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Wind Turbine Simulator For Seig Based Wind Energy Conversion System

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ABSTRACT

Wind power production has been under the main focus on for the past decade in power production and tremendous amount of research work is going on renewable energy. A real wind turbine (WT) may not be available for research and development. To provide a controllable environment, it is proposed to model and develop wind turbine simulator (WTS). Direct Current (DC) motor is simulated as wind turbine which has been coupled to induction machine, to monitor the wind power generation in laboratory test environment. For improving the control schemes and wind power extraction by various Maximum Power Point Tracking (MPPT) technologies this simulator can be used. The performance of the self-excited induction generator (SEIG) such as voltage developed, load current, frequency at constant and variable wind profile were analysed through MATLAB simulation

Keywords: wind turbine simulator (WTS), self-excited induction generator (SEIG), wind turbine (WT), maximum power point tracking (MPPT), wind energy conversion system.

1. INTRODUCTION

The major renewable energy technologies are hydro, wind, biomass and ocean energy. The efficiency of converting wind energy to useful energy form depends on the efficiency with which rotor interacts with the wind streams [1]. The design and development of a wind turbine simulator that operates on the typical power-speed characteristics of a WT were developed [2]. As the amount of installed wind power increases, it becomes more important to guarantee that the stability of the power system is not endangered by a large scale wind power installation. Issues of concern are small signal stability and the fact that voltage dips may lead to disconnection of wind power production [3], [4]. The modification of the input DC voltage has the same effect as the variation of wind speed in a fixed pitch WT. The emulator shows the novelty of working in open loop, while the current emulators work in closed loop, so it has an intrinsic structure more like WT's. The emulator consists of a variable DC voltage source, a power resistor and a DC motor connected in series. It uses a DC motor with separate excitation. Emulation is done by rheostat control method. The actual speed ofWT rotor is lesser than DC motor speed so as to match their characteristics a gear ratio conversion is necessary. The armature voltage variation in turn controls armature current according to the current reference [5], [6].

The AC capacitors are used to build up the process of an isolated induction generator, starts from charge in the capacitors or from a remnant magnetic field in the core. The WT is discussed based on energy generation, active and reactive power generations as well as harmonics. This scheme generates constant voltage and variable frequency using the converter which also acts as a reactive power compensator. The regulation of the active and reactive power exchanged between the generator and the grid by the generator inverter using the control algorithm based on vector control [7], [8]. The squirrel-cage induction machine is simple, reliable, cheap, lightweight, and requires very little maintenance. The induction generator is connected to the utility at constant frequency. In variable-speed operation, an induction generator needs an

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interface to convert the variable frequency output of the generator to the fixed frequency at the utility.Per unit frequency (fpu) is the ratio of operating frequency to the rated frequency. The balanced of reactive power is established between the ac capacitors and the air-gap flux condition at any operating condition [9]. An induction generator operates in self-excitation mode. It determines its own voltage and frequency. These two quantities depend on the size of the AC capacitor, the parameters of induction machine parameters, the electrical load, and the speed of the generator [10].

It is proposed to develop a WTS using armature current controlled DC shunt motor, for conditional monitoring of wind power generation. The WTS is coupled to squirrel cage induction machine of 1kW. LabVIEW a real time software is used for reference signal generation and analysis in hardware implementation.

2. MATHEMATICAL MODEL OFWIND TURBINE

The principle of working of WT is based on aerodynamics. The turbine's aerodynamic output power [2] is given in (1).

Aero Dynamic Power (P)

$$P = \frac{\rho CpAv^3}{2} \tag{1}$$

The amount of power available from wind is a function of the velocity of the wind cubed. Therefore, even a small increase in wind velocity will lead to an exponential increase in available power.

Where,

P : Air Density

A : Area swept by rotor blades

V : Velocity of air

C_p : Power Coefficient

$$C_p = f(\beta, \lambda) \tag{2}$$

Power coefficient is function of both pitch angle (β) and tip speed ratio (λ)

Where,

$$\lambda = \frac{\omega R}{v} \tag{3}$$

ω : Rotor angular velocity

R : Radius of wind turbine

The numerical approximation of power coefficient is

$$C_p(\lambda_i) = 0.22\left(\frac{116}{\lambda_i} - 5\right)e^{\frac{-12.5}{\lambda_i}} \tag{4}$$

With

$$\frac{1}{\lambda_i} = \frac{1}{\lambda} - \frac{0.003}{(\beta^3 + 1)} \tag{5}$$

The mechanical torque generated can be calculated from the WT power and the shaft speed as given by equation (6)

$$T_{ref} = \frac{p}{\omega} \tag{6}$$

3. MATHEMATICAL MODEL FOR DC MOTOR

To achieve WT simulator operation with a DC motor, it is required to study its torque speed characteristics.The equivalent circuit of separately excited DC motor is shown in Fig. 1.

Where,

V_a : Armature Voltage

V_e : Field Voltage

I_a : Armature current

R_a : Armature Resistance

L_a : Armature Inductance

R_f : Field Resistance

L_f : Field Inductance

E_g : Back emf

N : Speed in rpm

K_a : Torque Constant

Φ : Field Flux

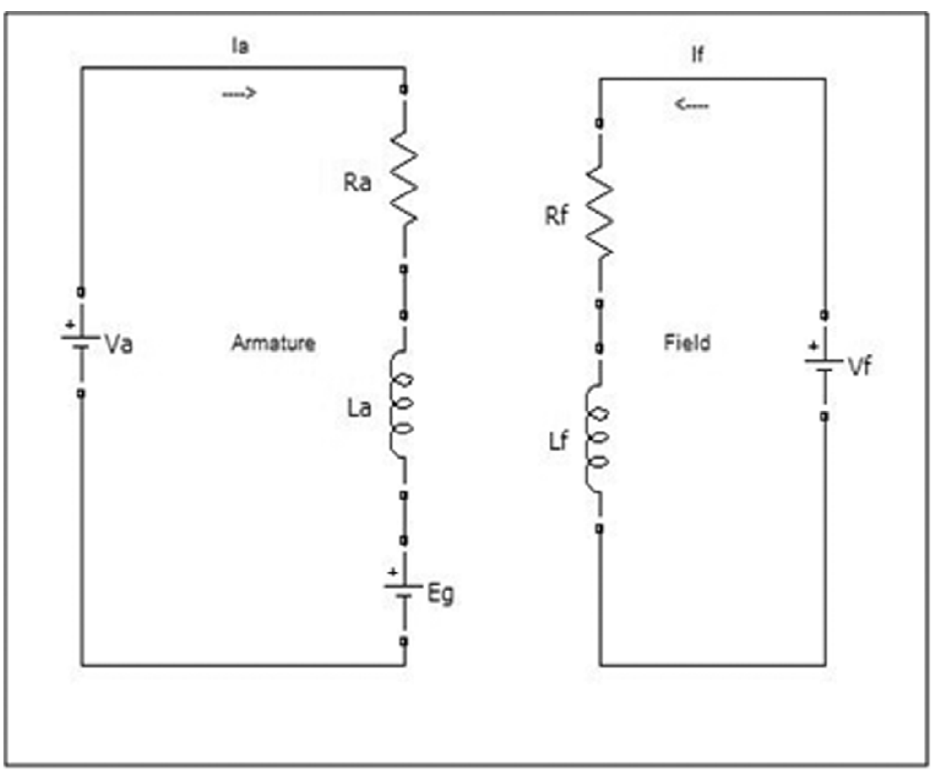


Figure 1: Equivalent circuit of DC motor

From the armature circuit

$$V_a = I_a R_a + L_a \frac{dI_a}{dt} + E_g \tag{7}$$

$$E_g = K_a \Phi N \tag{8}$$

$$T = T_l + BN + J\frac{dN}{dt} \tag{9}$$

Taking laplace transform for equations (7), (8) & (9)

$$V_a(s) = I_a(s)\, R_a + sI_a(s)\, L_a + E_g(s) \tag{10}$$

$$E_g(s) = K_a \Phi N(s) \tag{11}$$

$$T(s) = T_l(s) + BN(s) + JsN(s) \tag{12}$$

By solving the equations (10), (11) & (12)

$$I_a(s) = \frac{V_a(s) - E_g(s)}{R_a(1+s\tau_a)} \tag{13}$$

$$N(s) = \frac{T(s) - T_l(s)}{B(1+s\tau_m)} \tag{14}$$

Electrical time constant is given by equation (15)

$$\tau_a = \frac{L_a}{R_a} \tag{15}$$

Mechanical time constant is given by equation (16)

$$\tau_m = \frac{J}{B} \tag{16}$$

From equations (7) to (16) the speed torque characteristics of the motor to reproduce the torque developed by the wind turbine.

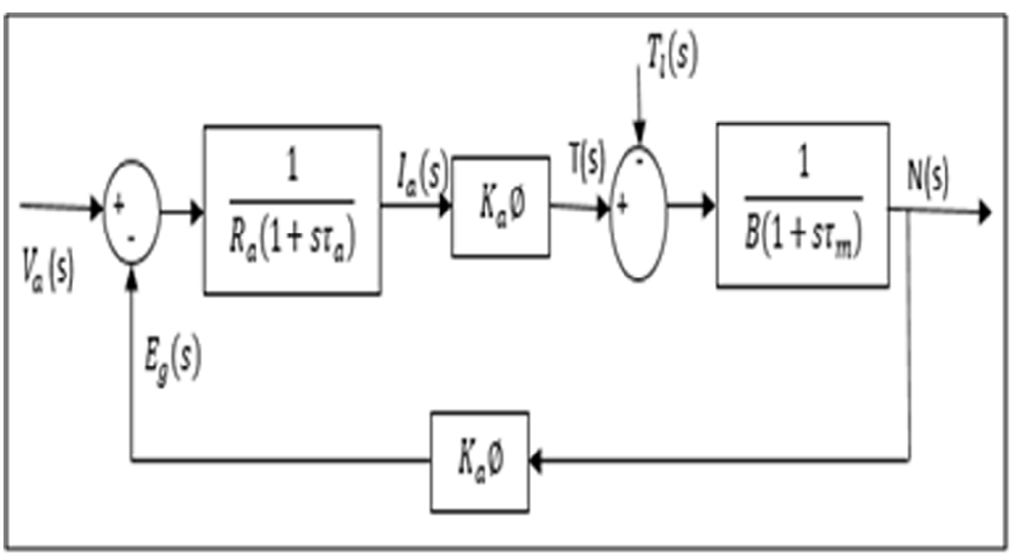


Figure 2: Electric model of DC motor

The functional model of the dc machine is shown in Fig 2. As it is a separately excited motor the flux created by inductive winding is constant

3. DESIGN OF EXCITATION CAPACITANCE

The magnetizing current needed for SEIG operation is provided from AC capacitors connected to the terminals of induction machine

$$S = \sqrt{3 * V * I} \tag{17}$$

$$Q = \sqrt{S^2 - P^2} \tag{18}$$

$$Q = \frac{3V^2}{X_c} \tag{19}$$

$$X_c = \frac{3V^2}{Q} \tag{20}$$

$$X_c = \frac{1}{2\pi fc} \tag{21}$$

$$C = \frac{1}{2\pi f X_c} \tag{22}$$

Where,

V : Rated voltage (V)

I : Rated current (A)

P : Real power (W)

Q : Reactive power (Var)

S : Apparent power (VA)

C : Capacitance per phase

For star connected load capacitance will be triple times than delta connected load

4. SCHEMATIC DIAGRAM OF WIND TURBINE SIMULATOR

The schematic diagram of WTS is shown in Fig 3. The reference torque obtained from WT is multiplied with torque constant. Then PI controller compares the reference signal and actual current of DC motor. Buck converter step downs the applied voltage to maintain the wind torque and DC motor torque as equal. Speed of the DC motor is coupled to induction machine for power generation and supplies to three phase balanced resistive load.DC machine drives an electrical generator in a similar way as a WT, by reproducing the torque developed for a given wind velocity.

Circuit model of WTS is shown in Fig. 4 which consists of one rectifier unit, chopper, three phase balanced resistive load and capacitor bank. The capacitor value is chosen according to equation (22).

5. SIMULATION AND RESULTS DISCUSSION

5.1. Simulation of WTS

For wind power of 800W the radius of WT is 1.4m and air density is 1.25Kg/m^3 [6] of constant pitch angle. WT is shown in Fig. 5 using (1) to (6).

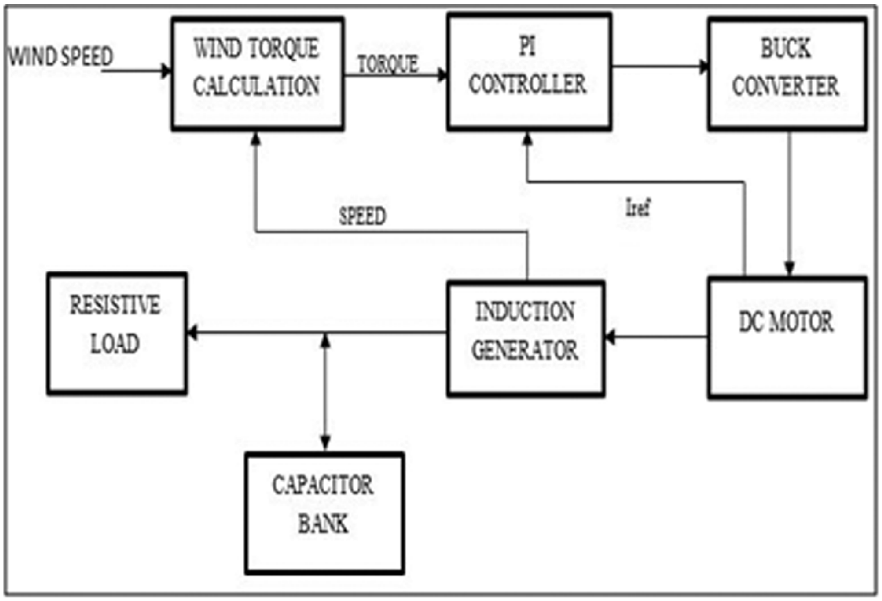


Figure 3: Schematic diagram of WTS

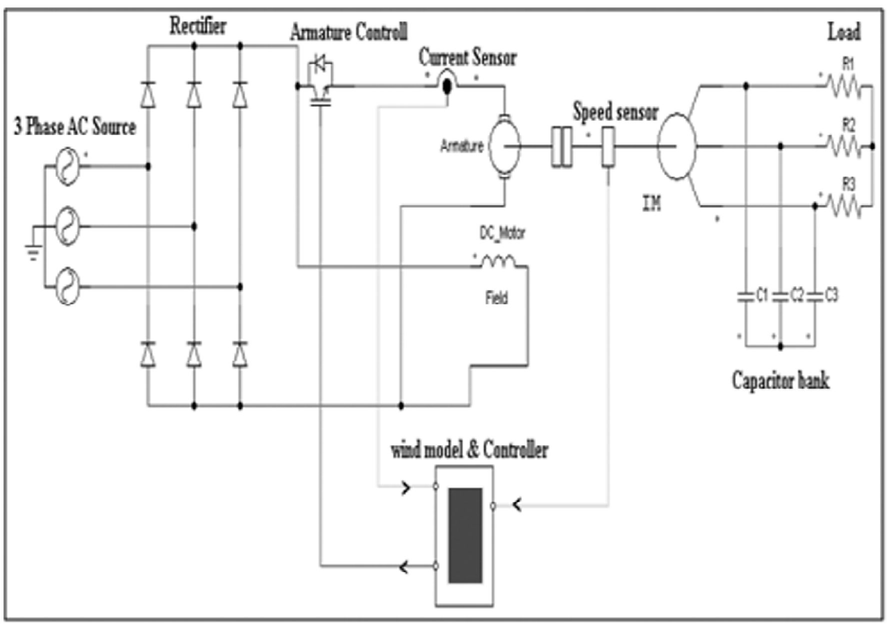


Figure 4: Circuit model of WTS

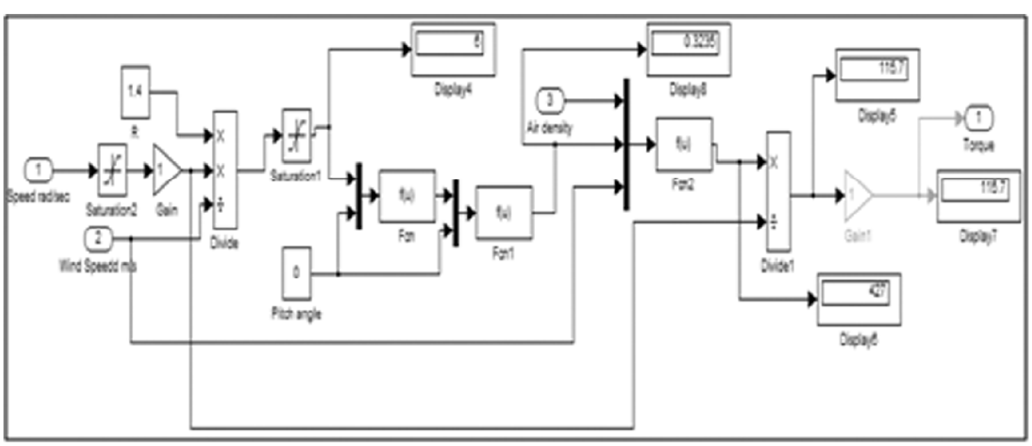


Figure 5: Wind turbine

The relationship between power co-efficient and tip speed ratio at a pitch angle of zero radians is plotted for wind speed of 8m/s as in Fig. 6. This characteristic is same for all wind speeds below the rated wind speed, provided the pitch angle is maintained at zero.

In the system, wind turbine and DC motor are combined to perform the operation of WTS and it is coupled with the induction generator. The Simulink model of WTS is shown in Fig. 7(a) & (b).

The wind torque obtained from WT model is multiplied with proper torque constant, because torque is converted into equivalent current of DC motor. The reference value obtained from WT is compared with

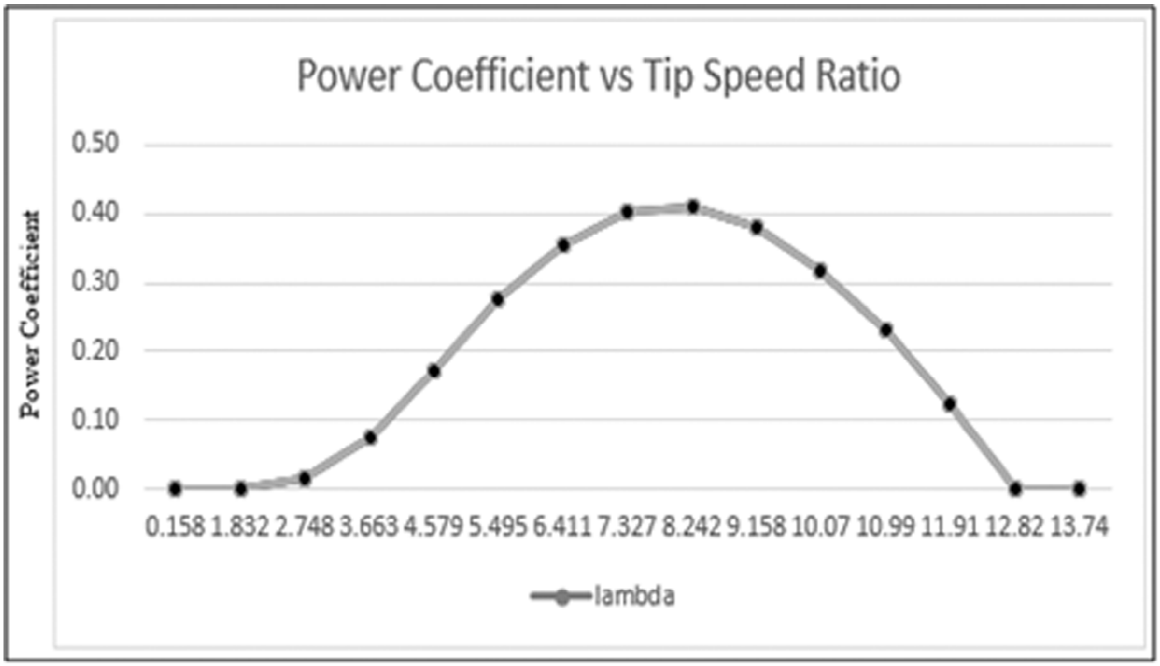
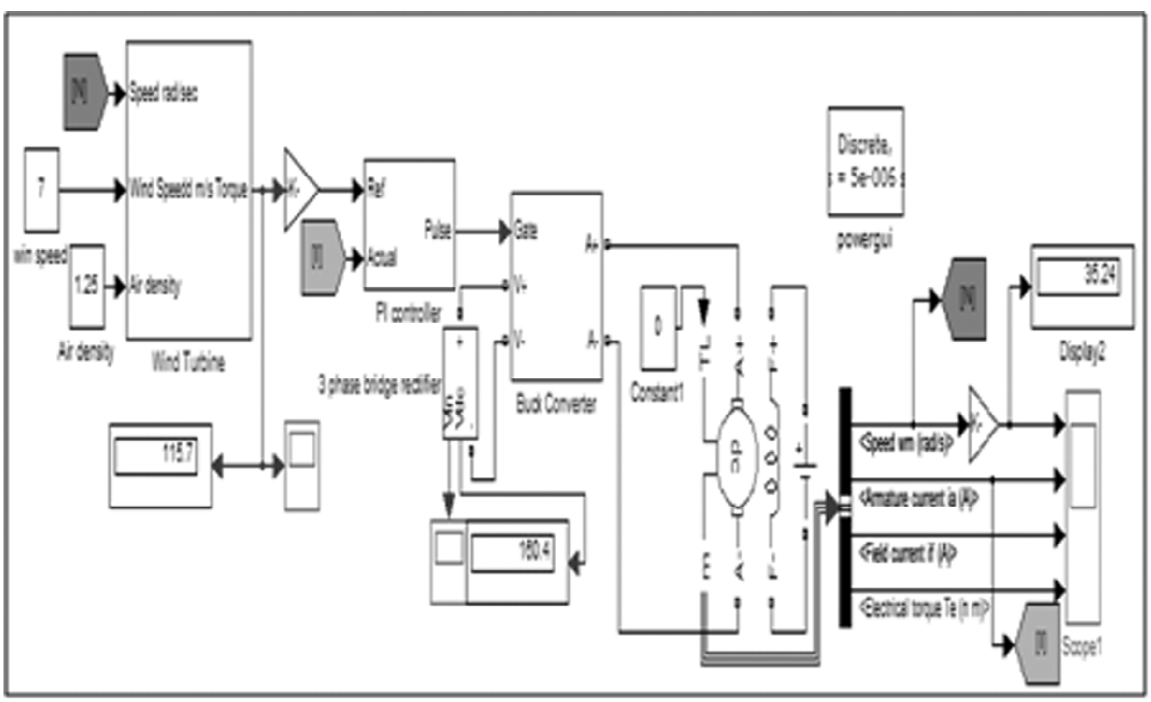
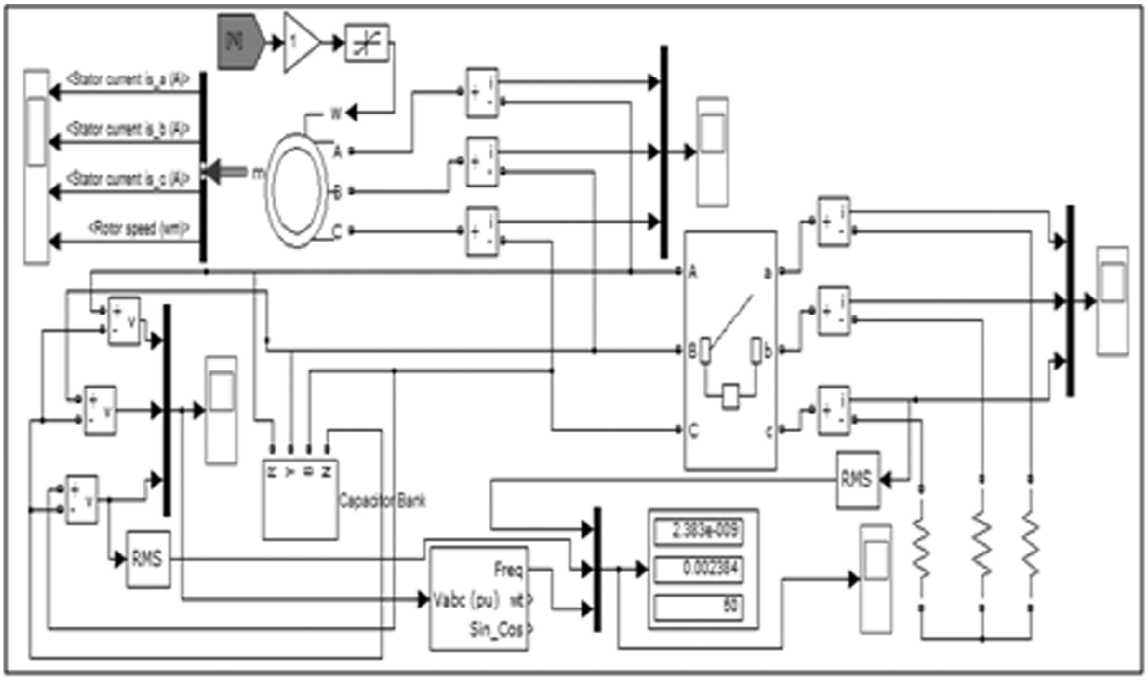


Figure 6: Power co-efficient vs Tip speed ratio



(a) Combination of wind turbine & DC motor



(b) SEIG, load, capacitive bank of WTS.

Figure 7: Wind turbine simulator

the actual armature current of the motor. Then PI controller compares the two current values and generates the pulse signal according to the error. Input to the buck converter is fed by three phase bridge rectifier. The controlled voltage obtained from the converter is fed to the motor correspondingly the motor is controlled with respect to wind speed. Field is excited by the constant DC source of 220V. DC motor is mechanically coupled to induction machine. AC capacitors are connected in machine terminals for excitation of stator terminals. The power generated from SEIG is fed to three phase balanced resistive load. A triple pole single through switch is used to turn ON/OFF the load. If the load is turned ON initially it consumes power from the capacitors. So the load is turned ON once the voltage is developed in SEIG.

5.2. SEIG performance

From Table I, it is observed that the frequency developed at synchronous speed of 1500rpm is 45.21 Hz. For obtaining rated frequency, the generator should be operated at above synchronous speed of 1700 rpm. Otherwise the output may be converted to DC and again inverted to AC of fundamental frequency by the use power electronic switches.

Table 1
Speed And Frequency

S. No	*Speed (rpm)*	*Frequency (Hz)*	*Voltage (V)*	*Current (A)*
1	1350	40.38	204.4	0.4088
2	1400	42.28	213.9	0.4218
3	1450	43.49	222.1	0.4442
4	1500	45.21	229.9	0.4597
5	1550	46.25	238.7	0.4774
6	1600	47.27	249.2	0.4983
7	1650	48.32	258.9	0.5178
8	1700	49.67	268.3	0.5367

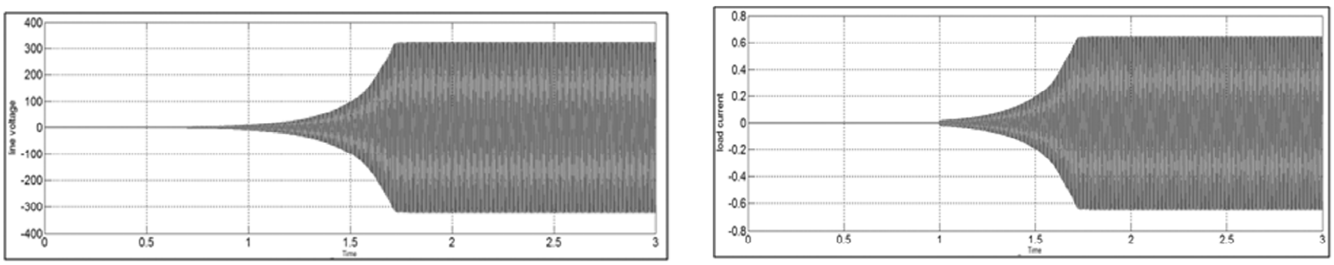
The peak value of developed voltage is 320V. The peak value of load current is 0.7A as shown in Fig.8 (a) & (b)

Fig 8(a) shows that voltage is developed after a time period of 1 second. So the load can be turned ON after a time period of one second is shown in Fig. 8(b). Zoom in view of voltage and current is shown in Fig. 9. It shows both the current and voltage developed in the SEIG will be in phase.

In Fig.10 voltage developed in SEIG at variable speed is shown. The various speed for the time duration up to 2 seconds the speed is 1600 rpm, 2 to 4 seconds the speed is 1300 rpm, and 4 to 6 minute the speed is 1500rpm. During the simulation time 2–2.7 sec and 4–4.3 sec transition of speed occurs. There are shown in Table II.

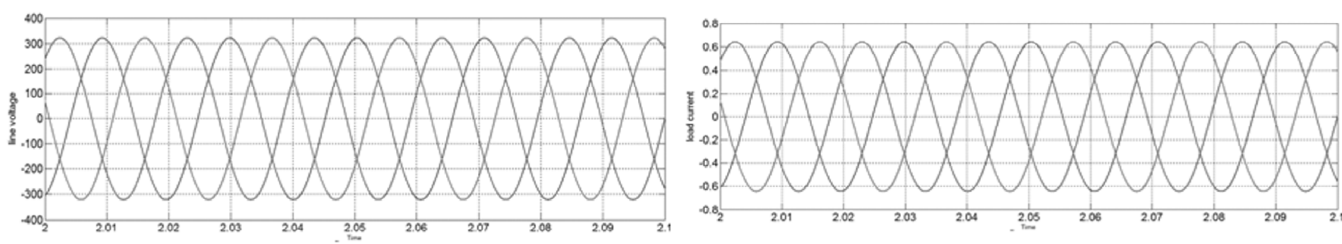
5.3. WTS performance

While increasing the speed of the WT, speed of the DC motor also varies as shown in Table III. The optimum wind speed is 7 to 10 m/s, because the speed for operation of generator is sufficient in this range.



(a) (b)

Figure 8: SEIG output (a) Line voltage, (b) load current



(a) (a)

Figure 9: Zoom in view of SEIG output (a) voltage, (b) current

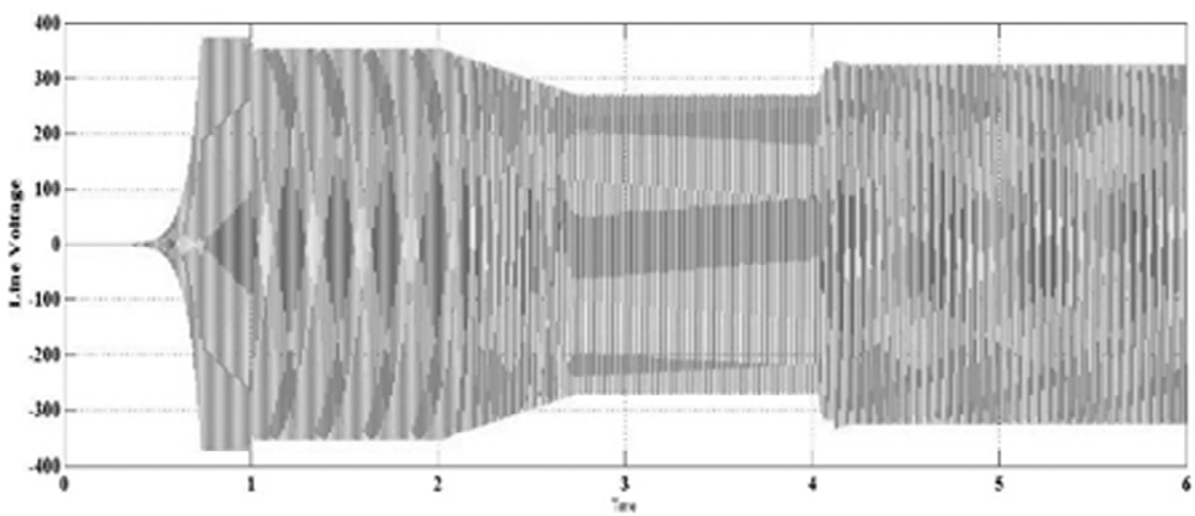


Figure 10: SEIG output at variable speed

Table 2
Frequency At Variable Speed

S. No	*Speed (rpm)*	*Simulation Time (sec)*		*Frequency (Hz)*	*Line Voltage (volt)*
		From	*To*		
1	1600	0	2	47.36	241.6
2	1300	2.7	4	40.07	208.8
3	1500	4.3	6	44.97	228.4

Table 3
Wind Simulator Speed

S. No	*Wind Speed (m/s)*	*Wind Torque (N-m)*	*DC motor Speed (rpm)*
1	4	2.402	355.4
2	5	3.226	577.1
3	6	3.448	795.5
4	7	4.039	1012
5	8	4.886	1249
6	9	5.796	1503
7	10	7.950	1812
8	11	10.61	2209
9	12	10.08	2916

6. CONCLUSIONS

In this paper the performance analysis of self-excited induction generator and wind turbine simulator are done and the results are obtained using simulation.Wind turbine simulator using DC motor coupled to induction generator has been modelled and developed. In the self-excited mode of induction generator, the machine can be operated below synchronous speed. In operation of SEIG at below synchronous speed the frequency of the emf developed is less than fundamental frequency. For obtaining the rated frequency, the generator operation should be above the synchronous speed. The developed voltage and current should be in phase. The variation of wind speed affects the voltage developed and frequency in the induction generator. For the self-excited operation mode proper size capacitor must be chosen for maintaining the minimum saturation voltage at the generator terminals. Capacitor size should be optimum otherwise it will consume power and act as load.

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