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Analysis and Control of Self Excited Induction Generator Driven by Wind Turbine Feeding Static Loads

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Abstract— this paper presents dynamic response of Self Excited Induction Generator(SEIG) driven by wind turbine and supplied power to an isolated static inductive load under different loading and wind speed condition .A dynamic model of the SEIG is presented in dq axis in stationery reference frame using MATLABE /SIMULINK software package . two type of control are used to maintain the voltage and frequency at its rated value in case of variation in the load or in the wind speed. the first control is the reactive control to adjust the terminal voltage at its rated value through variation of the self excitation using switching capacitor bank and The second control is the active control to adjust the frequency at its rated value by changing the value of the pitch angle for the blade of the wind turbine .this two type of the control can be applied to this system by Using proportional pulse integral controller (PI).

Index Terms— Self Excited Induction Generator (SEIG), wind turbine ,dynamic performance, PI-controller.

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1 Introduction

MOST of the electricity generated comes from fossil fuels (coal, oil and natural gas). These fossil fuels have finite reserves and will run out in the future. they produce pollutant gases when they are burned in the process to generate electricity. Fossil fuels are a non-renewable energy source. However, renewable energy resources (wind, hydro, solar, biomass, geothermal and ocean) are believed not to run out, and are environmental friendly. In renewable energy resources wind energy is the dominating source. It is a clean and abundant resource that can produce electricity with no pollutant gas. The wind generation systems produce electricity at variable wind speed conditions. Also, it is one of the faster growing energy technologies in the world . the application which use wind energy is called (WECS) [1,2,3].

The SEIG was used as the electromechanical energy converter in such generation schemes. The advantages of induction generators are low cost, robustness, absence of moving contacts and no need for DC excitation. The cost of an induction generator is about 40% - 50% of that of a synchronous generator of the same capacity. The SEIG is capable of generating electrical energy from constant speed as well as variable speed prime movers. Such an energy system can feed electrical energy to isolated locations, which in turn can enhance agriculture production and improve the standard of living in remote areas [4] . However, the induction generator offers poor voltage regulation and its value depends on the prime mover speed , capacitor bank size and load characteristics [5,6].

Many research are made to provide constant voltage at different load most of this research use PWM as a self excited IG controller [7,8] .

In this paper a dynamic response of Self Excited Indication Generator(SEIG) driven by wind turbine under different loading and wind speed condition is shown .

proportional pulse integral (PI) controller are used to maintain the voltage and frequency at rated value in case of variation in the load or in the wind speed .

2 System Modeling

The wind power generation system studied in this paper is shown in figure (1). The wind turbine is coupled to the shaft of an induction generator (IG) through a gear box .the IG is connected to capacitor bank for self –excitation and supplied power to an isolated static inductive load.

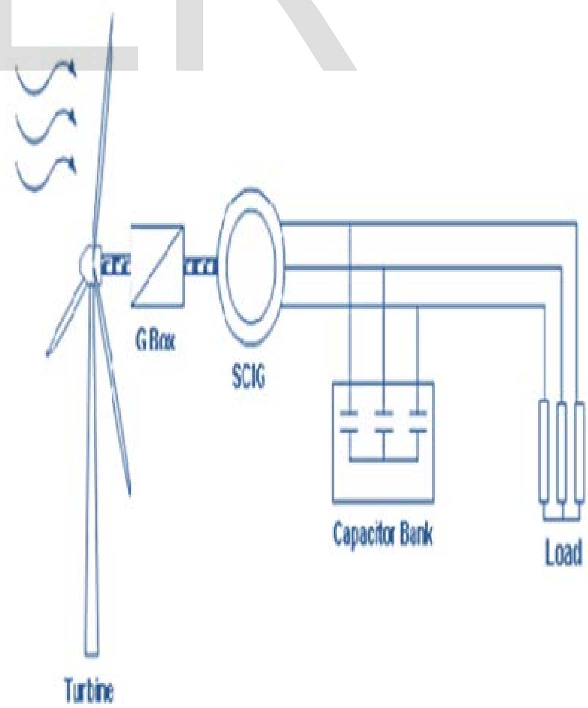

Fig.1 Stand-alone wind station.

2.1 Wind Turbine Mathematical Mode

The captured power by wind turbine depends on site conditions (wind speed V and air density ρ), turbine's blade geometry (blades radius R and pitch angle β) and power coefficient CP

$$P_m = \frac{1}{2} \cdot \rho \cdot A \cdot V^3 \cdot C_p \quad (1)$$

$$A = \pi R^2 \quad (2)$$

$$C_p = C_1\left[\frac{C_2}{\lambda_i} - C_3\beta - C_4\right]e^{\frac{C_5}{\lambda i}} + C_6\lambda \quad (3)$$

$$\lambda_i = \left[\frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3}\right]^{-1} \quad (4)$$

Where C1=.5176 , C2=116, C3=.4 , C4=5 and C6=.0068

Figure (2) shows the variation of C_P against λ at different bitch angle with rated wind speed

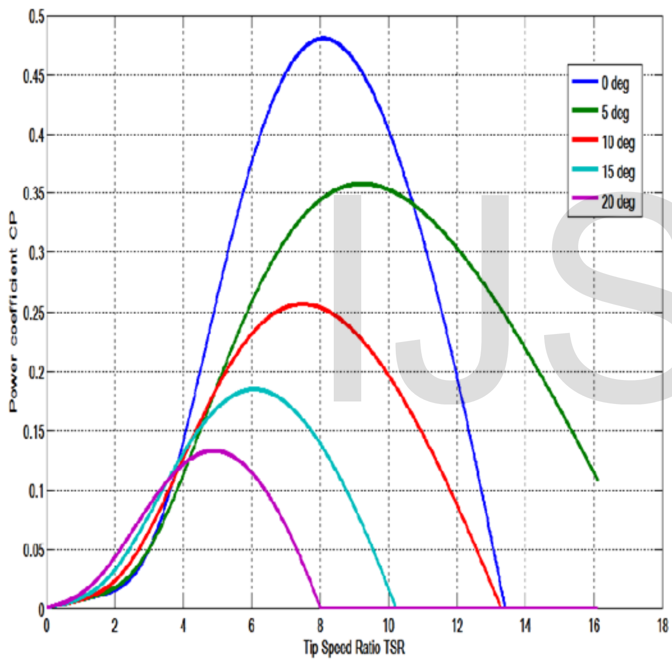

Fig. 2 CP-λ at different bitch angle.

Figure(2) shows that the wind turbine efficiency has maximum value at single point for each pitch angel.

Figure (3) shows Captured wind power against rotor speed at different wind speed.

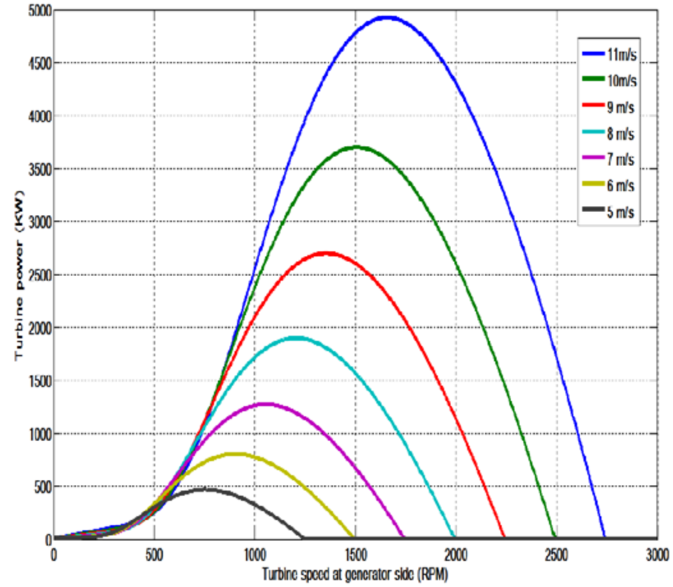

Fig. 3 Captured wind power against rotor speed at different wind speed.

2.2 Self Excited Induction Generator Modeling

Figure (4) shows a complete dq-axis model, of the SEIG with load, in the stationary reference frame. Capacitor C is connected at the stator terminals for the self-excitation.

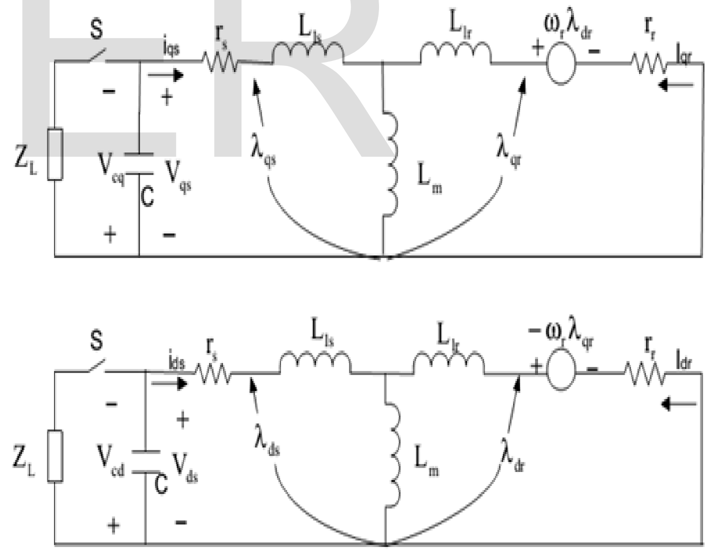

Fig. 4 Dq model of SEIG in stationary reference frame (all values referred stator

$$V_{ds} = r_s\, i_{ds} + L_s\, (di_{ds}/dt) + L_m\, (di_{dr}/dt) \quad (5)$$

$$V_{qs} = r_s\, i_{qs} + L_s\, (di_{qs}/dt) + L_m\, (di_{qr}/dt) \quad (6)$$

$$0 = r_r\, i_{dr} + \omega_r\, (L_r\, i_{qr} + L_m\, i_{qs}) + L_r\, (di_{dr}/dt) + L_m\, (di_{ds}/dt) \quad (7)$$

$$0 = r_r\, i_{qr} - \omega_r\, (L_r\, i_{dr} + L_m\, i_{ds}) + L_r\, (di_{qr}/dt) + L_m\, (di_{qs}/dt)$$

(8)

$$L_s = L_{Ls} + L_m \quad (9)$$

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

(10)

Where:

Lm Mutual inductance between stator and rotor windings .

L_{Ls} Leakage inductance of stator winding .

L_{Lr} Leakage inductance of rotor winding .

L_s Total Stator inductance .

L_r Total rotor inductance .

From Figure (4) the capacitor voltage can be represented as:

$$i_{qc} = C\frac{dV_{qs}}{dt} \quad (11)$$

$$i_{dc} = C\frac{dV_{ds}}{dt} \quad (12)$$

at no load $i_{qc} = i_{qs}$; $i_{dc} = i_{ds}$ (13)

at load $i_{qc} = (i_{qs} - i_{ql})$; $i_{dc} = (i_{ds} - i_{dl})$ (14)

For resistive load $i_{ql} = \frac{V_{qc}}{R}$; $i_{dl} = \frac{V_{dc}}{R}$ (15)

For indicative load $V_{qc} = i_{ql}R + L\, di_{ql}/dt$ (16)

$$V_{dc} = i_{dl}R + L\, di_{dl}/dt \quad (17)$$

The electromagnetic torque developed by the generator is given by [10]

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)L_m\left(i_{qs}i_{dr} - i_{ds}\, i_{qr}\right) \quad (18)$$

The mechanical torque equation of the machine is:

$$P\omega_r = \frac{1}{J}\frac{P}{2}(T_e - T_d) \quad (19)$$

Where:

P: Number of poles.

J: Inertia of the rotor in (Kg m2)

T_d: Drive torque in (Nm).

ω_r: rotor speed(rad/s).

In the modeling of an induction machine used for motoring applications, it is important to determine the magnetizing inductance, Lm=.18H at rated voltage. In the SEIG the variation of magnetizing inductance is the main factor in the dynamics of voltage build up and stabilization .

The variation of the magnetizing inductance, measured at rated frequency, for induction machine used in this investigation is given in [11].

$$L_m = -1.56*10^{-11}V^4_{ph} + 2.44*10^{-8}V^3_{ph} - 1.19*10^{-9}V^2_{ph} + 1.42*10^{-3}V_{ph} + .245 \quad (20)$$

Where Vph is the phase voltage

The induction machine used as the SEIG in this investigation is a three-phase squirrel cage rotor induction motor with specification: 4 pole, 415V star connected, 7.8A, 3.6kw,50 Hz. The parameters obtained from parameter determination tests at rated values of voltage and frequency are Lm=Lsr=181mH, Rs=1.66Ω; Rr =2.74Ω , J=.089.

Figure (5) Shows Modeling of SEIG Driven by Wind Turbine

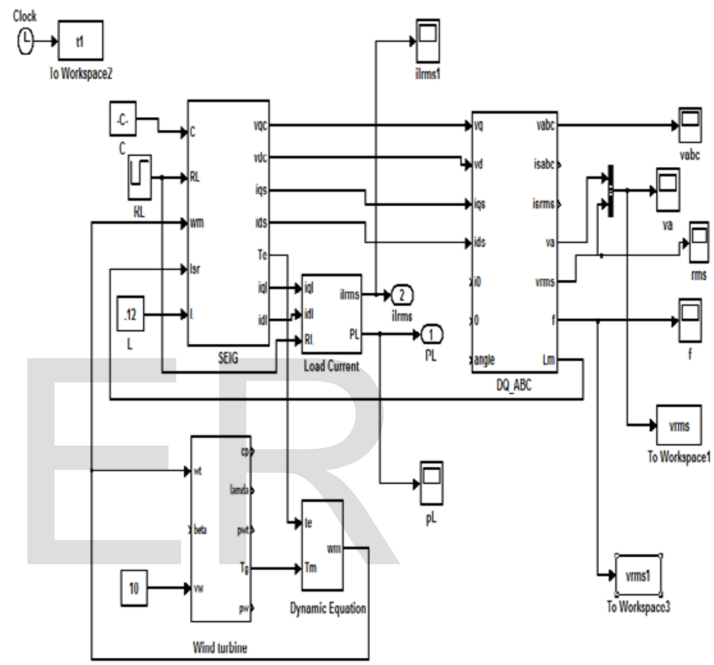

Fig. 5 Model of SEIG driven by wind turbine.

3. Dynamic Response of The SEIG-WECS

The dynamic response of the SEIG are obtained if there is no Control on the control variables excitation capacitor (C) and bitch angle of turbine blade(β).various disturbance condition in the load and in the wind speed. the disturbance in the load and in the wind speed assumed to be of step form

3.1 Dynamic Response of SEIG-WECS Due to Sudden Load Variation

The voltage and frequency generated by SEIG effected by any disturbance in the load . this disturbance is done by applying a sudden change of the standalone inductive load. The load is equivalent to R-L series circuit with load resistance (R_L) =100 ohm and the load inductance (L_L= .12 H per phase) after a sudden disturbance occurred to the resistance to increase from 100 ohm to 200 ohm so the load is become (200ohm,.12H) at t=10s , capacitor bank has the same value before and after disturbance C=100 μF and the wind turbine operate at rated wind speed V_W= 10 m/s .

Figures (6,7,8,9,10) Shows The dynamic response of SEIG corresponding to increasing in the load resistance (100ohm,.12H) →(200ohm,.12H) at t=10s and wind speed is constant V_W= 10 m/s.

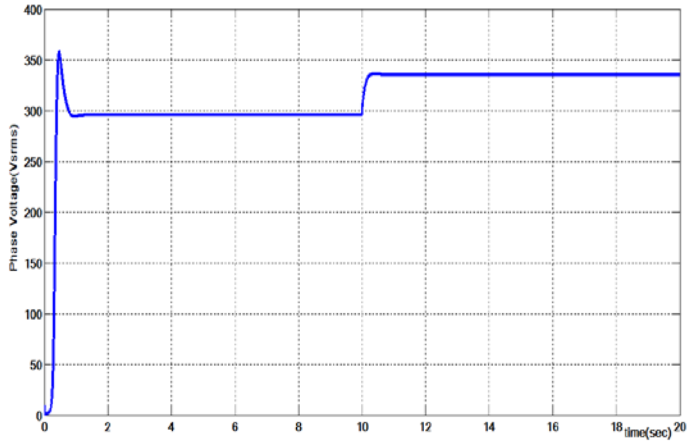

Fig.6 Dynamic response of phase voltage due to sudden load variation.

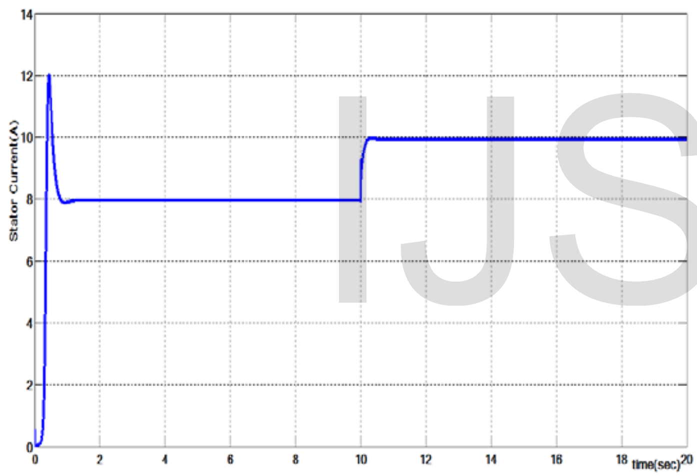

Fig.8 Dynamic response of stator current due to sudden load variation

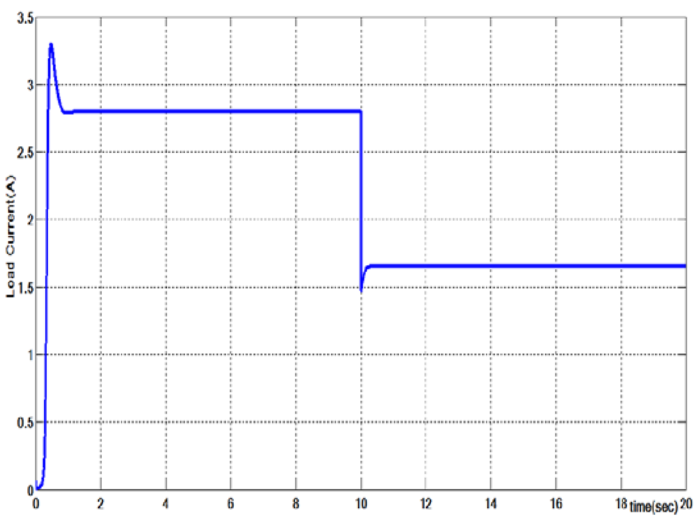

Fig.9 Dynamic response of load current due to sudden load variation

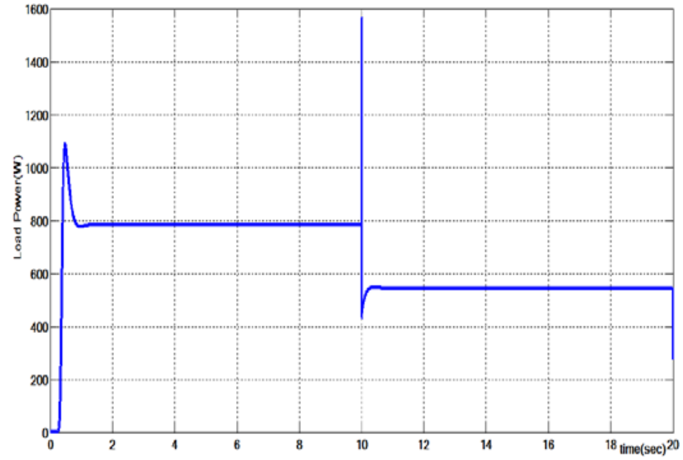

Fig. 10 Dynamic response of load power due to sudden load variation

As shown in figure (6,7,8,9,10) the load impedance increase at t=10s so load current is decrease because ILα ($1/Z_L$) and the load power will decrease because P_Lα I_L^2 as the load power decrease the speed is increase so the voltage and frequency is increased .

3.2 Dynamic Response of SEIG-WECS Due to Sudden Wind Speed Variation

For the simulation results shown below ,SEIG driven by wind turbine at rated wind 10 m/s speed ,at t=10sec the wind speed is increased to 12 m/s, the load has constant value (100ohm ,.12H) after and before increase in the wind speed and the capacitor bank remain constant C=100 μF

Figures (11,12,13,14,15) Shows The dynamic response of SEIG corresponding to increasing in the wind speed V_W 10m/s→12m/s at t=10s , load= (100ohm ,.12H) is constant.

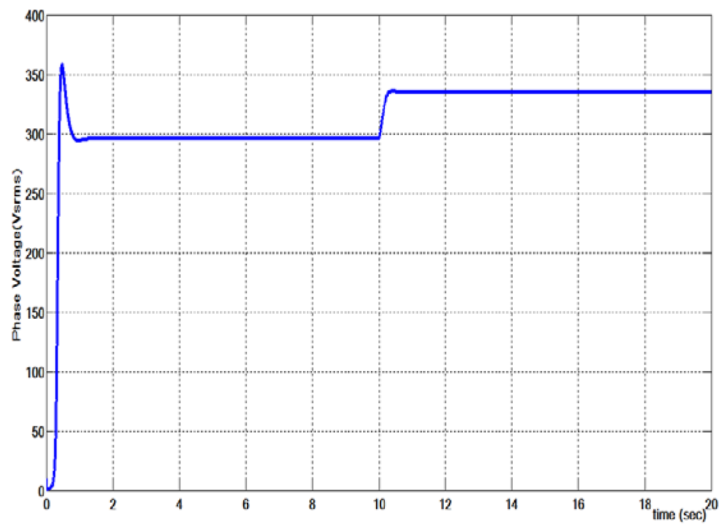

Fig. 11 Dynamic response of phase voltage due to sudden wind speed variation.

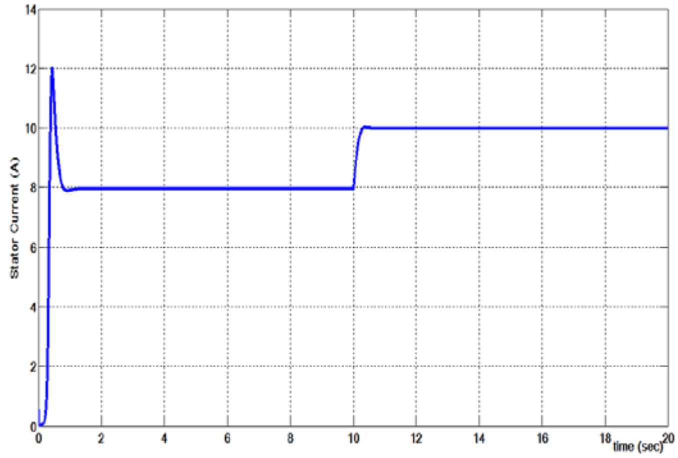

Fig.12 Dynamic response of stator current due to sudden wind speed variation

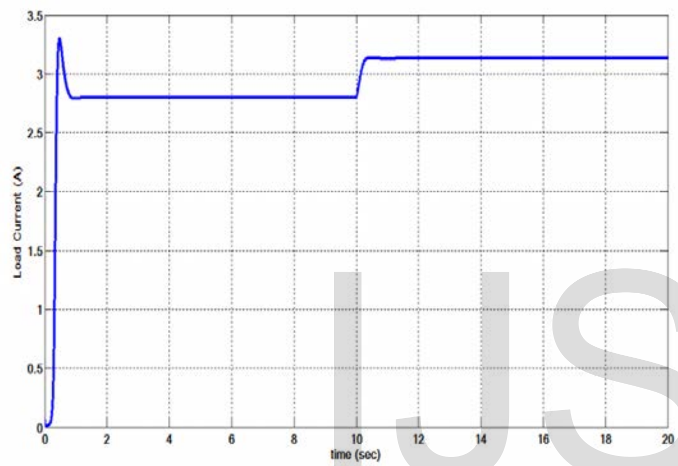

Fig.13 Dynamic response of load current due to sudden wind speed variation.

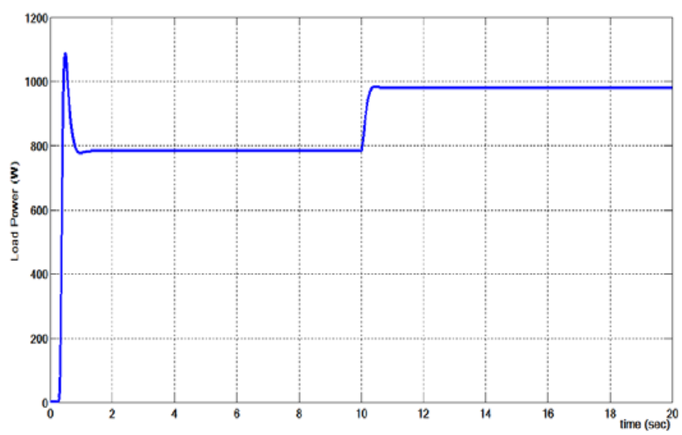

Fig.14 Dynamic response of load power due to sudden wind speed variation.

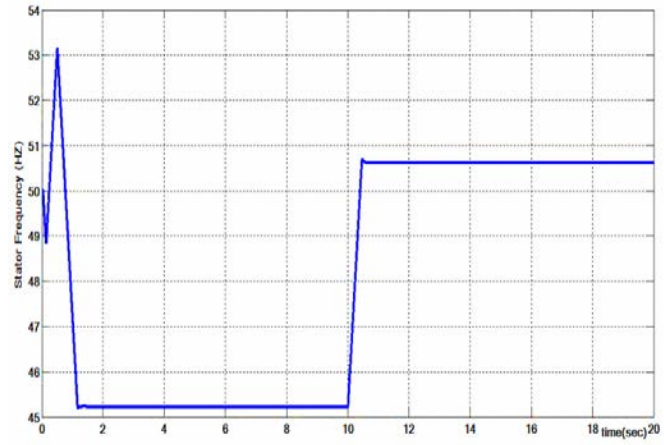

Fig. 15 Dynamic response of stator frequency due to sudden wind speed variation.

As shown in figures (11,12,13,14,15) the load impedance is constant and wind speed is increase from 10m/s →12m/s at t=10s. so the voltage and frequency and power is increased

4. Voltage And Frequency Control of SEIG Driven by Wind Turbine using PI Controller

The terminal voltage and frequency varies with load and wind speed so two type of control are used to maintain the voltage and frequency at its rated value in case of variation in the load or in the wind speed. the first one is the reactive control to adjust the terminal voltage at its rated value through variation of the self excitation using switching capacitor bank by a controlled duty cycle[9]. The second control is the active control to adjust the frequency at its rated value by changing the value of the pitch angle for the blade of the wind turbine . proportional plus integral controller (PI) is used for active and reactive control.

4.1 PI Active and Reactive Controller

The active and reactive control can be applied by using PI controllers which contain two variable gain the first gain is integral gain KI and the second gain is proportional gain KP .

The voltage and frequency error are used as an input to the PI controllers. Then the output of the PI reactive controller is used to regulate the duty cycle λ of the switching capacitor bank .while the output of the PI active controller is used to tune up the bitch angle which is maintain the frequency at its rated value . the gain of PI controllers are determined using trial and error method.

$$C_{eff}=\left[\frac{C_{max}}{(1-\lambda)^2+\sigma(\lambda)^2}\right] \quad (21)$$

Where C_{eff} is the effective capacitor bank value (micro–farad),C_{max} is the maximum capacitor value & C_{min} is the minimum capacitor value & $\sigma = (C_{max}/C_{min})$, λ is the duty cycle [9].

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Figure (16) show the block diagram of the system controlled by PI.

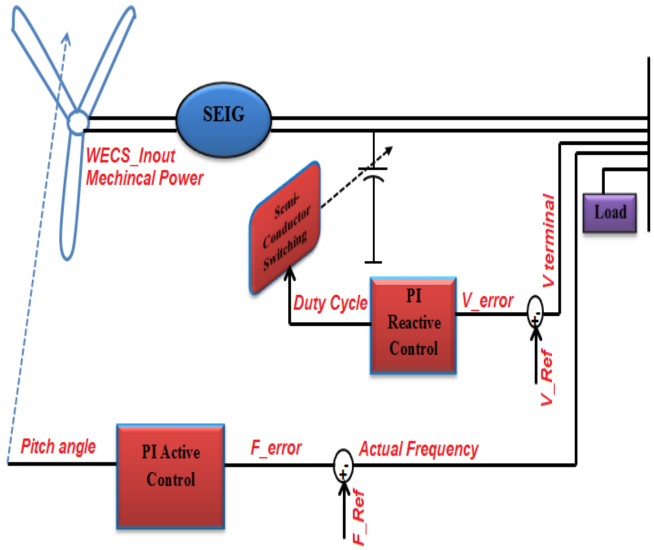

Fig. 16 Block diagram of the system controlled by PI.

Figure (17) shows model of PI reactive controller.

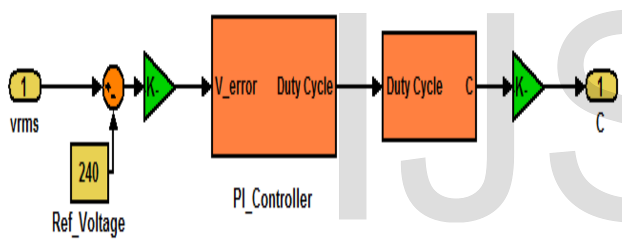

Fig. 17 Model of PI_Reactive controller.

Figure (18) shows model of PI active controller.

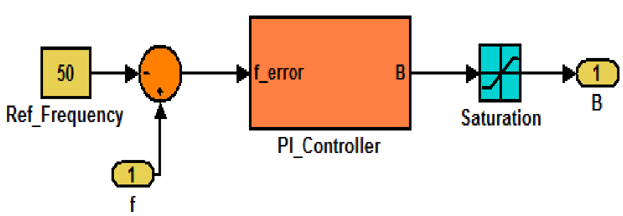

Fig. 18 Model of PI_Active controlle

4.2 Dynamic Response of SEIG-WECS Due to Sudden Load Variation with PI controllers

Figure (19) shows model of SEIG driven by wind energy conversion system (WECS) controlled by PI controllers

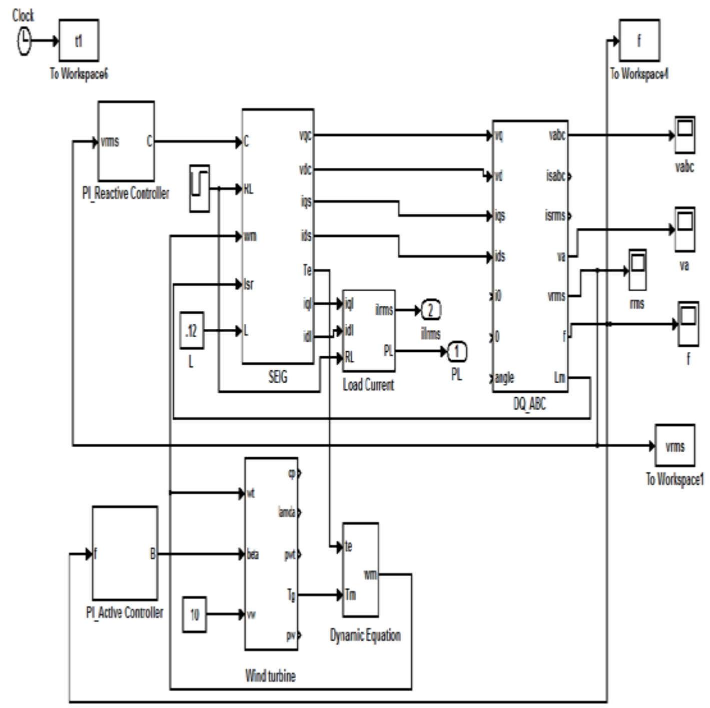

Fig. 19 Model of SEIG_WECS controlled by PI controllers

Figures (20, 21,22,23) simulation result of the system under study in case of using PI controller on the excitation capacitor and on the pitch angle for the blade of wind turbine when sudden disturbance on the load (100ohm,.12H) →(200ohm,.12H) at t=10s and wind speed is constant Vw =10 m/s. the simulation given in that figures shows the ability of the proposed controller to overcome the load variation and operate WECS-SEIG at its rated voltage and rated frequency .

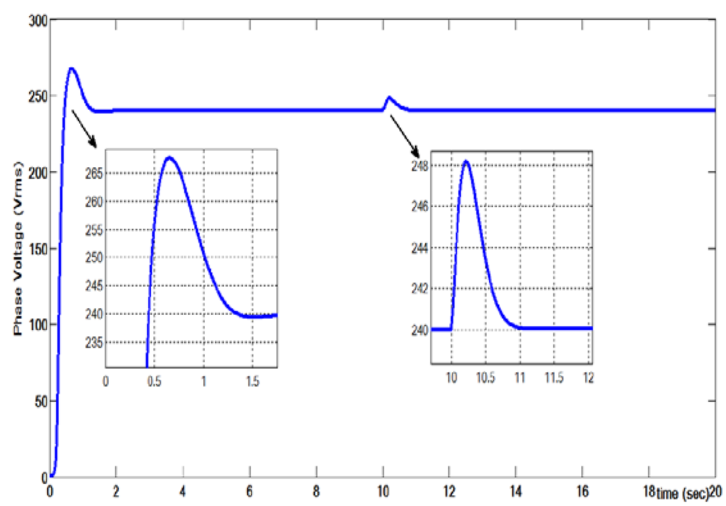

Fig.20 Dynamic response of the Phase Voltage for PI controllers corresponding to sudden load variation.

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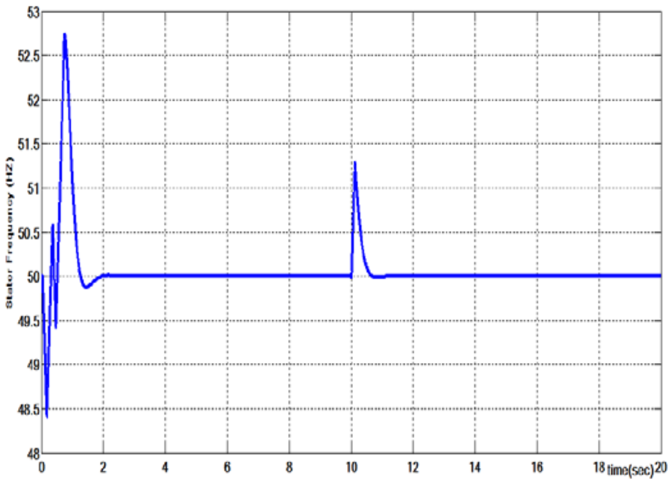

Fig.21 Dynamic response of the Stator Frequency for PI controllers corresponding to sudden load variation.

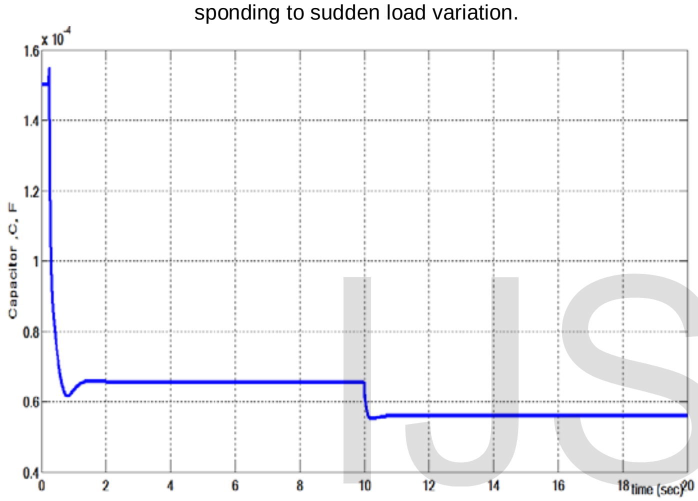

Fig.22 Dynamic response of the Capacitor variation for PI Reactive controller corresponding to sudden load variation .

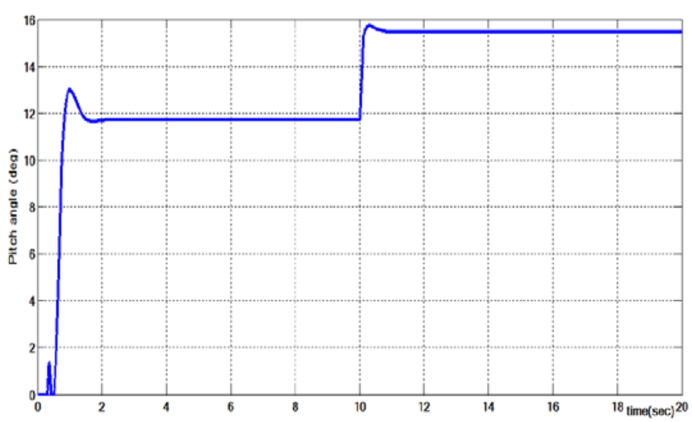

Fig.23 Dynamic response of the Pitch angle variation for PI Active controller corresponding to sudden load variation.

As shown in Figure (20,21,22,23) the load change from (100ohm ,.12H) →(200ohm,.12H) at t=10s and wind speed Vw =10 m/s constant .as the load impedance increased and wind speed is constant the voltage and frequency is increased . to maintain voltage and frequency at its rated value the excitation capacitor is decreased and decrease rotor speed by increasing pitch angle of the blade of turbine .

4.3 Dynamic Response of SEIG-WECS Due to Sudden Wind Speed Variation with PI controllers

Figures (24, 25, 26, 27) simulation result of the system under study in case of using PI controller on the excitation capacitor and on the pitch angle for the blade of wind turbine when sudden disturbance on the wind speed V_W =10 m/s →12 m/s at t=10s , load= (100ohm ,.12H) is constant.

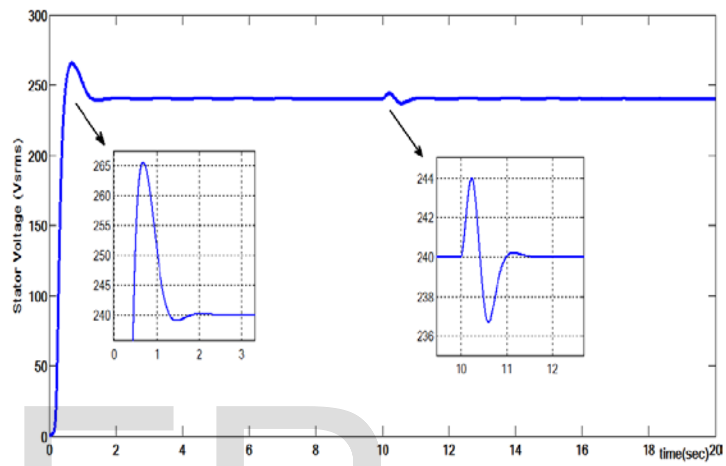

Fig.24 Dynamic response of the Phase Voltage for PI controllers corresponding to sudden wind speed variation .

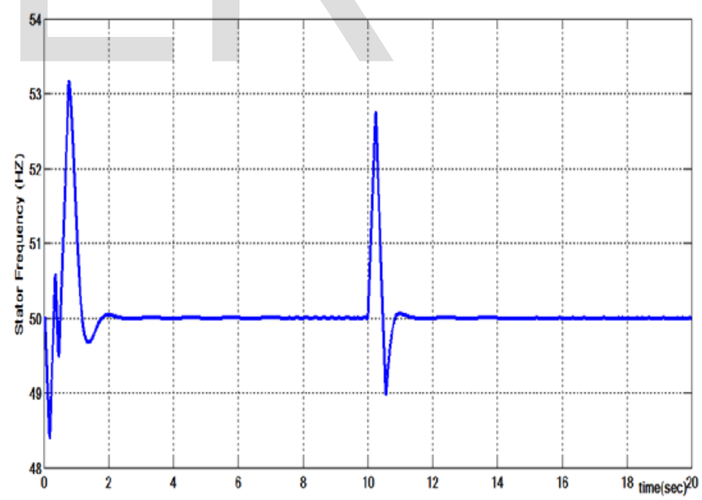

Fig.25 Dynamic response of the Stator frequency for PI controllers corresponding to sudden wind speed variation.

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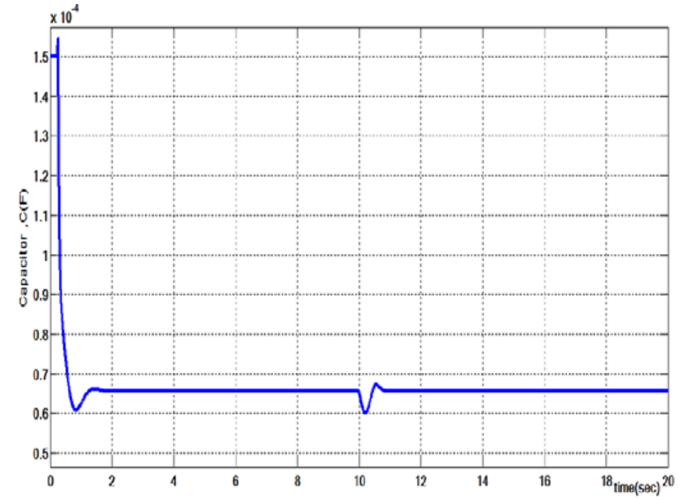

Fig.26 Dynamic response of the Capacitor variation for PI Reactive controller corresponding to sudden wind speed variation.

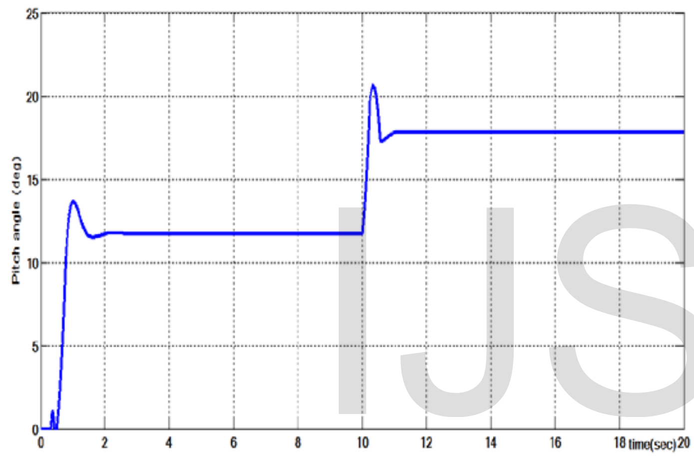

Fig.27 Dynamic response of the Pitch angle variation for PI Active controller corresponding to sudden wind speed variation

As shown in Figures (24,25, 26, 27) as the wind speed is increase the voltage and frequency is increased so the pitch angle is increased to maintain voltage and frequency at rated value . the simulation result shows that to adjust the voltage and frequency at its rated value in case of variations in the wind speed depend mainly on the PI active controller by adjusting the Pitch angle of the blade of wind turbine.

5 Conclusion

This paper studied the dynamic response of SEIG under different loading and wind speed condition . the system under study is implemented using Matlab/Simulink package .the simulation was carried out to show the effect of loading and wind speed variation on the dynamic performance of SEIG such as (out voltage , output frequency, load current and load power) . also this paper studied the voltage and frequency control of SEIG under different loading and wind speed condition . and used two type of control to adjust the voltage and frequency at rated value the first is reactive control and the second is active control .PI can be used to achieve active and reactive control.

the simulation result show that when the load impedance is increased and wind speed is constant the excitation capacitor is decreased and pitch angle is increased to decrease rotor speed to adjust the voltage and frequency at its rated value. When load is constant and wind speed is increase the controller is depend mainly on active controller to maintain voltage and frequency at rated value so the pitch angle is increased to decreased rotor speed and maintain voltage and frequency at rated value.

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