta & \widehat{M}pSin\Theta \\ 0 & -\widehat{M}pSin\Theta & \widehat{M}pCOS\Theta \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.10)$$

iii. Stator /rotor Impedance:

From equation (3.7) the impedance of stator to rotor may written as follow:

$$Z_{sr} = \begin{bmatrix} \widehat{M}pCOS\Theta + & \widehat{M}pCOS\Theta_2 & \widehat{M}pCOS\Theta_3 \\ \widehat{M}pCOS\Theta_2 & \widehat{M}pCOS\Theta_3 & \widehat{M}pCOS\Theta \\ \widehat{M}pCOS\Theta_3 & \widehat{M}pCOS\Theta & \widehat{M}pCOS\Theta_2 \end{bmatrix}$$

Z_{Sr}= is stator to rotor impedance.

$$Z'_{sr} = Z'_{rst} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & \widehat{M}pCOS\Theta & -\widehat{M}pSin\Theta \\ 0 & \widehat{M}pSin\Theta & \widehat{M}pCOS\Theta \end{bmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots... (3.11)$$

iv. Rotor /rotor Impedance:

From equation (3.7) the impedance of stator to stator may written as follow:

$$Z_{rr} = \begin{bmatrix} R_r + \hat{L}_r P & P\widehat{M_r} & P\widehat{M_r} \\ P\widehat{M_r} & R_r + \hat{L}_r P & P\widehat{M_r} \\ P\widehat{M_r} & P\widehat{M_r} & R_r + \hat{L}_r P \end{bmatrix}$$

Z_{rr}= is rotor to rotor impedance.

$$Z'_{rr} = C_{1t} Z_{rr} C_1 =$$

$$\sqrt{\frac{2}{3}} \begin{Vmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{Vmatrix} \begin{bmatrix} R_r + \hat{L}_r P & P\widehat{M_r} & P\widehat{M_r} \\ P\widehat{M_r} & R_r + \hat{L}_r P & P\widehat{M_r} \\ P\widehat{M_r} & P\widehat{M_r} & R_r + \hat{L}_r P \end{bmatrix} \sqrt{\frac{2}{3}} \begin{Vmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{Vmatrix} =$$

$$\begin{Vmatrix} R_r + L_{r0} P & 0 & 0 \\ 0 & R_r + L_r P & 0 \\ 0 & 0 & R_r + L_r P \end{Vmatrix} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.12)$$

Where:

$$L_{r0} = \hat{L}_r + 2\hat{M}_r \qquad , \qquad L_r = \hat{L}_r - \hat{M}_r$$

From equations (3.8), (3.10), (3.11) and (3.12) the new matrix will be:

$$Z` = \begin{bmatrix} R_S + L_{S0}P & 0 & 0 & M_3 p\cos 3\Theta & 0 & 0 \\ 0 & R_S + L_S P & 0 & 0 & Mp\cos\Theta & Mp\sin\Theta \\ 0 & 0 & R_S + L_S P & 0 & -Mp\sin\Theta & Mp\cos\Theta \\ M_3 p\cos\Theta & 0 & 0 & R_r + L_{r0}P & 0 & 0 \\ 0 & Mp\cos\Theta & -Mp\sin\Theta & 0 & R_r + L_r P & 0 \\ 0 & Mp\sin\Theta & Mp\cos\Theta & 0 & 0 & R_r + L_r P \end{bmatrix}$$

..........(3.13)

Under normal condition the zero component cannot flow and can ignored the zero component. The impedance will be:

$$[Z]` = \begin{bmatrix} R_S + L_S P & 0 & Mp\cos\Theta & Mp\sin\Theta \\ 0 & R_S + L_S P & Mp\sin\Theta & -Mp\cos\Theta \\ Mp\cos\Theta & Mp\sin\Theta & R_r + L_r P & 0 \\ Mp\sin\Theta & -Mp\cos\Theta & 0 & R_r + L_r P \end{bmatrix}$$

To transform the two phase machine to commutator machine by using C_2 , the stator is not require to transform.

Where:

$$C_2 = \begin{Vmatrix} \sin\Theta & \cos\Theta \\ \cos\Theta & -\sin\Theta \end{Vmatrix}$$

$$[Z"] = \begin{vmatrix} U & 0 \\ 0 & C_{2t} \end{vmatrix} \begin{vmatrix} Z'_{SS} & Z'_{Sr} \\ Z'_{rS} & Z'_{rr} \end{vmatrix} \begin{vmatrix} U & 0 \\ 0 & C_2 \end{vmatrix} = \begin{vmatrix} Z'_{SS} & Z'_{Sr}C_2 \\ C_{2t}Z'_{rS} & C_{2t}Z'_{rr}C_2 \end{vmatrix}$$

$$[Z"] = \begin{bmatrix} R_S + L_S P & MP & 0 & 0 \\ MP & R_r + L_r P & \omega_m M & \omega_m L_r \\ 0 & 0 & R_S + L_S P & MP \\ -\omega_m M & -\omega_m L_r & MP & R_r + L_r P \end{bmatrix} \quad \text{.......................................(3.14)}$$

$[V''] = [Z''][I'']$

Where:

V''= is the voltage.

I''= is the current.

Z''= is transferred impedance.

By arranging the elements of the matrix then:

$$\begin{bmatrix} V_D \\ V_d \\ V_Q \\ V_q \end{bmatrix} = \begin{bmatrix} R_S + L_S P & MP & 0 & 0 \\ MP & R_r + L_r P & \omega_m M & \omega_m L_r \\ 0 & 0 & R_S + L_S P & MP \\ -\omega_m M & -\omega_m L_r & MP & R_r + L_r P \end{bmatrix} \begin{bmatrix} i_D \\ i_d \\ i_Q \\ i_q \end{bmatrix} \quad \text{(3.15)}$$

$[V] = [R][i] + [L]P[i] + \omega_m [G][i]$

$P[i] = [L]^{-1} ([V] - [R][i] - \omega_m [G][i])$, [18].

3.3. SEIG Model

Basically the model of SEIG is similar to an induction motor. The only difference is that the self excited induction generator has capacitors connected across the stator terminals or excitation. The conventional steady state per-phase equivalent circuit representation of an induction machine is convenient to use for steady state analysis. However, the d-q representation is used to model the self excited induction generator under dynamic conditions. The d-q representation of SEIG with capacitors connected at the terminals of the windings and without any electrical input from rotor side is shown in figure 3.2.

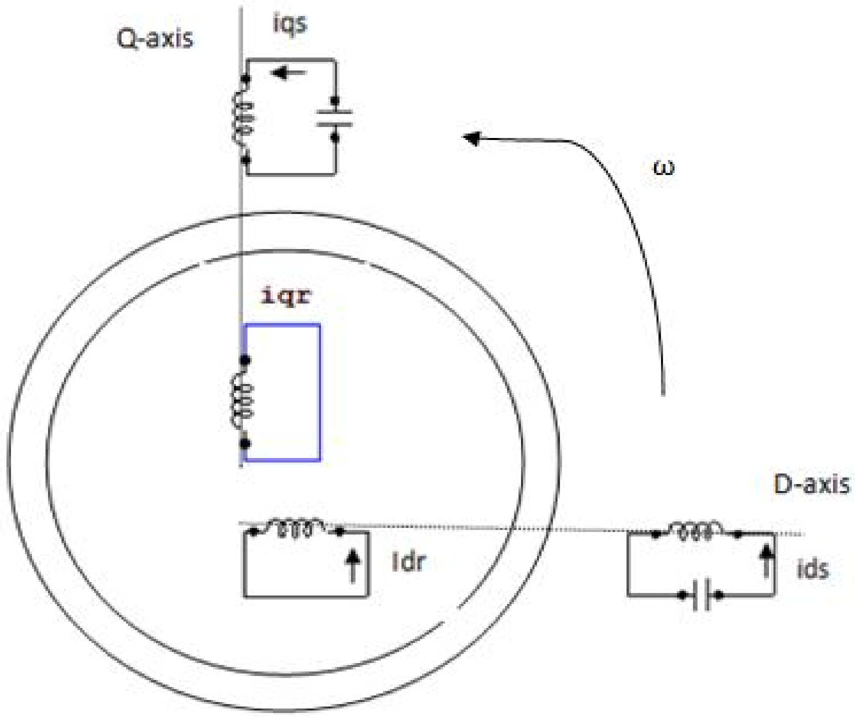


Figure 3.2: d-q representation of self excited induction generator (SEIG) with capacitor

From the figure 3.2 the voltage equations of Induction generator are:

$V_{ds} = R_s i_{ds} - \omega_e \Psi_{qs} + p\Psi_{ds}$ .... (3.16)

$V_{qs} = R_s i_{qs} - \omega_e \Psi_{ds} + p\Psi_{qs}$ ... ...(3.17)

$V_{dr} = 0 = R_r i_{ds} - (\omega_e - \omega_r)\Psi_{qs} + p\Psi_{ds}$ .... (3.18)

$V_{qr} = 0 = R_r i_{qs} - (\omega_e - \omega_r)\Psi_{ds} + p\Psi_{qs}$ .... (3.19)

Induction generator flux and current equations:

$\Psi_{ds} = L_s i_{ds} + L_m i_{ds}$ .... (3.20)

$\Psi_{qs} = L_s i_{qs} + L_m i_{qs}$ .... (3.21)

$\Psi_{dr} = L_r i_{dr} + L_m i_{ds}$ ....(3.22)

$\Psi_{qr} = L_r i_{qr} + L_m i_{qs}$ .... (3.23)

$i_{dm} = i_{ds} + i_{dr}$, direct axis magnetizing current

$i_{qm} = i_{qs} + i_{qr}$, quadrature axis magnetizing current

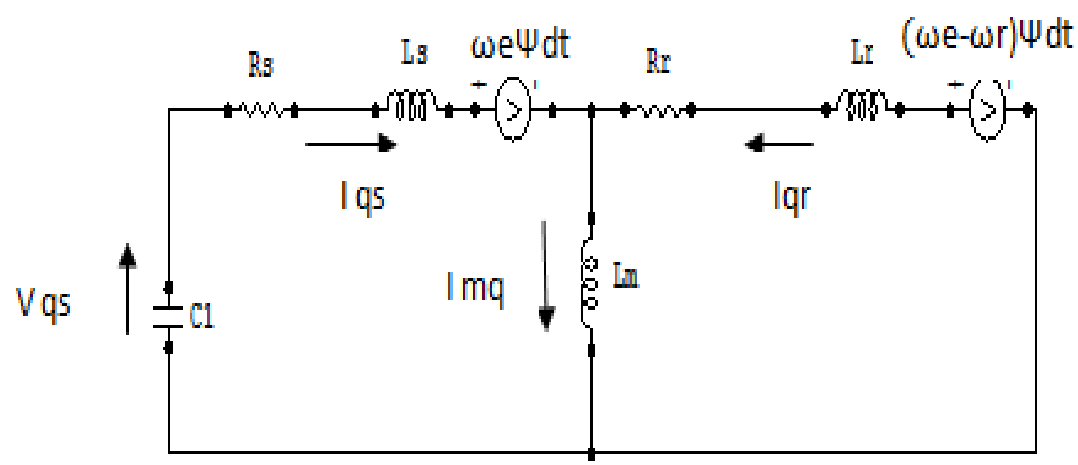
$i_m = \sqrt{{i_{dm}}^2 + {i_{qm}}^2}$, magnetizing current in the machine

Neglecting leakage :

$\Psi_{dm} = L_m i_{dm} = \frac{f_m(i_m)}{i_m} i_{dm}$ .... (3.24)

$\Psi_{qm} = L_m i_{qm} = \frac{f_m(i_m)}{i_m} i_{qm}$ .... (3.25)

Equations (3.24) and (3.25) can be redrawn in detail, in a stationary stator reference frame, with direct and quadrature circuits separately represented as given in figure 3.3.



a

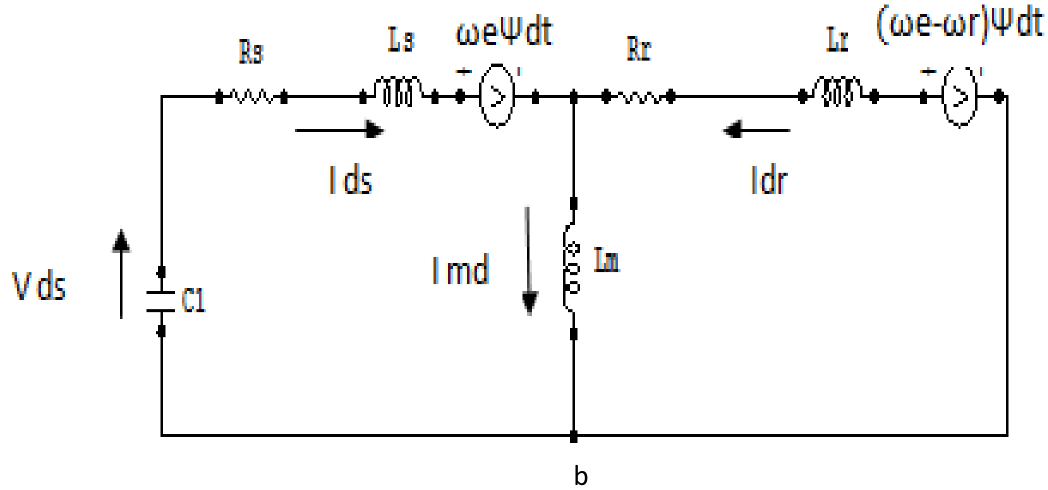


Figure 3.3: Detailed d-q model of SEIG in stationary reference frame

(a) q- axis circuit (b) d- axis circuit

The capacitor in Figure 3.3 can be represented as

$$V_{cq} = \frac{1}{C}\int i_{qs} dt \quad \text{...(3.26)}$$

$$V_{cd} = \frac{1}{C}\int i_{ds} dt \quad \text{...(3.27)}$$

The matrix equation for the d-q model of self excited induction generator in the stationary stator reference frame, using the SEIG model given in Figure 3.2 is given as:

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_S + L_S P + 1/PC & 0 & PL_m & 0 \\ 0 & R_s + L_s P + 1/PC & 0 & PL_m \\ PL_m & -\omega_r L_m & R_r + L_r P & \omega_r L_r \\ -\omega_r L_m & PL_m & \omega_r L_r & R_r + L_r P \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \quad \text{...(3.28)}$$

The SEIG equivalent circuit shown in figure 3.3 can be loaded with a resistive load by connecting a resistance R_L across the capacitor, C. with resistive load equation. Equation (3.15) is modified to the equation (3.29). [19]

$$
\begin{bmatrix} V_{qs} \\ V_{ds} \\ 0 \\ 0 \end{bmatrix} =
$$

$$
\begin{bmatrix} R_S + L_S P + \frac{R_L}{1+R_L PC} & 0 & PL_m & 0 \\ 0 & R_s + L_s P + \frac{R_L}{1+R_L PC} & 0 & PL_m \\ PL_m & -\omega_r L_m & R_r + L_r P & \omega_r L_r \\ -\omega_r L_m & PL_m & \omega_r L_r & R_r + L_r P \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \text{.........(3.29)}
$$

3.4. Calculation of Shunt Capacitor for SEIG

Two methods are available to calculate the value of shunt capacitor of SEIG.

i. Loop impedance method.

ii. Nodal analysis method.

3.4.1. Loop impedance method

Figure 3.4 shows the loop impedance method.

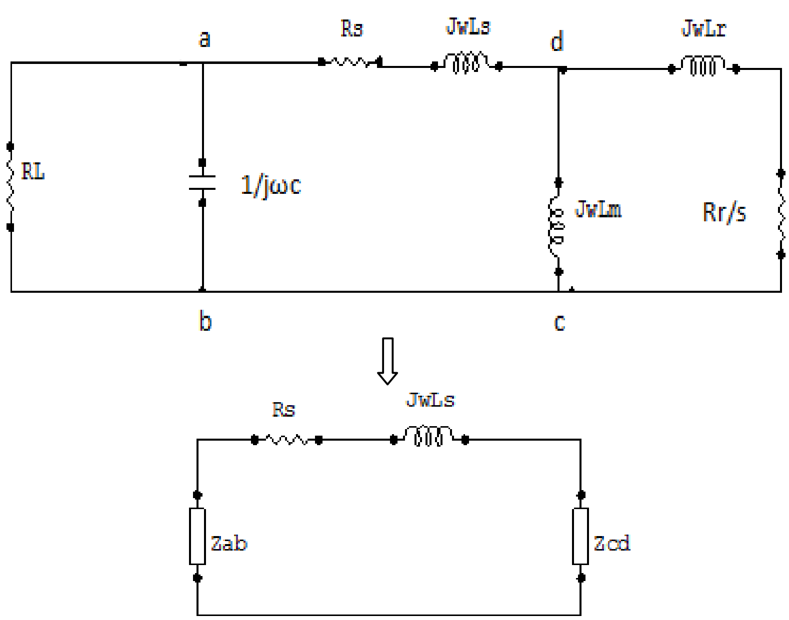


Figure 3.4: Loop impedance method

For loop impedance, considering the loop abcda and applying KVL

$$Z_{ab} + Z_{cd} + Z_{ad} = 0 \quad \text{.. (3.30)}$$

By equating real and imaginary part from equation (3.30) the form of solution will be

$$\left.\begin{aligned} F(f, X_C) = 0 \\ \\ G(f, X_C) = 0 \end{aligned}\right\} \quad \text{..................... (3.31)}$$

It can be shown that for a R-L load, the degrees of X_C in the two equations are 6 and 2 respectively. One of the variables can't be easily eliminated from the earlier and an iterative technique for solving the two variables simultaneously.

3.4.2. Nodal analysis method

Figure 3.5 shows the Nodal analysis method

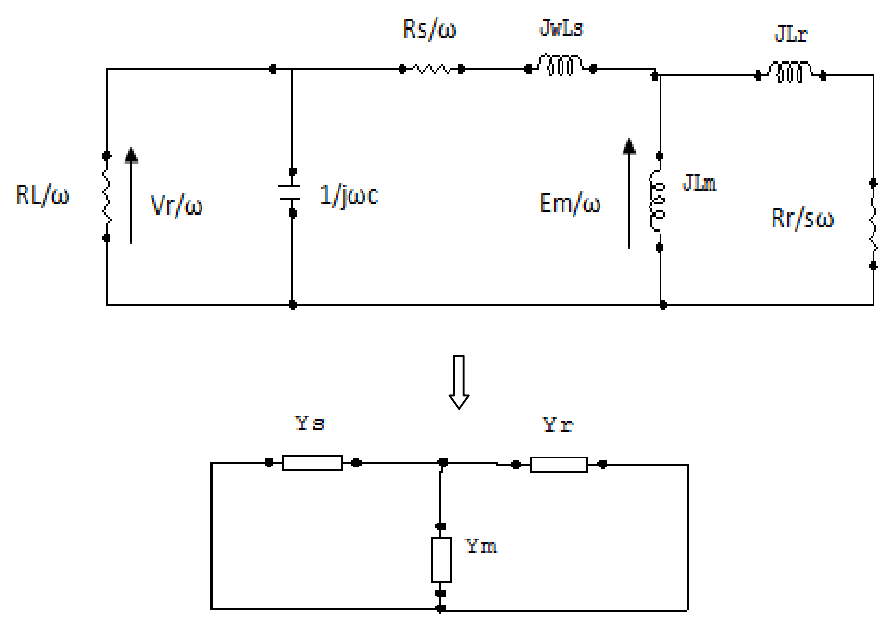


Figure 3.5: Nodal analysis method

A transformation has been applied so that all the reactance and voltage are referred to the base frequency (ω). For self excite, the excitation capacitance must be equal to minimum value of capacitor. In order to operate at stable voltage, the machine must operate at an appropriate level of magnetic saturation. Accordingly the magnetizing reactance X_M is not constant but varies with load condition.

At node d, the algebraic sum of current meeting is equal to zero.

$$\frac{E_m}{\omega}(Y_S + Y_R + Y_M) = 0 \quad \text{.........(3.32)}$$

Since E_m can't be zero

$$Y_S + Y_R + Y_M = 0 \quad \text{.........(3.33)}$$

This equation can be expanded, so real and imaginary parts equation equal to zero.

Equating real parts

$$\frac{R_{1L}/\omega}{(R_{1L}/\omega)^2 + {L_{1L}}^2} + \frac{R_r/s\omega}{(R_r/s\omega)^2 + {L_{lr}}^2} = 0 \quad \text{......... (3.34)}$$

And equating imaginary parts

$$\frac{1}{L_m} + \frac{L_{1L}}{(R_{1L}/\omega)^2 + {L_{1L}}^2} + \frac{L_{Lr}}{(R_r/s\omega)^2 + {L_{1r}}^2} = 0 \quad \text{......... (3.35)}$$

Where:

$$L_{1L} = L_S - \frac{CR_L}{(\omega CR_L)^2 + 1}$$

And
$$R_{1L} = R_S + \frac{R_L}{(\omega CR_L)^2 + 1}$$

R_{1L} and L_{1L} are the effective resistance and inductance respectively the stator winding and load as seen by node d. equation (3.34) can be used to find out capacitance required after having known slip and equation (3.35) can be used to find out L_M.

The following set of equations is used for a computer-based analysis of the induction generator operating with the output frequency, ω. A purely resistive loadR_L, is assumed. The load, capacitor, and stator currents,$\hat{I}_L$, $\hat{I}_C$, and $\hat{I}_S$, respectively, are determined as

$$\hat{I}_L = \frac{\hat{V}_S}{R_L} \quad (3.36)$$

$$\hat{I}_C = \frac{\hat{V}_S}{JX_C} \quad (3.37)$$

$$\hat{I}_s = \hat{I}_L + \hat{I}_C \quad (3.38)$$

Now the stator EMF ,E_S can be found as

$$\hat{E}_s = \hat{V}_s + (R_S + jX_{lS})\,\hat{I}_s \quad (3.39)$$

And the magnetizing current $\hat{I}_m$, as

$$\hat{I}_m = f^{-1}(\hat{E}_s)e^{j(\theta_E - \frac{\pi}{2})} \quad (3.40)$$

Where θ_E denotes the angle of phasor $\hat{E}_s$. Finally, the rotor current, $\hat{I}_r$ is given by

$$\hat{I}_r = \hat{I}_s + \hat{I}_m \quad (3.41)$$

The stator voltage, $\hat{V}_s$=V_s (reference phasor), in equations (3.36),(3.37), (3.38)

Must be such that the balance of reactive powers,

$$X_C I_C^2 = X_{ls} I_s^2 + X_{lr} I_r^2 + X_m I_m^2 \quad (3.42)$$

Is satisfied, this in addition to the nonlinear relation between the stator EMF and magnetizing current, requiring an iterative approach to the computations. Once the currents have been found, the balance of real power,

$$-R_C I_C^2 = R_r I_r^2 + R_s I_s^2 + R_L I_L^2 \quad (3.43)$$

3.5. Hydraulic turbine model

The representation of the hydraulic turbine and water column in stability studies is usually based on the following assumption:

1. The hydraulic resistance is negligible.
2. The penstock pipe is inelastic and the water is incompressible.
3. The velocity of the water varies directly with the gate opening and square root of the net head.

The turbine output power is proportional to the product of head and volume flow. Figure 3.6 shows the control system of hydraulic plant.

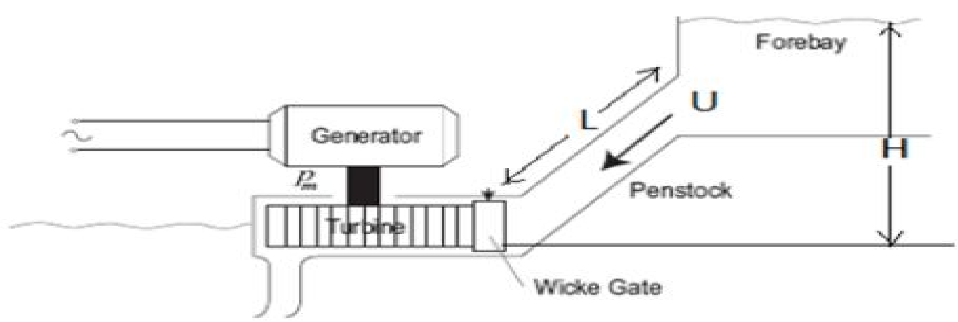


Figure 3.6: A typical control system of hydraulic plant

The velocity of the water in the penstock is given by

$$u = K_U G \sqrt{H}$$

Where

U = water velocity

G = gate position

H = hydraulic head at gate

K_U = a constant of proportional

$$\frac{\Delta \dot{P}_m}{\Delta \bar{G}} = \frac{1 - T_W s}{1 + 0.5 T_W s} \quad \text{...(3.44)}$$

Above equation represents the classical transfer function of a hydraulic turbine. It shows how the turbine power output changes in response to a change in gate opening for an idea lossless turbine. Figure (3.7) shows the mathematical model of hydraulic turbine.

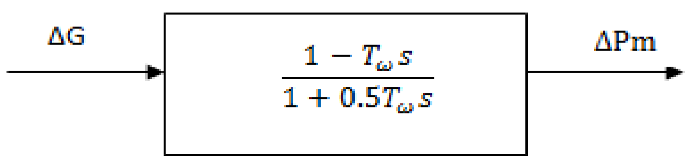


Figure 3.7: Mathematical model of hydraulic turbine

3.6. Governor model

The basic function of a governor is to control speed and/ or load. The primary speed/load control function involves feeding back speed error to control the gate position. In order to ensure satisfactory and stable parallel operation of multiple units, the speed governor is provided with a droop characteristic. The purpose of the droop is to ensure equitable load sharing between generating units. For stable control performance, a large transient droop with a long resetting time is therefore required. This is accomplished by the provision or a rate feedback or transient gain reduction compensation as shown in the figure 3.8.

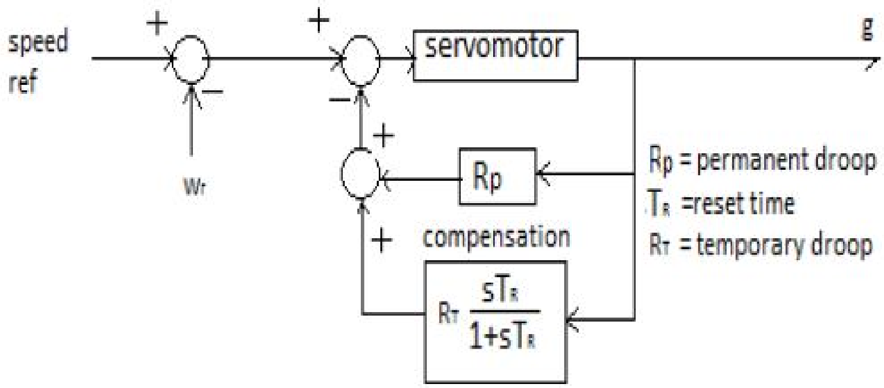


Figure 3.8: Governor with transient droop compensation

Formulation of plant models for micro hydro power (MHP) plant:

The block diagram of the MHP plant with PID controller can be reduced to a simpler transfer function representation as shown in Figure 3.9.

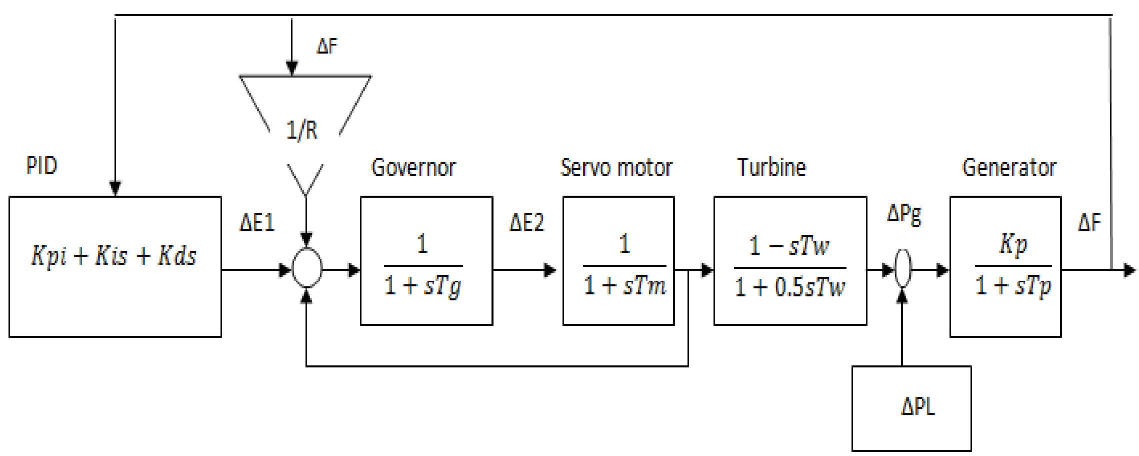


Figure 3.9: Models of MHP plant using servomotor as governor with PID-Controller

3.7. Simulation of PID controller for MHP plants

Using the simulated model enhancement through PID controller to reduce oscillations, overshoot and peak undershoot during transient period and also to improve the steady state response.

The transfer function of PID-Controller equations is transformed using Matlab/imulink based on neural network as shown in Figure (3.10).

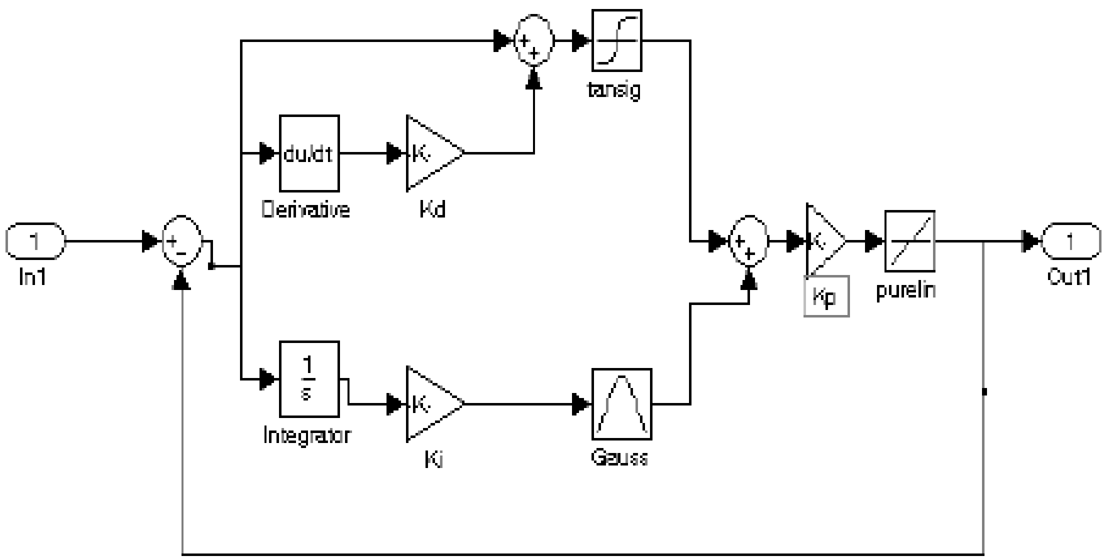


Figure 3.10: Simulink model of PID-Controller

PID transfer function:

$G_1 = K_p + \frac{K_i}{S} + Kd_s$ [20].

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 introduction

In this chapter the Matlab/simulink software is used to simulate the behavior of the tow identical self- excited induction generators connected to hydro-turbine, at steady state operation and during transient period. The behavior of the two generators model is then examined when feeding a purely resistive load connected to the stator terminals and isolated from the national network. The results from the simulation are analyzed and used to demonstrate the performance of the SEIGs system.

4.2. Model Configuration

The proposed system was validated in Matlab/Simulink software.The simulation was performed for the parameters given in tables 4.1, 4.2 and 4.3, for the two identical induction generators, turbine and governor and the PID respectively.The complete modle of system is shown in figure 4.1. [20]

Table 4.1: parameters of the two induction generators

Parameters	Value
P	746 KW
V_n	220 V
F	50 Hz
R_s	0.435Ω
R_r	0.816 Ω

L_s	2 mH
L_r	2 mH
L_m	69.31 mH
ωr	1430 rpm
J	0.089 Kg.m^2
$H = \frac{0.5 * J * \omega^2}{P_{nom}}$	0.7065 sec

Table 4.2: parameters of Turbine and Governor

Parameters	Value
T_a	0.07
R_p	0.05
K_p	3
K_i	0.1
K_d	3.26
T_d	0.2
K_a	10/3
g_{min}	0.01
g_{max}	0.97518
V_{min}	-0.1
V_{max}	0.1

Table 4.3: PID Data

Parameters	Value
K_p	0.01
K_i	-0.88
K_d	0

Figure 4.1 shows the complete model of the system

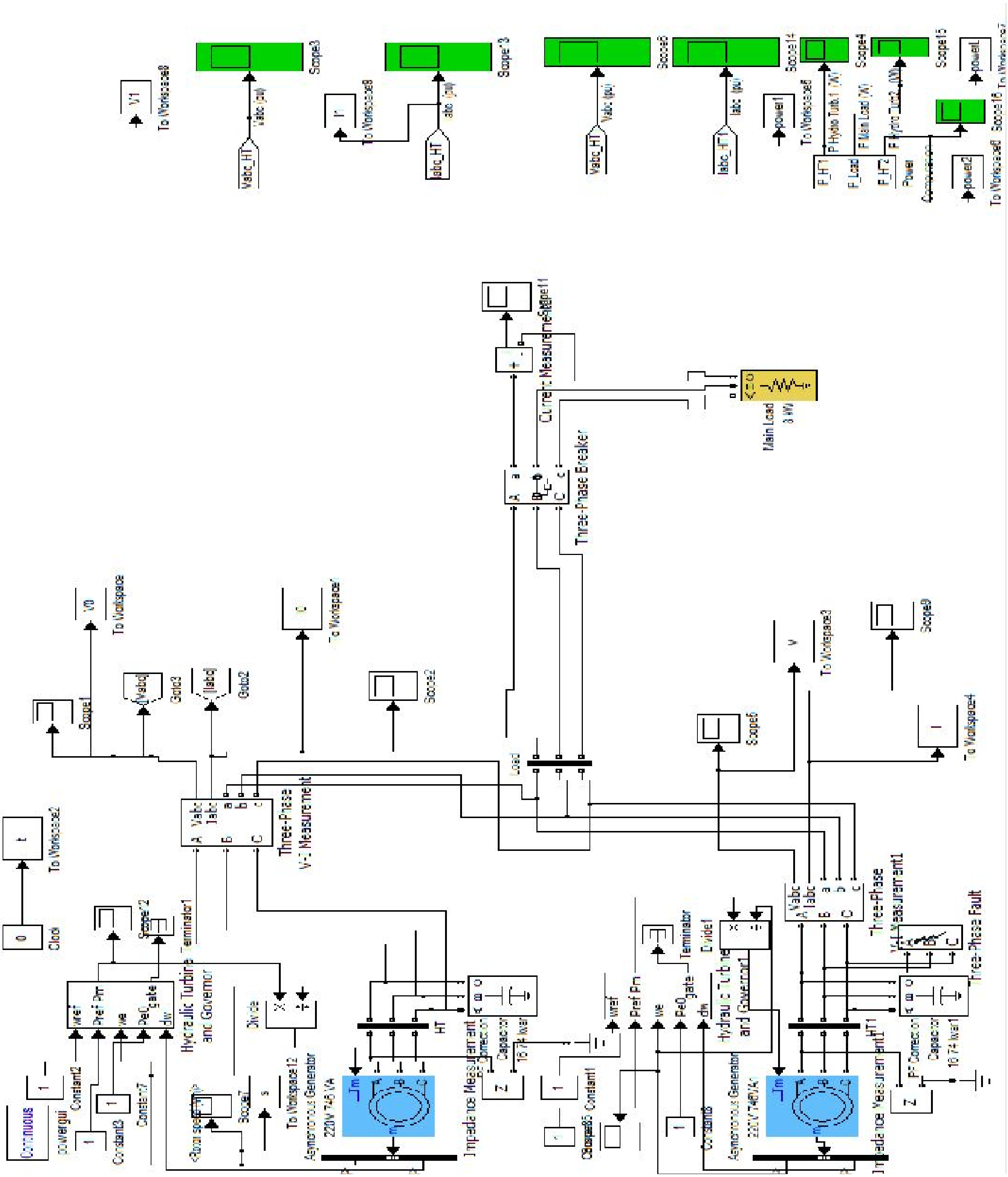


Figure 4.1 : Matlab simulation model of SEIG

4.3. Results at Steady- State Operation

The two induction machines shaft is initially rotated by hydro turbines as prime mover at a steady speed. When the three-phase, star connected self-excitation capacitor bank ($16.74\ KVAr$) calculated by the nodal analysis method, is applied to the stator terminals, the two machines work as induction generator. The speed of rotation is then altered until a steady-state stator voltage of 220V (rated voltage) was obtained. Then a resistive load (8Kw) is connected to the terminals of generators.

Figures 4.2 and 4.3 show the output voltage and current of one generator. It observed from the figures that the voltage and current are equal to zero from (t=0 sec) until (t=0.2 sec), then they increasing because the voltage built up by capacitor bank, and then reached to the steady-state value (220V) and (39A), respectively at (t=1sec).

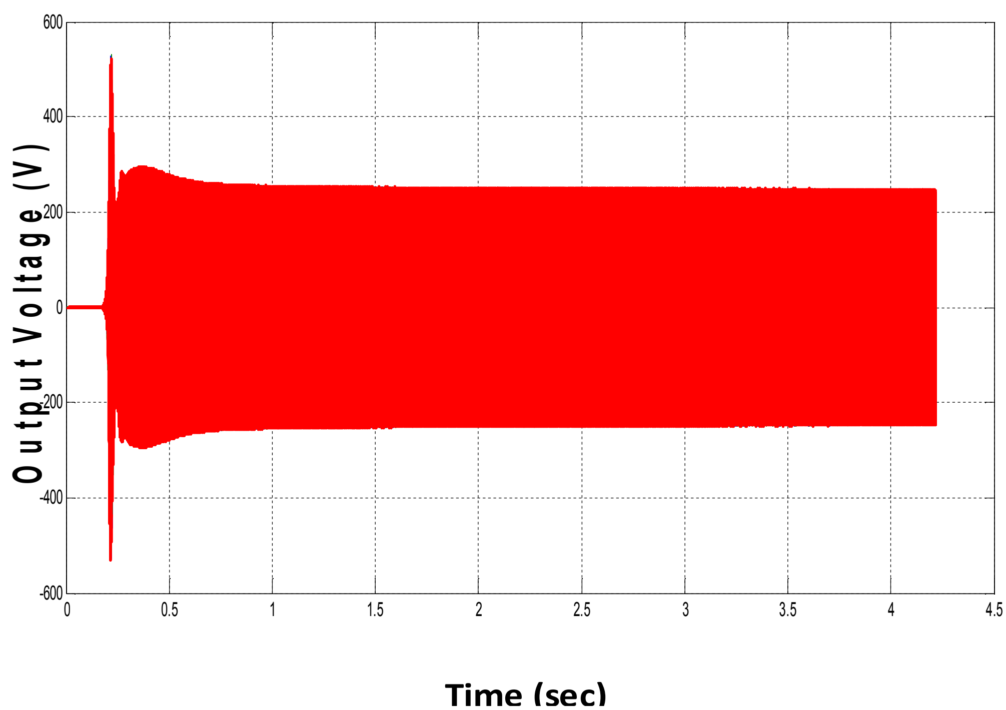


Figure 4.2: The Output Voltage of SEIG

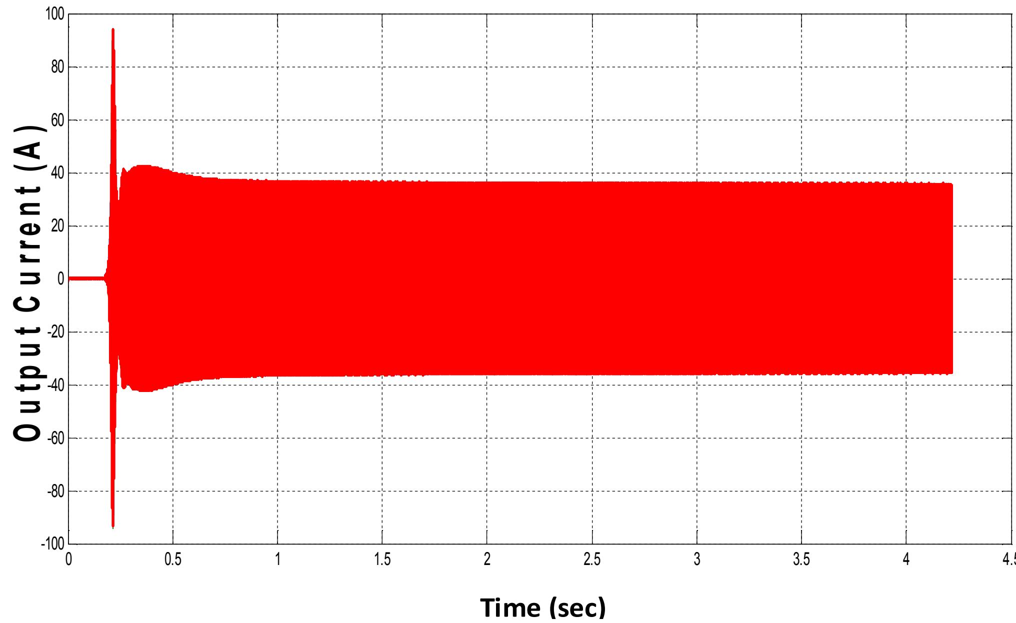


Figure 4.3: The Output Current of SEIG

Figures 4.4, 4.5 represent the generated power by the two generators and, it can be noted that generated power by the two generators start from zero to high value at starting, and then reached the steady state value (390Kw) at (t=1sec).

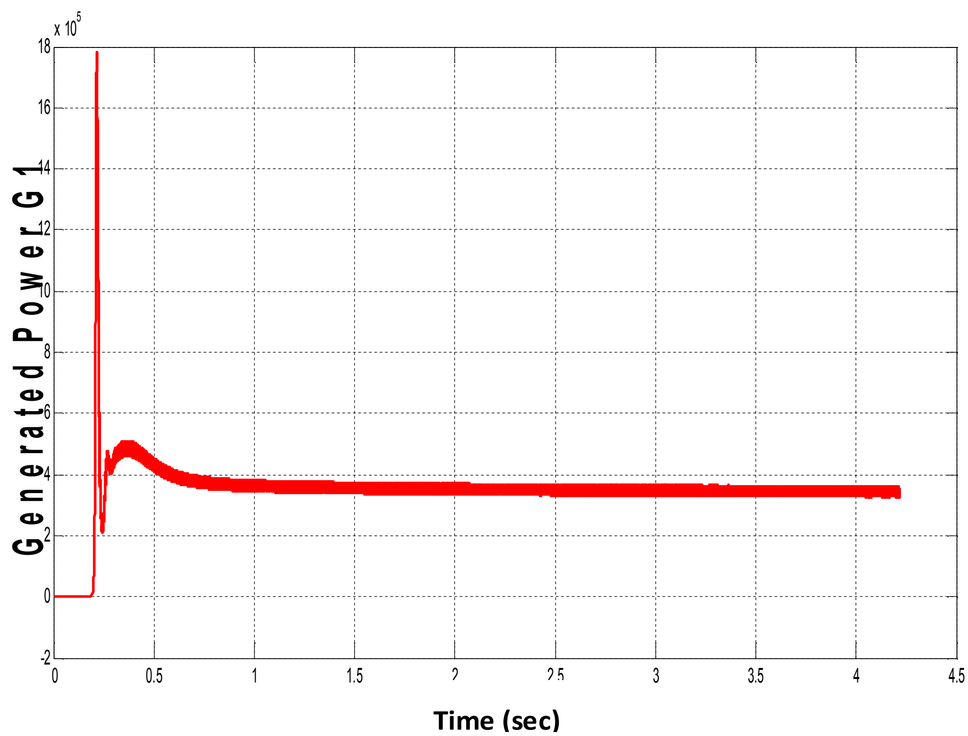


Figure 4.4: Generated Power by generator 1

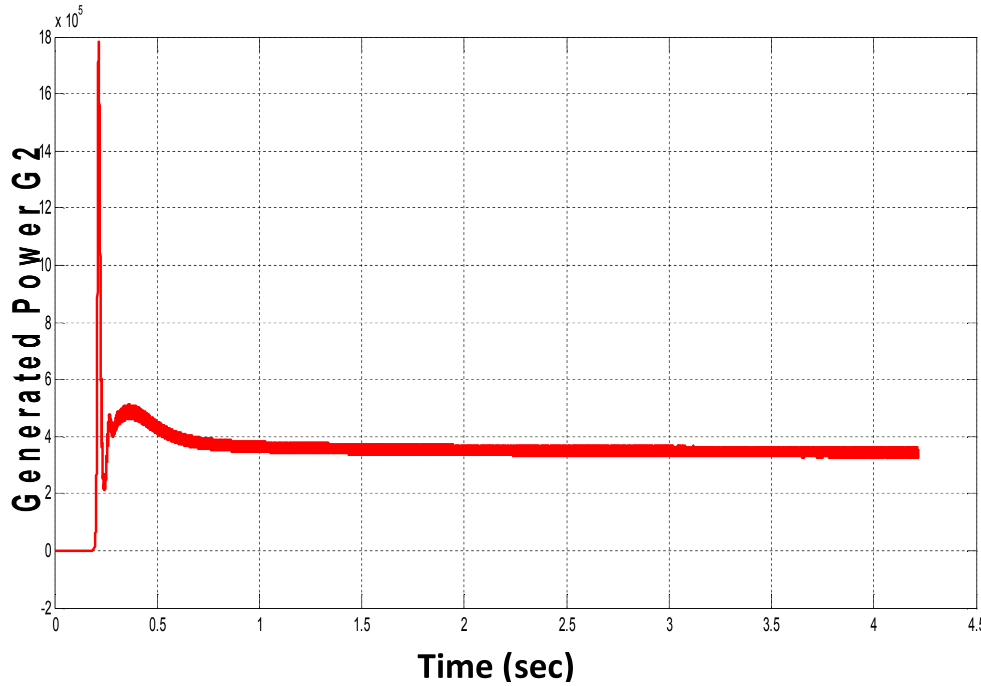


Figure 4.5: Generated Power by generator 2

Figure 4.6 shows the power transfer to the load. From the figure it observed that the power transfer increased to high value (3.2MW) at starting and then reach the steady-state value (0.7MW) at t=1sec.

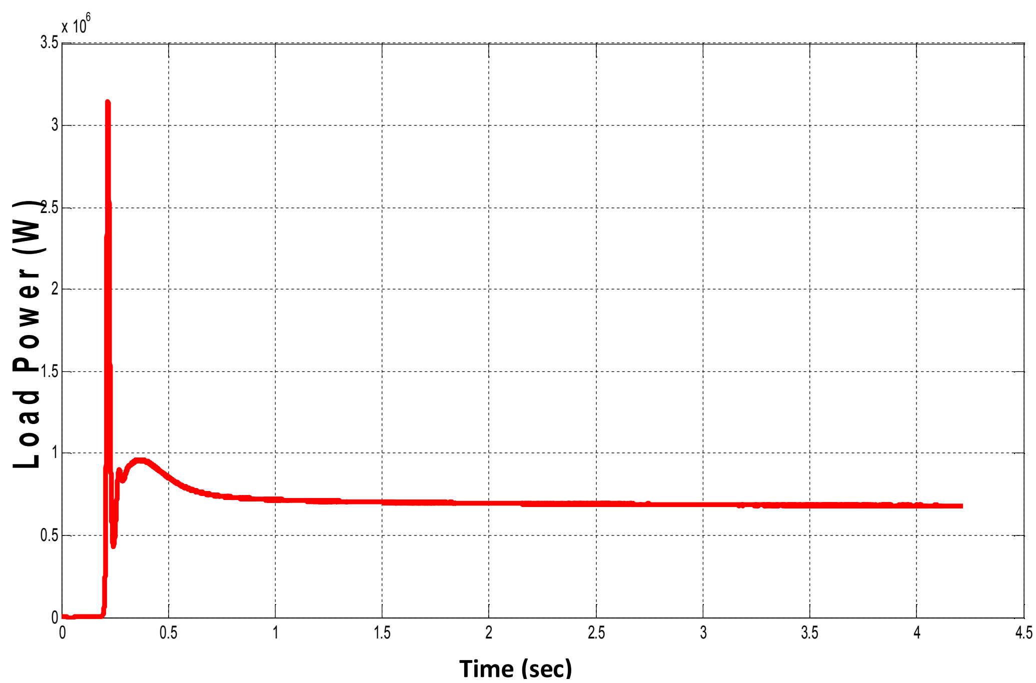


Figure 4.6: Power transferred to load

Figure 4.7 shows the rotor speed of generator 1. At starting period, the speed increased as linear relation to higher value, and at (t=1 sec), it reached to full load speed (steady state speed) (6.1p.u).

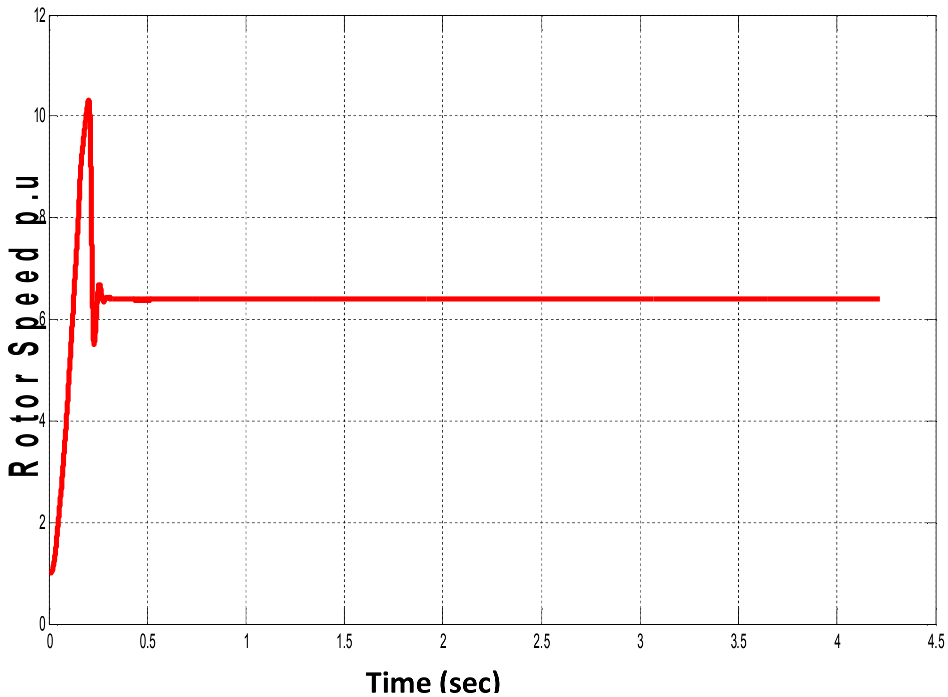


Figure 4.7: The Rotor Speed of Generator 1

4.4 Results at Three-Phase Fault

Figure 4.8 represents the output current of generator 2 during the 3-phase fault, it note that the current increase to high value (225A) when the fault occurs at the terminal of generator 2 at (t=3.8). And when the fault was clear at (t=4sec) the current back to steady state value at (t=4.2sec).

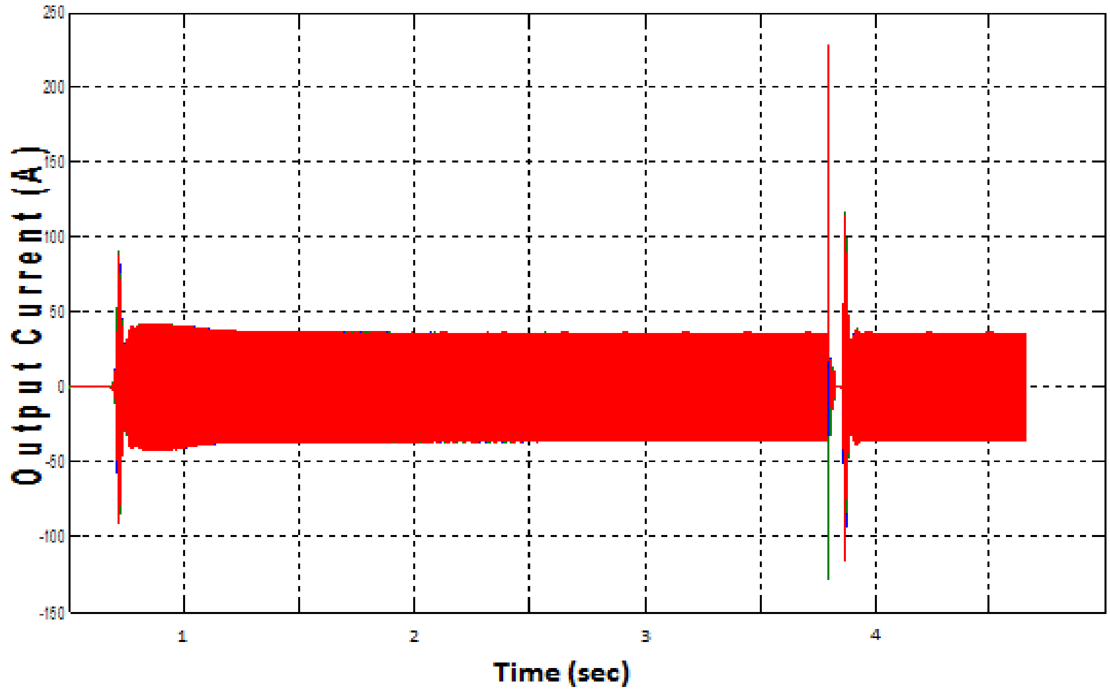


Figure 4.8: The Output Current of generator 2

Figure 4.9 shows the Output voltage of generator 2 during the 3-phase fault, it note that the voltage is decrease to zero when the fault occurs at the terminal of generator 2, at (t=3.8). And when the fault was clear the voltage back to steady state value at (t=4.2sec).

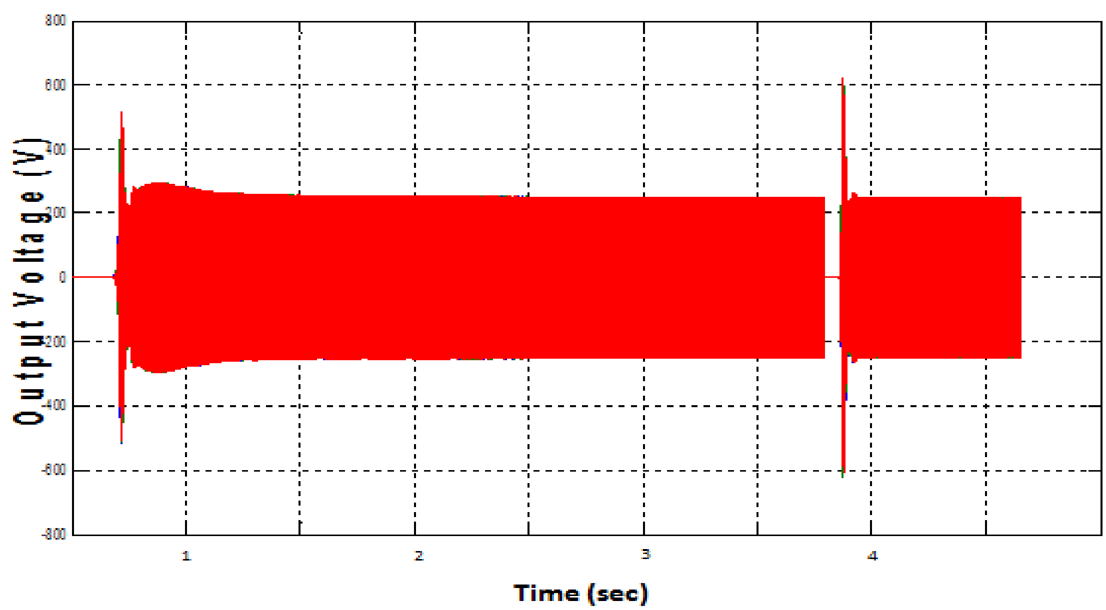


Figure 4.9: The Output Voltage of generator 2

Figure 4.10 and 4.11 represent the generated power by the generator 2 and generator 1 respectively, during the 3-phase fault occurs at the terminal of generator 2. It found that at (t=3.8 sec) the power generated by the generator 2 immediately became zero, as well as the generator 1 because the generator 1 can't feed the load. When fault clear at (t=4 sec), the generated power by the two generators return back to steady state value at (t=4.2sec).

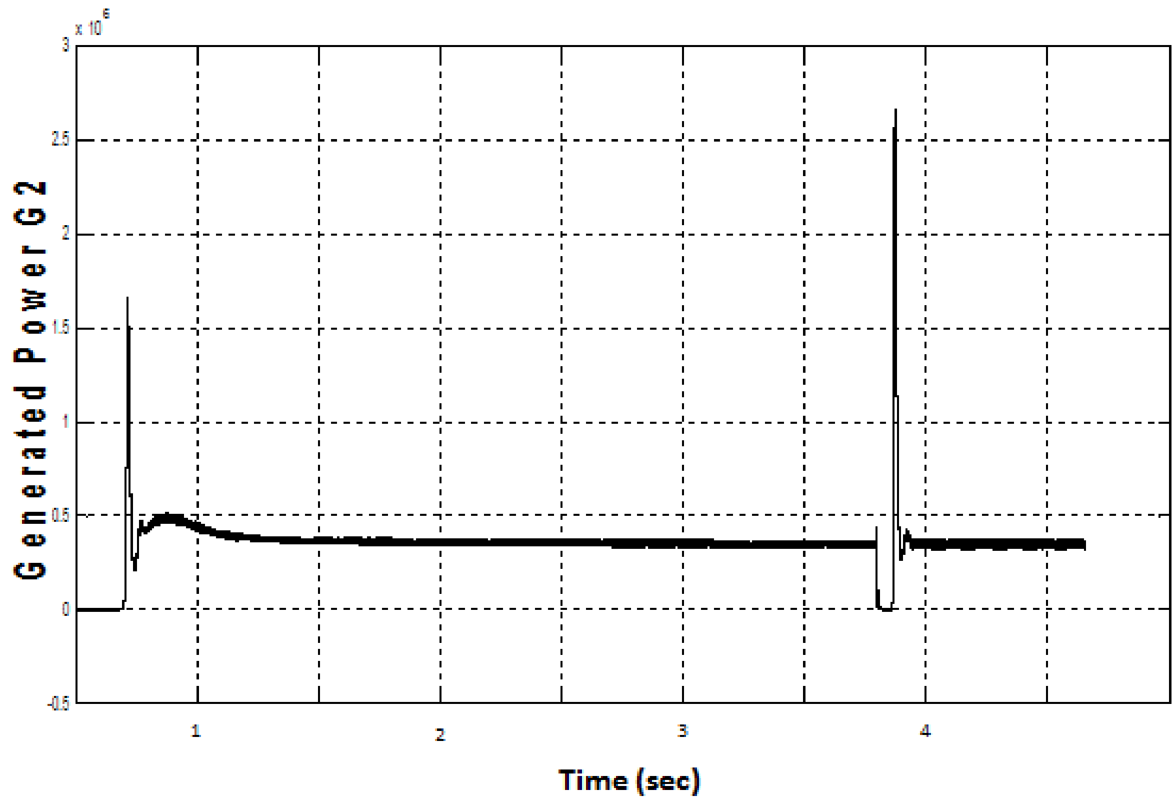


Figure 4.10: Generated Power by generator 2

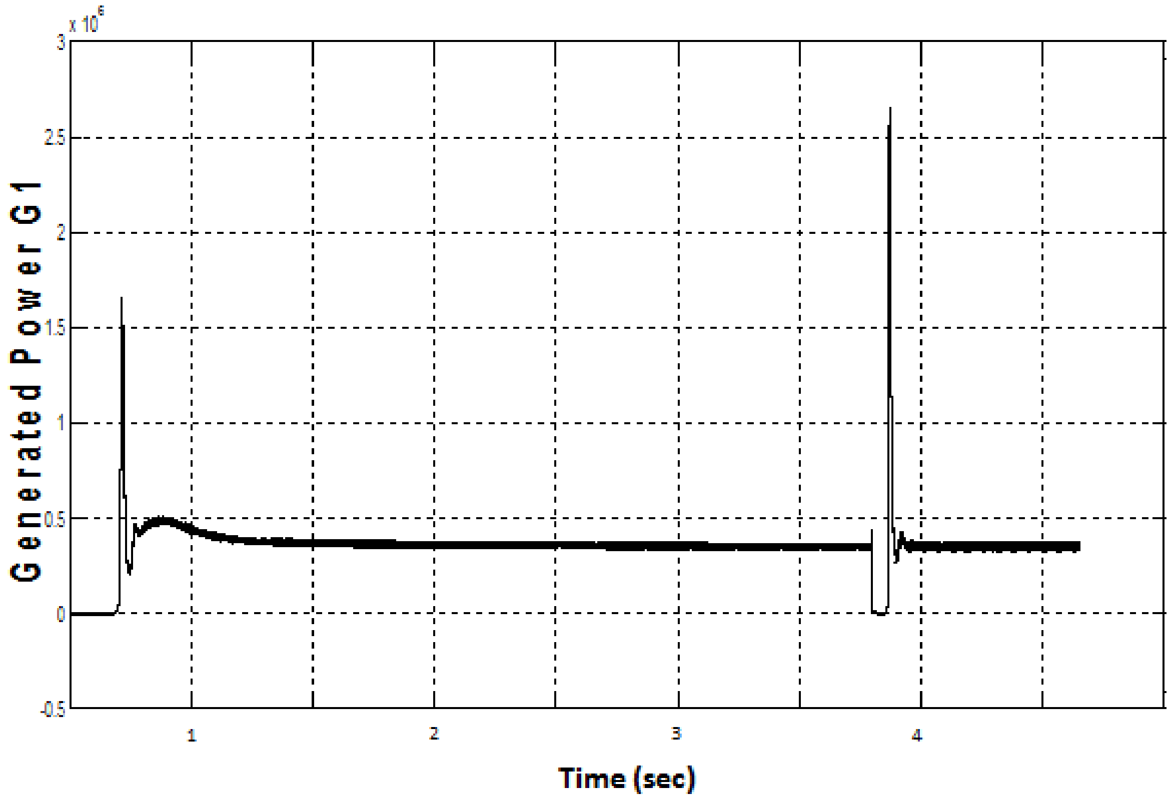


Figure 4.11: Generated Power by generator 1

Figure 4.12 illustrates the power which transferred the load, during the 3-phase fault occurs at the terminal of generator 2. From the figure it found that at (t=3.8 sec) the power transferred to the load became zero, because the generation power is equal to zero. After fault clear at (t=4 sec), the power transferred to the load return back to steady state value at (t=4.2sec).

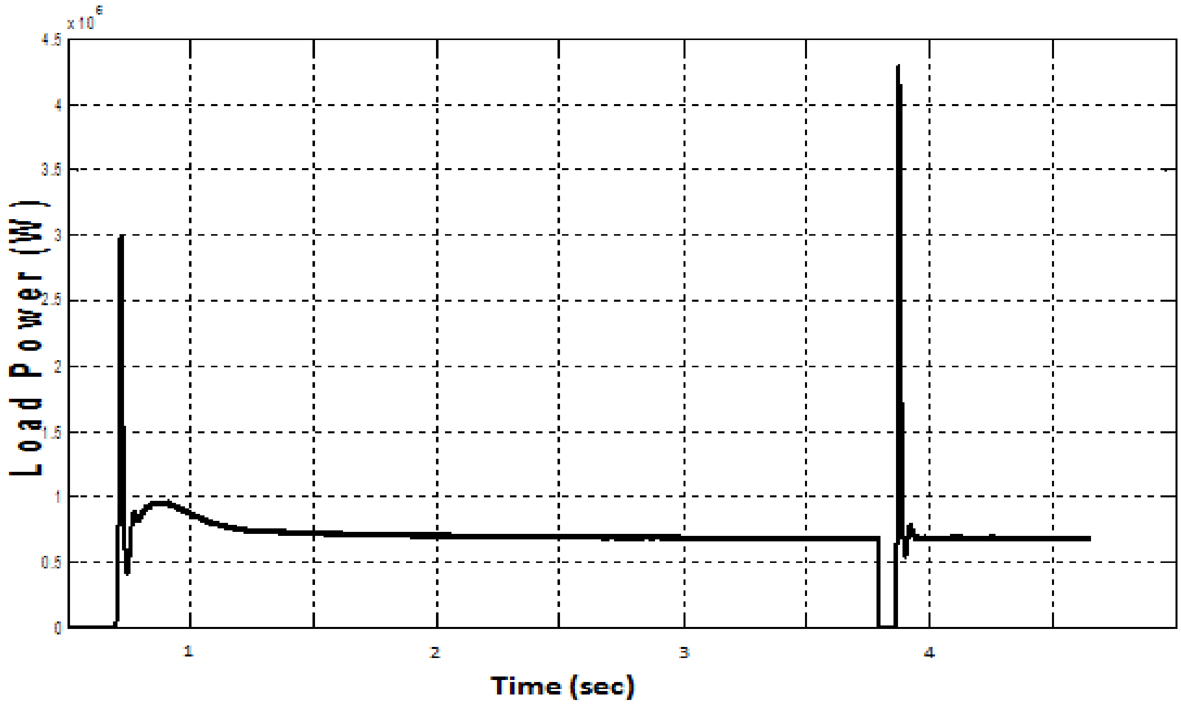


Figure 4.12: Power transferred to Load

Figure 4.13 represents the rotor speed of generator 1 during the 3-phase fault, it note that when the fault occurs the speed increase to high value 11.9p.u, and after clearing fault the speed return back to the rated speed at (t=4.3 sec).

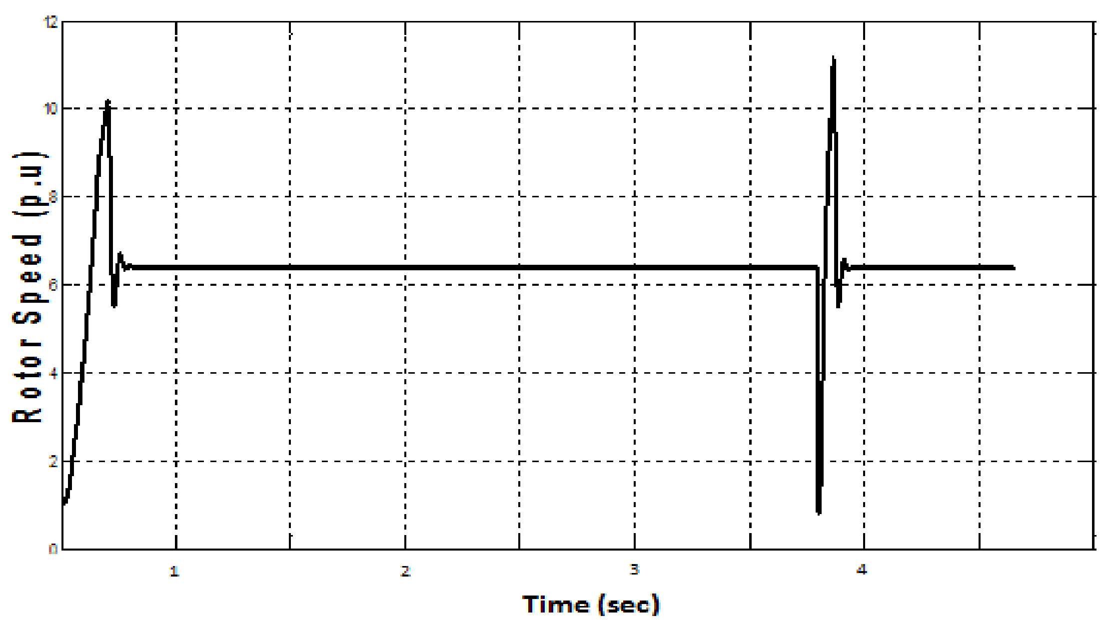


Figure 4.13: Rotor Speed of generator 1

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Use of an induction machine as a generator is becoming popular for the renewable energy sources. SEIG has its advantage that there is no need of reactive power from transmission line as it draws reactive power from capacitor bank connected in shunt (at the terminal of stator). Steady state analysis of SEIG carried out for evaluating running performance. Using the steady state analysis means voltage regulation, frequency regulation.

A micro-hydro system can be installed easily and economically in remote locations/rural areas. Many countries have enormous hydroelectric potential in isolated and remote location; hence the presented research is very significant.

This thesis has presented the simulation of dynamic modeling of two identical self-excited induction generators (SEIGs) driven by micro-hydro turbine. Matlab/Simulink software was used to simulate the system. The steady state operation and transient characteristics with constant load was presented. The results of simulation had been discussed, and from the results it proved that the model of two generators gives good dynamic and steady-state performance.

5.2. Recommendations

1. Future work will on the development direct torque control (DTC) to regulate the output stator flux linkage, voltage and frequency of SEIG.
2. The performance of SEIG can also be improved by better controlling the reactive power supplied/absorbed to the generator and load. The

STATCOM with batteries assisted SEIG may be the solution but the cost of the system will be increased. Such system with power electronic converter can be explored for optimum performance.

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