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Fuzzy Logic Control Strategy for Stand-Alone Self-Excited Induction Generator for a Variable Speed Wind Turbine

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Abstract— This paper presents a control strategy for the operation of a Self Excited Induction Generator (SEIG) based stand-alone variable speed wind turbine. To extract maximum energy form the generator and to regulate the terminal voltage of the generator a control strategy is present. In this system there is no grid connection, only stand-alone system is present. The topology of the system consists of a three phase squirrel-cage induction machine connected to a wind turbine through a step-up gear box, Pulse Width Modulation (PWM) Current Controlled Voltage Source Inverter (CC-VSI), Electronic Load Controller (ELC), three fuzzy logic PI controllers and one Hysteresis Current Controller (HCC). A dump-load resistance with IGBT chopper control and the dc link voltage is present to consume the maximum output power from the generator.

Dynamic and steady-state performance where simulated using Matlab/Simulink software

Index Terms — Self-Excited Induction Generator (SEIG), maximum power extraction, stand-alone variable speed wind turbine, voltage control.

I. INTRODUCTION

The conventional energy sources such as thermal power generation, nuclear power generation etc., are limited and pollute the nature. So more attention and interest have been paid to the utilization of renewable energy source such as Wind Energy, Fuel Cell, Solar Energy etc., Wind Energy is the fastest growing and most promising renewable energy source among them as it is economically viable.

Electrical generators are used to produce electricity, which are driven by the wind turbines by using the wind power. Blades are rotated when the wind passes over it, the blades are connected to the shaft so that the speed can be increased with the help of gear box the rotational speed is increased. The wind energy is converted into electrical energy. The output power form the generator is given to a transformer, which step up the electrical voltage from 700V to 33 kV. The energy produced from the Wind is not a constant source. It varies continuously and gives energy in sudden bursts. About 50% of the entire energy is given out in just 15% of the operating time. Wind strengths continuous vary and thus cannot guarantee continuous power.

The wind turbine output power can be calculated by the given formula:

$$Pw = 0.5\rho\pi\, R^2V^3Cp(\lambda,\beta) \tag{1}$$

Pw = extracted power from the wind,
ρ = air density, (1.225 kg/m^3 at 20° C at sea level)
R = blade radius (in m), (it varies between 40-60 m)
V = wind velocity (m/s) (velocity can be controlled between 3 to 30 m/s)
Cp = the power coefficient

Power coefficient (Cp) is defined as the ratio of the output power produced to the power available in the wind.

$$Cp = \frac{P_{wind\ Turbine}}{Wind\ Air} \tag{2}$$

$$P_{Air} = ½\, \rho AV3$$

$$P_{Wind\ Turbine} = Cp \times P_{Air}$$

$$P_{Wind\ Turbine} = ½\, Cp\, \rho\, A\, V^3$$

BETZ LIMIT:

No wind turbine could convert more than 59.3% of the kinetic energy of the wind into Mechanical energy and this is called as the Betz Limit. The maximum value of Cp according to Betz limit is 59.3. For good turbines it is in the range of 35-45%.

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PROPOSED SYSTEM

The power circuit diagram of the proposed system is shown in the fig 1. Self-Excited Induction Generator (SEIG) is connected to the variable speed wind turbine througt a step up gers box. The terminals of the SEIG is connected in

parallel with the fixed capacitor bank and main load resistance to the Current Control Voltage source inverter through a smoothing reactance. The fixed capacitor bank provides two functions one to avoid pre-charging of DC side capacitor Cdc of the CC-VSI for the start up process of the Induction generator and the second function it acts as

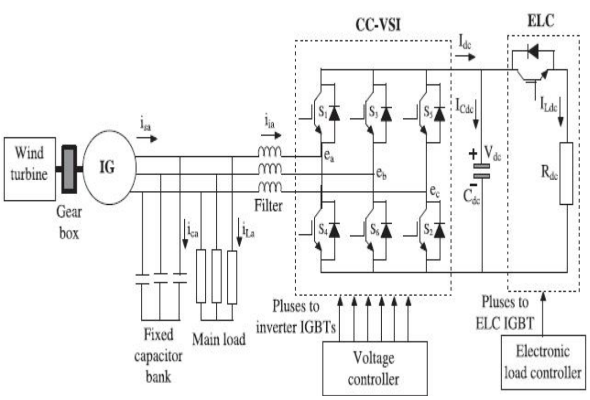

Fig 1 Power Circuit Diagram

a second order filter to reduce the higher order harmonics. The Electronics Load Controller(ELC) is Connected in parallel with the CC-VSI to extract to maximum available energy from wind turbine. The ELC and dump load resistance are connected in series. The dump load resistance may be a battery charger or a heater.

CONTROL STRATEGY

The active power and reactive power of the Wind Turbine Induction generator (WTIG) is used to control and extract maximum available energy from the wind turbine and to maintain the generated terminal voltage against wind speed and main load variations using control strategy.

Control strategy consists of two controllers

i. The Voltage controller
ii. The Electronics Load Controller

i. THE VOLTAGE CONTROLLER

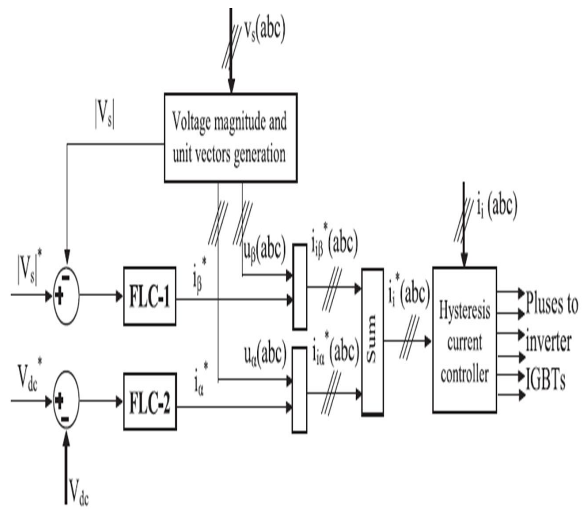

Fig 2 The Voltage controller

The voltage generated from the SEIG can by adjusting its reactive power (excitation).The output current of the CC-VSI is used to control or regulate the terminal voltage of the SEIG. Fig 2 shows the diagram of a voltage controller. There are two control loops. The Hysteresis Current Controller (HCC) provides the required switching pulses to the inverter which is generated from the two loops, the outer gives the reference current i_i*(abc) and the inner loop gives the actual inverter current i_i(abc). The reference current i_i*(abc) are formed by adding two current component of each phase.

1. The in-phase active current component $i_{i\alpha}$* (abc)
2. The quadrature reactive current component $i_{i\beta}$* (abc)

The in-phase active current component $i_{i\alpha}$*(abc) is also known as real power is used to keep the DC side capacitor charged to the specified level and excess real power is given to the dump load resistance as a wastage. The quadrature reactive current component $i_{i\beta}$*(abc) is also known as reactive power is used to regulate the generated voltage. The AC voltage magnitude of the SEIG is sensed and compared against the AC reference voltage magnitude. The AC voltage error output is given to the first fuzzy logic controller (FLC-1). The output of the FLC-1 is i_β* of the AC voltage control loop is multiplied by the quadrature unit vectors uβ (abc) which lead the unit vectors of AC voltages by a phase shift of 90° to give the reference reactive current components $i_{i\beta}$* (abc) that control the amplitude of the reactive power generated in the CC-VSI and the reference reactive current components

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lead by a phase shift of 90° the corresponding AC voltages for a positive sign of the AC voltage error. The negative sign of the AC voltage error, they lag by a phase shift of 90°. Thus, the CC-VSI operates in capacitive and inductive modes respectively for positive and negative sign of the AC voltage error. Similarly, the in-phase components $i_{i\alpha}$*(abc) are obtained through the DC voltage control loop. The DC voltage error is given the second fuzzy PI controller (FLC-2).The output of FLC-2 iα* is multiplied by the unit vectors uα(abc) (which in-phase with the corresponding AC voltages) to give the reference active current components $i_{i\alpha}$*(abc).

ii. ELECTRONIC LOAD CONTROLLER (ELC)

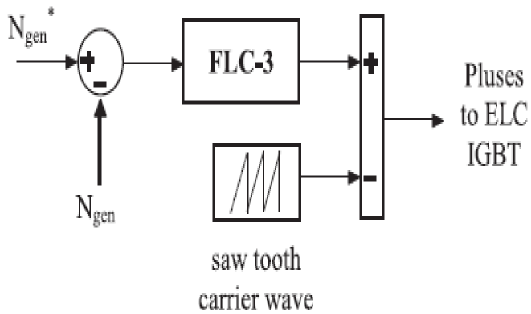


Fig 3 ELECTRONIC LOAD CONTROLLER (ELC)

The generator speed is controlled, by controlling the electrical load on the induction generator. An active power controller is used as an ELC. ELC circuit is shown in the fig 3 in which the generator speed and generator feedback speed is compared and the speed error is given and processed in the third fuzzy logic PI controller FLC-3. The output of FLC-3 and saw tooth carrier wave is compared to get the required PWM pulses for the IGBT of the ELC.

FUZZY LOGIC CONTROL

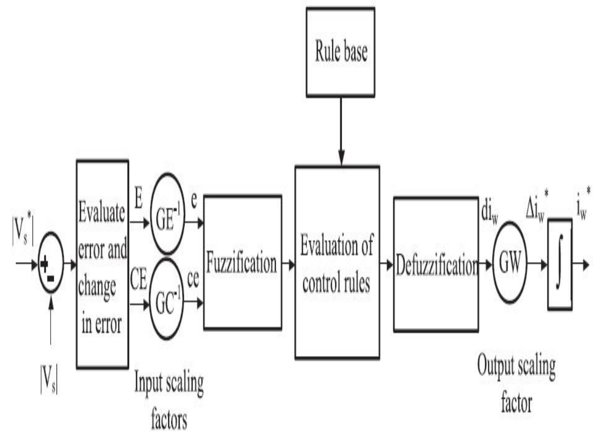
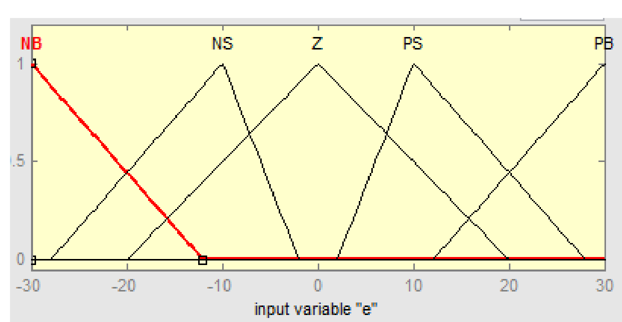


Fig 4 Block diagram of the FLC-1

The system performance is enhanced with the help of fuzzy logic PI controllers. The proposed system has three fuzzy logic PI controllers. The FLC-1 is discussed in this section. Fig 4 shows the block diagram of the FLC-1. FLC consists of three blocks fuzzification, defuzzification and evaluation of control rule. The AC voltage error e and change in error ce are the crisp inputs of the FLC-1. The input signals error e and change in error ce are converted to the corresponding per unit signals e and ce through dividing by the input scaling factors GE and GC respectively. The input signals are expressed in fuzzy set notation using linguistic labels characterized by membership grades before being processed by the fuzzy logic controller. Also, the output signal d_{iw} is expressed in fuzzy set notation using linguistic labels characterized by membership grades. The membership functions (MFs) for e, ce and diw are shown in Fig 5. There are five MFs for both e and ce signals, whereas there are five MFs for the output diw.



Error

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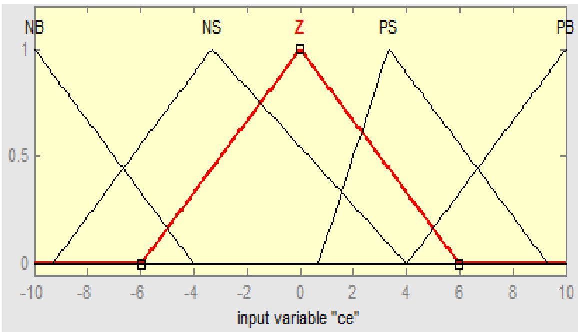
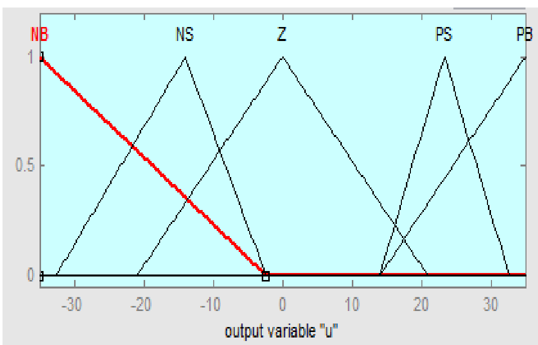


Change in Error



output variable di_w

Fig 5 Membership Function of the FLC – 1

Table 1 Rule Base of FLC

Error (e) Change in Error (ce)	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NS	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PS	PB
PB	Z	PS	PB	PB	PB

Table 1 shows the corresponding rule base of the FLC-1. The left column and top row of the table indicate the fuzzy sets of the variables ce and e respectively. The MFs of the output variable di_w are shown in the body of the table. There are 25 possible rules, which are used to decide the appropriate control action. The fuzzy logic controller is implemented, the input variables ce and e are fuzzified, the rules are evaluated and finally the fuzzy output is defuzzified. The crisp output of the FLC-1 di_w is converted to Di_w * by multiplying by the output scaling factor GW. This signal generates the actual command value i_w*. Therefore, the value of Di_w*, which is used to decide the required control action, is adaptive for the voltage AC error and dynamic response is achieved. Same techniques are implemented for FLC-2 and FLC-3.

DQO TRANSFORMATION

In electrical engineering, direct–quadrature–zero (or dq0 or dqo) transformation or zero–direct–quadrature (or 0dq or odq) transformation is a mathematical transformation used to simplify the analysis of three-phase circuits. In a balanced three-phase circuit application of the dqo transform reduces the three AC quantities to two DC quantities and simplified calculations is carried out on these imaginary DC quantities before performing the inverse transform to recover the actual three-phase AC results. It is used to simplify the analysis of three-phase synchronous machines or to simplify calculations for the control of three-phase inverters. The dqo transform presented here is similar to the transform first proposed in 1929 by R.H. Park. In fact, the dqo transform is often referred to as Park's transformation.

SIMULATION RESULTS

The proposed system is modeled and simulated using Matlab/ Simulink software program in order to study its dynamic performance with the proposed control strategy. Fig 6 (a) and Fig 6 (b) shows the dynamic response of the proposed system under sudden variations in the main load resistance and in the wind speed respectively.

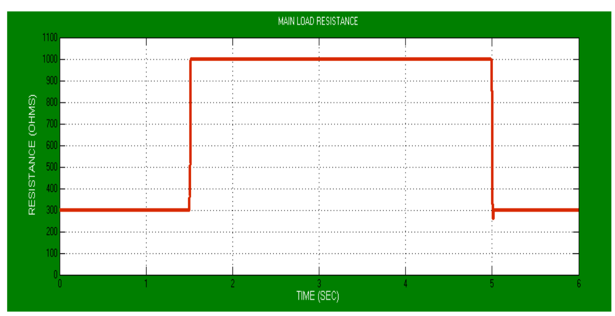


Fig 6 (a) Main Load Resistance

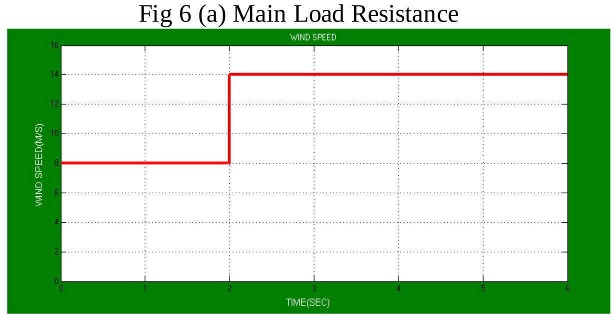


Fig 6 (b) Wind Speed

In this case, as the wind speed changes from 8 m/sec to 14 m/sec, step time of 2s, the control strategy forces the

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WTIG to operate. The control parameters DC link voltage; AC terminal voltage and generator speed are settled to their reference values against each sudden change both in main load and in wind speed as shown in Fig 7 (a) and Fig 7 (b) respectively.

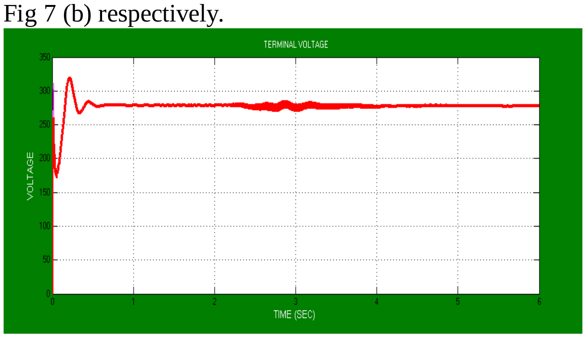

Fig 7 (a) AC TERMINAL VOLTAGE

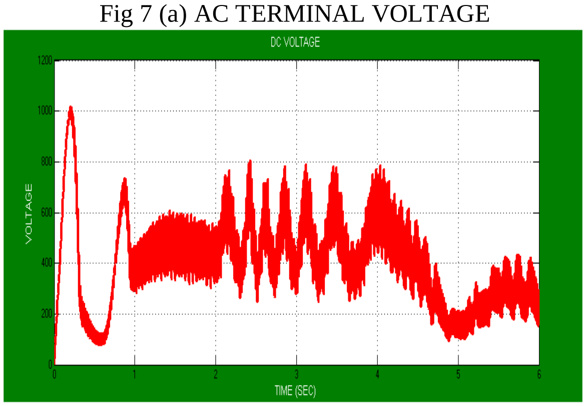

Fig 7 (b) DC Link Voltage

In this case, the proposed system is subjected to wind speed variations while, the main load resistance have a constant value of (R_L= 300Ω and 1000 Ω, step time of 1.5 sec to 5 sec) as shown in Fig 6(a)

As wind speed changes, the control strategy force the proposed system to operate in the specified control mode of operation. The AC Load voltage, generator speed, Inverter current, Main load power, Stator current, Electronic load power (Dump load Power), Load current, TSR, Turbine power, real power and reactive power respectively, are settled to their reference values of the proposed system are shown in fig 8 (a) to fig 8 (k).

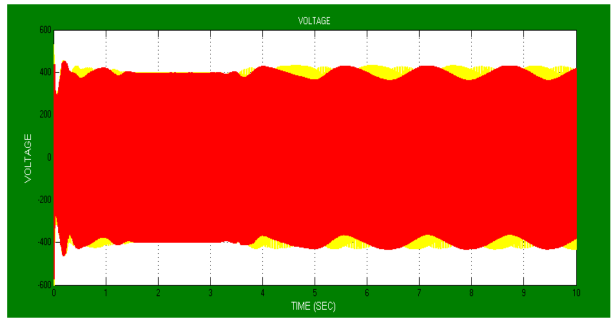

Fig 8 (a) AC Load Voltage

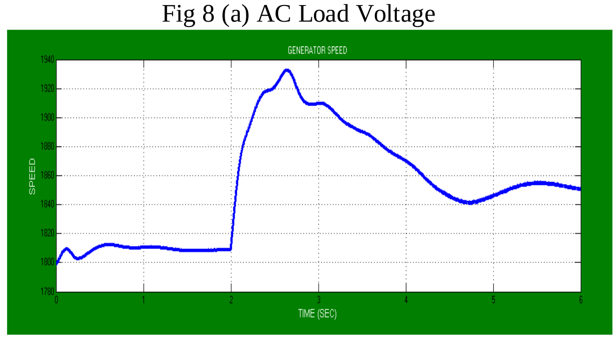

Fig 8 (b) Generator Speed

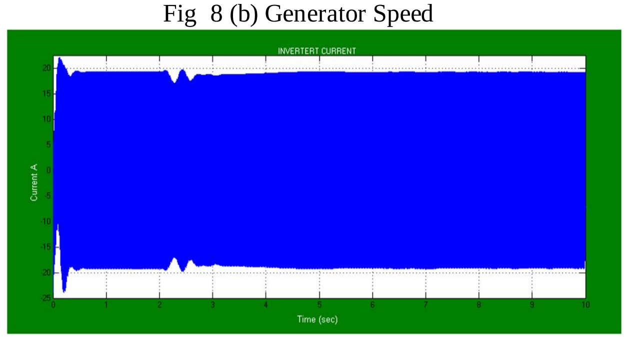

Fig 8 (c) Inverter Current

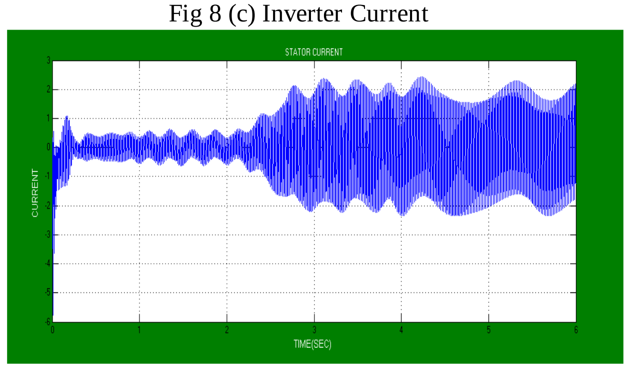

Fig 8 (d) Stator current

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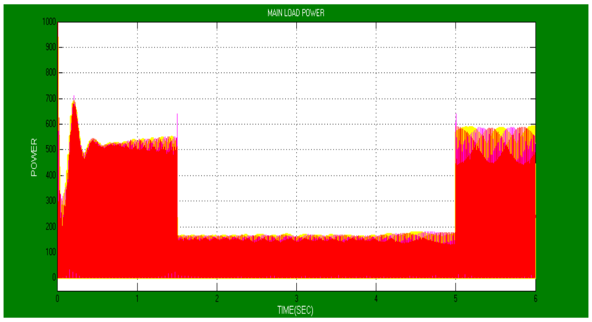

Fig 8 (e) Main Load Power

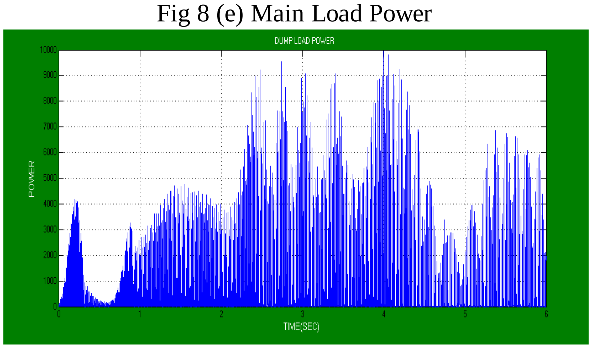

Fig 8 (f) Electronic Load Power

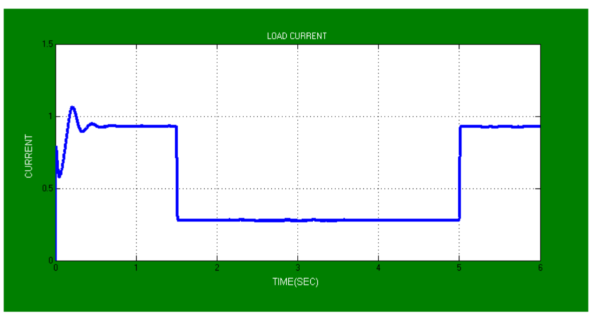

Fig 8 (g) Load Current

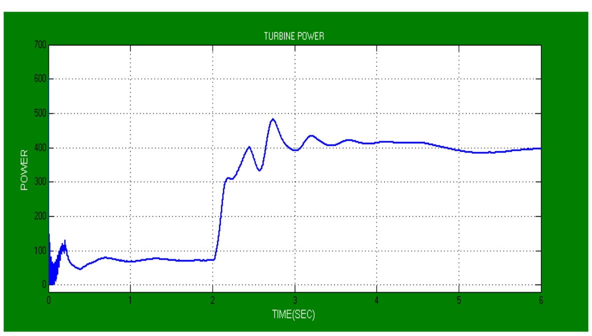

Fig 8 (h) Turbine Power

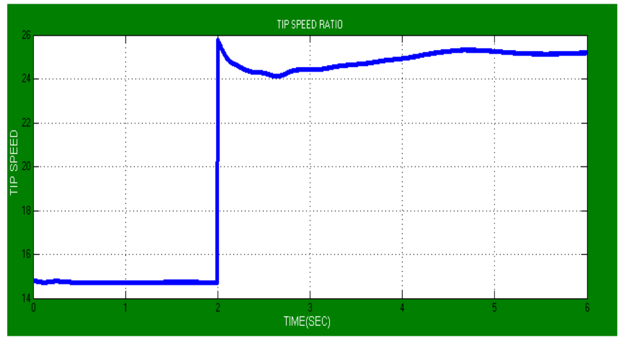

Fig 8 (i) Tip Speed Ratio

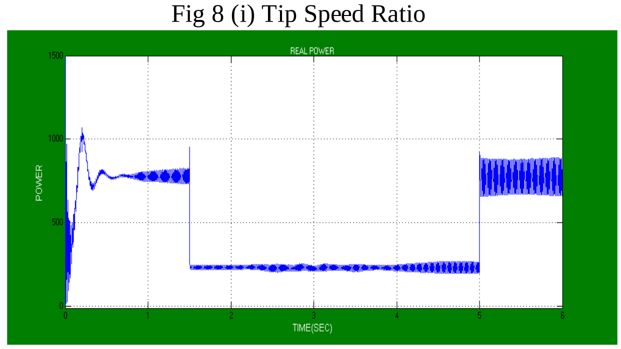

Fig 8 (j) Real Power

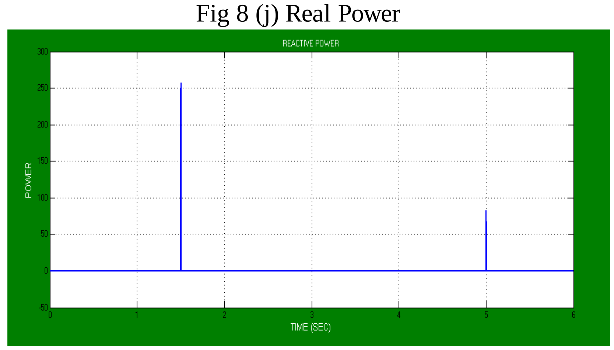

Fig 8 (k) Reactive Power

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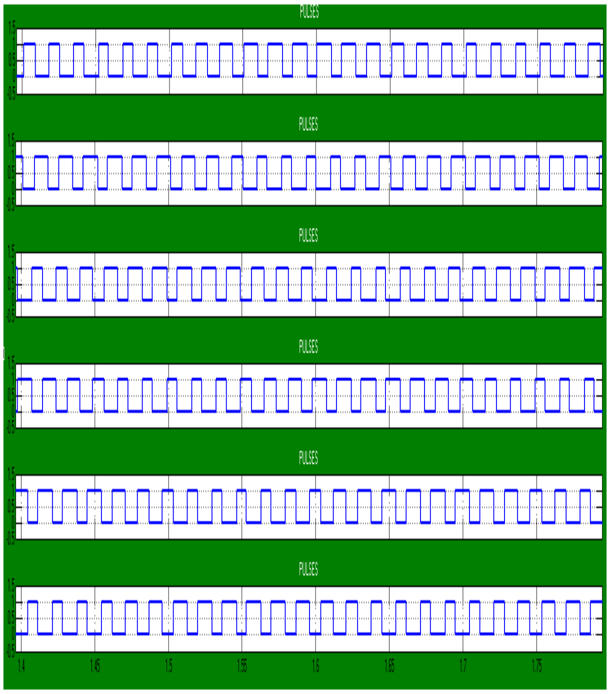

Fig 9 Pulse

Fig 9 shows the Pulses generated. If the pulses are generated the converter circuit will function as an inverter otherwise it will function as a rectifier.

CONCLUSION

A fuzzy logic control strategy for a stand-alone self-excited Induction generator driven by a variable speed wind energy conversion system is presented. The control strategy aims is used to extract the maximum available energy from the wind turbine and at the same time to regulate the generated voltage of the SEIG over a wide range of wind speed variations. The proposed system is modeled in d-q reference frame and simulated using Matlab/Simulink in order to investigate its dynamic performance. The dynamic performance of the proposed system is achieved using the three fuzzy logic controllers. Dynamic simulation results shows the effectiveness of the proposed control strategy.

PARAMETERS USED FOR SIMULATION

The value of circuit parameters used for the simulation of the wind turbine of the wind system is given in Table 2.

Table 2 Simulation parameters for the Induction Machine

Nominal Power	275 KVA
Input Voltage (line – line)	480 Volts
Frequency	50 Hz
Stator Resistance (R_s)	0.016 Ω
Stator Inductance(L_s)	0.06 H
Rotor Resistance (R_r)	0.015 Ω
Rotor Inductance(L_r)	0.06 H
Mutual Inductance	3.5 mH

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