PERFORMANCE ANALYSIS OF SELF EXCITED INDUCTION GENERATOR BASED STAND-ALONE WIND ENERGY CONVERSION SYSTEM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

Master of Technology

In

Electrical Engineering

By

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CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled "**PERFORMANCE ANALYSIS OF SELF EXCITED INDUCTION GENERATOR BASED STAND-ALONE WIND ENERGY CONVERSION SYSTEM**" in partial fulfilment of the requirements for the award of Master Of Technology Degree in Power Electronics & Drives submitted in department of Electrical Engineering at National Institute of Technology, Rourkela is an authentic record of my own work carried out under the supervision of Dr.Monalisa Pattnaik, Assistant Professor, EE department. The matter presented in this thesis has not been submitted for the award of any other degree of this or any other university.

(Bikash Chandra Barik)

This is certified that the above statement made by the candidate is correct and true to the best of my knowledge.

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ABSTRACT

The wind energy system is rapidly developing as one of the most favourable renewable energy sources in the present scenario. Due to the constant research in the field of wind energy related technology and generic growth in power electronics system, wind power generation becomes simpler and economical. For low power wind energy system, SEIG is a good choice as a wind power generator. It has lower cost compared to other generator, lower maintenance demands and natural protection against short circuit. The project mainly focuses on the dynamic analysis and modelling of self-excited induction generator used for low power wind energy system. A wind turbine emulator model using torque imitation scheme is developed to drive the IG using MATLAB/Simulink environment. WTE gives the real characteristics as of a wind turbine for better analysis of SEIG under roof. The dynamic performance of SEIG is carried through Simulink and the validation of the Simulink results are established by experiment.

CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS AND ABREVIATION

v_{ds}	d- axes stator voltage
v_{qs}	q- axes stator voltage
v_{qr}	q-axes rotor voltage
v_{dr}	d-axes rotor voltage
i_{ds}	d- axes stator current
i_{qs}	q- axes stator current
i_{dr}	d-axes rotor current
i_{qr}	q-axes rotor current
λ_{ds}	d- axes stator flux linkage, web-turn
λ_{qs}	q- axes stator flux linkage, web-turn
λ_{qr}	q- axes rotor flux linkage, web-turn
λ_{dr}	d- axes rotor flux linkage, web-turn
θ	Angle between two axes and three axes
ω_e	Angular speed of the excitation reference frame, synchronous speed rad/sec
R_s	Stator winding resistance
R_r	rotor winding resistance
L_{ls}	Stator leakage inductance
L_{lr}	Rotor leakage inductance
L_m	Magnetizing inductance
L_s	Stator inductance
L_r	rotor inductance
T_e	Electromagnetic torque
J	Inertia constant

T_m Mechanical torque

λ Tip Speed Ratio

C_p Power coefficient

r_r Rotor radius in meters

v Wind speed in m/s.

P_r Power extracted from turbine rotor

A Area of the incident air stream

U Velocity of air flow

ρ Density of air flow

PI Proportional and Integral controller

PMSG Permanent magnet Synchronous Generator

PWM Pulse Width Modulation

SEIG Self-Excited Induction Generator

VAR Volt ampere reactive

WESC Wind energy conversion system

CHAPTER 1

INTRODUCTION

Demand of energy in the world is increasing day by day. Electrical energy production from conventional sources like coal and natural gas are not enough to fulfil the excessive demand. So auxiliary energy sources in the form of renewable energy can be used to meet the requirements. Also generation of pollution free power and the rate of depletion in fossil fuels has attracted the attention of researchers for switching to renewable energy sources. Within the renewable sources wind energy can play an important role in eradicating the world energy problem. Wind energy is used thousands of years ago for the favour of mankind but extracting electrical energy from the wind appears to be a new concept which gains increasing interest with the advances in the turbine and control technologies. For wind energy system a wind turbine and electric generator is essential. Continues researches are going on for development of WECS. Wind turbine are now a days using aerodynamics principle for better efficiency. Normally induction generators are preferred over conventional synchronous generators for WECS due to its better slip factor. The dynamic analysis of the generator can be made easy by using wind turbine emulator. For small WECS system IG uses capacitors to assist the process of self-excitation. These types of generators are then called as self-excited induction generators (SEIG). SEIG are mostly used in standalone mode to attain isolated load demands where grid is not available. The only disadvantages of SEIG is it has poor voltage and frequency regulations due to variation in load impedance and turbine rotor speed. SEIG needs active and reactive power balances every time when operated in standalone mode. So a suitable controller can be used between generator and load in order to maintain voltage and frequency constant.

1.1 Motivation

Electric power consumption in the world is increased very rapidly causing the depletion of conventional energy sources like coal, gas etc. in a faster rate. So renewable energy can be used as substitute to slower the rate of depletion. This motivates researchers to pay attention towards every possible source of renewable energy. From the different forms of renewable energy wind energy is very important as it is a free and non-polluting source. The WECS uses a wind turbine and an electric generator to convert wind energy into electric energy. Turbine must be capable of using maximum wind energy with in the safety limits. Large scale wind power generation is at its peak on the basis of technology. However low power WECS is lagging behind in every aspect. This may be the motivating factor for researchers. Wind energy system normally uses induction generators for generating electric power. Grid connected induction generators can work properly as reactive power demand is fulfilled by the grid itself. But for isolated application simple capacitors or FACTS devices are used to balance the reactive power demand of IG. Now a days small wind turbines with SEIG are operated in standalone mode to attend remotely connected loads where electric grid is not available. SEIG uses capacitor bank at its stator terminal to provide self excitation. SEIG is very sensitive towards load impedances and speed variation of wind turbine rotor. Analysis of the transient characteristics of SEIG is very important. As wind turbines are not practicable in the laboratory to analyse the SEIG a wind turbine emulator is used to drive the generator. WTE imitates the dynamic characteristics of a wind turbine providing better flexibility to optimise the SEIG performance. These are the factors of motivation for this project.

1.2 Objective

- Modelling and Simulation of self-excited induction generator.
- Investigation of voltage build up process in SEIG by experiment.
- Simulation of WTE using DC motor.

1.3 Literature Review

Wind generation takes a significant place in the present time, thus they are considered as the most favourable to the mankind [1]-[2]. Integration of renewable energy in the existing power systems is the future demand due to the environmental concerns with conventional power plants [3]. Huge wind turbine with aero dynamics characteristics is used to capture wind efficiently and drive three phase induction generator for the massive production of electric power [4]. For generating power for in low power application self-excited induction generators are preferred. SEIG has lower cost compared to other generator, lower maintenance demands and natural protection against short circuit [5]-[6]. The project mainly focuses on the dynamic analysis and modelling of self-excited induction generator used for low power wind energy system. For studying the transient and steady state behaviour of SEIG several approaches are available i.e. impedance and admittance based model, d-q reference frame model [7]-[8]. The d-q analysis used for the project, considering air gap constant, sinusoidal distribution of the air gap magnetic field and absence of harmonic. The Core losses are neglected and rotor parameters must be referred to the stator side [8]. Furthermore detailed operational outline of self-excited induction generator are described. The self-excitation process and variation in output voltage and current in accordance with the change in excitation and load are verified experimentally. The minimum capacitance value essential to build up voltage has been calculated. Finally a dynamic model of SEIG is developed to analyse the transient conditions [9]. After analysis it is observed that though the self-excited induction generator is capable of building voltage with help of capacitor bank and can drive fixed load at constant speed, it cannot able to maintain the terminal voltage constant in the event of load variation and wind speed change. In other words the SEIG system have poor voltage and frequency regulation [10]. To improve the regulations i.e. voltage and frequency respectively several approaches are made using different control strategies. When SEIG works in stand-alone mode only capacitor excitation is not self-sufficient for driving the load because the load and wind speed are not certain with respect to time [11]. A constant threat of loss of excitation is persisted. Which imposes the use of an additional voltage and frequency control unit for providing dynamic stability to the system [12]. For driving the IG an emulator model is developed in MATLAB/Simulink environment using a D.C. motor. Due to simple and perfect performance characteristics D.C. motor is superior over other machines in order to imitate or emulate wind turbine for laboratory purpose [13]-[14]. The torque imitation scheme gives better performance and easy control over power imitation scheme [15]. For the project work a torque imitation scheme is used in order to imitate the wind turbine characteristics [16]. Experiments are conducted in lab to observe self-excitation and voltage build up process of SEIG.

1.4 Organization of the Thesis

The thesis contents are divided into four number of chapters. The summary of each chapter is given below.

Chapter 1: In this chapter the importance of renewable energy and most importantly the wind energy system is discussed. The motivating factors behind the project work is also described.

Chapter 2: This chapter describes about the self-excited induction generator and its analysis. This chapter fundamentally gives a clear picture of self-excitation phenomena in induction generator experimentally and detailed operational out line of SEIG.

Chapter 3: Different turbines and their constructions are discussed here. Also different controlling technique for wind turbines, governing equations are presented. Wind turbine emulator with D.C. motor is described.

Chapter 4: This chapter presents the conclusion and proposed future work.

CHAPTER 2

ANALYSIS OF SELF EXCITED INDUCTION GENERATOR

2.1 Introduction

For wind energy system induction generators are preferred over synchronous generators to produce electric power. The induction generators are externally driven machines. The construction and working is very simple and requires less maintenance. The dynamic characteristics of IG are excellent allowing the machine for use of both grid connected and standalone generation. The constant need of reactive power is the only demerits of IG. Reactive power flow can be managed by using simple capacitors or some power converters. In grid connected system the reactive power can be taken from the grid for real power generation via slip control when the machine is rotated above the synchronous speed. The operation of grid connected system is simple and autonomous as the voltage and frequency are controlled by the grid. Power generation for far flung areas can be done using self excited induction generators. The SEIG system uses capacitor for voltage build up. The reactive power from the stator capacitor are shared by load and the machine for self excitation. SEIG is very sensitive to wind speed change. Also load impedance governs the voltage regulation of the overall system. So some intermediate systems must be used to improve the voltage and frequency regulation. Power converters and FACTS devices can be used to make SEIG operate in steady condition.

2.2 SEIG System ConFiguration

Self-excited induction generator is simply an induction machine coupled with a prime mover. For generator action the magnetization field is created by the use of capacitor bank at the stator terminals. The detailed conFiguration of the SEIG system is shown in the Fig. 2.1. The active power required by the load is supplied by the induction generator by extracting power from the prime mover.

The capacitors bank for self-excitation must be connected to the stator terminals of the induction machine to generate sufficient amount of reactive power so as to fulfil the reactive power requirement of the load as well as the induction generator.

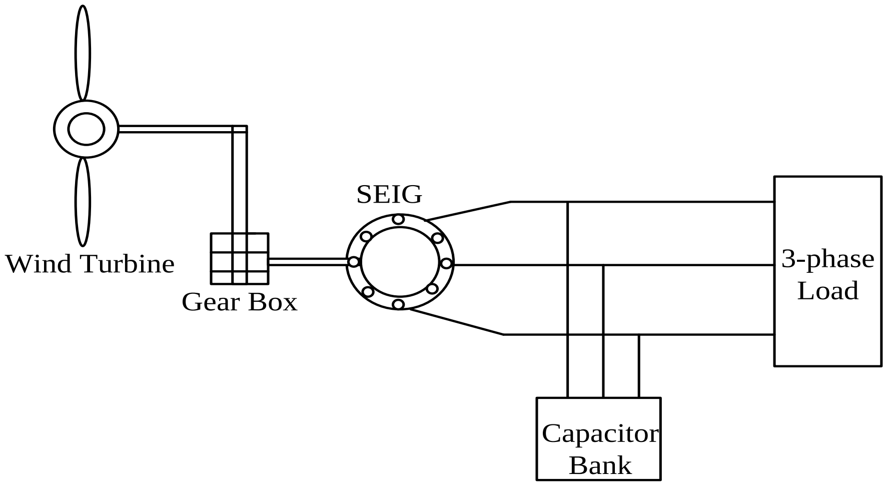

Fig. 2.1. Schematic diagram of a self-excited induction generator

The excitation capacitor must be well calculate in accordance to load to avoid the excitation failure. If the load or wind speed varies then the excitation process is directly disturbed so excitation failure occurs. If the load impedance is increased the reactive power demand goes beyond the capability of excitation capacitor as the reactive power is mutually shared between load and the generator itself. Therefore, increased impedance of the load creates drop in generating voltage resulting poor voltage regulation. Due to change in wind speed the slip is changed which causes poor frequency regulation. For constant load application capacitor excited system is suitable.

2.3 The Self-excitation Process

Self excitation process allows the induction generator to work as SEIG when the rotor is running at a speed greater than the stator magnetic field. For self excitation the rotor core must have sufficient residual magnetism and capacitor connected with the stator should have some initial magnetizing current. Capacitor bank having suitable capacitance values are necessary at the stator terminals of an externally driven induction machine to develop e.m.f. For self excitation the machine windings must possess some residual magnetism. If there is a loss in residual magnetism then it can be regained by connecting a charged capacitor across the winding terminals or by simply driving the IM at no load for few minutes. The e.m.f. which is induced will cause a leading current to flow through the capacitor. Flux produced due to the current will help to gain more residual magnetism. So the machine flux will increase constantly inducing larger e.m.f. Therefore the current and flux increases. The SEIG works closer to the saturation limits. The value of excitation capacitance, magnetization characteristics, prime mover speed and electrical load are the factors governing the steady state operation of SEIG. The value of excitation capacitor for voltage build up mainly depends on rotor speed, load parameters and magnetising characteristics of the machine.

2.4 Mathematical modelling of SEIG

By the help of mathematical transformations the complexity for analysis of SEIG is solved. Three axes to two axes transformation gives simplified mathematical expression for the generator and helps in developing machine model in MATLAB. More clear understanding of different circuit parameters and its importance can be visualised by observing the equation obtained from axes transformation. Let us consider a three phase symmetrical machine and the three axes are separated at120 degree from each other. The real three phases of the supply are represented by the three axes. d and q are the two imaginary phases in tangent to each other. For the analysis it is assumed that all the axes are in a stationary reference frame. The abc to dq0 transformation by the help of Kron's primitive machine mode is discussed. The Fig. 2.2 shows the three axes and two axes representation of SEIG. The per-phase equivalent circuit representation from conventional analysis is helpful for steady state analysis. For dynamic analysis d-q modelling is used to represent the SEIG. The transformation makes a systematically changes in variables to obtain a desired reference frame. Transforming SEIG to rotating reference frame is simple.

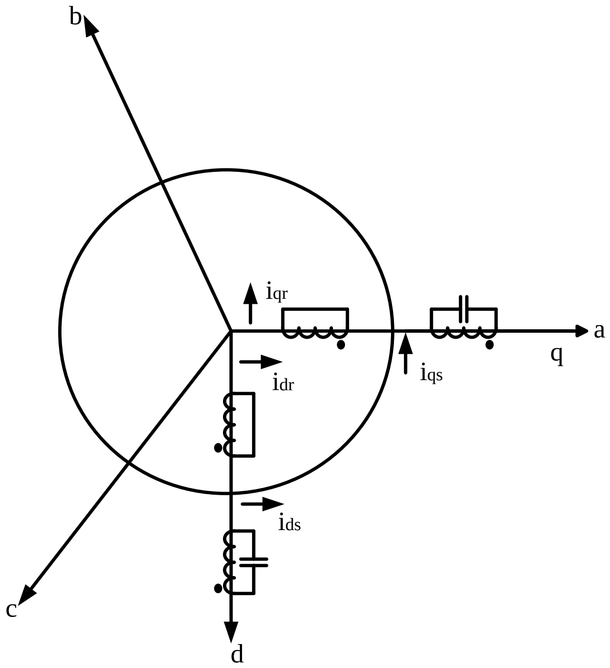

Fig. 2.2. Axes transformation of induction generator.

A rotating reference frame come to be stationary if the rotational speed of the reference frame is zero. If the angular speed of reference frame is equal to excitation frequency, the variables will seems as constant instead of time-varying values after transformed into the rotating reference frame. d-q axes of SEIG are shown in Fig. 2.3.

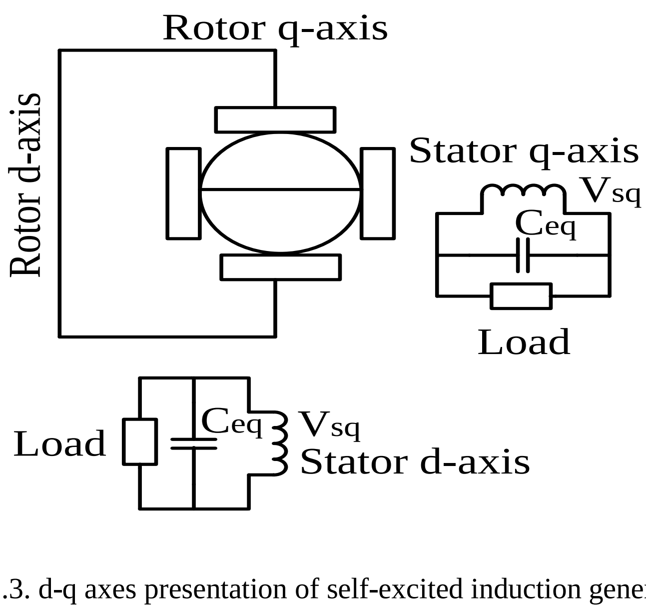

Fig. 2.3. d-q axes presentation of self-excited induction generator.

The current direction and voltage polarities are shown in the d-q equivalent circuits.

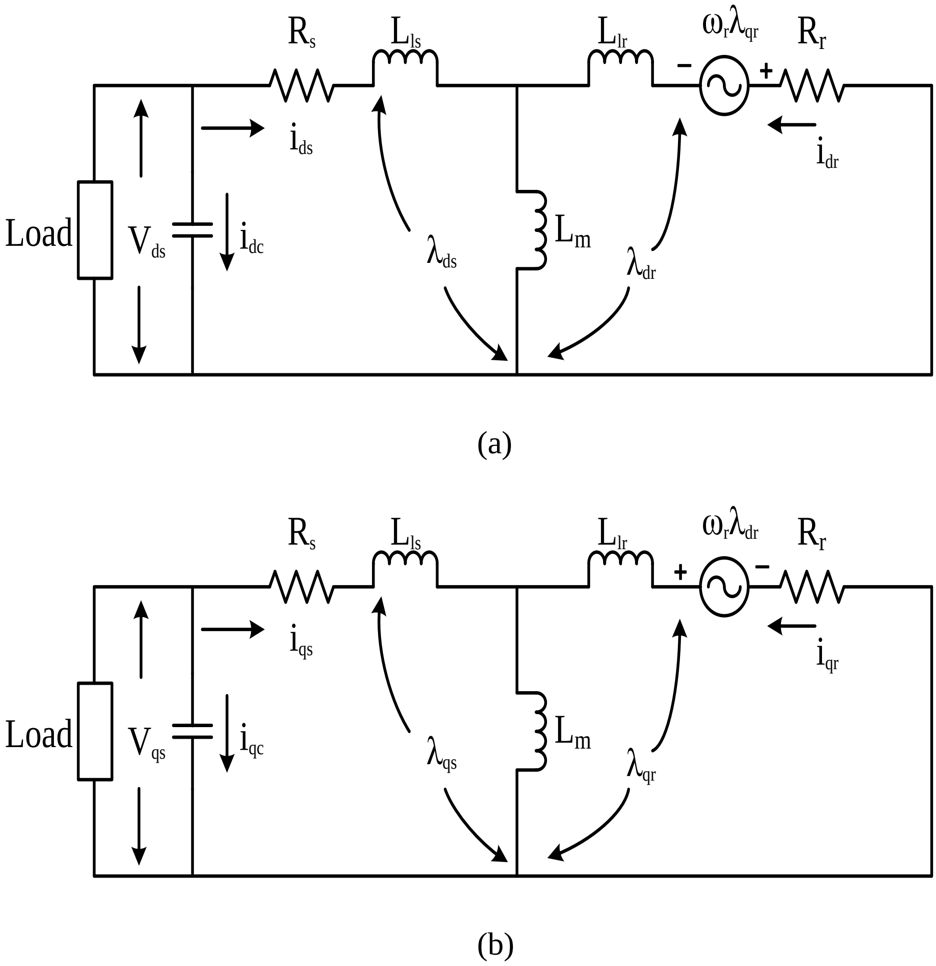

Fig. 2.4. Equivalent circuit of SEIG in d-q stationary reference frame (a) d-axis, (b) q-axis

From the d-q equivalent circuit the differential equations are derived which helps for mathematical analysis to determine the final expressions. Mathematical analysis are done by taking several books and journals as references [3]-[4]. The dynamic model of SEIG represented in terms voltage and flux linkage equations is given below.

$$V_{qs}^{s} = R_s i_{qs}^{s} + \frac{d\lambda_{qs}^{s}}{dt} \tag{2.1}$$

$$V_{ds}^{s} = R_s i_{ds}^{s} + \frac{d\lambda_{ds}^{s}}{dt} \tag{2.2}$$

$$0 = R_r i_{qr}^{s} + \frac{d\lambda_{qr}^{s}}{dt} - \omega_r \lambda_{qr}^{s} \tag{2.3}$$

$$0 = R_r i_{dr}^s + \frac{d\lambda_{dr}^s}{dt} - \omega_r \lambda_{dr}^s \tag{2.4}$$

Taking, $V_{qr} = V_{dr} = 0$

The expression for flux linking are given as,

$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr} \tag{2.5}$$

$$\lambda_{qr} = L_s i_{qr} + L_m i_{qs} \tag{2.6}$$

$$\lambda_{ds} = L_s i_{ds} + L_m i_{ds} \tag{2.7}$$

$$\lambda_{dr} = L_s i_{dr} + L_m i_{ds} \tag{2.8}$$

$$\frac{di_{qs}}{dt} = \frac{1}{(\mathrm{L}_s \mathrm{L}_r - \mathrm{L}_m^2)}[-\mathrm{L}_s\, r_s\, \mathrm{i}_{qs} - \omega_r\, \mathrm{L}_m^2 \mathrm{i}_{ds} + L_m\, \mathrm{r}_r \mathrm{i}_{qs} - \omega_r\, \mathrm{L}_m \mathrm{L}_r \mathrm{i}_{dr} + \mathrm{L}_s \mathrm{V}_{qs}] \tag{2.9}$$

$$\frac{di_{ds}}{dt} = \frac{1}{(\mathrm{L}_s \mathrm{L}_r - \mathrm{L}_m^2)}[\omega_r\, \mathrm{L}_m^2 \mathrm{i}_{qs} - \mathrm{L}_r\, r_s\, \mathrm{i}_{ds} + \omega_r\, \mathrm{L}_m \mathrm{L}_r \mathrm{i}_{qr} + L_m\, \mathrm{r}_r \mathrm{i}_{dr} + \mathrm{L}_r \mathrm{V}_{ds}] \tag{2.10}$$

$$\frac{di_{qr}}{dt} = \frac{1}{(\mathrm{L}_s \mathrm{L}_r - \mathrm{L}_m^2)}[L_m\, \mathrm{r}_s \mathrm{i}_{qs} + \omega_r\, \mathrm{L}_m \mathrm{L}_s \mathrm{i}_{ds} - \mathrm{L}_s\, r_r\, \mathrm{i}_{qr} + \omega_r\, \mathrm{L}_s \mathrm{L}_r \mathrm{i}_{dr} - \mathrm{L}_m \mathrm{V}_{qs}] \tag{2.11}$$

$$\frac{di_{dr}}{dt} = \frac{1}{(\mathrm{L}_s \mathrm{L}_r - \mathrm{L}_m^2)}[-\omega_r\, \mathrm{L}_m \mathrm{L}_s \mathrm{i}_{qs} + L_m\, \mathrm{r}_s \mathrm{i}_{ds} - \omega_r\, \mathrm{L}_r \mathrm{L}_s \mathrm{i}_{qr} - \mathrm{L}_s\, r_r\, \mathrm{i}_{dr} + \mathrm{L}_m \mathrm{V}_{ds}] \tag{2.12}$$

Where,

$$L_s = L_{ls} + L_m$$

$$L_r = L_{lr} + L_m$$

$$\lambda_{ds} = L_s i_{ds} + L_m i_{dr}$$

$$\lambda_{qs} = L_s i_{qs} + L_m i_{qr}$$

The torque can be expressed in terms of current as,

$$\text{Electromagnetic torque } T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right) L_m [i_{qs} i_{dr} - i_{ds} i_{qr}] \tag{2.13}$$

Mathematical modelling of induction machine is done and implemented in simulation model.

2.5 Modelling of excitation capacitor

The following state equation are involved for the excitation system,

$$i_{dc} = i_{ld} + i_{cd} \tag{2.14}$$

$$i_{qc} = i_{lq} + i_{cq} \tag{2.15}$$

$$\frac{dv_{ld}}{dt} = \left(\frac{i_{dc}}{c} - \frac{i_{ld}}{c}\right) \tag{2.16}$$

$$\frac{dv_{lq}}{dt} = \left(\frac{i_{qc}}{c} - \frac{i_{lq}}{c}\right) \tag{2.17}$$

2.6 Modelling of load impedance

Magnetizing reactive power of a capacitor bank causes self-excitation to an IG, which is connected to a balanced resistive load. The d-q axis current equation for balanced resistive load can be given by equation

$$i_{rq} = \frac{v_{sq}}{R_L} \tag{2.18}$$

$$i_{rd} = \frac{v_{sd}}{R_L} \tag{2.19}$$

If the load is of R-L in nature then, the load equation will be

$$v_{ld} = Ri_{ld} + \frac{di_{ld}}{dt}L$$

$$i_{ld} = \int\left[\left(\frac{1}{L}\right)v_{ld} - \left(\frac{R}{L}\right)i_{ld}\right] \tag{2.20}$$

$$v_{lq} = Ri_{lq} + \frac{di_{lq}}{dt}L$$

$$i_{lq} = \int\left[\left(\frac{1}{L}\right)v_{lq} - \left(\frac{R}{L}\right)i_{lq}\right] \tag{2.21}$$

Capacitance value of the load is added parallel with the excitation capacitor. SEIG dynamic behaviour can be represented by state space matrix. By solving these state variables we can get the values of voltage and current at any instant during self-excitation process as well as during varying load condition can be obtained by solving the state space matrix and the state variables. The state variables in matrix form is given below.

$$\frac{d}{dt}\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \\ v_{ds} \\ v_{qs} \\ i_{dl} \\ i_{ql} \end{bmatrix} = K\begin{bmatrix} R_sL_r & -\omega L_m^2 & -R_rL_m & -\omega L_mL_r & L_r & 0 & 0 & 0 \\ \omega L_m^2 & R_sL_r & \omega L_mL_r & -R_rL_m & 0 & L_r & 0 & 0 \\ -R_sL_m & \omega L_mL_s & R_rL_s & \omega L_sL_r & -L_m & 0 & 0 & 0 \\ -\omega L_mL_s & -R_sL_m & -\omega L_sL_r & R_rL_s & 0 & -L_m & 0 & 0 \\ -1/c_{cd}k & 0 & 0 & 0 & 0 & 0 & -1/c_{cd}k & 0 \\ 0 & -1/c_{cq}k & 0 & 0 & 0 & 0 & 0 & -1/c_{cq}k \\ 0 & 0 & 0 & 0 & 1/L_lk & 0 & -R_l/L_lk & 0 \\ 0 & 0 & 0 & 0 & 0 & -1/L_lk & 0 & -R_l/L_lk \end{bmatrix}\begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \\ v_{ds} \\ v_{qs} \\ i_{dl} \\ i_{ql} \end{bmatrix}$$

$$+\begin{bmatrix} -L_r & 0 & L_m & 0 \\ 0 & -L_r & 0 & L_m \\ L_m & 0 & -L_s & 0 \\ 0 & L_m & 0 & -L_s \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}\begin{bmatrix} v_{ds} \\ v_{qs} \\ v_{dr} \\ v_{qr} \end{bmatrix} \tag{2.22}$$

Where, $k = \dfrac{1}{L_m^2 - L_sL_r}$

C_{dc}, C_{qc} are the equivalent capacitor values for d and q axes respectively.

Relating the above equations, the voltage and current can be given in matrix form as,

$$\begin{bmatrix} v_{ds} \\ v_{ds} \\ v_{ds} \\ v_{ds} \end{bmatrix} = \begin{bmatrix} R_s + \frac{dL_S}{dt} + \frac{(\mathrm{R}+\frac{dL}{dt})}{(\frac{d^2(LR)}{dt} + \mathrm{RC}+1)} & 0 & \frac{dL_m}{dt} & 0 \\ 0 & R_s + \frac{dL_S}{dt} + \frac{(\mathrm{R}+\frac{dL}{dt})}{(\frac{d^2(LR)}{dt} + \mathrm{RC}+1)} & 0 & \frac{dL_m}{dt} \\ \frac{dL_m}{dt} & \omega_r L_m & \frac{dL_r}{dt} & \omega_r L_r \\ -\omega_r L_m & \frac{dL_m}{dt} & -\omega_r L_r & \frac{dL_r}{dt} \end{bmatrix} \quad (2.23)$$

For the simulation of SEIG the mathematical equations obtained from the D-Q analysis are used. Different sub systems based on mathematical expressions are put together to get final SEIG model.

CHAPTER 3

ANALYSIS OF WIND TURBINE AND MODELLING OF WINDTURBINE EMULATOR

3.1 Introduction

As the real wind turbines are not practically viable for research analysis in the laboratory. A model based system called as wind turbine emulator can be developed and used in place of practical wind turbines. The WTE basically uses a motor and a control unit to imitate the wind turbine characteristics. The development of the large and medium size wind turbine and the technology related to this is at the optimum point but the advancement of small scale wind turbines is lagging in terms of technological maturity and cost effectiveness. To improve and enhance the ability of small wind turbines, a laboratory setup is required using D.C. motors. It also gives the opportunity to synthesize the steady state and dynamic behaviours of isolated wind power generation system under roof. Many research studies are going on the concerned areas to develop better wind turbine models for driving SEIG.

3.2 Basic principles of wind turbines

There have been a rapid growth in utilization of wind power over last few decades. Wind power generation has become a vital contributor to recent power systems due to its outstanding features, encouraging researchers to give concerns over proper design and development of wind turbines. In wind energy system the turbine captures the wind energy and delivers it to the generator for electrical energy generation. The rotation of turbine depends on wind speed and several other factors. So it is very significant to study the different characteristics of wind turbine. One more important thing is how more and more wind energy can be obtained in a controlled manner. So more research are going on to improve the performance capability of wind turbine.

Several wind turbine models are available till date, they are basically divided in two types based on position of the axis of rotation. They are,

(a) Horizontal axis wind turbines

In this type of turbine the shaft the rotor and generator are kept on the upper most portion of tower and the blades are facing to wind flow direction. The slow rotation of blades are converted to moderate speed by the use of proper gear arrangements. The gearbox is important for driving the rotor shaft in a perfect way. Present horizontal axis wind turbines consists of blade and rotors assembly that is analogous to aircrafts propellers operating on aerodynamic concept.

(b)Vertical axis wind turbines

For vertical-axis turbines, the shaft of rotor is placed in traverse direction not necessarily in vertical direction, to the wind flow and the main apparatuses are placed at the turbine base. This arrangement permits the gearbox and generator to be positioned close to the ground level, giving greater flexibility for maintenance work. Vertical axis wind turbines do not need to be directed towards the wind, so wind sensing and orientation mechanisms are not required.

Terms related to wind turbine

Some important nomenclatures regarding the wind turbine is described below. Which gives a clear idea of wind turbine models and the controlling parameters.

(a) Solidity

Solidity is the ratio between projected areas of blade to the intercepted wind area. The area of blade which is faced to the wind direction is called projected area.

$$Solidity = \frac{Projected\ blade\ area}{Rotor\ swept\ area}$$

(b)Tip Speed Ratio (TSR)

Ratio between linear velocity of wind turbine rotor blade tip and speed of air called as tip speed ratio.

$$\lambda = \frac{\omega_r r_r}{V_w}$$

Where, r_r = radius of rotor (m)

ω_r= angular speed (rad/sec)

V_w= speed of wind flow (m/s).

(c) Performance coefficient

Coefficient of performance is a measure how efficiently the wind turbine converts the energy in the wind into electricity. It is also known as the power conversion coefficient.

$$C_P = \frac{P_r}{P}$$

Here C_P is the power conversion coefficient that shows the efficiency of the blades to acquire the power from wind.

3.3 Wind energy conversion system

Now a days the horizontal axis wind turbine are extensively used amongst the other range of wind turbine designs. Cost effective low power horizontal axis turbine design is more beneficial in rural and remote areas. The main blocks of wind power system is divided as follows,

(a)Rotor assembly

The rotor consists of aerodynamic blades connected to the hub. The performance of a wind turbine is critically affected by geometrical position of the blade, and in all wind turbine designs, this is likely to be the most costly part of the unit.

(b)Drive train

The drive train links the turbine rotor shaft to the generator unit. In big wind turbine generation systems, the drive train consists of gear box to intensify the rotational velocity from the rotor into the generator in order to rotate the generator at preferred speed.

But in case of Small turbines gear arrangement are not provided, the drive train for those systems are simply a connecting shaft.

(c) Generator

The generator unit alters the mechanical rotational power of the drive train into electrical power. For Small wind turbine generators normally 3-phase permanent magnet type machines are used. Small power application for isolated system normally uses induction generators with capacitor bank in order to generate power.

(d)Controller

Power electronics interface circuits are necessary for protecting the system from possible breakdown. A suitable controller is needed to convert the output voltage of the generator to domestic voltage level.

3.4 Wind turbine characteristics

Study of different characteristics of wind turbine are very essential to know the behaviour of the overall system during different dynamic conditions. Important wind turbine characteristics are shown below.

(a) Speed torque Characteristics

The curve between rotor speed and developed torque is defined as speed torque characteristics of wind turbine. The characteristic for a normal two blade system is shown in Fig. 3.1.

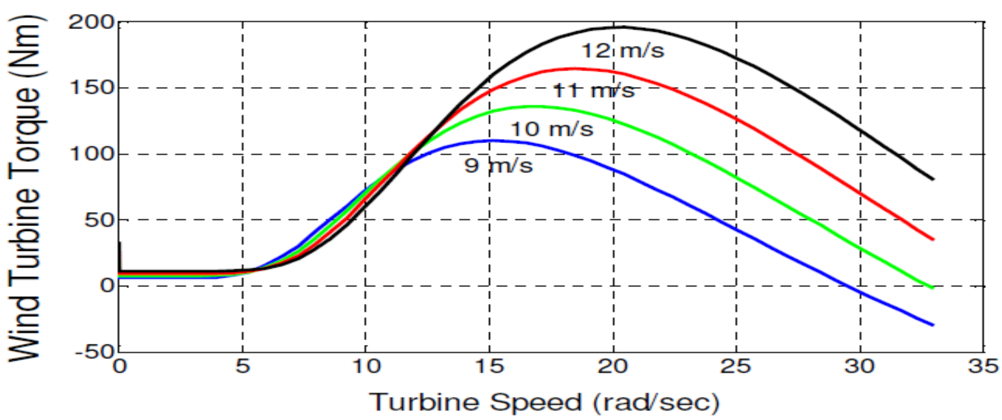

Fig.3.1. Speed torque characteristics of wind turbine

The Wind turbine mechanical torque can be stated as

$$T_m = 0.5 * \rho A r_r C_M V_w^2$$

Where ρ = Density of air in kg/m^3

A= area enclosed by rotor blades in (m^2)

$$C_M = \frac{C_p}{\lambda}$$

C_r = torque coefficient

r_r= radius of rotor in meters.

(b) Power-Speed Characteristics

Total mechanical power transferred to the rotor shaft is:

$$P = 0.5 * C_p A \rho V_w^3$$

Where, ρ is the air density in kg/m^3

V_w implies to the wind speed in m/s

A is the captured area in m^2

The curve between power and speed shows the relationship of mechanical power harvested from the wind and the rotor speed at different wind flow conditions. At a particular wind speed the turbine speed reaches its maximum value so higher power can be achieved at output side.

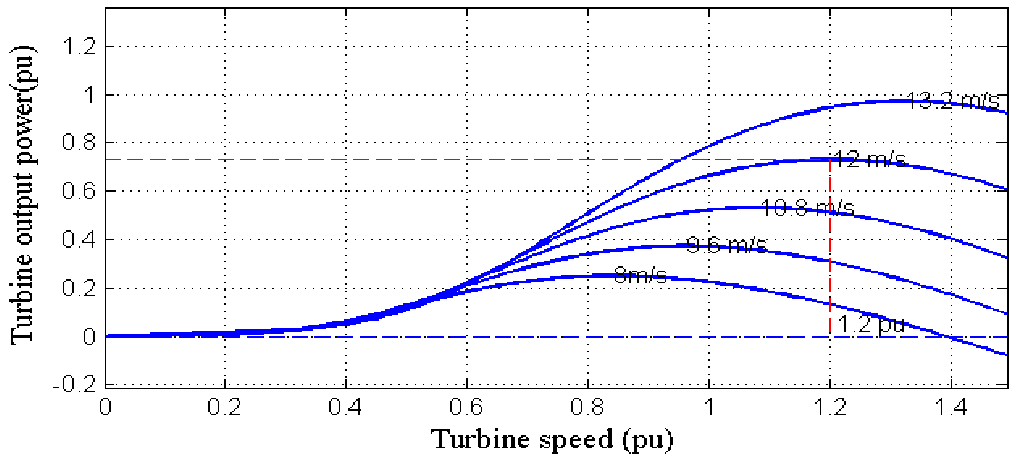

Fig. 3.2. Power-speed characteristics of wind turbine

3.5 The wind turbine emulator

Wind Turbine Emulator (WTE) is a hardware configuration that imitates the static and dynamic characteristics of a real wind turbine. Due to simple and perfect performance characteristics D.C. motor is superior over other machines in order to imitate or emulate wind turbine for laboratory purpose. For the perfect imitation of wind turbine characteristics the operating principles and power-torque characteristics of D.C. motor is compared with the turbine. Then different imitation scheme are studied. The power and a torque imitation scheme were put forward and compared. The torque imitation scheme gives better performance and easy control over power imitation scheme. For the project work a torque imitation scheme is used in order to imitate the wind turbine characteristics and driving the SEIG. The wind turbine emulator model is developed in MATLAB. The wind turbine emulator can be employed for different experiments, for example for studying the influence of wind shear and tower shadow in power quality. The emulation of the wind turbine is done by means of a commercial DC motor drive under torque control. The emulator schematic diagram is shown in Fig. 3.3.

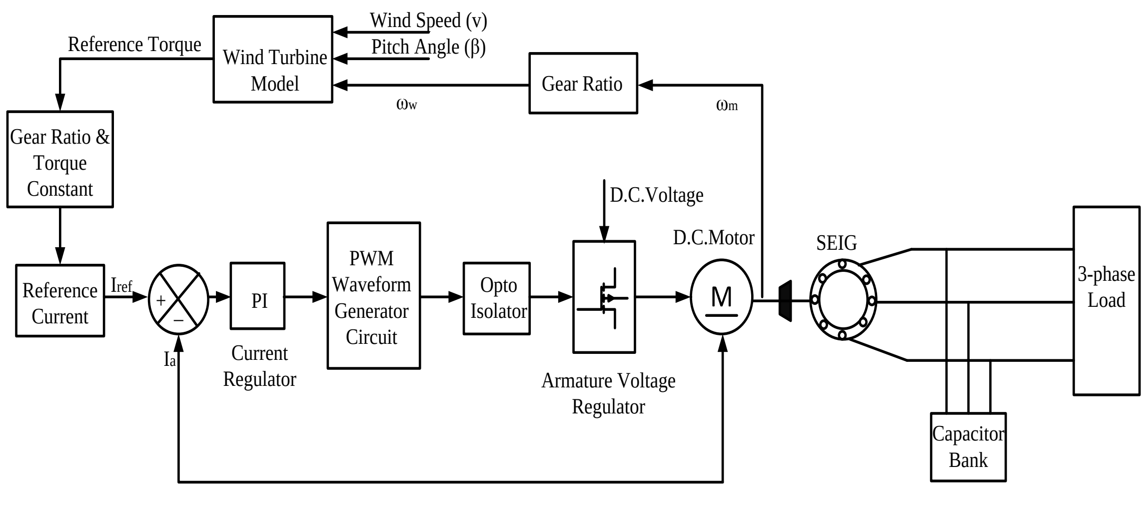

Fig. 3.3. Wind turbine emulator schematic diagram

The proposed model of the WTE using a DC motor is shown in the above. Here the wind turbine model is the important block, inputs to the model are the wind speed, angular speed and pitch angle.

The armature current is obtained by using current sensors. After getting the current from sensor end it is compared with the theoretical current value obtained from torque. The error value is passed through the PI controller. The current regulator give a signal to the PWM waveform generator circuit which compares it with a ramp signal having high frequency to generate the required PWM pulse for driving the power switch which is nothing but a MOSFET. As MOSFET is a controlled switch it can control the armature voltage. The variation in armature voltage in turn controls the armature current in accordance with the reference current and the system eventually reaches a steady state. At steady state power and current of WTE are very closely matching with the reference power and current value provided the speed of shaft changes according to the wind speed variation.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Simulation results of WTE

The wind turbine emulator model created in MATLAB is simulated and the results are given below. Fig. 4.1 shows the curve between power coefficient and the tip speed ratio. The power coefficient is maximum at a particular speed.

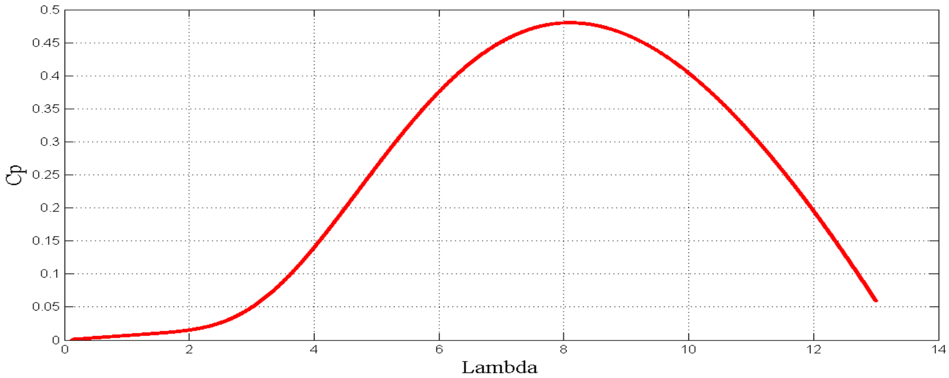

Fig. 4.1. Curve between power coefficient and tip speed ratio

The actual armature current of the D.C. motor used for WTE is measured with the help of current sensor and compared with the reference value calculated from the torque equation.The difference is processed by a PI controller for proper tuning. A PWM generator is used to generate the gatting pulse for the armature voltage control switch.The Fig. 4.2 shows both the actual and reference armature current of D.C. motor.

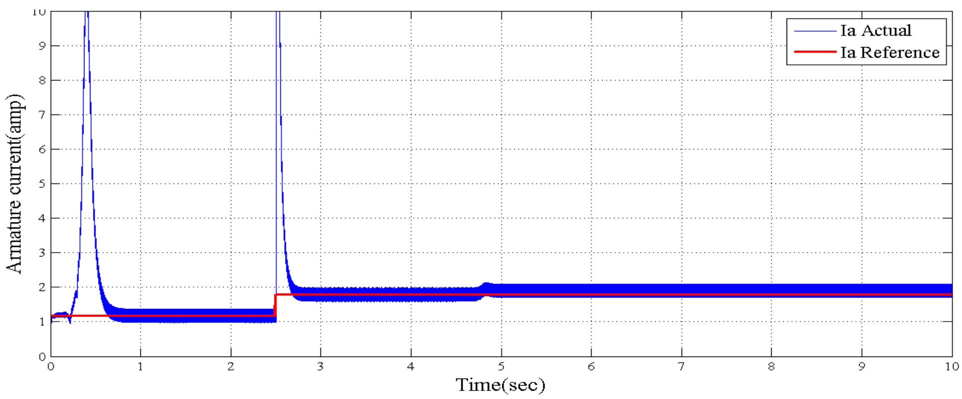

Fig. 4.2. Armature current

The speed of the WTE is show in the Fig. 4.3 .The speed increases up to 100 rad/sec and then there is a step change at 2.5 sec due to wind variation. The speed reaches at 150 rad/sec.

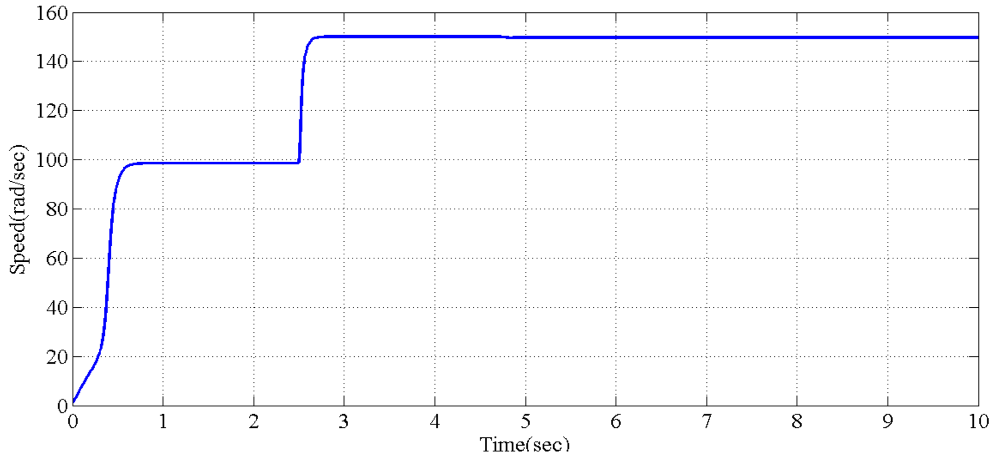

Fig. 4.3. Rotor speed of WTE

Fig. 4.4 shows the torque generated from WTE which is fed to the IM for operating as generator.

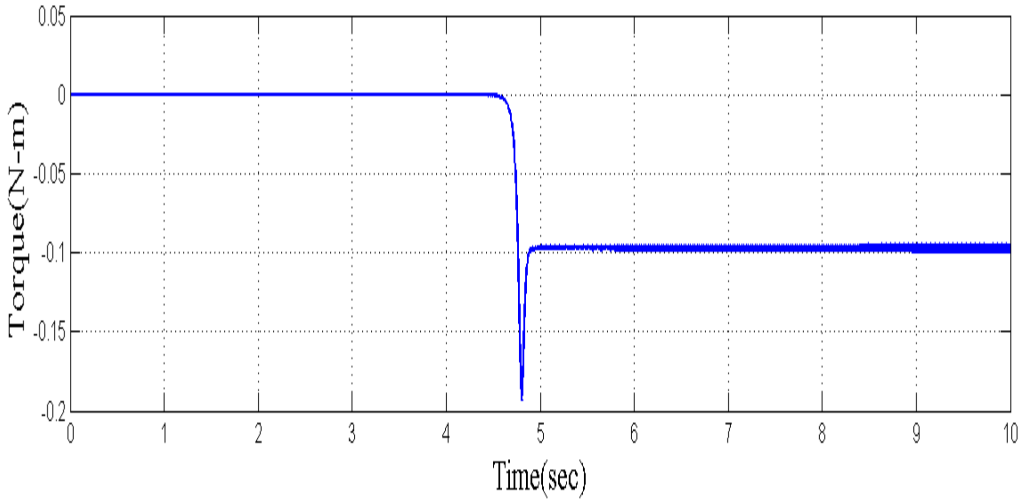

Fig. 4.4. Torque of WTE

4.2 Results and discussion for SEIG

The simulation of an induction machine operating as generator is simulated using capacitor excitation in MATLAB environment. The simulation result and experimental results are shown below.

The Fig. 4.5 shows the magnetizing current curve of the self-excited induction generator with respect to time.

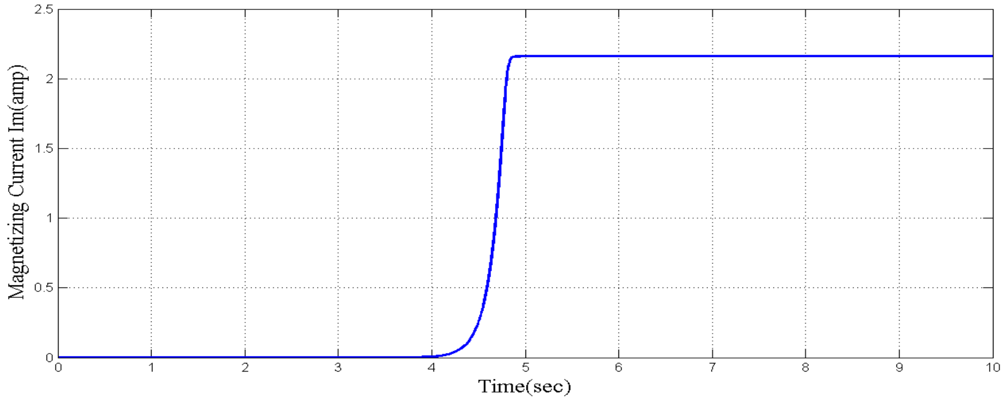

Fig. 4.5 Curve for magnetizing current w.r.t time

Fig. 4.6 shows the magnetizing inductance. The plot between L_m and I_m given in Fig. 4.7 shows the magnetization curve.

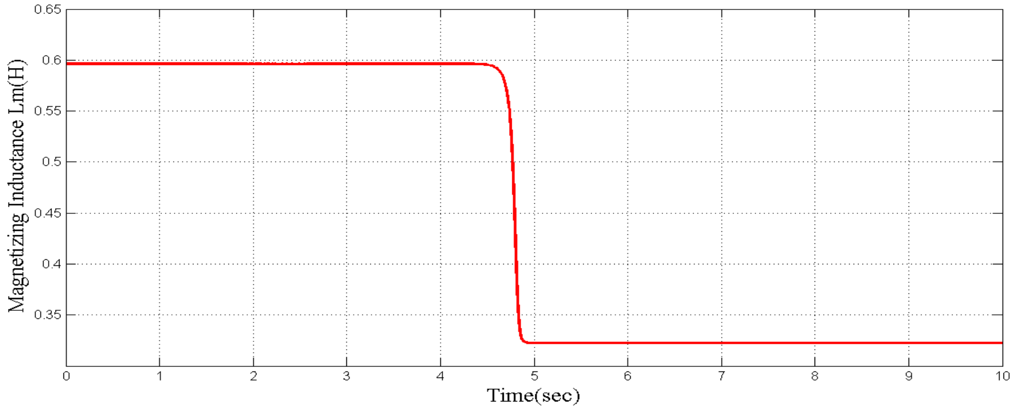

Fig. 4.6. Magnetizing inductance Vs. Time

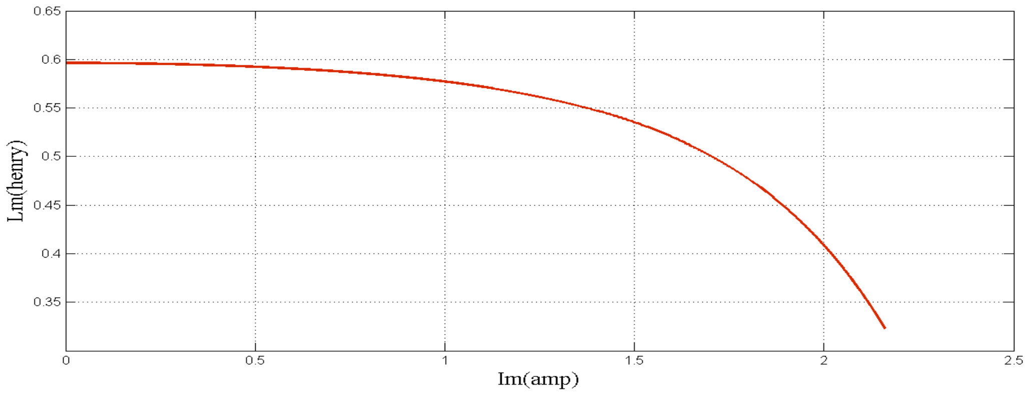

Fig. 4.7. Magnetizing current Vs. Magnetizing inductance

The stator terminal voltages and currents are obtained both by simulation and laboratory experiment. From the simulation result shown in Fig. 4.8 it is observed that voltage gradually build up sinusoidaly from zero to rated output voltage. At t = 4.77 sec the voltage reaches to the peak value and then slightly deacresed when UPF load of 0.5 KW is applied.After t =4.8 reaches its steady state with magnitude 280 Volt.

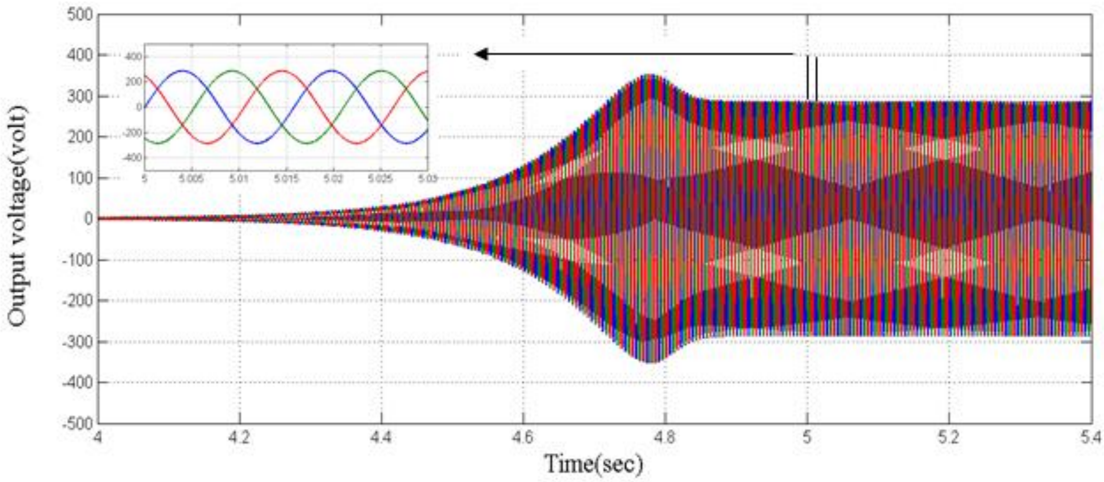

Fig. 4.8. Stator terminal voltage (Simulation result)

Fig. 4.9 shows the generator voltage obtained from experiment.

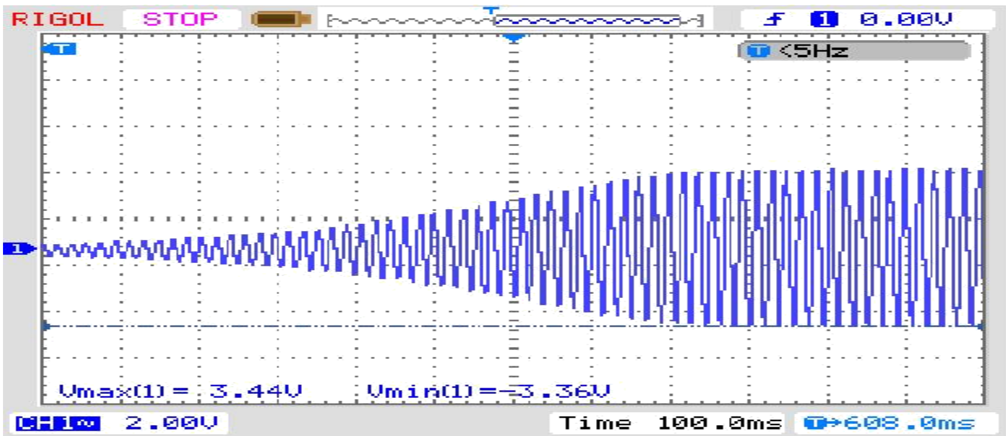

Fig. 4.9. Stator terminal voltage (Experiment result)

Experiments are done with a 3.7 KW induction machine and an appropriate capacitor value is chosen for excitation i.e. 23μF. The voltage build up process is initially observed by taking suitable capacitor value.

As UPF load is applied the current wave form is in phase with voltage .The steady state current value obtained from simulation is 2.33Amp shown in Fig. 4.10.

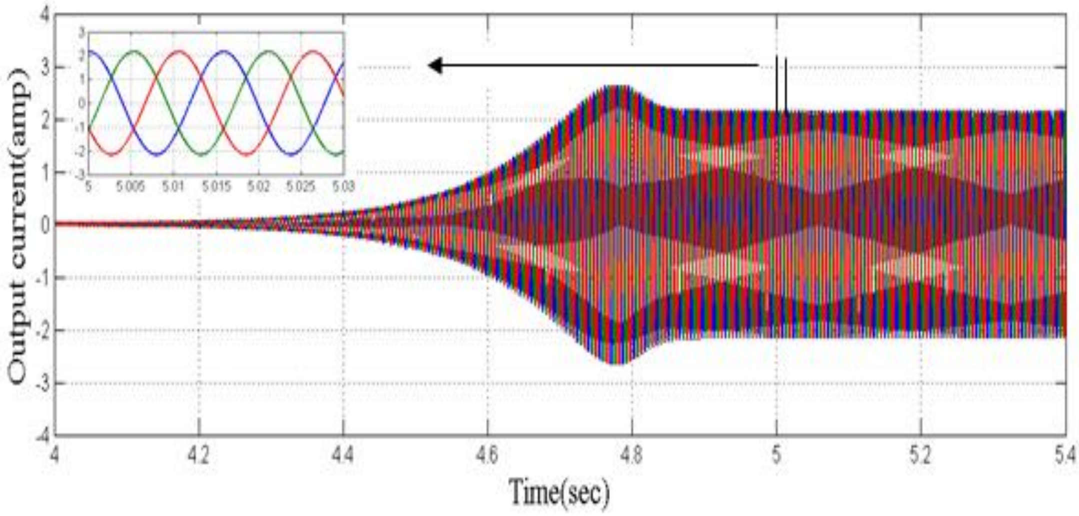

Fig. 4.10. Output current (Simulation result)

UPF load of 0.5 KW is inserted when the generator is builing voltage, it can be observed that the voltage is droped to a lower value. Current can be measured by using standard resistance series with the load having value 1Ω. The frequency measured is 50.064 Hz. The second wave form of Fig. 4.11 shows the voltage across the stanard resistance. From that the value of load current can be calculated which is nearly 2.38 amp.

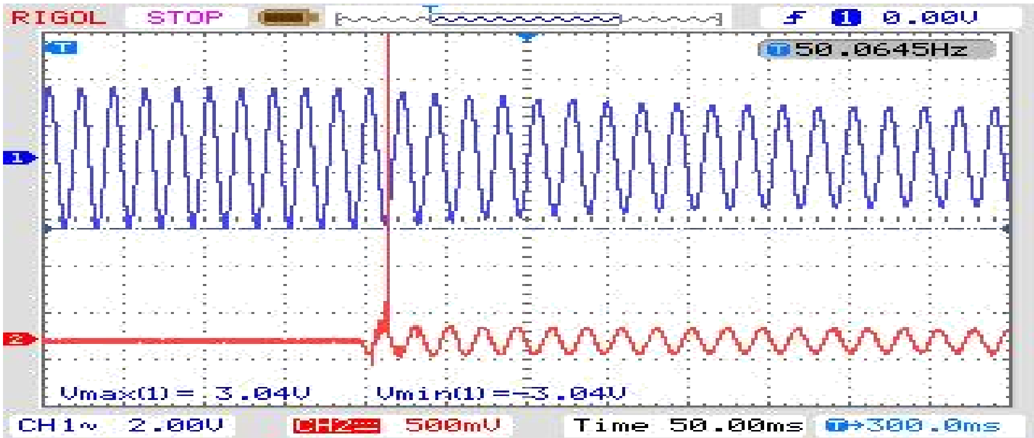

Fig. 4.11. Variation of voltage when load is applied

The peak value of per phase voltage is shown in Fig. 4.12.

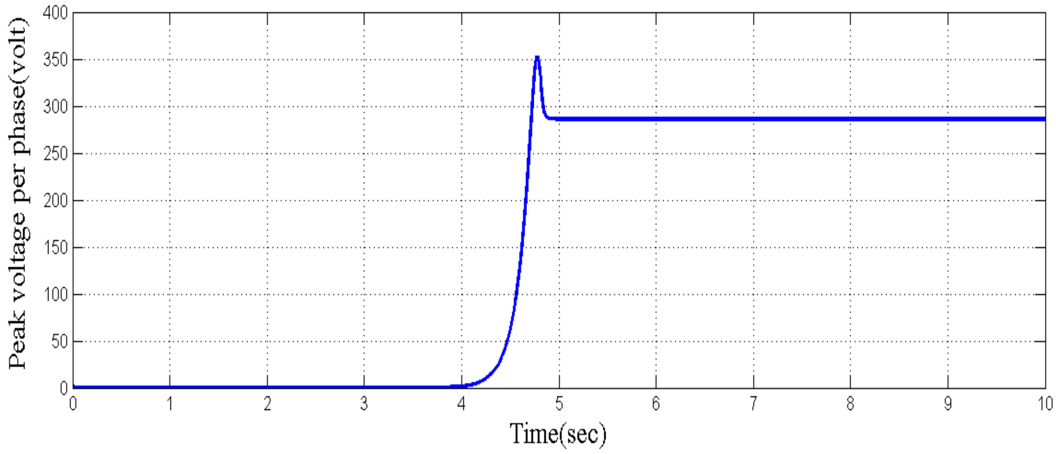

Fig. 4.12. Phase voltage of SEIG

The results obtained from the simulation and from the experiment are observed carefully and the validation of the results are established.

CHAPTER 5

CONCLUSION

The performance characteristics of a SEIG used for isolated generation system are studied and MATLAB simulation model is developed. Also experiments are performed to validate the simulation result. Dynamic analysis of the induction machine is done by modelling the induction machine in stationary reference frame. The key parameter governing the self-excitation process and voltage build up across the generator is the Magnetizing inductance. Mathematical expressions obtained from the abc-dq0 analysis gives a clear insight of different variables and their behaviour during dynamic condition. The concepts and advances in wind turbine technology is studied. Emulation of wind turbine is done using a D.C. motor. The wind turbine emulator driving the SEIG is simulated in MATLAB/Simulink environment. The outcomes of this project are mathematical modelling of SEIG, d-q analysis and study the importance of excitation capacitance, mutual inductance and speed on self-excitation process of induction generator. By the help of WTE it is very simple to analyse the dynamic behaviour of SEIG during transient conditions as the wind emulator gives similar characteristics as that of a real wind turbine.

FUTURE SCOPE

The analysis and explanations presented in the thesis gives clear idea about the strength and weakness of capacitor excited induction generators. It is observed that the SEIG system have poor voltage and frequency regulation. A suitable FPGA controller can be developed taking balanced and unbalanced load. The laboratory set up of wind turbine emulator can be developed including MPPT technique.

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APPENDIX A

Induction Machine Parameters operated as SEIG

3.7 KW, 415 Volt, 7.6 Amp, 4Pole machine

R_s (Ω)	R_r (Ω)	X_{lr} (Ω)	X_{ls} (Ω)	L_m (H)	J(kgm^2)
6.53	**5.86**	**9.3**	**9.3**	**0.69**	**0.086**

D.C. motor parameters used for WTE

Rated power	**3.5 Kw**
Rated Speed	**1500RPM**
Rated current	**18.5Amp**
Rated voltage	**220Volts**
Excitation voltage	**220Volts**