Control of Self-Excited Induction generator based wind turbine using by IM controller

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Abstract-This paper focuses on the electrical generation part of a wind energy conversion system. After a brief introduction of the induction machine, the electrical generator used in this paper, a detailed analysis of the induction machine operated in stand-alone mode is presented. This paper shows the effect of magnetic saturation during self- excitation process in an isolated three phase induction generator, for a given capacitance and rotor speed value. When the steady state condition of a self-excited induction generator (SEIG) is attained, an increase of load causes a decrease in the magnitude of generated voltage and its frequency. The dynamic model of the SEIG system is developed using dq variables in stationary reference frame. For the validation of mathematical modelling, model of Matlab Simulink is developed and performed on three phase SEIG machine with the internal model controller (IMC).Simulation results of the self-excited induction generator driven by the variable speed wind turbine are presented in the last section of this paper. The process of voltage build up and the effect of saturation characteristics are also explained.

Index Terms— induction machine, magnetizing current, self-excitation, self-excited induction generator (SEIG), steady-state analysis, transient model.

I. INTRODUCTION

Induction machine is used in a wide variety of applications as a means of converting electric power to mechanical work. The primary advantage of the induction machine is its rugged brushless construction and no need for separate DC field power. These machines are very economical, reliable, and are available in the ranges of fractional horse power (FHP) to multi –megawatt capacity. Also, unlike synchronous machines, induction machines can be operated at variable speeds. For economy and reliability many wind power systems use induction machines, driven by a wind turbine through a gear box, as an electrical generator. The need for gearbox arises from the fact that lower rotational speeds on the wind turbine side should be converted to high rotor speeds, on the electricalgeneratorside,for electricalenergyproduction.There are two types of induction machine based on the rotor construction namely, squirrel cage type and wound rotor type. Squirrel cage rotor construction is popular because of its ruggedness, lower cost and simplicity of construction and is widely used in stand-alone wind power generation schemes. Wound rotor machine can produce high starting torque and is the preferred choice in grid- connected wind generation scheme. Another advantage with wound rotor is its ability to extract rotor power at the added cost of power electronics in the rotor circuit.

They have derived the performance equation using symmetrical component theory and machine parameters are determined by Hook and Jeeves method. Single-phase induction generator feeding single phase load is rarely reported. Rahim et al. [9] have described the performance of the single-phase induction generator. Ojo [10] has given the modelling and transient performance of single-phase self-excited induction generator. He has simulated the generator self-excitation and voltage collapse phenomenon. Murthy et al. [11] have given the experimental findings on a two-winding singlephase SEIG. They have given the effect of power output, power factor, tapping in main winding and speed on the terminal voltage of SEIG. Ojo et al. [12-14] have proposed single-phase SEIG with a bi-directional single-phase PWM inverter-battery system connected to the auxiliary winding to supply the reactive power and load is connected to its main winding. In this case, battery supplies the deficit power to meet the active power demand of the load or absorbs the excess power generated by turbine. Marra and Pomilio [15] have used a PWM inverter with dc voltage to regulate the speed to keep the generated voltage constant. Many types of electronic controllers are reported in the literature [16] but dynamic behavior of three-phase SEIG with internal model controller (IMC)is not reported while supplying single-phase loads. However, the knowledge of transient voltage, current, torque and speed are required for the proper design of IMC-SEIG system. This paper presents the dynamic modelling of IMC for a three-phase self-excited induction generator with single-phase loading. However, in stand-alone micro-hydel system, mechanical energy is obtained from running water, which is available free of cost at micro-hydel sites. Therefore, there is no restriction in using the whole available hydropower continuously. In this case, the available hydro potential isfullyconverted in to electrical energy thus eliminates the need of a turbine governor. As it is mentioned earlier, that induction generator does not have its own excitation so external VARs should be supplied. Capacitors are used to supplying the VARs to the SEIG system. In the proposed system connecting the sufficient capacitors across the generator according to full consumer load sets magnitude and frequency of the generated voltage. However, when the consumer load decreases the terminal voltage and frequency of the SEIG increase. It is very harmful to the health of remaining loads, which are still connected at generator terminals. So the proper voltage regulation can be achieved by keeping the effective load connected to the machine constant. This is achieved by having an internal model controller (IMC)at the SEIG terminals. The principle of the load controller is that it consumes the difference between the constant output power generated by the generator and the power absorbed by the connected consumer load given as:

Pout = Pd+Pc

Where, Pout is generated power of the generator, which should be constant, Pc is the consumer power and Pd is the dump load power. The internal model controller (IMC) is consisting of a single-phase uncontrolled rectifier in series with a chopper and dump load. Duty cycle of the chopper is adjusted so that the output power of the generator remains constant. Simulation results of the self-excited induction generator driven by the variable speed wind turbine are presented in the last section of this chapter. The process of voltage build up and the effect of saturation characteristics are also explained in the same section.

INDUCTION MACHINE

In the electromagnetic structure of the Induction machine, the stator is made of numerous coils with three groups (phases), and is supplied with three phase current. The three coils are physically spread around the stator periphery (space-phase), and carry currents which are out of time-phase. This combination produces a rotating magnetic field, which is a key feature of the working of the induction machine. Induction machines are asynchronous speed machines, operating below synchronous speed when motoring and above synchronous speed when generating. The presence of negative resistance (i.e., when slip is negative), implies that during the generating mode, power flows from the rotor to the stator in the induction machine.

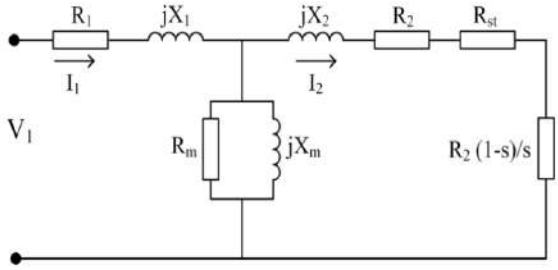

Fig. 1. Per-phase equivalent circuit of the induction machine referred to the stator.

A. *Equivalent Electrical Circuit of Induction Machine*

The theory of operation of induction machine is represented by the per phase equivalent circuit shown in Figure 1. [1],[2],[3].

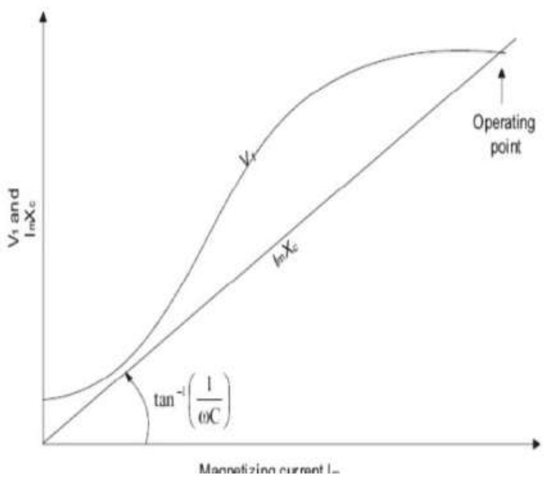

Fig. 2. Self-excited induction generator with external capacitor.

In the above figure, R and X refer to the resistance and inductive reactance respectively. Subscripts 1, 2 and m represent stator, rotor values referred to the stator side and magnetizing components, respectively.

Induction machine needs AC excitation current for its running. The machine is either self-excited or externally excited. Since the excitation current is mainly reactive, a stand-alone system is self- excited by shunt capacitors. In grid-connected operation, it draws excitation power from the network, and its output frequency and voltage values are dictated by the grid. Where the grid capacity of supplying the reactive power is limited, local capacitors can be used to partly supply the needed reactive power [3].

II. SELF-EXCITED INDUCTION GENERATOR (SEIG)

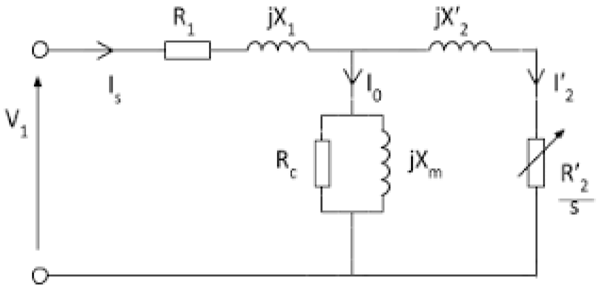

Fig. 3. Determination of stable operation of self-excited induction generator.

Self-excited induction generator (SEIG) works just like an induction machine in the saturation region except the fact that it has excitation capacitors connected across its stator terminals. These machines are ideal choice for electricity generation in stand-alone variable speed wind energy systems, where reactive power from the grid is not available. The induction generator will self-excite, using the external capacitor, only if the rotor has an adequate remnant magnetic field. In the self-excited mode, the generator output frequency and voltage are affected by the speed, the load, and the capacitance value in farads [3]. The steady-state per-phase equivalent circuit of a self- excited induction generator is shown in the Figure 2.

The process of self-excitation in induction machines has been known for many decades [4]. When capacitors are connected across the stator terminals of an induction machine, driven by an external prime mover, voltage will be induced at its terminals. The induced electromotive force (EMF) and current in the stator windings will continue to rise until the steady-state condition is reached, influenced by the magnetic saturation of the machine. At this operating point the voltage and the current will be stabilized at a given peak value and frequency. In order for the self-excitation to occur, for a particular capacitance value there is a corresponding minimum speed [5],[6],[7],[8]. So, in stand-alone mode of operation, it is necessary for the induction generator to be operated in the saturation region. This guarantees one and only one intersection between the magnetization curve and the capacitor reactance line, as well as output voltage stability under load as seen in the Figure 3:*At no-load, the capacitor current Ic=V1/Xc must be equal to the magnetizing current Im=V1/Xm. The voltage V1 is a function of Im, linearly rising until the saturation point of the magnetic core is reached. The output frequency of the self-*

excited generator is, f=1/(2πCXm) and ω=2πf where C is self-exciting capacitance.

III. METHODS OF ANALYSISTHE DYNAMIC D-Q MODEL USING PARK'S TRANSFORMATION

In the previous modeling methods, per phase equivalent circuit of the machine was considered. This was valid only in the steady-state condition. The equivalent circuit that was used for obtaining the mathematical model of the IM is shown in Figs. 4 and 5, respectively **[7]**.

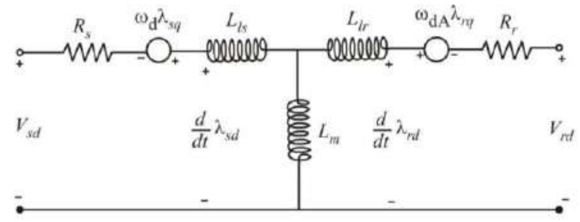

Fig. 4: IM Equivalent circuit in the *d*-axis frame

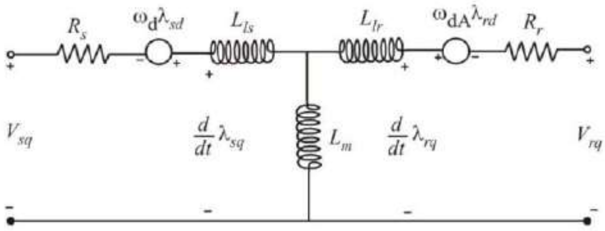

Fig. 5: IM Equivalent circuit in the q-axis frame

In the current methods of modeling and control of SCIMs, especially one with an adjustable AC drive, the machine should have certain feedback loops. Therefore, the transient behavior should be taken into consideration in the machine model. Furthermore, high-performance drive control requires a better understanding of the vector/field-oriented control. This section provides a better understanding of the concepts relating to the development of the *d–q* theory. In the IM, the 3-phase rotor windings move with respect to the 3-phase stator windings. Generally, any machine model could be best described by a set of non-linear differential equations with time-varying mutual inductances. However, such a model tends to be very complex and the controller design becomes further complex **[7]**.

The mathematical model of the IMs (the 3-phase IM) could be represented by an equivalent 2-phase, where *ds, qs, dr and qr*correspond to the stator, rotor, direct and quadrature axes, respectively. Although this model looks quite simple, the problem of time-varying parameters still remains. Hence, to solve this problem, R. H. Park, in 1920, developed the transformation technique to solve the problem of time-varying parameters. The stator variables are referred with respect to the rotor reference frame, which rotates at a synchronous speed. The time-varying inductances that occur due to the interaction between the electric and magnetic circuits can be removed using this Park transformation.

Later, in 1930, H.C. Stanley demonstrated that the time-varying inductances that appear in the *v–i*equations of the IM due to electric and magnetic effects can be removed by transforming the variables with respect to the fictitious stationary windings. In this case, the rotor variables are transformed to the stator reference frame. In this thesis, a dynamic machine model in synchronously rotating and stationary references frame is presented, which is further used to develop sophisticated controllers to control the speed of the IM. The stator voltage equations formulated from stationary reference frame **[7]** are as follows:

$$V_{sA}(t) = R_s i_{sA}(t) + \frac{d\psi_{sA}(t)}{dt}$$
$$V_{sB}(t) = R_s i_{sB}(t) + \frac{d\psi_{sB}(t)}{dt}$$
$$V_{sB}(t) = R_s i_{sB}(t) + \frac{d\psi_{sB}(t)}{dt}$$

The rotor voltage equations formulated to the rotating frame fixed to the rotor are as follows **[7]**:

$$V_{sa}(t) = R_r i_{ra}(t) + \frac{d\psi_{ra}(t)}{dt}$$
$$V_{sb}(t) = R_r i_{rb}(t) + \frac{d\psi_{rb}(t)}{dt}$$
$$V_{sc}(t) = R_r i_{rc}(t) + \frac{d\psi_{rc}(t)}{dt}$$

where the flux linkages related to the stator and rotor windings are given as

$$\begin{aligned}\psi_{sA} = {} & \overline{L_s} i_{sA} + \overline{M_s} i_{sB} + \overline{M_s} i_{sC} + \overline{M_{sr}}\cos(\theta_m) i_{ra} \\ & + \overline{M_{sr}}\cos(\theta_m + \frac{2\pi}{3}) i_{rb} \\ & + \overline{M_{sr}}\cos(\theta_m + \frac{4\pi}{3}) i_{rc}\end{aligned}$$

$$\begin{aligned}\psi_{sB} = {} & \overline{M_s} i_{sA} + \overline{L_s} i_{sB} + \overline{M_s} i_{sC} \\ & + \overline{M_{sr}}\cos(\theta_m + \frac{4\pi}{3}) i_{ra} \\ & + \overline{M_{sr}}\cos(\theta_m) i_{rb} \\ & + \overline{M_{sr}}\cos(\theta_m + \frac{2\pi}{3}) i_{rc}\end{aligned}$$

$$\begin{aligned}\psi_{sc} = {} & \overline{M_s} i_{sA} + \overline{M_s} i_{sB} + \overline{L_s} i_{sC} \\ & + \overline{M_{sr}}\cos(\theta_m + \frac{2\pi}{3}) i_{ra} \\ & + \overline{M_{sr}}\cos(\theta_m + \frac{4\pi}{3}) i_{rb} \\ & + \overline{M_{sr}}\cos(\theta_m) i_{rc}\end{aligned}$$

$$\begin{aligned}\psi_{ra} = {} & \overline{M_{sr}}\cos(-\theta_m) i_{sA} \\ & + \overline{M_{sr}}\cos(-\theta_m + \frac{2\pi}{3}) i_{sB} \\ & + \overline{M_{sr}}\cos(-\theta_m + \frac{4\pi}{3}) i_{sC} + \overline{L_r} i_{ra} \\ & + \overline{M_r} i_{rb} + \overline{M_r} i_{rc}\end{aligned}$$

$$\begin{aligned}\psi_{rb} = {} & \overline{M_{sr}}\cos(-\theta_m + \frac{4\pi}{3}) i_{sA} \\ & + \overline{M_{sr}}\cos(-\theta_m) i_{sB} \\ & + \overline{M_{sr}}\cos(-\theta_m + \frac{2\pi}{3}) i_{sC} + \overline{M_r} i_{ra} \\ & + \overline{L_r} i_{rb} + \overline{M_r} i_{rc}\end{aligned}$$

$$\psi_{rc} = \overline{M_{sr}}\cos\left(-\theta_m + \frac{2\pi}{3}\right)i_{sA} + \overline{M_{sr}}\cos\left(-\theta_m + \frac{4\pi}{3}\right)i_{sB} + \overline{M_{sr}}\cos(-\theta_m)i_{sC} + \overline{M_r}i_{ra} + \overline{M_r}i_{rb} + \overline{L_r}i_{rc}$$

Note that *L, M and i*are, respectively, the self-inductance, mutual inductance and the currents referred to the stator and rotor windings. Substituting Equations (3.12)–(3.17) in Equations (3.6)–(3.11) and further simplifying, the equations for the stator and rotor can be written in the vector-matrix notation form as follows:

$$\begin{bmatrix} V_{sA} \\ V_{sB} \\ V_{sC} \\ V_{ra} \\ V_{rb} \\ V_{rc} \end{bmatrix} = \begin{bmatrix} R_s + p\bar{L}_s & p\overline{M}_s & p\overline{M}_s & p\overline{M}_{sr}\cos(\theta_m) & p\overline{M}_{sr}\cos(\theta_{m1}) & p\overline{M}_{sr}\cos(\theta_{m2}) \\ p\overline{M}_s & R_s + p\bar{L}_s & p\overline{M}_s & p\overline{M}_{sr}\cos(\theta_{m2}) & p\overline{M}_{sr}\cos(\theta_m) & p\overline{M}_{sr}\cos(\theta_{m1}) \\ p\overline{M}_s & p\overline{M}_s & R_s + p\bar{L}_s & p\overline{M}_{sr}\cos(\theta_{m1}) & p\overline{M}_{sr}\cos(\theta_{m2}) & p\overline{M}_{sr}\cos(\theta_m) \\ p\overline{M}_{sr}\cos(\theta_m) & p\overline{M}_{sr}\cos(\theta_{m1}) & p\overline{M}_{sr}\cos(\theta_{m2}) & R_s + p\bar{L}_r & p\overline{M}_r & p\overline{M}_r \\ p\overline{M}_{sr}\cos(\theta_{m2}) & p\overline{M}_{sr}\cos(\theta_m) & p\overline{M}_{sr}\cos(\theta_{m1}) & p\overline{M}_r & R_s + p\bar{L}_r & p\overline{M}_r \\ p\overline{M}_{sr}\cos(\theta_{m1}) & p\overline{M}_{sr}\cos(\theta_{m2}) & p\overline{M}_{sr}\cos(\theta_m) & p\overline{M}_r & p\overline{M}_r & R_s + p\bar{L}_r \end{bmatrix} \begin{bmatrix} i_{sA} \\ i_{sB} \\ i_{sC} \\ i_{ra} \\ i_{rb} \\ i_{rc} \end{bmatrix}$$

The 3-phase stator and rotor voltage equations written in vector-matrix can be further transformed into 2-phase stator and rotor voltage equations using the well-known Park's transformation. To obtain this, a 3-phase SCIM with stationary axis *as-bs-cs* 1200 apart is considered.

The 3-phase stationary reference frame variables *as-bs-cs* are transformed into 2-phase stationary reference frame variables (*ds–qs*). Furthermore, these 2-phase variables are transformed into synchronously rotating reference frame variables (*de–qe*) and vice-versa. Let us assume that (*dS–qs*) axes are oriented at an angle of θ. The direct axis voltage *vsds* and quadrature axis voltage *vsqs*are further resolved into another type of component, viz., *as-bs-cs*, and finally, writing them in the vector-matrix notation form, we obtain

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 1 \\ \cos(\theta - 120\,°) & \sin(\theta - 120°) & 1 \\ \cos(\theta + 120°) & \sin(\theta + 120°) & 1 \end{bmatrix} \begin{bmatrix} V_{qs}^s \\ V_{ds}^s \\ V_{0s}^s \end{bmatrix}$$

Taking the inverse of the above, we obtain the following:

$$\begin{bmatrix} V_{qs}^s \\ V_{ds}^s \\ V_{0s}^s \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \cos(\theta - 120°) & \cos(\theta + 120°) \\ \sin(\theta) & \sin(\theta - 120°) & \sin(\theta + 120°) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix}$$

where is added as the zero sequence component, which may or may not be present. Note that in the above equations, voltage was considered as the variable. Similarly, the current and flux linkage equations can also be transformed into similar equations. Note that if θ is set to zero, the *qs*-axis will be aligned with the *as*-axis.

A. The Internal Model Control Structure

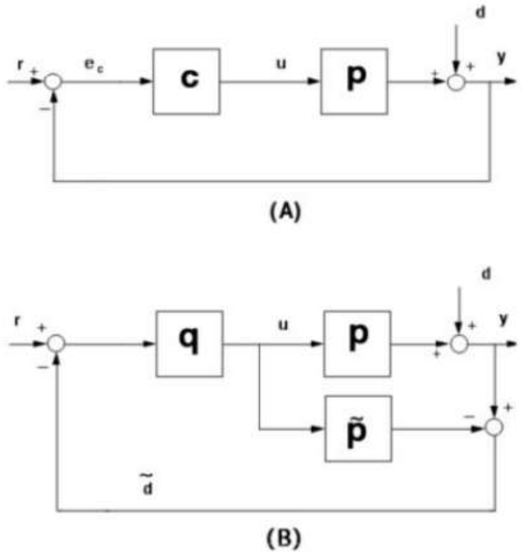

Fig.6: Classical (A) and Internal Model Control (B) Feedback Structures. p is the plant model, c is the classical feedback controller, pis the internal model, and q is the IMC controller.

The first issue one needs to understand regarding IMC is the IMC structure (to be distinguished from the IMC design procedure). Figure 1B is the “Internal Model Control” or “Q-parameterization” structure. It consists of an internal model p(s) and an IMC controller q(s). The IMC structure and the classical feedback structure (Figure 6(A) are equivalent representations; Figure 7 demonstrates the evolution of the IMC structure. A significant benefit of the IMC structure is that a design procedure for q(s) can be developed that is more straightforward and intuitive than the direct design of a classical feedback controller c(s). Having designed q(s), its equivalent classical feedback controller c(s) can be readily obtained via algebraic transformations, and vice-versa

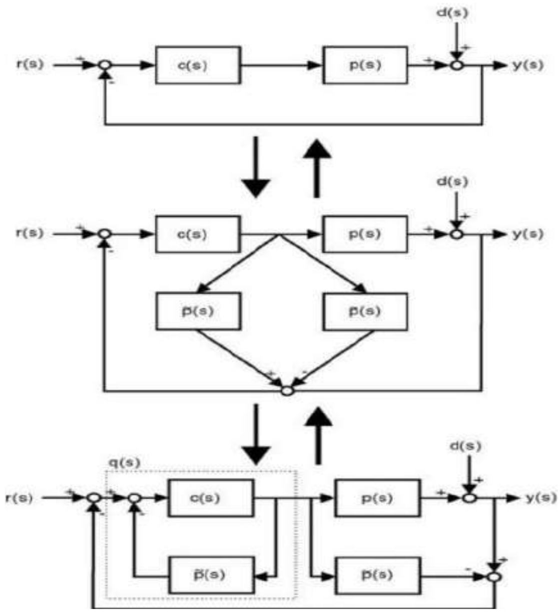

Fig. 7: Evolution of the Internal Model Control Feedback Structure.

$$c = \frac{q}{1 - \check{p}q}$$

$$q = \frac{c}{1+\check{p}q}$$

For linear, stable plants in the absence of constraints on u, it makes no difference to implement the controller either through c or q. However, in the presence of actuator constraints, one can use the IMC structure to avoid stability problems arising from input saturation without the need for special anti-windup measures.

B. Closed-loop Transfer Functions for IMC

The sensitivityε and complementary sensitivity η operators define the closed-loop behavior of a classical feedback linear control system.

$$y = \eta\mathrm{r} + \varepsilon\mathrm{d}$$
$$\mathrm{u} = p^{-1}\eta(\mathrm{r}-\mathrm{d})$$
$$e_c = \varepsilon(\mathrm{r}-\mathrm{d})$$

Recall that $p^{-1}$and 1 $\varepsilon(\mathrm{r}-\mathrm{d})$ for classical feedback control system. A statement of the sensitivity and complementary sensitivity operators in terms of the internal model pand the IMC controller q(s) corresponds to:

$$\eta(\mathrm{s}) = \frac{pq}{1+q(p-\tilde{p})}$$
$$\varepsilon(\mathrm{s}) = \frac{\tilde{p}q}{1+q(p-\tilde{p})}$$

In the absence of plant/model mismatch, p = $\tilde{p}$these functions simplify to

$$\tilde{\eta}(s) = \tilde{p}q;\ \tilde{\varepsilon}(\mathrm{s}) = 1-\tilde{\eta}(\mathrm{s}) = 1-\tilde{p}q;\ p^{-1}\tilde{\eta} = q$$

which lead to the following expressions for the input/output relationships between y, u, ec, r and d:

$$y = \tilde{p}q\mathrm{r} - (1-\tilde{p}q)\mathrm{d}$$
$$\mathrm{u} = q(\mathrm{r}-\mathrm{d})$$
$$e_c = (1-\tilde{p}q)(\mathrm{r}-\mathrm{d})$$

From examining Eqs.(9)-(11), one is able to recognize the benefits of the IMC parameterization. The closed-loop response between set-point r and output y is readily determined from the properties of the simple product pq. Furthermore, the manipulated variable response is determined through the design of q. As a consequence, both analysis and synthesis tasks in the control system are simplified.

Asymptotic closed-loop behavior (System Type)

Another important requirement for a feedback control system is that it leads to no offset for set-point and disturbance changes. Meeting this requirement for so-called Type 1 and Type 2 inputs is described in the following:

Type 1 (step Inputs): No offset to asymptotically step set-point/disturbance changes is obtained if

$$\lim_{s\to 0}\tilde{p}q = \tilde{\eta}(0) = 1$$

Type 2 (Ramp Inputs): For no offset to ramp inputs, it is required that

$$\lim_{s\to 0}\tilde{p}q = \tilde{\eta}(0) = 1$$
$$\lim_{s\to 0}\frac{d}{ds}(\tilde{p}q) = \frac{d\tilde{\eta}}{ds}|_{s=0} = 0$$

These requirements will form part of the IMC design procedure, as noted

IV. SIMULATION RESULTS

A model based on the first order differential equation (equation 25) has been built in the MATLAB/Simulink to observe the behavior of the self-excited induction generator.

A. Process of Self-excitation

The energy source, referred to above be provided by the kinetic energy of the rotor [7].With time varying loads, new steady-state value of the voltage is determined by the self-excitation capacitance value, rotor speed and load. Any current flowing in a circuit dissipates power in the circuit resistance, and an increasing current dissipates increasing power, which implies some energy source is available to supply the power. These values should be such that they guarantee an intersection of magnetization curve and the capacitor reactance line, which becomes the new operating point.

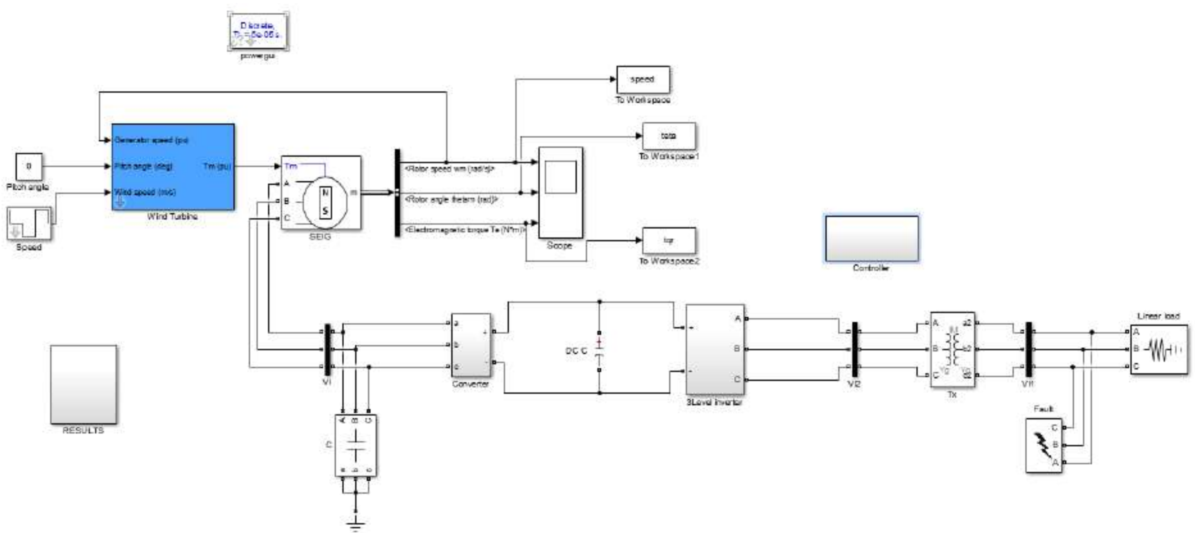

Fig 8. Simulation Diagram of the proposed system

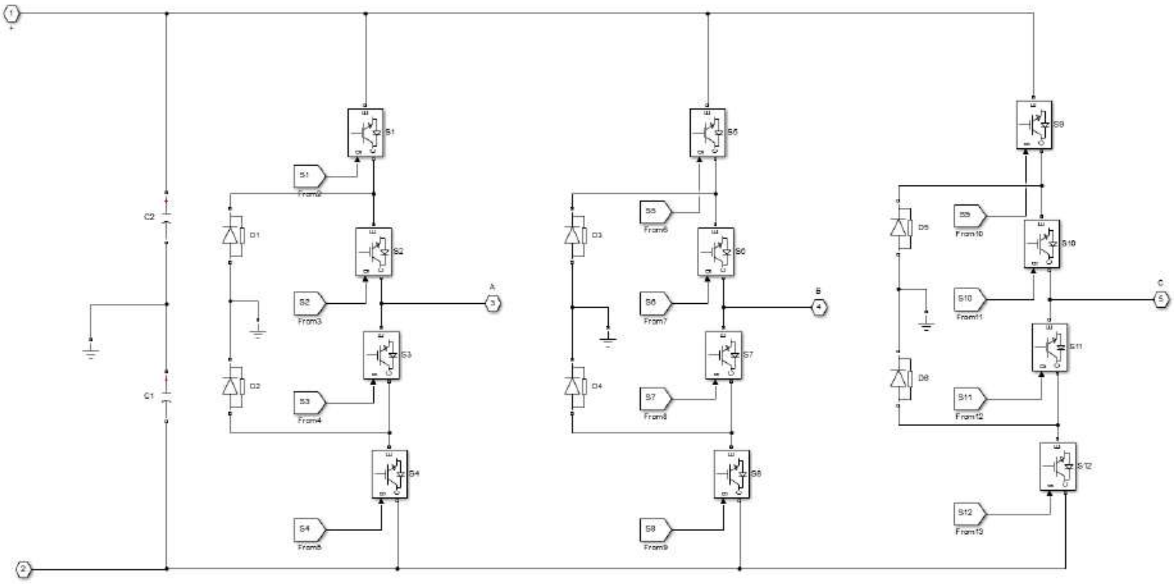

Fig 9. Simulation Diagram of Five Level inverter.

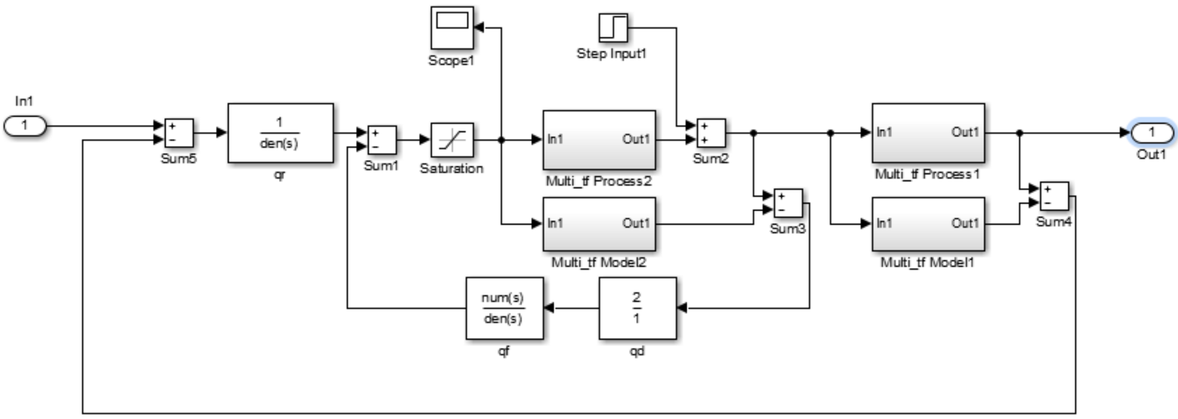

Fig 10. Simulation Diagram of the proposed controller IMC

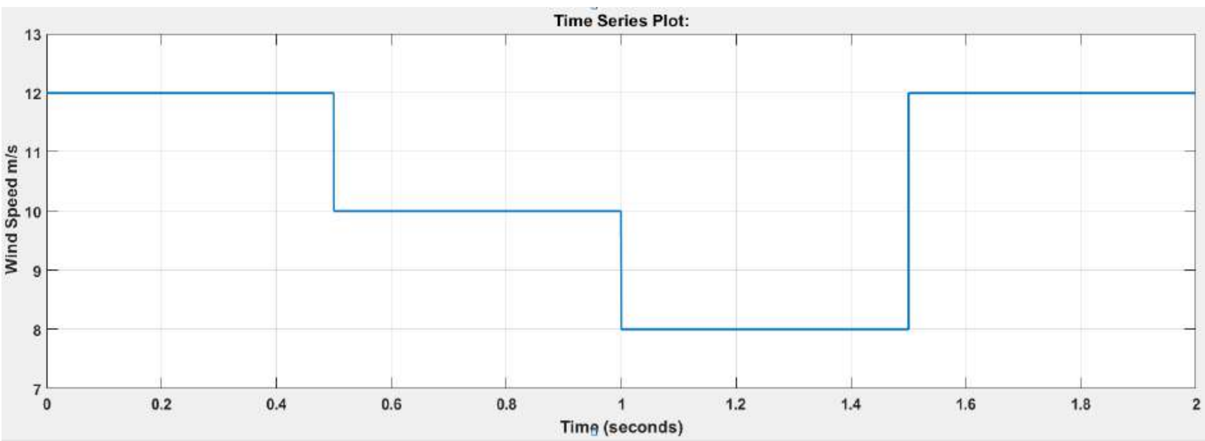

Fig 11. Wind Speed of the Wind turbine m/s

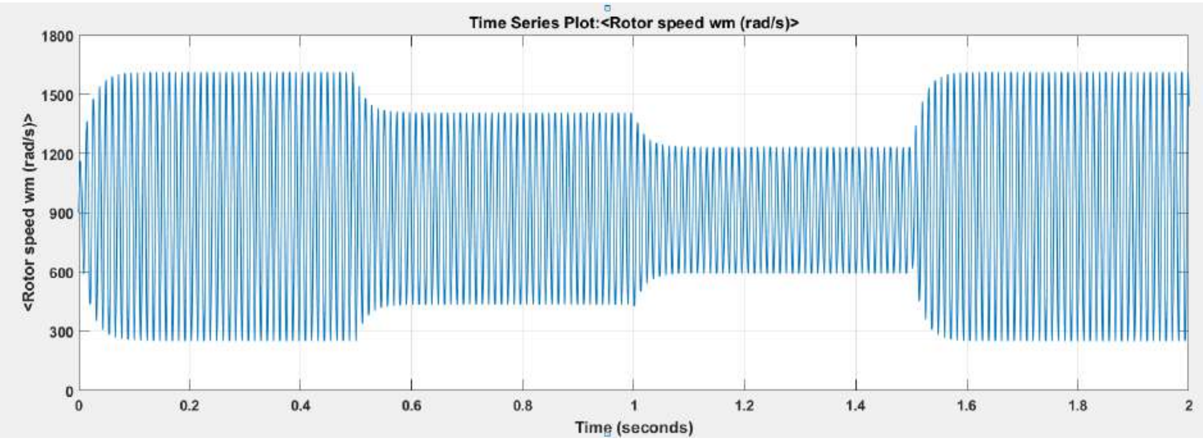

Fig. 12. Generator speed (For failed excitation case)

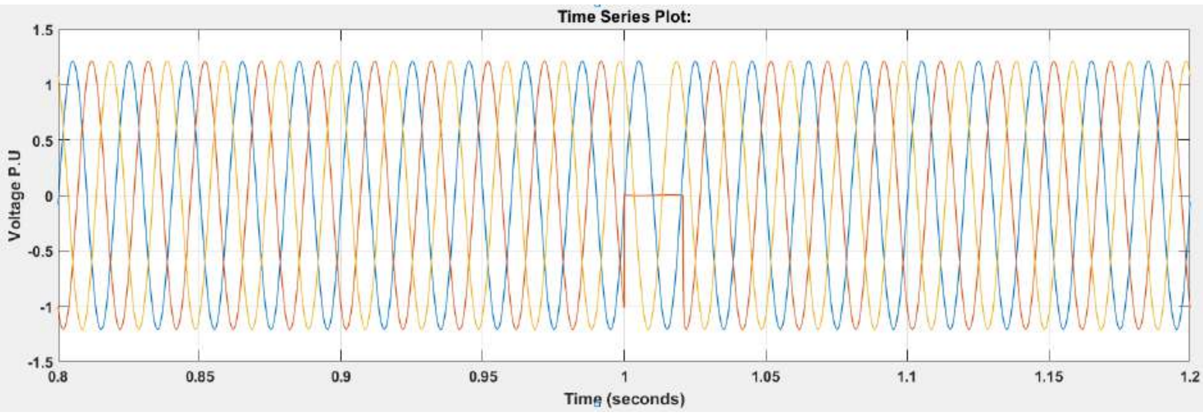

Fig.13. Voltage build up in a self-excited induction generator.

The following figures13 show the process of self-excitation in an induction machine under no load condition.For the following simulation results the WECS consisting of the SEIG and the wind turbine is driven by wind with velocity of 6 m/s to 12m/s, at no-load. At this wind velocity it can only supply a load. At t=1 sec load is applied on the WECS.

The new steady-state values of voltage is determined by intersection of magnetization curve and the capacitor reactance line. While the magnitude of the capacitor reactance line is influenced by the magnitude of *Im*, slope of the line is determined by angular frequency which varies proportional to rotor speed. If the rotor speed decreases then the slope increases, and the new intersection point will be lower to the earlier one, resulting in the reduced stator voltage. Therefore, it can be said that the voltage variation is proportional to the rotor speed variation. The variation of magnetizing current and magnetizing inductance are shown in the Figure13.

Figure 13 shows the rotor speed variations with load during the loss of excitation. The increase in load current should be compensated either by increasing the energy input (drive torque) thereby increasing the rotor speed or by an increase in the reactive power to the generator. None of these conditions were met here which resulted in the loss of excitation. It should also be noted from the previous section that there exists a minimum limit for speed (about300-1500 rpm for the simulated machine with the self-excitation capacitance equal to 70 micro-farads), below which the SEIG fails to excite.In a SEIG when load resistance is too small (drawing high load currents), the self-excitation capacitor discharges more quickly, taking the generator to the de-excitation process. This is a natural protection against high currents and short circuits.

For the simulation results shown below, the SEIG-wind turbine combination is driven with an initial wind velocity of 11m/s at no- load, and load was applied on the machine at t=1 seconds. At t = 1.01 seconds there was a step input change in the wind velocity reaching a final value of 12m/s. In both cases the load reference remained.

Figure 13 shows the electric power output of the SEIG and mechanical power output of the wind turbine. The electric power output of the SEIG (driven by the wind turbine), after *t*=1 seconds after a short transient because of sudden disturbance in the load current, at t=1 sec. Pitch controller limits the wind turbine output power, for wind speeds above 11.5 m/s, to the maximum rated power. This places a limit on the power output of the SEIG also, preventing damage to the WECS. Since, the pitch controller has an inertia associated with the wind turbine rotor blades, at the instant *t*=1.01seconds the wind turbine output power sees a sudden rise in its value before pitch controller starts rotating the wind turbine blades out of the wind thereby reducing the value of rotor power coefficient.

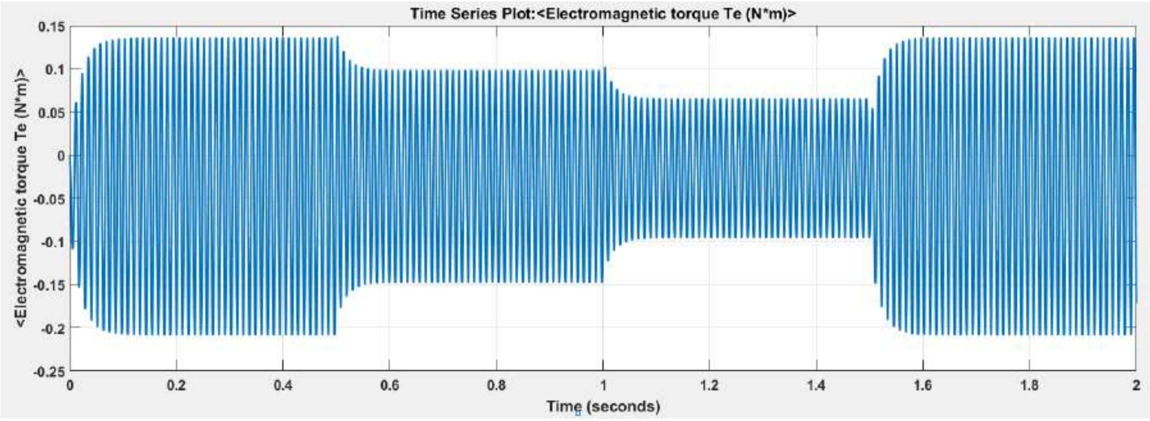

Fig 14. Shows the electromagnetic torque *Te* and the drive torque *Tdrive* produced by the wind turbine.

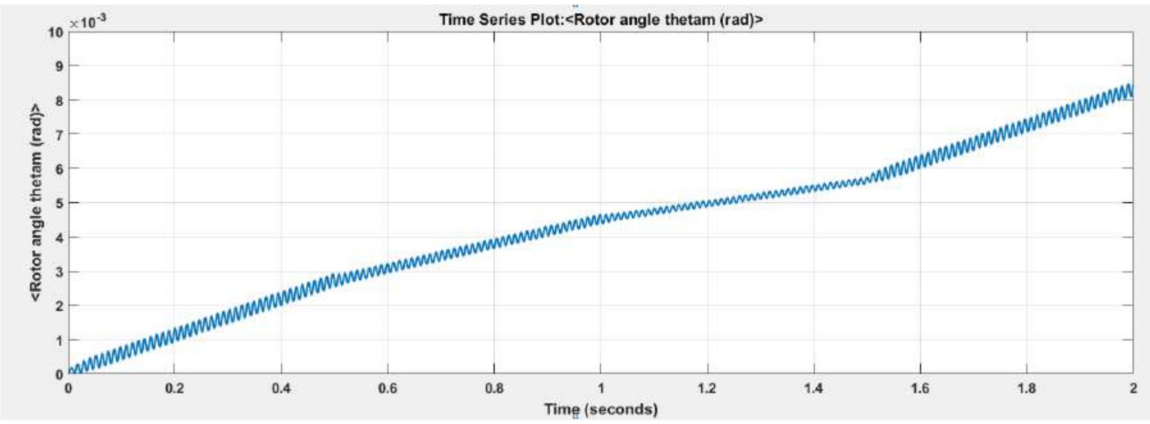

Fig15. Rotor angle theta

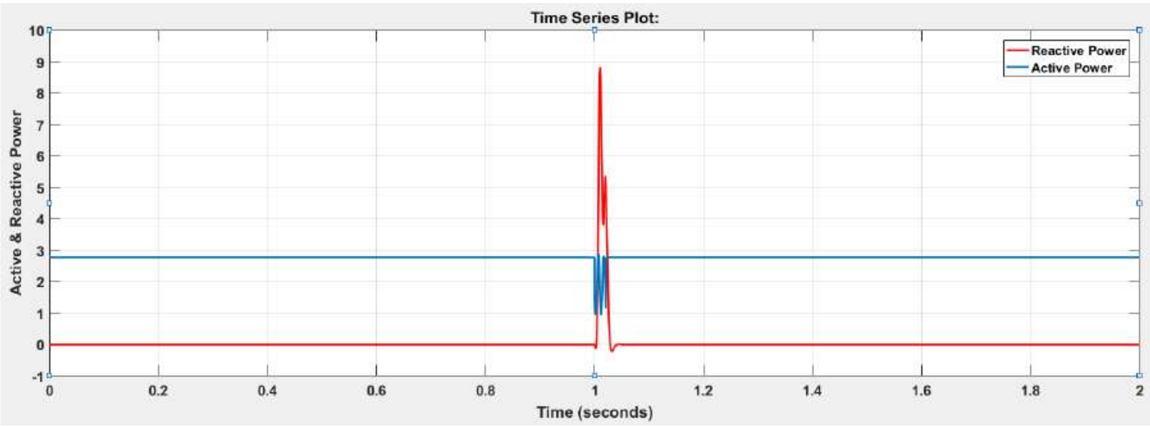

Fig. 16. Output Active and Reactive power produced by wind turbine and SEIG.

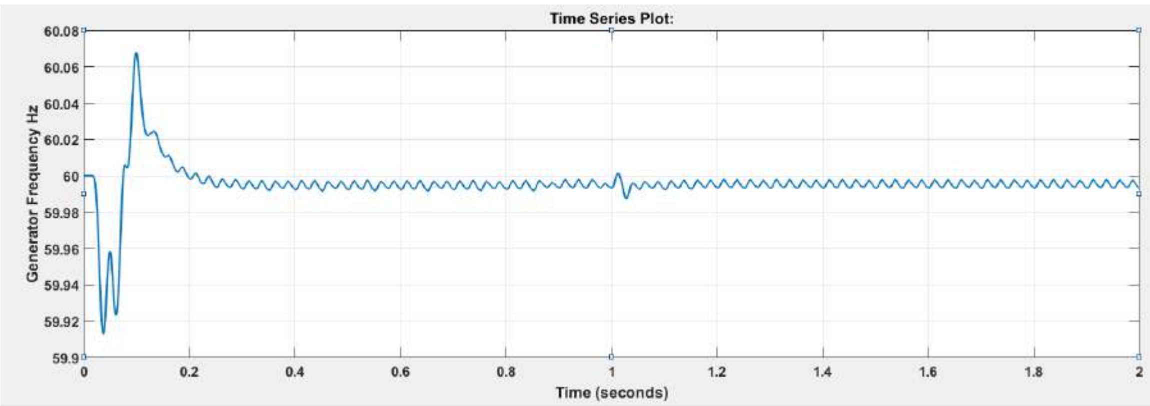

Fig17. Frequency of the Wind Turbine SEIG.

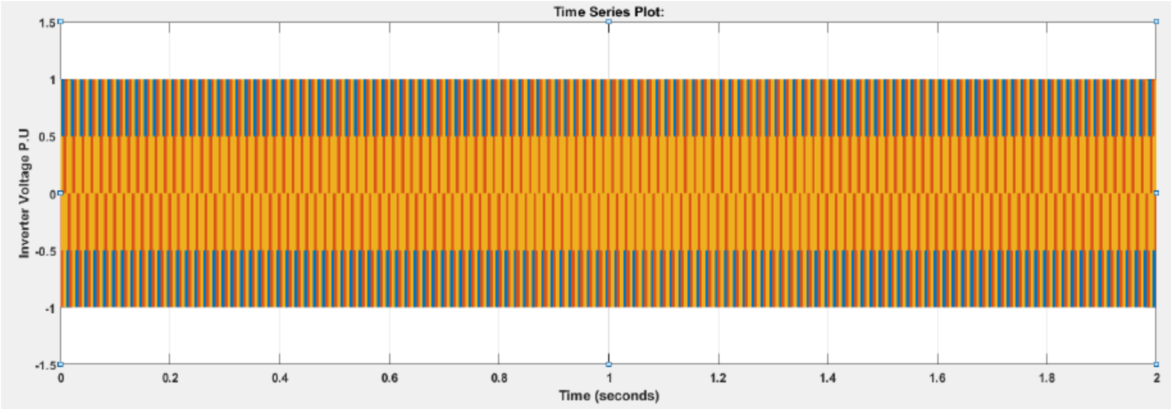

Fig18.Five Level inverter Voltage

Figure 15 also shows the electromagnetic torque *Te* and the drive torque *Tdrive*produced by the wind turbine at different wind speeds.

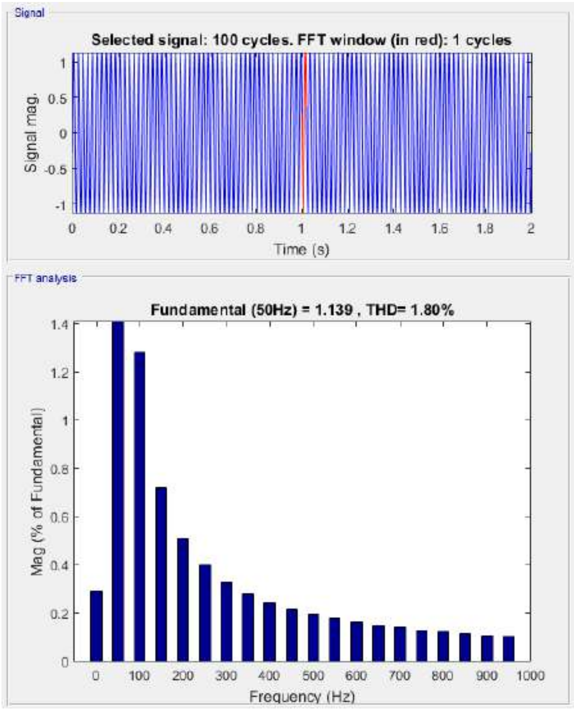

Fig19. Source Voltage with the 1.80% THD.

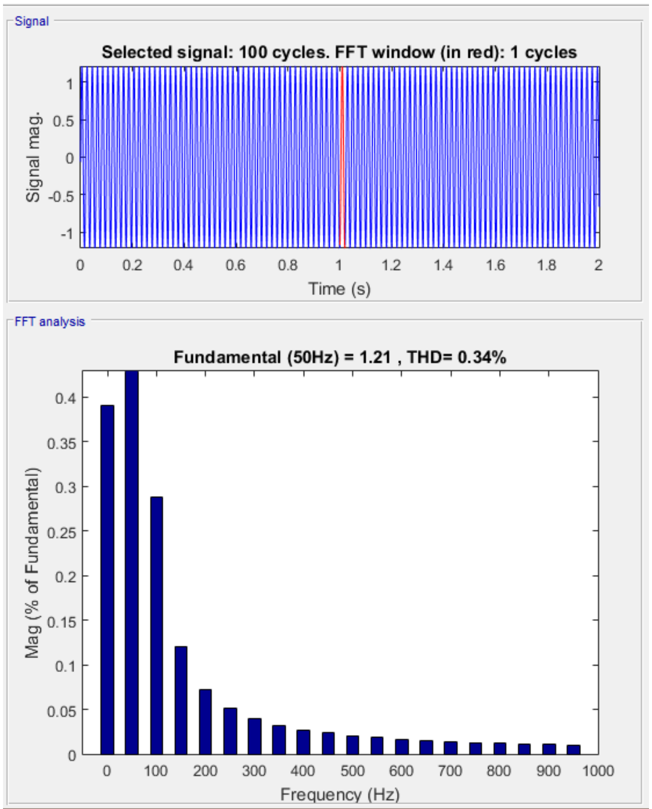

Fig 20. Load Voltage with the 0.34% THD.

TABLE I. THD OF THE VOLTAGE AT THE SOURCE AND LOAD

SEIG	**Objectives**			
	Dynamic response		**Power Quality Improvement (Controlling of THD Or Efficiency %)**	**Reactive Power Compensation**
	V_L(Load Voltage) % Regulation	**Frequency control (f-Hz)**		
With PI	15.6% poor voltage regulation	45Hz poor frequency slight deviations	8.6%-THD	Compensated partially
With Fuzzy	0.8% Good voltage regulation	60-50Hz better frequency deviations with slight oscillations	1.06%-THD	Compensated good
With ANN	0.6% good voltage regulation	60-50Hz, and good in dynamic response.	99.95% 0.8% -THD	Compensated excellent
With ANFIS	0.4% Very good voltage regulation	60-50Hz, and good in dynamic response.	99.86%	Compensated good
With IMC controller	0.5% Very good voltage regulation	60-50Hz, and good in dynamic response.	1.5%	Compensated good
P&O	-	-	99.93%	-

V. CONCLUSION

In this paper the electrical generation part of the wind energy conversion system has been presented. Modelling and analysis of the induction generator, the electrical generator used in this thesis, was explained in detail using dq-axis theory. The effects of excitation capacitor and magnetization inductance on the induction generator, when operating as a stand-alone generator, were explained. From the simulation results presented, it can be said that the self-excitedinduction generator (SEIG) is inherently capable of operating at variable speeds. A mathematical model of three-phase SEIG supplying single-phase consumer load with ELC has been developed and verified with Simulation results. The induction generator can be made to handle almost any type of load, provided that the loads are compensated to present unity power factor characteristics. Based on a close agreement between the simulated and experimental results, it can be concluded that the approach made in the development of dynamic model is elegant. The dynamic behavior of the three-phase SEIG with load controller has revealed that this system can be used satisfactorily in wind energy application, with the help of internal model controller (IMC).

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