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Green Energy Generation Using FLC Based WECS With Lithium Ion Polymer Batteries

Baskar M [1*], Jamuna V [2].
[1]Pallavan College of Engineering, Kanchipuram, Tamilnadu -631502, India, [2]Jerusalem College of Engineering, Chennai, Tamilnadu -631502, India.

ABSTRACT

Green Energy Generation Using Wind energy conversion system is achieved using Lithium Ion Polymer Batteries and Fuzzy logic controller. Presented scheme also provides the constant output power for the stand alone loads like Island, Hills Stations, Ships and Remote locations etc. A fuzzy-logic controller based Wind energy conversion system with permanent magnet synchronous machine is simulated using MATLAB Simulink. The controller provides the constant output voltage in Buck Boost Converter with the wind fluctuations. The SPWM based inverter can be used to produce the constant output voltage with constant frequency. Also a thin and light weight Lithium Ion Polymer Batteries provides the energy back to the Wind energy conversion system , when the wind speed decreases below the base wind velocity. Simulation results are provided to demonstrate the validity of the proposed fuzzy-logic-based controller and comply with the theoretical results. The performance of the system is compared using various controllers.

Key Words: Fuzzy Logic Controller , Sinusoidal pulse width modulation , Wind energy conversion system .

[*]Author for correspondence: mgbaskar2002@gmail.com

INTRODUCTION

Wind energy wins the energy demand, toxic gases production, pollution and difficulty in distribution of electricity to isolated places (Hill Stations, Ship etc...). The less maintenance and space offered by wind energy are the most key factors for receiving vast global attention. Due to the increasing demand on electrical energy, a significant amount of effort is being made to generate electricity from harmless renewable energy sources. The villages are not fulfilling with electricity, some of them are isolated with transmission and distribution network. Only way to utilize the power supply is using renewable energy sources. Well popular renewable energy sources are wind energy and solar energy. Wind energy has a lower installation cost and occupies less space compared to the solar energy. The wind energy system means that it converts kinetic energy (wind energy) in to mechanical energy and then to electrical energy. In this system, the wind velocity decides the output power. Due to the variations in wind velocity , it is difficult to maintain the turbine with constant output and maximum power output for all wind speed conditions[1–3]. In the wind turbine system, two types of power generations like fixed speed and Variable speed power generations are used [4]. Instead of fixed speed power generation, variable speed power generation is most popular. Energy captured by variable speed power generation is higher than the fixed speed power generation. There are various kinds of generators used in WECS such as induction generator (IG), doubly fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG)[5] . The PMSG based on WECS can connect to the turbine without using gearbox. The need of gearbox decrease the weight of nacelle PMSG has the more attention because of small in size, low installation cost and also direct driven machine. Hence PMSG works at low speed without decreasing the efficiency, thus usage of gear box can be avoided [6–7].The Buck or Boost converters are used to give the Variable DC Voltage. The controller is used to give the constant DC voltage for charging the Battery [8-11].

In the present method the buck, boost converters are replaced by Buck-Boost converter to give efficient output. The Normal lead acid batteries are exchanged by Lithium Ion Polymer batteries. SPWM based inverter gives the smooth variations. Finally, WECS is simulated for different wind speeds with different controllers [12-13] and the outputs are obtained.

MODELING OF WECS

The configuration of wind energy conversion system is shown in Figure 1. Wind turbine converts kinetic energy of the wind’s motion to mechanical energy transmitted by the shaft then it is converted in to an electrical energy using PMSG. The PMSG generates the three phase AC supply, which again converted in to DC supply using Diode rectifier. The buck boost converter used to produce the controlled DC given to the SPWM inverter as an input and also charges the battery. The three phase SPWM inverter converts the controllable DC in to controllable AC and it is given to the local distributor networks or stand alone load. P, PI, PID and Fuzzy Logic controllers are used to ensure the constant output voltage[14].

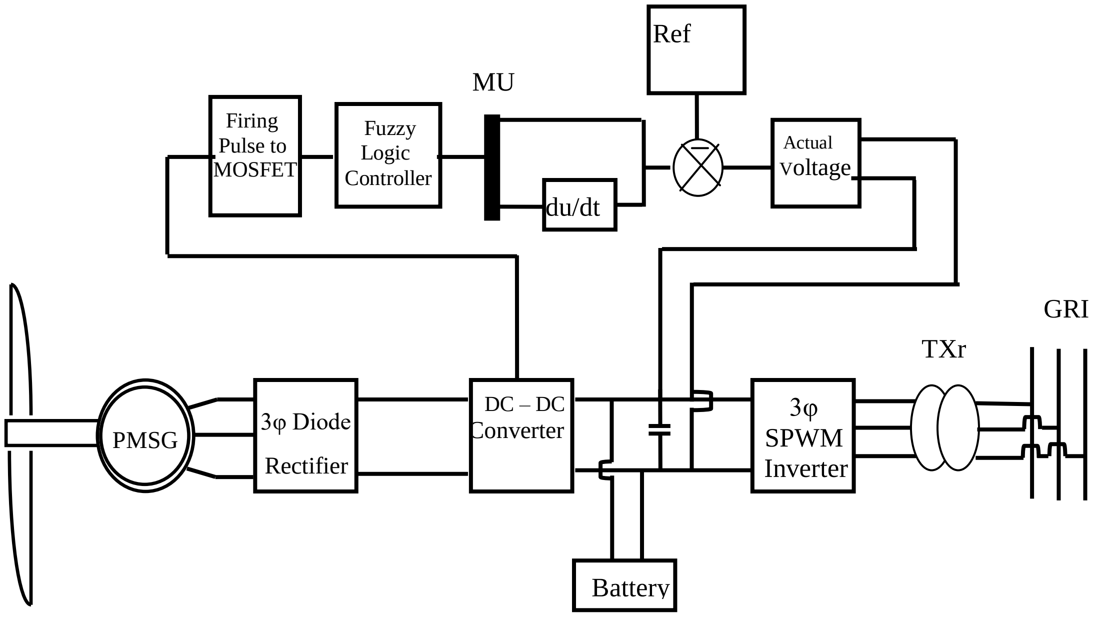

Figure 1: Configuration of PMSG Based WECS

Wind Turbine Model

According to Newton's second law of motion

$F = ma$ (1)

An object having the mass m and velocity v, then the kinetic energy of that mass is equal with work done in displacing that object from rest to some distance s under a force F [15]

$E = W = Fs$

then

$E = mas$ (2)

According the third equation of motion

$v^2 = u^2 + 2as$ (3)

$a = \frac{v^2-u^2}{2s}$ (4)

Initial velocity of object u is zero

$a = \frac{v^2}{2s}$ (5)

Substitute equation (5) in to (2)

$E = \frac{1}{2}mv^2$ (6)

The power can be obtained by the rate of change of kinetic energy

$P = \frac{d}{dt}E$ (7)

$P = \frac{1}{2}\frac{dm}{dt}v^2$ (8)

$\frac{dm}{dt} = a\rho v_\omega$ (9)

$P = \frac{1}{2}a\rho {v_\omega}^3$ (10)

Actual mechanical power

$P = \frac{1}{2}a\rho v_\omega({v_u}^2 - {v_d}^2)$ (11)

Mass flow rate,

$\rho a v_\omega = \rho a(v_u + v_v)/2$ (12)

Equation (11) becomes,

$P = \frac{1}{2}\rho a({v_u}^2 - {v_d}^2)(\frac{v_u+v_v}{2})$ (13)

$P = \frac{1}{2}\rho a(0.5{v_u}^3\left(1 - \frac{{v_v}^2}{{v_u}^2}\right)\left(1 + \frac{v_v}{v_u}\right)$ (14)

$P = \frac{1}{2}\rho a{v_u}^3 C_p$ (15)

Let consider $C_p = 0.5\left(1 - \frac{{v_v}^2}{{v_u}^2}\right)\left(1 + \frac{v_v}{v_u}\right)$ (16)

$\lambda = \frac{v_v}{v_u}$

$C_p -$ betz limit

λ=blade tip speed/wind speed

Blade tip speed (m/s) =Angular speed of turbine (w)*R/wind speed

Substitute λ value in equation (16).

$C_p = \frac{1}{2}(1 + \lambda)(1 - \lambda^2)$ (17)

To attain the maximum value of c_p, c_p is differentiated with respect to 'λ'

Then,

$\frac{dC_p}{d\lambda} = \frac{1}{2}(1 - 2\lambda - 3\lambda^2)$ (18)

The roots of the 'λ' are,

λ=-1 & 0.33 or 1/3

Where,

$m \ = a\rho v_{\omega}t = \ \pi r^2\rho v_{\omega}t$ (19)
P - Air density
A - Swept area of the wind turbine rotor
r -Radius of the wind turbine rotor
Substitute equation 19 in to 6

$E \ = \frac{1}{2}\ \pi r^2\rho {v_{\omega}}^3 t$ (20)

Expression (15) is the actual wind power. At any instant of time wind power can be written as,

$P_{wind} \ = E/t = \ \pi r^2\rho {v_{\omega}}^3$ (21)

P_{wind} - potentially available power in the wind

From equation 21, It is observed that the wind power is proportional to the cube of the wind speed, which means that a small increase in the wind speed will result in a large increase of the wind power.

Moreover the power can also be increased by enlarging the radius of wind turbine rotor radius, since the power is proportional to the square of this rotor radius. This is the reason that more and more large scale wind turbine system (up to 10MW) are being investigated and contemplated

The relationship between the power that is captured by the wind turbine and potential maximum power in the wind can be written as,

$C_p \ = \frac{P_{turbine}}{P_{wind}}$ (22)

C_p is the aerodynamic power coefficient which is a function of the pitch angle β and the tip speed ratio λ . Since ρ and *A* are constant parameters, the wind turbine can produce maximum power at a certain wind speed only when the turbine operates at the maximum C_p. A generic equation is used to express C_p, is based on the turbine characteristics on Figure 2.[8]

$C_p(\lambda\ ,\beta) = C_1\left(\frac{C_2}{\alpha} - C_3\beta - C_4\right)e^{\frac{-C5}{\alpha}} + C_6\lambda$ (23)

With $\frac{1}{\alpha} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1}$ (24)

where β is blade pitch angle, and λ is defined by,

$\lambda = \frac{\omega_m R}{V_w}$ (25)

λ,is the tip speed ratio , ω_m is an angular speed of the wind turbine and C1 –C6 are the coefficients. Now the power captured by the wind turbine,

$P_{Turbine} = \ \frac{1}{2}\rho\pi r^2 C_p(\lambda,\beta)V_w^3$ (26)

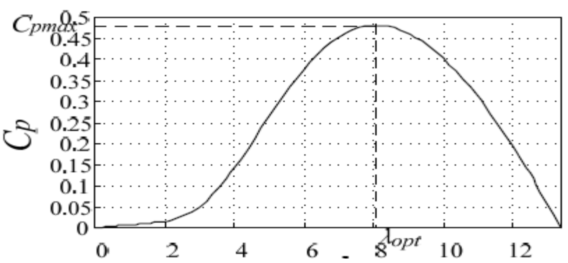

Figure 2: Characteristics B/w $C_p and\ \lambda$

In this, V_ω is the turbine angular velocity and *R* is the turbine radius. In small wind turbine generation systems, β is rarely changed.

Modeling of PMSG

The equivalent circuit consists of two axis namely direct axis and quadrature axis. The quadrature axis rotates ahead with 90 degree to the direct axis. The d–q model is based on the assumption that the stator self-inductance and mutual inductance are either constant or vary sinusoidally with the rotor position[16–19].

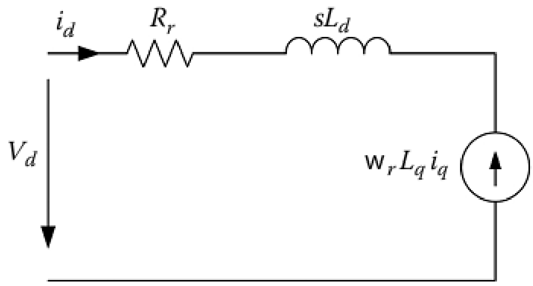

Figure 3: Direct axis equivalent circuit of PMSG (d Axis)

The voltage equation from the direct axis equivalent circuit is given by,

$$V_d = i_d R_s + L_d \frac{di_d}{dx} - \omega_r L_q i_q \quad (27)$$

$$i_d R_s = V_d - L_d \frac{di_d}{dx} + \omega_r L_q i_q \quad (28)$$

$$i_d R_s - V_d = -L_d \frac{di_d}{dx} + \omega_r L_q i_q \quad (29)$$

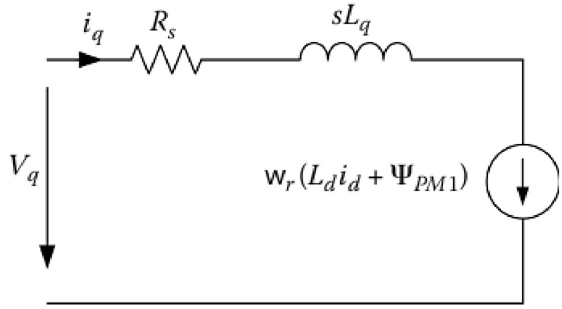

Figure 4: Quadrature axis equivalent circuit of PMSG (q Axis)

The voltage equation from the Quadrature axis equivalent circuit is given by,

$$V_q = i_q R_s + L_q \frac{di_q}{dx} + \omega_r (L_d i_d + \Psi_{PM}) \quad (30)$$

$$i_q R_s = V_q - L_q \frac{di_q}{dx} - \omega_r (L_d i_d + \Psi_{PM}) \quad (31)$$

$$i_q R_s - V_q = -L_q \frac{di_q}{dx} - \omega_r (L_d i_d + \Psi_{PM}) \quad (32)$$

With

$$\Psi_s = \Psi_d + j\Psi_q \quad (33)$$

$$\Psi_d = \Psi_{PM} + L_d i_d \quad (34)$$

$$\Psi_q = L_q i_q \quad (35)$$

$$V_s = V_d + jV_q \quad (36)$$

$$i_s = i_d + ji_q \quad (37)$$

$$V_s = i_s R_s + \frac{d\Psi s}{dt} + j\omega_r \Psi_s \quad (38)$$

$$i_s R_s - V_s = -\frac{d\Psi s}{dt} - j\omega_r \Psi_s \quad (39)$$

The torque equation is obtained by

$$T_e = P_1 \frac{P_e}{\omega_r} \quad (40)$$

$$T_e = \frac{3}{2} P_1 Re\,(ji^*{}_s \Psi_s) \quad (41)$$

$$T_e = \frac{3}{2} P_1 Re\,(j(i_d + ji_q)(\Psi_d + j\Psi_q)) \quad (42)$$

$$T_e = \frac{3}{2} P_1 (\Psi_d i_q - \Psi_q i_d) \quad (43)$$
$$T_e = \frac{3}{2} P_1 ((\Psi_{PM} + L_d i_d) i_q - L_q i_q i_d) \quad (44)$$
$$T_e = \frac{3}{2} P_1 (\Psi_{PM} + (L_d - L_q) i_d) i_q \quad (45)$$

Hence this is the torque equation for the Permanent Magnet Synchronous Generator (PMSG).If the PMSG is surface mounted permanent magnet, $(L_d = L_q)$ then the torque equation becomes,

$$T_e = \frac{3}{2} P_1 \Psi_{PM} i_q \quad (46)$$

Mechanical equation

$$T_e = T_e + B\omega_m + J\frac{d\omega_m}{dt} \quad (47)$$

J=Moment of inertia, B=Viscous friction, T_t=Load torque, T_e=Electromagnetic torque and
ω_m=Mechanical angular velocity.

Diode Rectifier

The three phase diode bridge rectifier is employed to convert AC to DC as shown in Figure 5 . The impedance of supply lines is assumed to be low and it is neglected. A distorted three phase voltage system supplies the rectifier with a balanced input. [20–21].

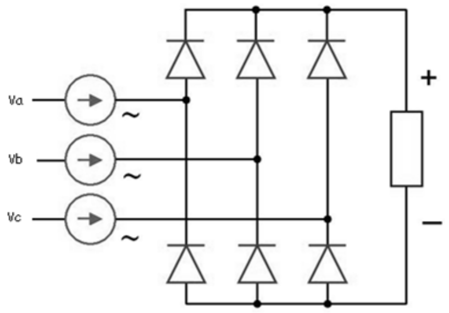

Figure 5: Three phase diode rectifier

The PMSG output is then rectified by means of three phase rectifier whose output voltage can be given as

$$V_{rec} = \frac{3\sqrt{2}}{\pi} V_{rms} \quad (48)$$

Buck-boost Converter

A buck-boost converter circuit is a combination of the buck converter topology and a boost converter topology in cascade. The output to input conversion ratio is also a product of ratios in buck converter and the boost converter. The output voltage is controlled by controlling the switch-duty cycle [22-24]. Buck – boost converter is shown in the Figure. 6. DC voltage V_{rec} , may be greater than or less than the input voltage. The output voltage V_{dc} and output current I_{dc} are given as

$$V_{dc} = -\frac{k}{1-k} V_{rec} \quad (49)$$
$$I_{dc} = \frac{1-k}{k} I_{rec} \quad (50)$$

Where k is the duty ratio. To achieve continuous current the inductor is properly chosen and included. Polarity of V_{dc} is opposite to that of input voltage as “k” changes between 0 and 1.

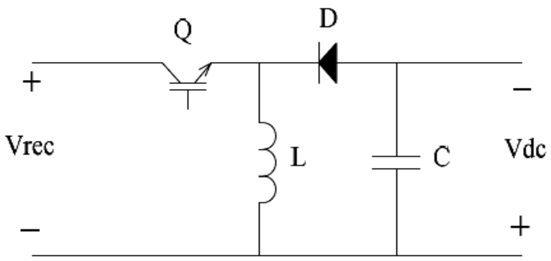

Figure 6: Circuit Diagram of Buck – Boost Rectifier

To get a constant DC output voltage, the value of "k" in the converter is varied with difference in the reference output voltage and actual output voltage at various wind speed. As the losses are eliminated, the buck-boost converter maintains the constant power like other DC converters. The constant dc voltage for the three phase SPWM inverter is provided by the combination of buck-boost converter with the voltage control loop[9].The buck-boost converter along with the voltage control loop maintains a constant dc voltage to the three-phase SPWM inverter.

Batteries

Energy storage device (Battery) is important in the WECS to give the back up source to the Inverter when the wind velocity comes below the base wind speed. Lead Acid Batteries are used to store the electric energy , it occupies more space and produce the less efficiency. Wind generators respond to changing wind conditions by automatically adjusting the angle that the blade makes with the oncoming wind using power from the electrical grid. When the grid fails, there is no load on the generator and the wind generator is in risk of severe damage if the blades are not turned into a neutral position using power provided by the batteries. Presently, lead acid batteries are used for back-up power to readjust the rotors. These, however, require frequent maintenance, which is a significant burden due to the position of the heavy batteries high up on the wind generator and the often remote location. Li poly batteries are one third of the weight, are maintenance-free and have an electronic battery management system that allows checking the status of the battery remotely. A lithium polymer battery, or more correctly lithium-ion polymer battery (abbreviated variously as LiPo, LIP, Li-poly and others), is a rechargeable battery of lithium-ion technology in a pouch format. Unlike cylindrical and prismatic cells, LiPos come in a soft package or pouch, which makes them lighter but also less rigid. Renewable energy generation having a struggle to keep up with the demand from portable products for smaller, lighter and higher-capacity rechargeable. The most recent answer to the challenge is the rechargeable lithium-ion polymer battery, which is expected to serve the growing demand for power-hungry products in the future.

SVPWM Based Inverter

Instead of, maintaining the uniform width of all pulses, the width of each pulse is varied in proportion to the amplitude of a sine wave. The distortion factor and lower order harmonics are reduced significantly. The gating signals are generated by comparing a sinusoidal reference signal with a triangular carrier wave of frequency fc. The modulation index, m, is given by

$$m = \frac{V_{control}}{V_{tri}} \quad (51)$$

Where $V_{control}$ is the peak amplitude of control

$$m_f = \frac{f_s}{f_1} \quad (52)$$

FUZZY LOGIC CONTROLLER

Fuzzy Logic Controller (FLC) is designed as an alternative to conventional control methods to give better solution of complex systems. The fuzzy logic controller is created with following steps, first step is definition of input and output variables , second step is decision making of fuzzy control rules. After that, fuzzy logic inference is made. Finally, defuzzification and aggregation is made. The overall control scheme of the proposed system is shown in Figure. 7 [25–27]

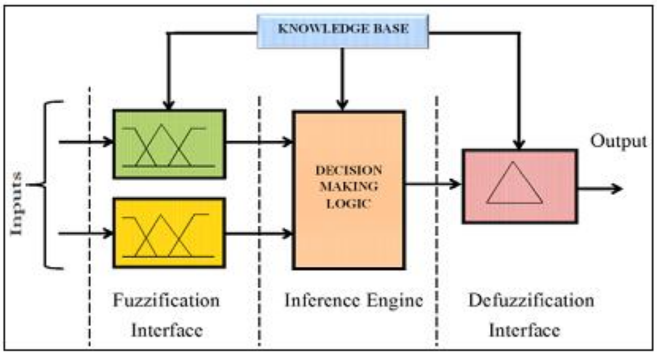

Figure 7: Functional Block diagram of FLC

A fuzzy variable has values which are defined by linguistic variables (fuzzy sets or subsets) such as low, medium, high, big, slow, etc. Each fuzzy set is defined by a gradually varying membership function. The shape of fuzzy sets can be triangular, trapezoidal, etc

A fuzzy control essentially embeds the intuition and experience of a human operator. The data base and the rules form the knowledge base which is used to obtain the inference relation R. The data base contains a description of input and output variables using fuzzy sets. The rules base is essentially the control strategy of the system. It is usually obtained from expert knowledge or heuristics containing a collection of fuzzy conditional statements expressed as a set of IF-THEN rules.

In fuzzy logic controller design, action of identification of the main control variables and action of sets that describe the values of each linguistic variable is very important. The specific structure of the FLC is shown in Figure.7. The input variables of the FLC are the output voltage error, e(n), and the change of this error, Δe(n). The output of the FLC is the duty cycle of the, δ(n), that regulates the output voltage. Figures. 8 - 10 shows the membership functions of the inputs and output of the Buck Boost Converter. The triangular membership functions are used for the FLC for easier computation. A five-term fuzzy set, Negative Big (NB), Negative Small (NS), Zero (ZE), Positive Small (PS), Positive Big (PB), is defined to describe each linguistic variable.

The fuzzy rules of the proposed Buck Boost DC-DC converter can be represented in a symmetric form, as shown in TABLE I. The Mamdani fuzzy inference method is used for the proposed FLC, where the maximum of minimum composition technique is used for the inference and the center-of-gravity method is used for the defuzzification process.

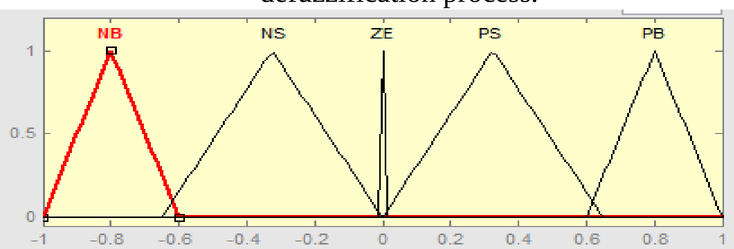

Figure 8: Member ship function of INPUT 1 (error)

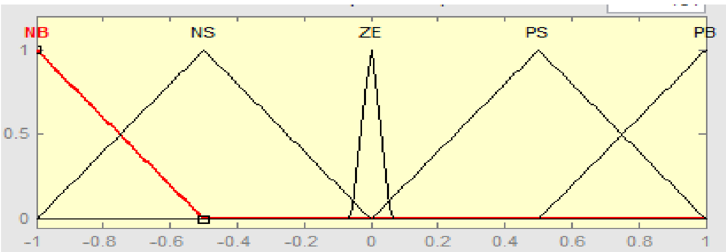

Figure 9: Member ship function of INPUT 2 (change in error)

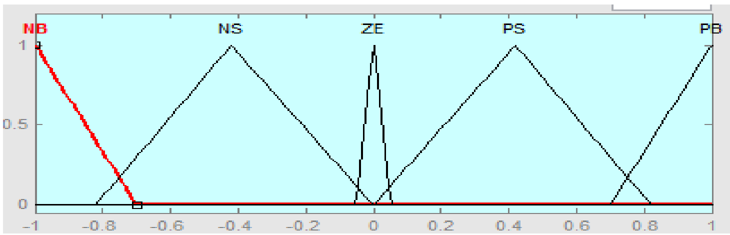

Figure 10: Member ship function of OUTPUT (Firing Angle)

Thus, the membership function in Figure. 10 is guaranteed to produce the stable output signal. The design of the focused membership function values depends on the nature of the signal. The control signal value is confined between -1 and 1 owing to the PWM carrier wave. The input signal values are between -1 and 1 because of the error signal, resultant from the difference between output signal and the desired reference signal. Also, most of error values are centered from -0.2 to 0.2. The sharpness of the control signal is very essential for minimizing the error signal to zero in short time, therefore; the pulse membership function is used to configure the control signal fuzzy sets.

Table I : FLC rules for the converter

e(n)/Δe(n).	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	NB	NS	NB	PB	PB
NS	NS	ZE	NB	PS	PB
ZE	NB	NS	ZE	PS	PB
PS	NB	NB	PS	PS	PS
PB	NB	NS	PB	PB	PB

RESULT AND DISCUSSON

The Matlab-Simulink diagram of PMSG-based WECS is shown in figure 11.The sampling time used for the simulation is 2 sec. The wind velocity of 7 m/s is taken as a base speed for the period, fluctuations in the wind speed are taken between 4 m/s – 15 m/s for the period of (0.5 – 1.8) secs. PMSG based WECS is simulated for open loop control and closed loop control using PI, PID and FLC. The PMSG generates the different level of voltages during the wind fluctuations as shown in Figure 13. Three phase diode rectifier produces the corresponding DC voltages and it is connected as source with Buck-Boost converter. The buck boost converter is connected with three phase inverter as well as energy storage device. The output voltages of PMSG, Three Phase diode Rectifier , Buck Boost converter and Three phase inverter for different wind speeds gets the variations for the corresponding changes in wind velocity as in Figures 13 and 14. Load side cannot be the constant output voltage and frequency. This problem can be rectified by introducing a controller circuit at the Buck Boost converter. WECS for the closed loop control is simulated with PI , PID controller and FLC. Buck Boost converter obtain constant output voltage by controlling duty cycle of the chopper is shown in Figures 15 -17.

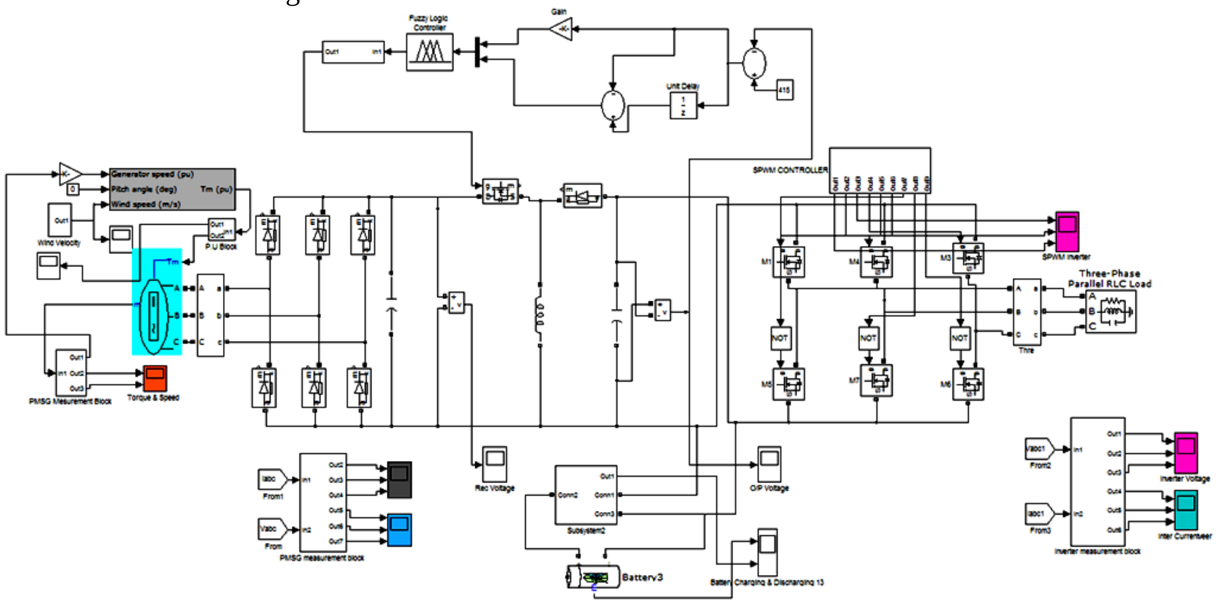

Figure11: Simulated Circuit diagram of PMSG based WECS

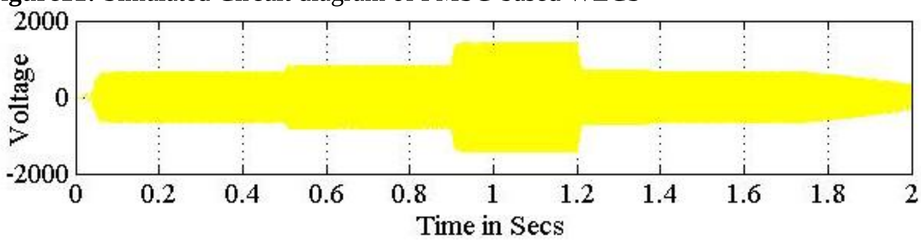

Figure12: Output voltage of PMSG

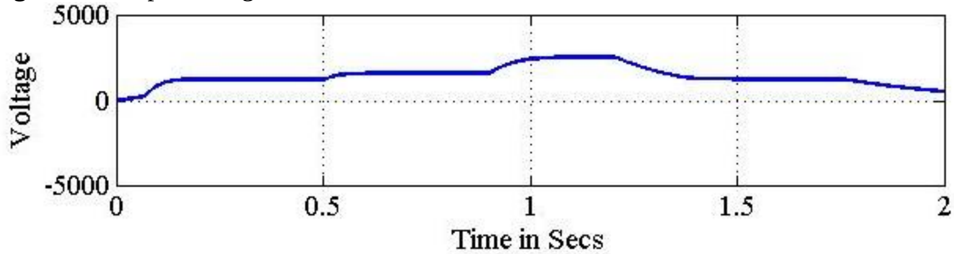

Figure13: Output voltage of Buck Boost Converter without control

Simulation circuit of WECS with PMSG using Fuzzy Logic controller is shown in the Figure 12 .The output voltage for Buck Boost Converter and SPWM based inverter is shown in the Figure 18.The constant output voltage is obtained with fluctuations in the wind side during period of 0.5 – 1.8secs . After 1.8 sec, the wind speed becomes zero, now the battery acts as a source for the Inverter. Now the load is always connected with constant voltage and frequency.

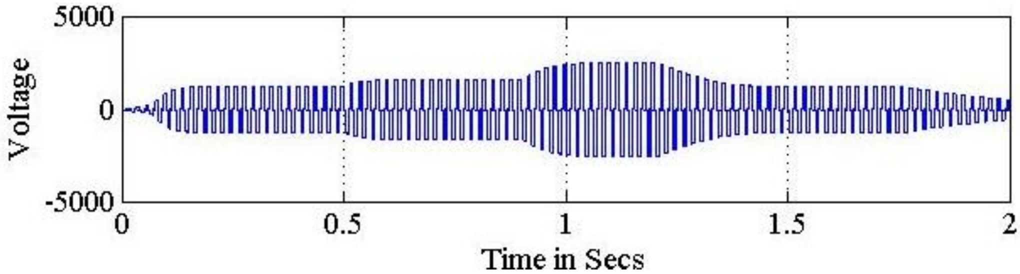

Figure 14: Output voltage of inverter without control

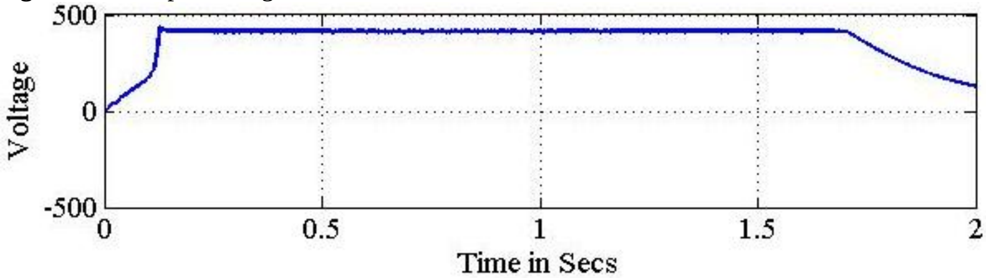

Figure15: Output voltage of Buck Boost Converter with PI control

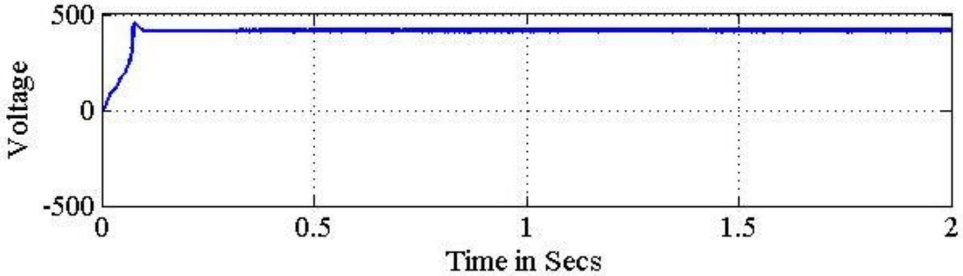

Figure16: Output voltage of Buck Boost Converter with PID control

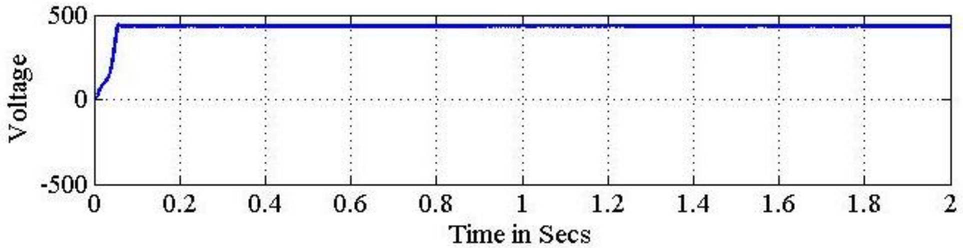

Figure17: Output voltage of Buck Boost Converter with FLC

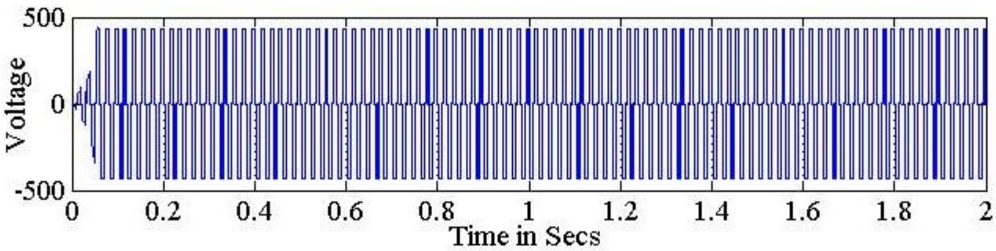

Figure18: Output voltage of Inverter with FLC

Table II Comparison of Controllers

Parameters	PI	PID	FLC
Rise Time in sec	0.127	0.076	0.0556
Peak Voltage in volt	440	455	440
Peak Time in sec	0.128	0.077	0.056

Settling Time in sec	0.14	0.1	0.059
Max Peak Overshoot in %	25	40	25

CONCLUSION

This paper illustrates a closed loop strategy of a variable-speed wind energy conversion system connected with grid .The obtained constant DC voltage from Buck Boost converter, is fed as an input voltage to the inverter at variable wind speeds. FLC based converter gives the quick dynamic response, accurate control compared with conventional controllers as given in the table. SPWM can be varied to control frequency of the AC output voltage. Inverter produces the constant output voltage for a Stand-Alone Wind-Driven PMSG. The Simulation is successfully done and open loop / closed loop simulation results are presented. The Simulation results coincide with the theoretical results. In future work the battery will be connected with solar energy system to obtain the hybrid renewable energy conversion system.

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