DESIGN AND DEVELOPMENT OF A SIMPLE LOAD SWITCH BASED CONTROL STRATEGY FOR THE OPERATION OF WIND DRIVEN GENERATOR

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Abstract : The increasing importance of fuel saving has been responsible for the revival of alternate source of energy. Thus, there exists a drive towards the decentralization of power generation and an increased use of renewable energy sources like wind, solar, biogas etc. With the increased use of wind turbine for power generation, wind energy is being harnessed extensively for electrical power generation. The kinetic energy from the wind is converted into electrical energy by means of an alternator. For the extraction of constant AC output voltage, switching schemes are used. Loads are switched in and out in order to maintain the voltage within the band. This is done using closed loop control.

***IndexTerms*–decentralization, Wind turbine, SEIG.**

I. INTRODUCTION

With increasing environmental concern, and approaching limits to fossil fuel consumption, wind power has regained interest as a renewable energy source. It is increasingly becoming more useful and sufficient in providing energy for many areas of the world, especially in temperate climates. Wind power is the ability to make electricity using the air flow that occurs naturally in the earth’s atmosphere. Wind turbine blades capture kinetic energy from the wind and turn it into mechanical energy, spinning a generator that creates electricity. A wind energy conversion system or wind energy harvester is a machine that, powered by the energy of the wind, generates mechanical energy that can be used to directly power machinery or to power an electrical generator for making electricity.Analysis and design of electronic load controller for self excited induction generator has been reported by BhimSingh*et al*[3]. In this design, a suitable control scheme was proposed such that the load on SEIG remains constant despite the change in consumer load. Simplified methods for the analysis of Self-Excited Induction Generators has been discussed by Krishnan Arthishri*et al* [9].The concept of using simple programming techniques such as linear search and binary search for the steady state analysis of SEIG has been described. .MATLAB programming does not require lengthy mathematical derivations nor any advanced optimization techniques to solve equivalent circuit of SEIG.A new control strategy for standalone induction generator driven by variable speed wind turbine was illustrated byS.A.Deraz*et al* [6]. In this, fuzzy logic control is used which involves complex analysis. This can be simplified by the use of simple switching algorithm.Microprocessor based voltage controller for wind driven induction generators was illustrated by N.Ammasaigounden*et al* [2].

The system has been developed for wind-driven self-excited induction generators using a controlled rectifier to maintain a constant dc load voltage with varying rotor speeds. The measured dc voltages, the microprocessor adjusts the firing angle until the two voltages become equal; it also generates the gate trigger pulses for the thyristors at the appropriate inside.A survey about self excited induction generator research was carried out by G.K. Singh *et al* [15].An induction machine connected to an ac source of appropriate voltage and frequency can be operate either as a motor or as a generator. The terminal voltage applied to the machine maintains the excitation by supplying lagging magnetizing current, which in turn results in rotating magnetic field for both the motoring, and generating mode of operation. Analysis and control of self-excited induction generator –converter systems for battery charging application has been proposed by R.Karthigaivel *et al* [7]. A system like that described in has been presented by lopes et al, but will the addition of an excitation capacitor bank and a controllable bump load across the stator terminal of the generator. The voltage source inverter is design with only a fraction of the generator rating and the dump load absorbs whenever there is excess active power in the ac system. A method of calculating the load can be supplied by this proposed system with regulated voltage and frequency has also been described in this paper.Voltage control of self-excited induction generator has been discussed by K. Sowndarya*et al* [16]. An induction generator must be excited with loading voltage. This is usually done by connecting induction generator to an electrical grid, however they are self-excited by phase correcting capacitor. There are various methods are involved in the voltage regulation. For a given stator load impedance, both the voltage and frequency can be maintained as the speed is varied, without changing the excitation capacitance. A simple wind driven self-excited induction generator with regulated output voltage has been presented by ShashakWekhande*et al* [14]. A mechanical arrangement is used to maintain the rotor speed above the synchronous speed. A static PWM inverter is used for controlling excitation. The terminal ac voltage is regulated for varying rotor speed and changing load conditions. The controller does not require any real time mathematical computation for estimating reference current.

Analysis of wind driven self excited induction generator supplying isolated DC loads has been studied by S. KhaledSakkoury*et al* [8]. The transient performance of a SEIG feeding an induction motor showed that the system can operate with careful selection of the excitation capacitors and proper control. Simple control for a wind driven induction generator has been investigated by ShashankWekhande*et al* [13]. A mechanical arrangement is used to maintain the rotor speed above synchronous speed. The PWM inverter can be used as a variable capacitor, which can accommodate inductive reactance from the generator and load.A two stage PWM controller based on an ac-dc-ac link can generate with fixed frequency, fixed voltage output with varying rotor speed.A simple decoupled reference current generation is used, which does not require any real-time mathematical computation.Standaloneself excited induction generator driven by a wind turbine has been discussed by MhamdiTaoufik*et al* [10]. The controlled voltage source is performed by using a controller, which adjust voltage by varying the amount of injected reactive power. Two strategies are developed to alleviate the problem of voltage regulation.Steady state analysis of isolated self excited induction generator driven by regulated and unregulated turbine has been discussed byS.M.Alghuwainem*et al* [1].Analysis and control of wind driven self excited induction generators connected to the grid through power converters has been discussed by S.Senthil Kumar *et al* [12]. A method of representingthe grid power as equivalent load resistance in the steady state equivalent circuit has been formulated. A novel control strategy for a stand alone SEIG in renewable energy system has been developed by G.Vijaykumar*et al* [17].

A variable-speed generator system was proposed by him which uses a three phase cage rotor induction machine with self excitation capacitor and a double sided PWM converter.Steady state analysis of self excited induction generators has been proposed by TF Chan*et al* [5]. They proposed two techniques where by the steady state performance of SEIG can be computed by solving only a single polynomial `a'.An iterative technique to obtain the generated frequency in steady state analysis of SEIG has been proposed by BhimSingh *et al*[4]. The algebraic equation is solved for the initialvalue calculation of generated frequency, where the final value is obtained in subsequent iterations. Operation and closed loop control of wind driven stand alone doubly fed induction generators using a single inverter battery system was discussed by G. Vijayakumar*et al* [18]. A controllable AC voltage of desired magnitude and frequency at the stator terminals of DFIG for supplying isolated loads is obtained using battery inverter system at the rotor side. In this system, a digital controller is used which uses components like PI controller, ADC etc.Use of conventional induction motor as a wind driven self excited induction generator for autonomous operation has been proposed by S.S.Murthy*et al* [11]. A few constraints which have to be kept in mind while designing an autonomous wind energy system. As wind turbine is directly coupled to the generator, there is wide range of speed depending upon the wind velocity over which the unit is required to operate. From the above literature survey, it is evident that the wind energy can be harnessed to supply isolated loads efficiently. Various methods are discussed as above in order to maintain constant AC output voltage from the generator which include electronic load controller, fuzzy logic system etc. The authors in this paper proposed and developed a generator and simple switching schemes used to reduce the complexity and system design compare to those listed above.

1.1WIND ENERGY CONVERSION SYSTEM

The term can thus refer to windmills, wind pumps as well as wind turbines. There are three major types of wind power.

Utility-scale wind,Distributed or small wind, and Offshore wind.Wind turbines erected in large bodies of water, usually on the continental shelf.The most modern generations of windmills are more properly called wind turbines, or wind generators, and are primarily used to generate electricity and electrical energy. The conversion of the energy of the wind into more useful forms can be done using a rotor fitted with blades or sails. Note that a suitable location needs to be chosen for the WECS, preferably an open area. Also, some general locations lend themselves far better than others for WECS.The largest wind turbines can generate up to 6MW of power.

1.2 ISOLATED SYSTEM

In remote communities, interconnected electrical grid is unreachable due to economics and physical reasons. Due to the long distance and difficult access to these isolated areas, electrical generation systems use isolated grid system. It is the set of electricity generators and possible energy storage systems interconnected to a distributed network that supplies electricity to a localized group of customers. The market for using wind technology to support isolated power generation has recently progressed from a topic discussed by researchers to commercial operating systems. The integration of wind turbines with conventional isolated generation has become a commercial reality.For grid-isolated induction generators, the voltage build-up takes place when capacitors of suitable value are connected across the stator windings. The capacitors provide the magnetizing current necessary for maintaining the magnetic field. These induction generators do not depend on the power system for excitation and are hence called self-excited induction generators (SEIG).Three –phase SEIG can be built using a three-phase induction machine with per-phase connected terminal capacitors across the stator terminals. Three-phase loads can be connected across the stator terminals, once the generator starts to generate. It may also static excitation converter like a three-phase inverter. But in in the proposed work capacitor banks are used for self -excitation of the machine.

1.3 WIND TURBINE CHARACTERISTICS

The amount of mechanical power that can be extracted from the wind by a turbine rotor depends on the characteristics of wind turbine. Furthermore, the aim of the characteristics of any wind turbine is to provide an expectation of how to design the generator's control system in order to track these characteristics and achieve the desired output. A wind turbine installation consists of the necessary systems needed to capture the wind's energy, point the turbine into the wind, convert mechanical rotation into electrical power, and other systems to start, stop and control the turbine.

In most instances, generating electricity from wind turbines is a two stage process. In the first stage, the turbine rotor converts kinetic energy from the wind into mechanical rotational power. In the second stage, a generator converts mechanical power into electrical power. There are presently two options for coupling a turbine rotor to a generator shaft. One option, which is the most popular, involves coupling the two components physically via a gearbox. The other option is to connect the rotor directly to the generator.The efficiency of a wind turbine is the highest at its designed wind velocity, and efficiency decreases with the fluctuations in wind. The lowest velocity at which the turbine develops its full power is known as rated wind velocity. Below some minimum wind velocity, no useful power output can be produced from wind turbine. There are limits on both the minimum and maximum wind velocity for the efficient operation of wind turbines. The maximum theoretical power output of a wind machine is thus 0.59 times the kinetic energy of the air passing through the effective disk area of the machine.

$$P=0.59\frac{1}{2}\rho v^3A \qquad (1)$$

The power curve of a wind turbine is a graph that indicates how large the electrical power output will be for the turbine at different wind speeds. The reason is that in practice the wind speed always fluctuates, and one cannot measure exactly the column of wind that passes through the rotor of the turbine.

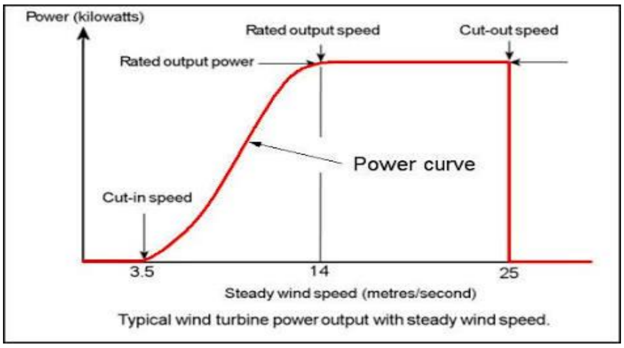


Fig.1.1 Typical wind turbine power output with steady wind speed

Fig.1.1 shows the characteristic of a wind turbine based on wind speed. It also shows the cut-in, cut-out and rated speed. Based on this the base wind speed for the simulation block is given. The base speed chosen for this project is 12m/s. With this base speed the minimum wind velocity for which the turbine generates power is 7m/s. For different wind velocity the generation of power against speed of rotor is plotted in the form of a graph. For each wind velocity the desired output voltage can be obtained at one particular speed of rotor. The speed can be adjusted by connecting the corresponding load across the line.

1.4 SELF EXCITED INDUCTION GENERATOR

An isolated induction generator is also known as a Self-Excited Induction Generator (SEIG). It is so called because it uses capacitor bank for excitation which is connected across its stator terminals as shown in the Fig.1.2.

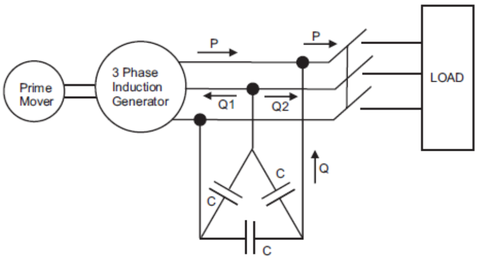


Fig.1.2Three phase induction generator with capacitor bank

The function of the capacitor bank is to provide the lagging reactive power to the induction generator as well as load. So mathematically we can write total reactive power provided by the capacitor bank is equals to the summation of the reactive power consumed by the induction generator as well as the load.

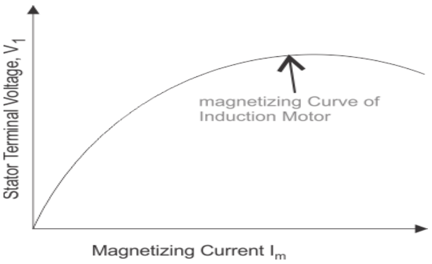


Fig.1.3 Magnetizing curve of induction motor

The above Fig.1.3 shows the varying magnetizing current with respect to stator terminal voltage. The current increases in parabolic manner and saturates at a point.

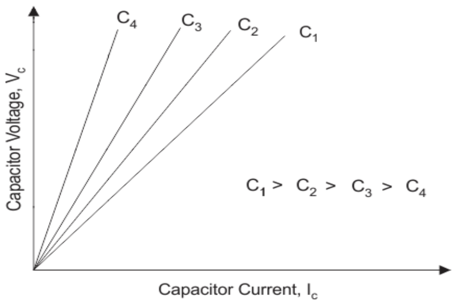


Fig .1.4 Capacitor Characteristic

The capacitor current against capacitor voltage is shown in Fig.1.4. It is seen that the current increases. The curve is more linear when the capacitance value is high.

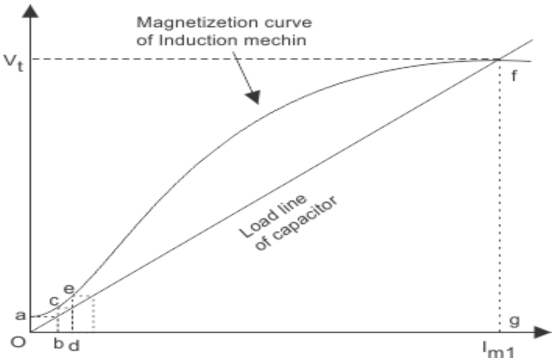


Fig.1.5 Operating curve characteristics of induction generator

The Fig.1.5shows the generation of small terminal voltage 'oa', across the stator terminal due the residual magnetism when the rotor of the induction machine runs at the required speed. Due to this voltage'oa' the capacitor current 'ob' is produced. The current'bc' sends current 'od' which generates the voltage 'de'.The cumulative process of voltage generation continues till the saturation curve of the induction generator cuts the capacitor load line at some point. This point is marked as 'f' in the given curve.

II. STEADY STATE ANALYSIS OF SEIGP

Owing to shrinking energy resources facing mankind, have led to exhaustive hunt for environment friendly ways of energy generation. A novel trend in electric power production is the decentralization of power generation and increased use of non-conventional energy sources such as wind energy, bio-gas, solar and hydro potential, etc. Induction generators are increasingly being used in non-conventional energy systems such as wind, micro/mini hydro, etc. The advantages of using an induction generator instead of a synchronous generator are reduced unit cost and size, ruggedness, brushless (in squirrel cage construction), absence of separate dc source, ease of maintenance, self-protection against severe overloads and short circuits, etc. In isolated systems, squirrel cage induction generators with capacitor excitation, known as self-excited induction generators (SEIGs), are very popular.

2.1 ASSUMPTIONS MADE ON SEIG

Some of the assumptions considered while doing the steady state analysis are as follows

(i) Only the magnetizing reactance varies with the level of saturation, all other parameters being constant.
(ii) Time harmonics in the induced voltage and current waveforms and the space harmonics in the magneto motive force (MMF) are ignored.
(iii) Resistance representing the core loss is neglected.
(iv) Leakage reactance and the load reactance correspond to rated frequency.

2.2REALIZATIONOF EQUIVALENT CIRCUIT OF SEIG

The equivalent circuit of SEIG was derived from that of an induction generator.For SEIG, the excitation capacitor bank is also considered and the load is connected across the stator terminals.The circuit for the steady state analysis of SEIG is as shown in Fig.2.1

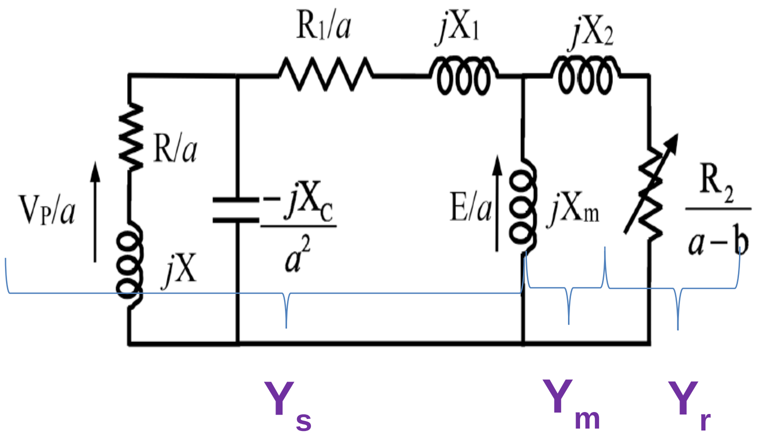


Fig.2.1Steady-state equivalent circuit of *SEIG*

All reactance correspond to rated frequency, From above figure,

$$Y = Y_s + Y_m + Y_r \qquad (1)$$

IY=0 ,I cannot be zero. Therefore, Y=0

2.3 EVALUATION OF VARIOUS PERFORMANCE PARAMETERS

The performance parameters of SEIG derived from Fig.2.1 are:

Stator voltage, $V_P = E\dfrac{Z_{LC}}{Z_S + Z_{LC}}$ (2)

Load current, $I_P = \dfrac{V_P / a}{Z_L}$ (3)

Capacitor current, $I_C = \dfrac{V_P / a}{Z_C}$ (4)

Stator current, $I_S = I_C + I_P$ (5)

Rotor current, $I_R = \dfrac{E}{Z_R}$ (6)

Electrical poweroutput, $P_e = 3re\left(V_P I_P^{\,*}\right)$ **(7)**

Stator copper loss, $P_S = 3 \times |I_S|^2 \times R_1$

Rotor copper loss, $P_R = 3 \times |I_R|^2 \times R_2$ (8)

Mechanical power input, $P_M = 3|I_R|^2 R_2\left(\dfrac{b}{a-b}\right)$ **(9)**

2.4 AIR GAP VOLTAGE (E)VS MAGNETISING REACTANCE (X_m)CHARACTERISTICS

R_1, R_2, X_1 and X_2can be obtained experimentally by a conventional block rotor test and stator resistance measurement test.The magnetization characteristic of the induction machine can be obtained at rated frequency of 50 Hz (a=1p.u.).

For this, the rotor of the induction machine was driven by a separately excited DC motor at constant speed of 1500 rpm, this being the synchronous speed for 4-pole machine (*b* = 1 p.u.). Under this condition, *a* = *b*.

At this speed setting, stator is fed from a variable voltage source at rated frequency. The input current and power are measured for each input voltage V_{in}. Then X_m and air-gap voltages E at various input voltages can be calculated.

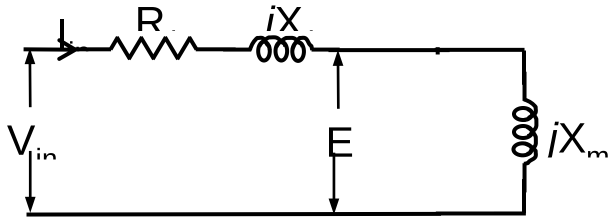


Fig.2.2Equivalent circuit of SEIG for E VsX_m characteristics

The Fig.2.2 Shows the SEIG circuit characteristics. The experimentally obtained (E/a) versus X_m characteristic of the machine is

$$\frac{E}{a} = -296.35\times10^{-10} X_m^6 + 759.97\times10^{-8} X_m^5 - 784.84\times10^{-6} X_m^4 + 40.75\times10^{-3} X_m^3 - 111.07\times10^{-2} X_m^2 + 12.92 X_m + 245.92 \quad (10)$$

III.PERFORMANCE PREDETERMINATION METHODOLOGY

3.1 INTRODUCTION ABOUT BINARY SEARCH ALOGORITHM

The binary search method in mathematics is a root-finding method that repeatedly bisects an interval and then selects a subinterval in which a root must lie for further processing.It is a very simple and robust method, but it is also relatively slow. Because of this, it is often used to obtain a rough approximation to a solution which is then used as a starting point for more rapidly converging methods.The method is also called the interval halving method, bisection methodor the dichotomy method.

3.2 BASIC PRINCIPLE OF BINARY SEARCH

The method is applicable for numerically solving the equation $f(x) = 0$ for the real variable x, where f is a continuous function defined on an interval $[a, b]$ and where $f(a)$ and $f(b)$ have opposite signs. In this case $a$and b are said to bracket a root since, by the intermediate value theorem, the continuous function f must have at least one root in the interval (a, b).

At each step the method divides the interval in two by computing the midpoint $c = (a+b) / 2$ of the interval and the value of the function $f(c)$ at that point. Unless c is itself a root (which is very unlikely, but possible) there are now only two possibilities: either $f(a)$ and $f(c)$ have opposite signs and bracket a root, or $f(c)$ and $f(b)$ have opposite signs and bracket a root.The method selects the subinterval that is guaranteed to be a bracket as the new interval to be used in the next step. In this way an interval that contains a zero of f is reduced in width by 50% at each step. The process is continued until the interval is sufficiently small.

Explicitly, if $f(a)$ and $f(c)$ have opposite signs, then the method sets c as the new value for b, and if $f(b)$ and $f(c)$ have opposite signs then the method sets c as the new a. (If $f(c)=0$ then c may be taken as the solution and the process stops.) In both cases, the new $f(a)$ and $f(b)$ have opposite signs, so the method is applicable to this smaller interval.

3.2.1 Iteration tasks

The input for the method is a continuous function f, an interval $[a, b]$, and the function values $f(a)$ and $f(b)$. The function values are of opposite sign (there is at least one zero crossing within the interval). Each iteration performs these steps

(i) Calculate c, the midpoint of the interval, $c = (a+b)/2$

(ii) Calculate the function value at the midpoint, $f(c)$.

(iii) If convergence is satisfactory (that is, $c - a$is sufficiently small, or $|f(c)|$ is sufficiently small), return c and stop iterating.

(iv) Examine the sign of $f(c)$ and replace either $(a, f(a))$ or $(b, f(b))$ with $(c, f(c))$ so that there is a zero crossing within the new interval.

When implementing the method on a computer, there can be problems with finite precision, so there are often additional convergence tests or limits to the number of iterations. Although f is continuous, finite precision may preclude a function value ever being zero. For example, consider $f(x) = x - \pi$; there will never be a finite representation of x that gives zero. Additionally, the difference between a and b is limited by the floating point precision; i.e., as the difference between a and b decreases, at some point the midpoint of $[a, b]$ will be numerically identical to (within floating point precision of) either a or b.

3.3 PREDETERMINATION OF SEIG PARAMETERS USING BINARY SEARCH

In order to predetermine the parameters of SEIG such as stator voltage, stator current, load current, capacitor current, frequency etc. for the given rotor speed, binary search algorithm has been employed. For the given wind speed, the rotor speed is noted from simulation result.Hence, the value of ***b*** is known, Where b = N / $N_{r,,}$

From *fig(2.1)*, it can be deduced that,

$$\frac{1}{Z_{SR}} = \frac{1}{Z_S + Z_{LC}} + \frac{1}{Z_R} \quad (11)$$

$$Z_L = (R/a) + jX \quad (12)$$

$$Z_C = -jX_C / a^2 \quad (13)$$

$$Z_{LC} = Z_L Z_C / (Z_L + Z_C) \quad (14)$$

$$Z_S = (R_1/a) + jX_1 \quad (15)$$

$$Z_R = (R_2/(a-b)) + jX_2 \quad (16)$$

$$Y = Y_s + Y_m + Y_r$$

(17) $$\frac{1}{Z_{SR}} = \frac{j}{X_m}$$

Under steady-state condition Y = 0

Hence, (18)

$$Y = \frac{1}{jX_m} + \frac{1}{Z_{SR}}$$

The real and imaginary part of the above equation is

(19) $$\mathrm{re}\left(\frac{1}{Z_{SR}}\right) = 0$$

IVSTRUCTURE OF PROPOSED MODEL IN OPEN LOOP AND CLOSED LOOP REPRESENTATION

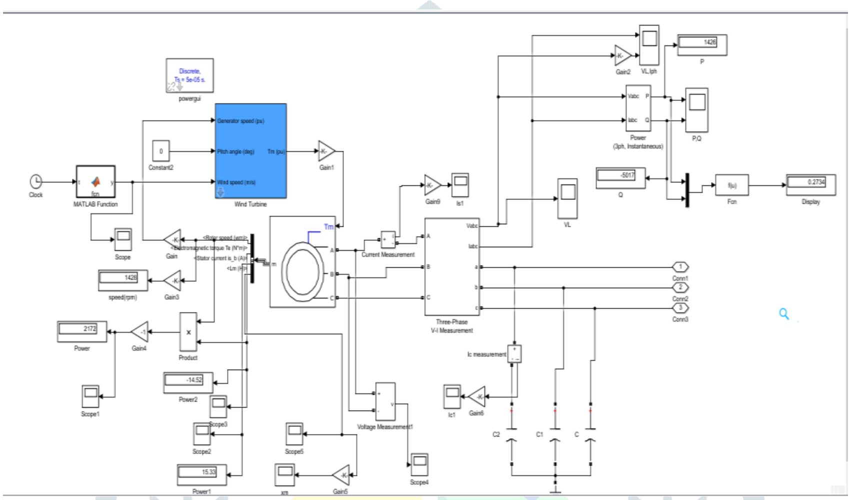


Fig.4.1 Open loop control scheme

Fig.4.1 represents the open loop model of the proposed work in MATLAB simulation . In open loop operation the loads are changed manually for different wind velocity. The load at which the desired voltage obtained is noted. Also other parameters like current, frequency and magnetizing current are tabulated.

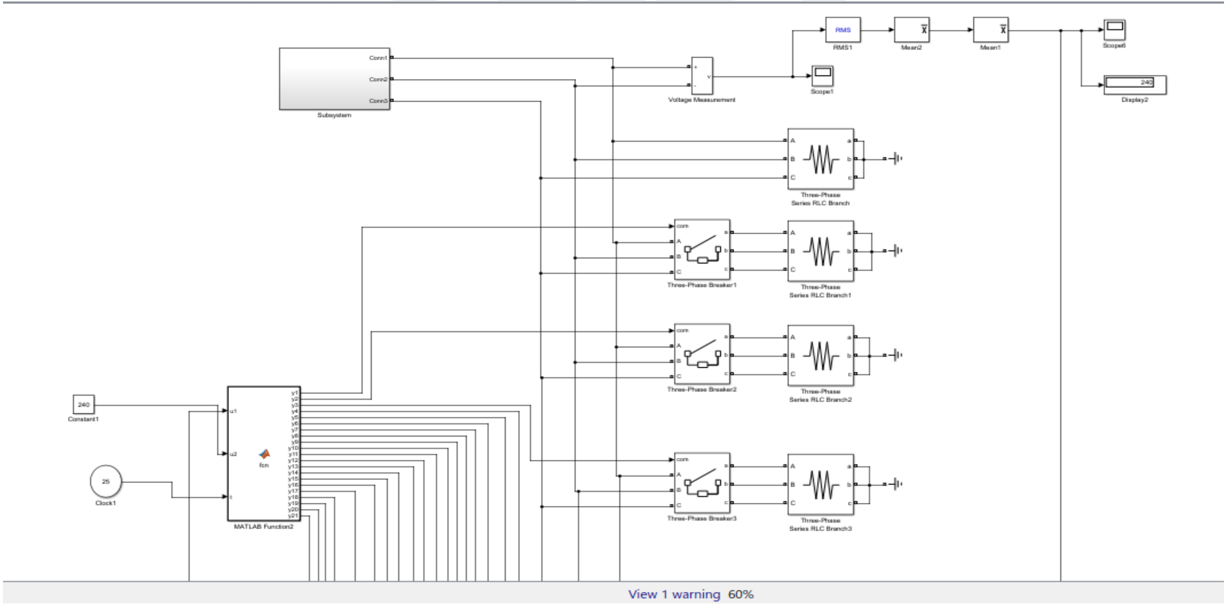


Fig.4.2Closed loop control scheme

Fig.4.2 shows the closed loop model of the system. The open loop model is taken as the subsystem. The closed loop system is developed as an extension of subsystem. A function block is used to exhibit the switching logic which is used as control scheme for adding and removing the load. Totally there are 22 loads connected in parallel. The output of generator is given as feedback for the function block as one of the input. A clock is connected to provide the time delay in the output.

4.1SIMULATION BLOCK REALIZATION OF SEIG

4.1.1Setting up of parameter values

The asynchronous machine implements a three phase asynchronous machine. It operates either in generator or motor mode. The mode of operation is dictated by the sign of mechanical torque. If Tm is positive, machine acts as motor. If Tm is negative machine acts as generator. In this project it is used as generator.The electric part of machine is represented by a 4th order state space model and mechanical part by a 2nd order system. All electrical variables and parameters referred to stationary frame.

Rating of power (VA) = 3700
Voltage (L-L) = 230
Frequency = 50
Rated speed =1500

- **Mechanical input**

Select torque Tm to specify a torque input in Nm and change labeling of block input to Tm. The machine speed is determined by the machine inertia J (or inertia constant H for pu machine) and by the difference between the applied mechanical torque Tm and internal electromagnetic torque Te. The sign convention for mechanical torque is when speed is positive a positive torque signal indicates motor mode and a negative signal indicates generator mode.

- **Reference frame**

Specifies the reference frame that is used to convert input voltages (abc reference frame) to dq reference frame and output current (dq reference frame) to abc reference frame.

(i) Rotor (default)
(ii) Stationary (Clarke or αβ transformation)

(iii)Synchronous

The following relationships describe the abc-to-dq reference frame transformations applied to the Asynchronous Machine phase to phase voltages.

$$\begin{bmatrix} V_{qs} \\ V_{ds} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2cos\theta & cos\theta + \sqrt{3}sin\theta \\ 2sin\theta & sin\theta - \sqrt{3}cos\theta \end{bmatrix}\begin{bmatrix} V_{abs} \\ V_{bcs} \end{bmatrix}$$

$$\begin{bmatrix} V'_{qr} \\ V'_{dr} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2cos\beta & cosc\beta + \sqrt{3}sin\beta \\ 2sin\beta & sin\beta - \sqrt{3}cos\beta \end{bmatrix}\begin{bmatrix} V'_{abr} \\ V'_{bcr} \end{bmatrix}$$

In the preceding equations, θ is the angular position of the reference frame, while $\beta = \theta - \theta_r$ is the difference between the position of the reference frame and the position (electric) of the rotor. Because the machine windings are connected in a three-wire Y configuration, there is no homopolar (0) components. This configuration also justifies that two line-to-line input voltages are used inside the model instead of three line-to-neutral voltages. The following relationships describe the dq-to-abc reference frame transformations applied to the Asynchronous Machine phase currents.

$$\begin{bmatrix} i_{as} \\ i_{bs} \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ \frac{-cos\theta+\sqrt{3}sin\theta}{2} & \frac{-\sqrt{3}cos\theta-sin\theta}{2} \end{bmatrix}\begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix}$$

$$\begin{bmatrix} i'_{ar} \\ i'_{br} \end{bmatrix} = \begin{bmatrix} cos\beta & sin\beta \\ \frac{-cos\beta+\sqrt{3}sin\beta}{2} & \frac{-\sqrt{3}cos\beta-sin\beta}{2} \end{bmatrix}\begin{bmatrix} i_{qr} \\ i'_{dr} \end{bmatrix}$$

$$i_{cs} = - i_{as} - i_{bs}$$

$$i'_{cr} = -i'_{ar} - i'_{br}$$

The table 4.1 shows the values taken by θ and β in each reference frame (θ_e is the position of the synchronously rotating reference frame).

TABLE :4.1 REFERENCE FRAME VALUES

Reference frame	**Θ**	**B**
Rotor	θ_r	0
Stationary	0	$-\theta_r$
Synchronous	θ_e	$\theta_e - \theta_r$

The choice of reference frame affects the waveforms of all dq variables. It also affects the simulation speed and in certain cases the accuracy of the results. The following guidelines are suggested in [1]:

(i) Use the stationary reference frame if the stator voltages are either unbalanced or discontinuous and the rotor voltages are balanced(or 0).

(ii) Use the rotor reference frame if the rotor voltages are either unbalanced or discontinuous and the stator voltages are balanced.

(iii)Use either the stationary or synchronous reference frames if all voltage are continuous.

- **Parameter tab**

This tab contains the electrical parameters of the machine.
Nominal power, voltage (line-line), and frequency: [3700 230 50]
Stator resistance and inductance: [1.3 0.00827]
Rotor resistance and inductance: [1.75 0.00827]
Inertia constant (kgm^2), friction factor (N.m.s) and pole pairs: [0.05 0.005879 2]

- **Initial conditions**

Specifies the initial slip s, electrical angle θ_e (degree), stator current, magnitude (A or pu) and phase angles (degrees): [1,0°, 20 e^{-6}, 20 e^{-6}, 20 e^{-6} , 0°, 0°, 0°]
Simulate saturation
Specifies whether magnetic saturation of the rotor and stator iron is simulated or not. Default is cleared.

4.2 COUPLING OF SEIG WITH WIND TURBINE

The wind turbine model from simscape is chosen. The base wind speed is set to 12m/s and the wind turbine characteristics curves are taken for the base wind speed.The various parameters are given as
Nominal mechanical output power (w): 4000
Base power of the electric generator (VA): 3700
Base wind speed (m/s): 12
Maximum power at base wind seed (pu of nominal mechanical power): 0.95
Base rotational speed (p.u. of base generator speed): 1
Pitch angle beta to display wind-turbine power characteristics (beta>=0) (deg): 0

The inputs of the turbine are wind velocity, pitch angle and generator speed. The wind velocity is given through a constant block and it will be changed over a range of velocity depending upon the base wind speed characteristic.

The pitch angle refers to turning the angle of attack of the blades of a propeller into or out of the wind to control the production or absorption of power. Wind turbines use this to adjust the rotation speed and the generated power. It is set to be zero using a constant block.The generator speed is given from the asynchronous machine. The output of machine is given to a bus selector the output port of bus selector is chosen as speed (w) and is converted to pu by dividing the speed with base speed using a gain.The output of turbine is the torque in p.u. This output is given as input to the generator. It is converted into actual torque value by adding a gain block. The gain is set to 23.57 which is the base torque value.The rotor speed from the asynchronous machine is given as input for the turbine block in pu value. The actual speed is converted into pu value by including a gain block that divides the speed by base speed value. The speed is denoted in rad/sec. Thus wind turbine is coupled with the generator by providing torque to the generator and obtaining the speed.

4.3.DETERMINATION OF APPROPRIATE LOAD FOR VARIOUS WIND SPEED

The wind velocity varied from 7.5m/s to 12m/s. Based upon the wind velocity the resistive loads are changed in order to get constant voltage at a particular speed.eg: If the wind velocity is 7.5 the resistive load is set to certain value. Then the simulation was run and the output was monitored to maintain 240v.which is the desired output voltage. If we did not get 240v we can change the resistive load till 240v can be reached. By repeating the process, the appropriate load for this velocity was found to be 500 Ω

Table.4.2 Loads for various wind speed

Wind Velocity	Load	Speed (rpm)
7.5	500	1251
8	165	1269
8.5	98	1291
9	68	1313
9.5	52	1338
10	41	1362

Again the wind velocity is changed to 8m/s we need to maintain 240v. So depending upon the wind velocity the load will be changed. And the following parameters like speed, voltage, power, stator current, capacitive current, load current, Xm, a, b are noted down.

4.4 AUTOMATED CONTROL STRATEGY USING CLOSED LOOP

4.4.1.CHOICE OF LOADS

These loads are also called as dummy loads. The selection of a dummy load, formerly considered a per forma matter, has now become an important part of the process of engineering a new facility. The load switching is used to maintain constant.

The load switching is chosen as resistive load in order to avoid the phase difference between the three phase voltage measured across the line. Such complexity can be overcome by using resistive load. The loads are star connected three phase resistive loads connected across the line where the neutral is grounded.

The loads are changed manually to determine appropriate load for the each wind speed. For closed loop operation the number of loads are connected in parallel. Single load is connected to the system initially. Since the loads are connected in parallel the effective resistance decrease with the addition of loads. The loads are added by determining the voltage for the initial load condition. Depending upon the variation of load the voltage at the output terminal varies.

Before closed loop operation the corresponding load for each wind velocity is determined manually. This had been tabulated and with this table the closed loop system is setup. The range of loads needed for this project is 500Ω to 22Ω.

For each wind velocity the loads get added till the desired output reaches. At low velocity the loads are maximum and for maximum velocity the loads are minimum. The initial load is chosen as 500Ω. The number of similar loads are connected in parallel for closed loop operation. A breaker is used for providing the time delay of 1 sec for each load. In this project similar three phase resistive loads of 500 ohms are connected in parallel. There are total 20 loads were used. For example the required load for the wind velocity of 7.5m/s is 500Ω. At this velocity the initial load is enough for obtaining the constant voltage. Therefore the loads will not be switched into the system after attaining the steady state.

Suppose if the velocity is 10m/s then the desired output can be obtained at 41Ω. The initial load is more than the required resistance value. The loads are switched into the system one by one. Hence closed loop operation will carry out till the desired voltage value attains. Since 20 loads were connected to this system the simulation time is nearly 30 seconds.

4.5 LOGIC OF SWITCHING ALGORITHM

Depending upon the voltage build up at the output terminal the loads are switched in and out of the circuit. If the voltage at the output terminal is more than desired voltage, then the loads are switched into the system one by one. Since the loads are connected in parallel the effective resistance decreases when loads are switched in. The breakers are used for providing the time delay between each load. Suppose if the voltage is less than the desired voltage then the load is to be removed from the system. So that the effective resistance increases and the voltage at the output also gets increased.

This control logic is given through the matlabfunctional block. The open loop output is given as feedback input for the function block. The another input is fed from a constant block with a value of 240. Also a clock is connected to provide a time delay. The output is given to the corresponding loads.

V RESULTS AND DISCUSSION

5.1 PREDETERMINATION RESULTS

The binary search algorithm is used as a predetermination method. The resistive load and speed for each wind velocity to maintained the constant line voltage voltage(RMS) is determined from the simulation which is given as input for predetermination method. Then, the power in watts (P_E), stator current(I_S), capacitive current(I_C), load current(I_L), Magnetising Reactance(X_M) and a, b where a and b depends on speed and frequency are tabulated in Table.5.1

Table.5.1 Parameters obtained using predetermination method

Wind Velocity (m/s)	Load (ohm)	Speed (rpm)	Pe (watts)	V_0 (L-L) (rms)	Is (rms) (A)	Ic (rms) (A)	I_L (rms) (A)	Xm (ohm)	a (pu)	b (pu)
7.5	500	1251	84.67	205.75	9.3132	9.3102	0.2376	43.58	0.8919	0.9080
8	165	1269	266.9021	209.85	9.6347	9.6067	0.7343	42.73	0.9074	0.9267
8.5	98	1291	471.68	215	10.0647	9.9847	1.2666	41.69	0.9244	0.9473
9	68	1313	710.40	219.789	10.5166	10.3497	1.8661	40.76	0.9410	0.9680
9.5	52	1338	976.43	225.32	11.0666	10.78	2.5018	39.74	0.9602	0.9913
10	41	1362	1290.6	230.03	11.625	11.1646	3.2393	38.94	0.8316	0.8340
10.5	34	1390	1636.6	235.89	12.316	11.6461	4.0	37.97	0.8413	0.8460
11	29	1421	2025.3	242.348	13.11	12.1905	4.8248	36.9668	0.8535	0.8607
11.5	25	1452	2465.4	248.26	13.945	12.7122	5.7334	36.1483	0.8654	0.8753
12	22	1487	2961.6	255.25	14.9248	13.3371	6.6987	35.2094	0.8792	0.8920

5.2..Simulation observation

The wind velocity and resistive load are varied to maintain the constant ac output voltage(240v).Then find the power(p_e), stator current, capacitive current, load current, Xm, a, b. The a and b is a frequency and speedand frequency variable which are shown in below Table.5.2

Table.5.2 Parameters obtained from simulation model

Wind Velocity (m/s)	Load (ohm)	Speed(rpm)	Pe (Watts)	V_0(L-L) (rms)	Is (rms) (A)	Ic (rms) (A)	I_L (rms) (A)	Xm (ohm) (A)	a (pu)	b (pu)
7.5	500	1251	542.1	240	10.67	10.66	0.277	34.86	0.8332	0.834
8	165	1269	792.1	239.6	10.72	10.69	0.838	34.86	0.8332	0.846
8.5	98	1291	1063	240	10.88	10.79	1.414	36.36	0.869	0.860
9	68	1313	1361	240	11.05	10.86	2.03	36.38	0.869	0.875
9.5	52	1338	1680	240.5	11.3	10.98	2.671	36.36	0.869	0.892
10	41	1362	2028	239.5	11.5	11.01	3.373	34.86	0.8332	0.908
10.5	34	1390	2396	239.6	11.84	11.12	4.06	34.86	0.8332	0.926
11	29	1421	2790	240.1	12.23	11.26	4.77	34.86	0.8332	0.947
11.5	25	1452	3211	239.7	12.63	11.35	5.536	34.86	0.8332	0.968
12	22	1487	3660	239.9	13.12	11.51	6.29	34.86	0.8332	0.991

5.3 Output graph representation of openloop model

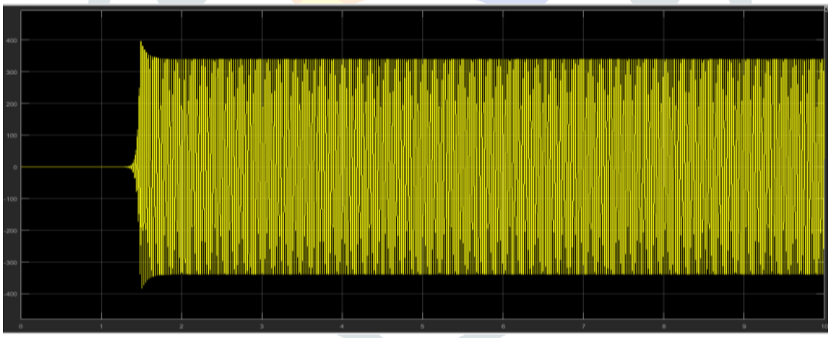
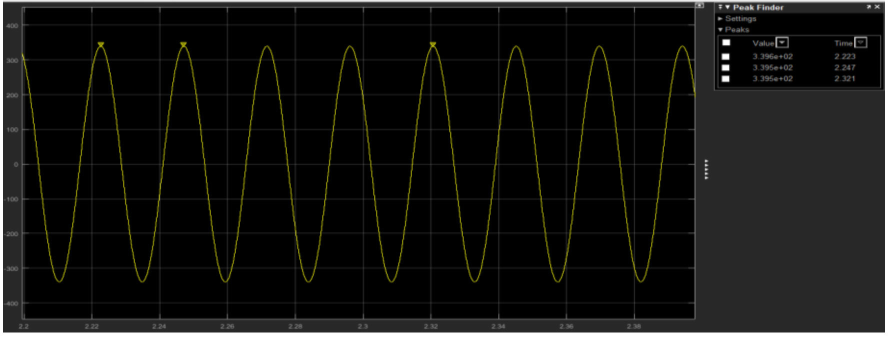


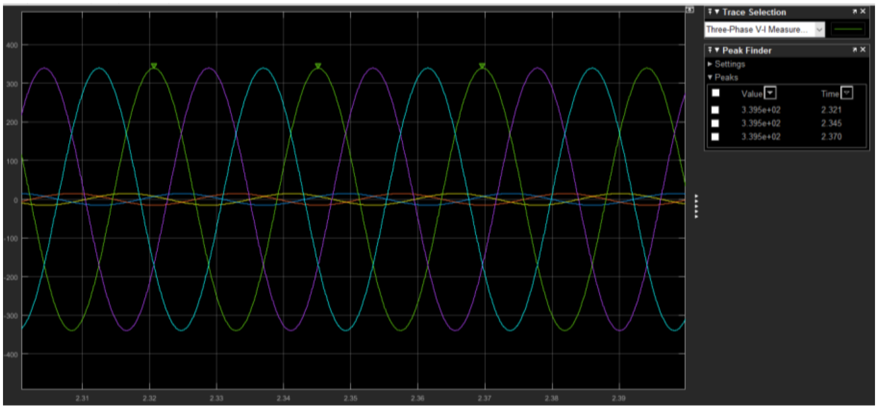
Fig.5.1 Output graph of open loop system



```
Value        Time
3.396e+02    2.223
3.395e+02    2.247
3.395e+02    2.321
```

Fig.5.2Output line to line voltage

Fig.5.1& Fig.5.2 shows that the Output terminal ac voltage obtained in open loop scheme in which load was switched manually. From the graph it is seen that the peak voltage is maintained at 240v which is the rms value of output.



☐	Value	Time
☐	3.395e+02	2.321
☐	3.395e+02	2.345
☐	3.395e+02	2.370

Fig.5.3Three phase Stator Voltage and Current

In the above graph Fig.5.3 the three phase output voltage is shown which is measured from three phase v-i measurement block.

5.4Output graph representation of closed loop model

The closed loop control maintains 340 voltage (peak)as constant ac at the output. The output graphs obtained from closed loop model is shown below

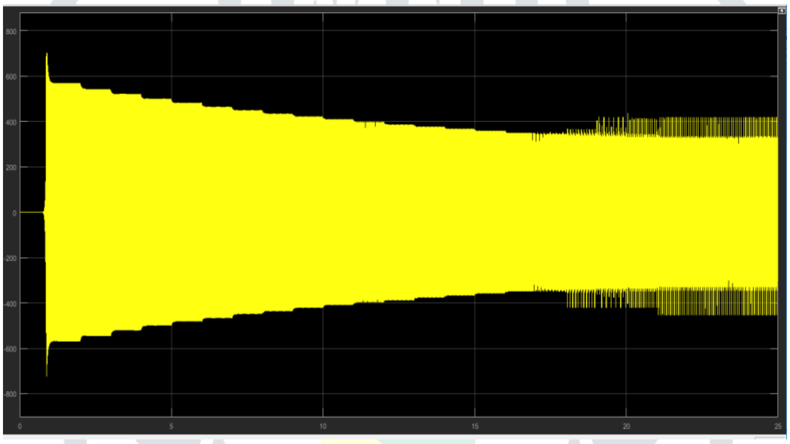


Fig.5.4 Control scheme Output graph

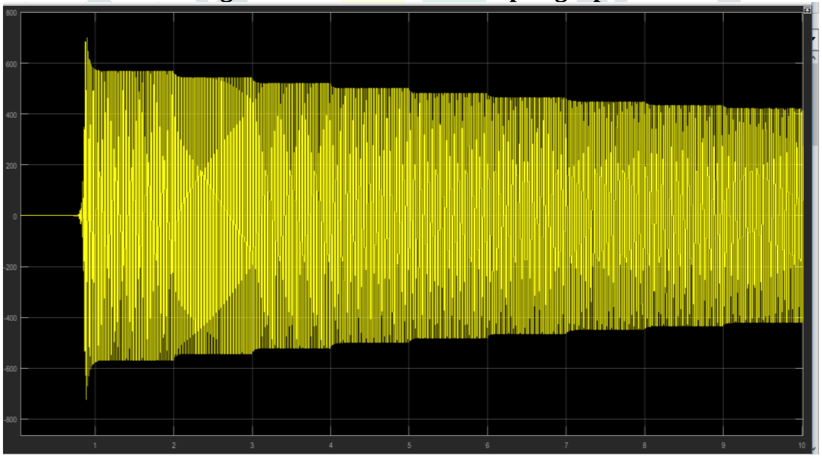


Fig.5.5 Enlarged view for 0<t<10

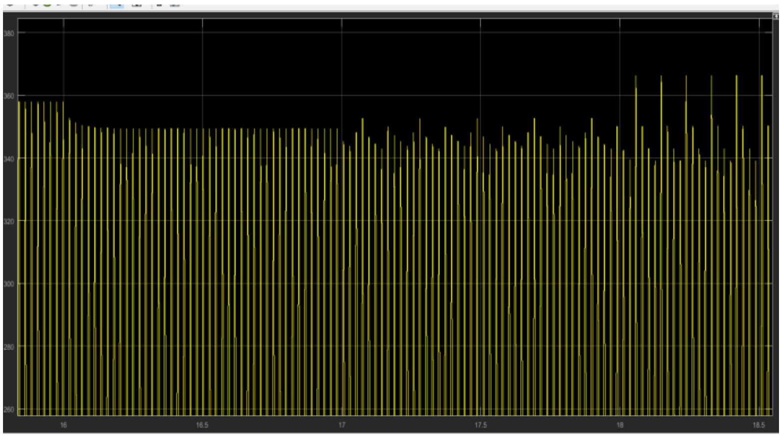


Fig.5.6Enlarged view as it approaches the desired voltage output

Fig.5.4 to Fig.5.6 shows that output voltage of closed control scheme. From the graph it is seen that initially the voltage was nearly 600v and it gradually decreases after the loads are switched in one by one. The desired voltage is around 16 sec .The enlarged view of control scheme desired output voltage.

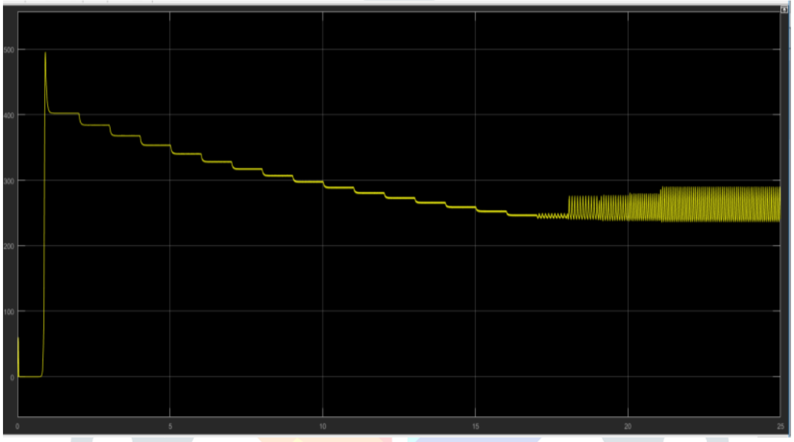


Fig.5.7Closed loop mean output

The mean block is used to maintain the output voltage at 340v(peak).The sinusoidal ac output is converted into a single line output using mean block whose wave form is shown in the Fig.5.7.

VI CONCLUSION

The AC line to line voltage at the stator terminals of SEIG are maintained at 340V peak (RMS 240V). The use of resistors as load in order to control the output voltage was successfully executed.The wind velocity which variesbetween 7.5 m/s and 12m/s can be harnessed to give out electrical energy to supply isolated systems. According to the wind velocity and the terminal voltage sensed, the loads are added or removed thereby modulating the power in order to get a higher turbine speed which in turn gives out constant AC output voltage. The loads where connected in a parallel fashion with the aid of a function block which controls the entire system. The closed loop control scheme was automated and the voltage settles at the desired tolerance band.Thus this constant AC output voltage is used to feed isolated loads with the aid of an asynchronous generator with capacitor bank for excitation. Switching scheme used in this proposed work is a very simple logic,extraction of the energy available from the wind using simple design and programming concepts compared to existing configurations.The simulation results are also verified with predetermination output and the results were satisfactory. There is no need for use of converters in the system which was essential in other existing systems.

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