International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE)
ISSN: 0976-1353 Volume 25 Issue 5 – APRIL 2018 (SPECIAL ISSUE).

WECS FOR STANDALONE LOAD WITH SEPIC CONVERTER USING FLC

Baskar M [#1], Ananthi G [*2], Girija M [*3], Jayalakshmi T [*4], Jinoslinpunitha J *[5]
Department of Electronics and Communication Engineering
Kings Engineering College, Chennai, Tamilnadu, India.
[1] *Assistant Professor, mgbaskar2005@gmail.com*
[2] *UG SCHOLAR, anandhi818@gmail.com*
[3] *UG SCHOLAR mgirijagayathri@gmail.com.com*
[4] *Student, jeyabanu87@gmail.com*
[5] *Student,jinojames@gmail.com*

***Abstract*: Wind energy conversion system is achieved using SEPIC Converter 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 SEPIC 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 .**

I 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 SEPIC 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.

II MODELING OF WECS

The configuration of wind energy conversion system is shown in Fig 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 SEPIC 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].

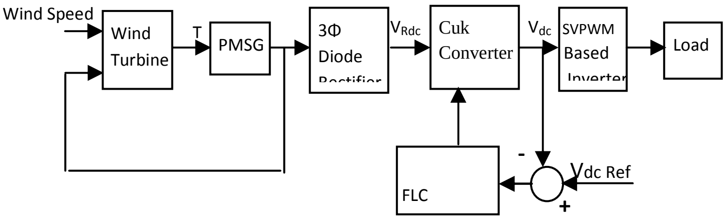

Fig .1. Configuration of PMSG Based WECS

A. Wind Turbine Model

According to Newton's second law of motion

$$F=ma \quad (1)$$

where,

a=acceleration constant

m=mass

F=force

Thus the kinetic energy becomes,

$$E= mas \quad (2)$$

From kinematics of solid motion, $v^2=u^2+2as$

$a=v^2-u^2/2s$ assume u=0

$$a=v^2/2s \quad (3)$$

Substitute (3) in (2)

$$E=½(mv^2) \quad (4)$$

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

$$P=\frac{dE}{dt}=½(\frac{dm}{dt})\ v\omega^2 \quad (5)$$

Consider

$$\frac{dm}{dt}=a\rho v\omega \quad (6)$$

Substitute (6) in (5),

$$P=½\rho Av\omega^3 \quad (7)$$

Actual mechanical power

$$P\omega=½\rho Av_\omega\ (v^2-v_d^2) \quad (8)$$

Mass flow rate,

$$\rho Av_\omega = \rho A((v_u+v_d)/2)$$

Equation (8) becomes,

$$p\omega =½\rho A(v_u^2-v_d^2).((v_u+v_d)/2)$$

$$=½\rho A\ [\frac{vu}{2}(v_u^2-v_d^2) + \frac{vd}{2}(v_u^2-v_d^2)]$$

$$=½\rho A\ (0.5(v_u^3)-0.5(v_uv_d^2) +0.5(v_u^2v_d)-0.5(v_d^3))$$

$$=½\rho Av_u^3\ (0.5(1-(\frac{vd}{vu})^2 + \frac{vd}{vu}-(\frac{vd}{vu})^3)$$

$$P\omega=½\rho Av_u^3c_p \quad (9)$$

C_p = betz limit

$$c_p=(0.5(1+\frac{vd}{vu})(1-\frac{vd^2}{vu})) \quad (A)$$

$$\lambda=\frac{vd}{vu} \quad (10)$$

λ=blade tip speed/wind speed

Blade tip speed (m/s) =Angular speed of turbine (w)*R/wind speed (11)

Substitute (10) in (A)

$$c_p= 0.5(1+\lambda)(1-\lambda^2) \quad (12)$$

To attain the maximum value of c_p, we have to differentiate c_p with respect to 'λ'

Then,

$$\frac{dcp}{d\lambda}=0.5((1+\lambda)(-2\lambda)+(1-\lambda^2)(1))$$

$$=0.5(1-2\lambda-3\lambda^2)$$

The roots of the 'λ' are,

λ=-1 & 0.33 or 1/3

From equation (4),

Where,

$$m=\rho Av_\omega t=\rho\pi r^2v_mt \quad (13)$$

ρ=air density

A=swept area of the wind turbine rotor

r=radius of the wind turbine rotor

Substitute (13) in (4)

$$E=0.5(\rho\pi r^2v_m^3t) \quad (14)$$

Expression (14) is the actual wind power. At any instant of time can be written as,

$$P_{wind}=E/t=0.5(\rho\pi r^2v_m^3) \quad (15)$$

P_{wind}= potentially available power in the wind

From equation (15), It is observed that the wind power is proportional to the cube of the wind speed, which means that a small increase in of the wind speed will result in a large increase of the wind power.

Moreover the power can also be increased by enlarging the 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 nowadays.

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

$$C_p=\frac{P_{turbine}}{P_{wind}} \quad (16)$$

$C_p$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 as in Fig 2.[8]

$$C_p(\lambda\ ,\beta) = C_1\left(\frac{C_2}{\alpha} - C_3\beta - C_4\right)e^{\frac{-C_5}{\alpha}} + C_6\lambda \quad (17)$$

With $\frac{1}{\alpha} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1}$ (18)

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

$$\lambda = \frac{\omega_m R}{V_w} \qquad (19)$$

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,

$$P_{Turbine} = \frac{1}{2}\rho\pi r^2 C_p(\lambda,\beta)V_w^3 \qquad (20)$$

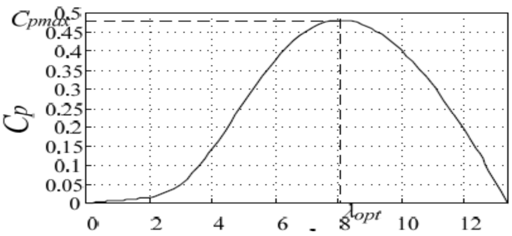

Fig .2. Characteristics B/w C_p and λ

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.

B. PMSG

The equivalent circuit of PMSG is shown in Fig 3 and it consists of two axis namely direct axis and quadrature axis respectively The quadrature axis rotates ahead with 90 degree to the direct axis.

The voltage across the direct axis is given by,

$$V_d=R_sI_d+d/dt\lambda_d-\omega_e\lambda_q \qquad (21)$$

The voltage across the quadrature axis is given by,

$$V_q=R_sI_q+d/dt\lambda_q+\omega_e\lambda_d \qquad (22)$$

Where,

$$\lambda_d=L_dI_d+\lambda_m \qquad (23)$$

$$\lambda_q=L_qI_q \qquad (24)$$

Sub eqn (23) and (24) in (21) and (22)

The dq axis inductance is given by,

$$L_d=L_q=L_s$$

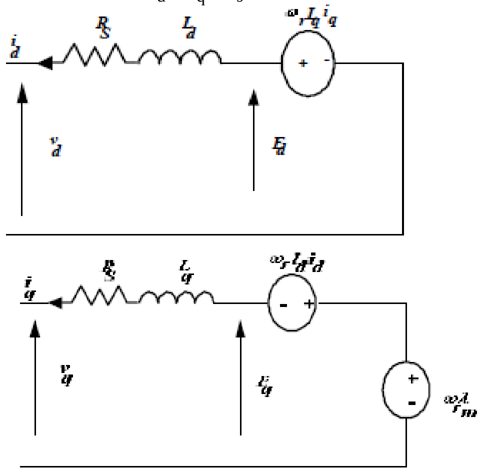

Fig. 3. Equivalent circuit of PMSG

$$V_d=R_sI_d+Ls\,(dI_d/dt)-\omega_eL_qI_q \qquad (25)$$

$$V_q=R_sI_q+Ls\,(dI_q/dt)-\omega_e\,(L_dI_d+\lambda_m) \qquad (26)$$

Torque equation can be derived from the power balance equation. The power is given as,

$$P_e=3/2(V_dI_d+V_qI_q) \qquad (27)$$

Sub eqn (25) and (26) in (27)

$$P_e=3/2(R_sI_d+R_sI_q)+3/2(d/dtL_d(I_d)^2/2+d/dtL_q(I_q)^2/2)+3/2(\omega_e\lambda_dI_q-\omega_e\lambda_qI_d) \qquad (28)$$

- $3/2(R_sI_d+R_sI_q)$ =Power loss in the conductor.
- $3/2(d/dtL_d\,(I_d)^2/2+d/dtL_q\,(I_q)^2/2)$ =Rate of change of stored energy in magnetic field.
- $3/2(\omega_e\lambda_dI_q-\omega_e\lambda_qI_d)$ = Conversion of electrical energy to mechanical energy.

The power output from the generator shaft must be equal with electro mechanical power.

$$P=\omega_eT_e$$

$$P=3/2(\omega_e\lambda_dI_q-\omega_e\lambda_qI_d) \qquad (29)$$

Where

$$\boldsymbol{\omega_e}=\text{Number of pole pairs} * \boldsymbol{\omega_m}$$

$$\boldsymbol{\omega_e}=\boldsymbol{\omega_r} \qquad (30)$$

Sub eqn (23) and (24) in (29),

$$T_e=3/2\omega_e\,[L_dI_dI_q+\lambda_mI_q-L_qI_qI_d]$$

$$T_e=3/2\omega_e\,[\lambda_mI_q+(Ld-L_q)I_qI_d] \qquad (31)$$

Sub eqn (10) in (11)

$$T_e=3/2\omega_r\,[\lambda_mI_q+(L_d-L_q)\,I_qI_d] \qquad (32)$$

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

$$T_e=3/2\omega_r\lambda_mI_q$$

Mechanical equation

$$T_e=T_t+B\,\omega_m+Jd/dt\,\omega_m$$

J=Moment of inertia

B=Viscous friction

T_t=Load torque

T_e=Electromagnetic torque

ω_m=Mechanical angular velocity.

C. Diode rectifier

The rectifier circuit employs the three phase diode bridge in Fig 4 . 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.

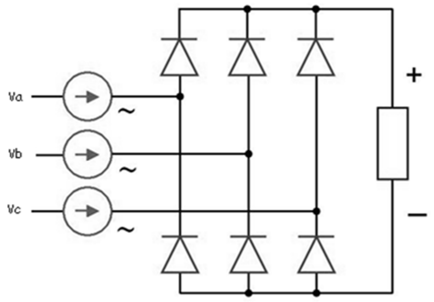

Fig. 4. Three phase diode rectifier

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

$$V_{rec} = \frac{3\sqrt{2}}{\pi} V_{rms} \quad (33)$$

D. SEPIC Converter

All dc-dc converters operate by rapidly turning on and off a MOSFET, generally with a high frequency pulse. What the converter does as a result of this is what makes the SEPIC converter superior. For the SEPIC, when the pulse is high/the MOSFET is on, inductor 1 is charged by the input voltage and inductor 2 is charged by capacitor 1. The diode is off and the output is maintained by capacitor 2. When the pulse is low/the MOSFET is off, the inductors output through the diode to the load and the capacitors are charged. The greater the percentage of time (duty cycle) the pulse is low, the greater the output will be. This is because the longer the inductors charge, the greater their voltage will be. However, if the pulse lasts too long, the capacitors will not be able to charge and the converter will fail as shown in Fig 5.

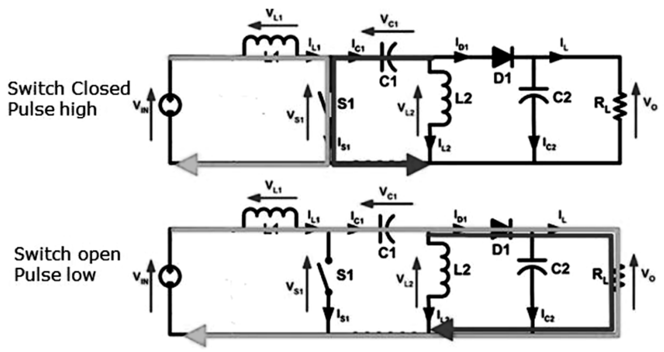

Fig .5 . Circuit Diagram of SEPIC Converter

The amount that the SEPIC converters step up or down the voltage depends primarily on the Duty Cycle and the parasitic elements in the circuit. The output of an ideal SEPIC converter is

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 Fig. 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

$$V_{dc} = \frac{k}{1-k} V_{rec} \quad (34)$$

However, this does not account for losses due to parasitic elements such as the diode drop VD

These make the equation:

$$V_{dc} + V_D = \frac{k}{1-k} V_{rec}$$

$$I_{dc} = \frac{1-k}{k} I_{rec} \quad (35)$$

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.

To get constant DC output voltage, the value of “δ” 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 SEPIC 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 SEPIC converter with the voltage control loop [9].The SEPIC converter along with the voltage control loop maintains a constant DC voltage to the three-phase SVPWM inverter.

E. Three phase 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

$$m = \frac{V_{control}}{V_{tri}} \quad (36)$$

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

$$m_f = \frac{f_s}{f_1} \quad (37)$$

III 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 Fig. 7 [25] –[27]

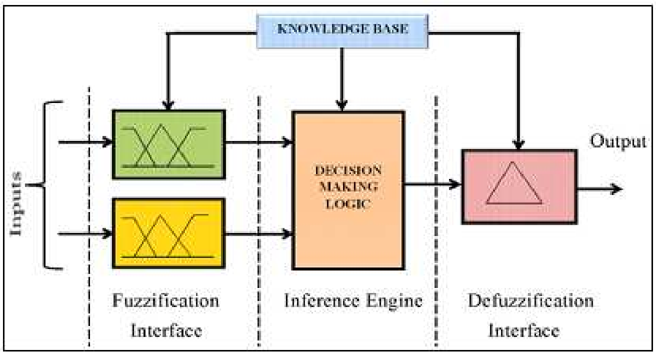

Fig .6 .: Functional Block Diagram of FLC

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, such as:

$R^{(i)}$: **If** x_1 is F_1 and x_2 is F_2 …and x_n is F_n **THEN** Y is $G^{(i)}$, i=1, …, m

where x :($x_1,x_2……..x_n$) is the input variables vector , Y is the control variable, m is the number of rules, n is the number of fuzzy variables, ($F_1,F_2……..F_n$) are the fuzzy sets. For the given rules base of a control system, the fuzzy controller determines the rule base to be fired for the error voltage and changing error voltage and then computes the duty ratio to the switch to control action

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 Fig.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. Figs. 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.

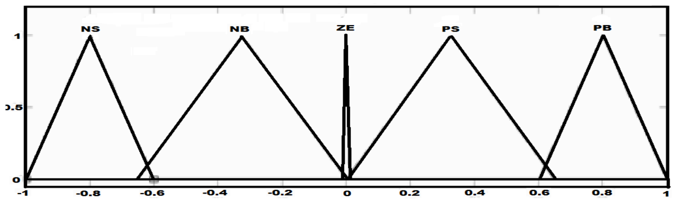

Fig 8: Membership function of INPUT 1 (error)

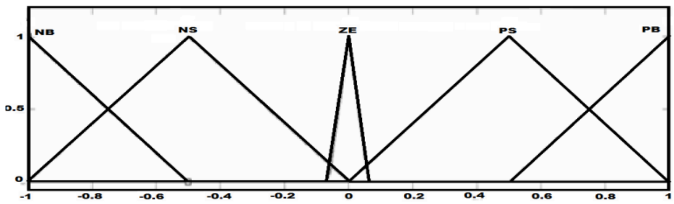

Fig9: Membership function of INPUT 2 (Change in error)

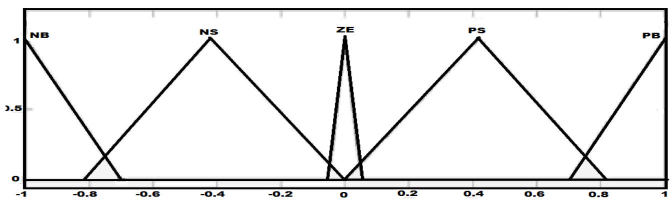

Fig10: Membership function of OUPUT

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. Thus, the membership function in Fig. 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 Fuzzy Rules

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

IV RESULTS AND DISCUSIONS

The Matlab-Simulink diagram of PMSG-based WECS is shown in fig 10.The sampling time used for the simulation is 2 sec. The wind velocity of 12 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 Fig 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 , SEPIC converter and Three phase inverter for different wind speeds gets the variations for the corresponding changes in wind velocity as in Figs 13 and 14.

Fig. 11. Simulated output of wind speed as step input

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	25	40	25

Load side cannot be the constant output voltage and frequency. This problem can be rectified by introducing a controller circuit at the SEPIC 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 Figs 15 -17. Simulation circuit of WECS with PMSG using Fuzzy Logic controller is shown in the Fig 12 . The output voltage for Buck Boost Converter and SPWM based inverter is shown in the Fig 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.

Fig. 12. Output Voltage of PMSG

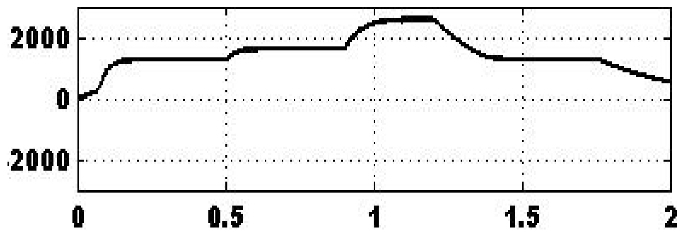

Fig. 13. Output Voltage of SEPIC Converter with Controller

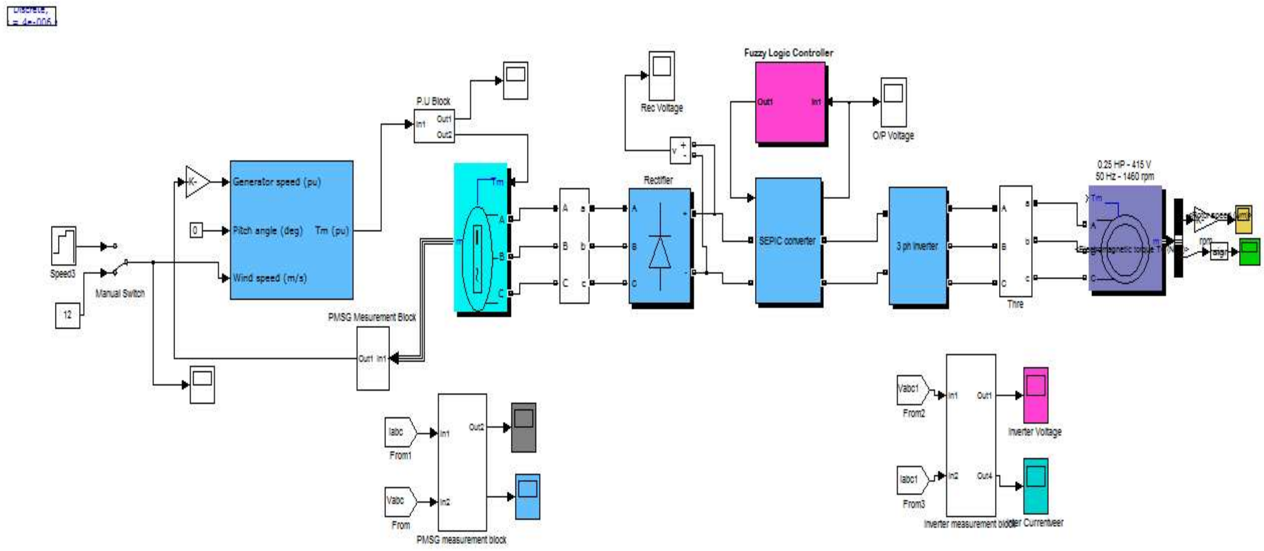

Fig . 14. Simulated Circuit diagram of PMSG based WECS

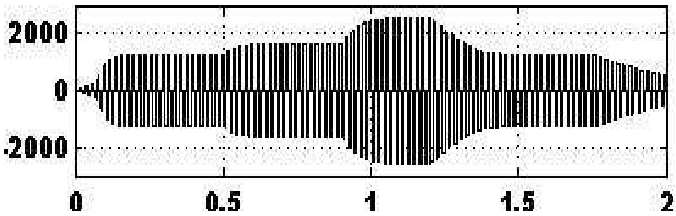

Fig. 15. Output Voltage of Inverter without control

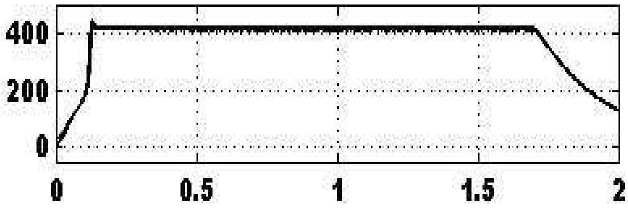

Fig16: Output Voltage of SEPIC with PI Control

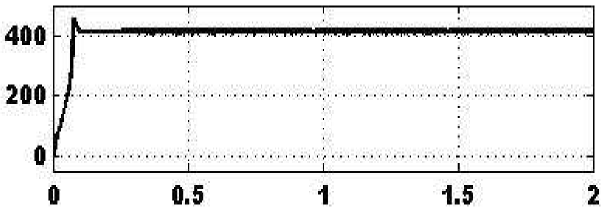

Fig17: Output Voltage of SEPIC with PID Control

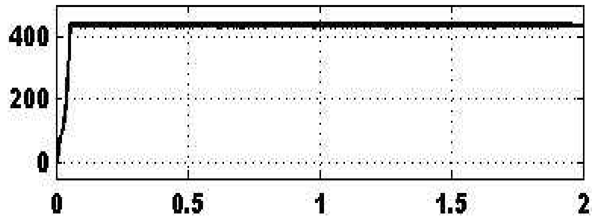

Fig 18: Output Voltage of SEPIC Converter with FLC

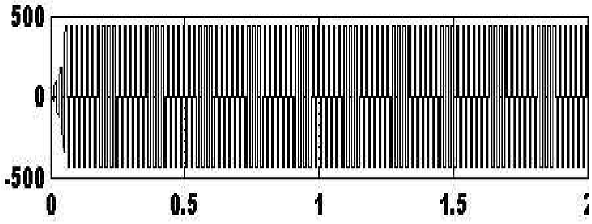

Fig 19: Output Voltage of Inverter with FLC

IV 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.

REFERENCES

[1] Yuanye Xia, Khaled H. Ahmed, and Barry W. Williams "A New Maximum Power Point Tracking Technique for Permanent Magnet Synchronous Generator Based Wind Energy Conversion System," *IEEE Trans On Power Electronics, vol. 26, no. 12, December 2011*

[2] Natalia Angela Orlando, Marco Liserre ,Rosa Anna Mastromauro , and Antonio Dell'Aquila, "A Survey of Control Issues in PMSG-Based Small Wind-Turbine Systems" *IEEE trans on industrial informatics, vol. 9, no.3, August 2013*

[3] A. Akhilesh Kumar Gupta B. HimanshuBhushan C. Paulson Samuel. "Generator Topologies with Power Electronics Converters for a Wind Energy Conversion System: A Review" in Proc. IEEE Int. Conf.

[4] OmidAlizadeh, AmirnaserYazdani, "A Strategy for Real Power Control in a Direct-Drive PMSG-Based Wind Energy Conversion System" *IEEE trans on power delivery, vol. 28, July 2013*

[5] Jiacheng Wang, Dewei (David) Xu ,BinWu , and Zhenhan Luo "A Low-Cost Rectifier Topology for Variable-Speed High-Power PMSG Wind Turbines" *IEEE trans on powerelectronics, vol. 26, no. 8, Aug*

[6] Changliang Xia, QiangGeng, XinGu, Tingna Shi, and Zhanfeng Song. "Input–Output Feedback Linearization and Speed Control of a Surface PMSG With the Boost-Chopper Converter" *IEEE trans on indus electro, vol. 59, no. 9,September 2012*

[7] Changliang Xia, Zhiqiang Wang, Tingna Shi, and Zhanfeng Song "A Novel Cascaded Boost Chopper for the Wind EnergyConversion System Based on the PMSG" *IEEE trans on energy conve, vol. 28, no. 3, Sep013*

[8] Jiawei Chen, JieChen, and Chunying Gong, "New Overall Power Control Strategy for Variable-Speed Fixed-Pitch Wind Turbines Within the Whole Wind Velocity Range" *IEEE trans on indus electronics, vol. 60, no. 7, july 2013*

[9] AbdelouahedMesbahi*, AbdellahSaad, Mohamed Khafallah, Omar Bouattane, AbdelhadiRaihani "Boost Converter analysis to optimise variable speed PMSG Wind Generation System" in Proc. 18th IEEE Int. Conf.

[10] Jiacheng Wang, Dewei (David) Xu , BinWu , and Zhenhan Luo "A Low-Cost Rectifier Topology for Variable-Speed High Power PMSG Wind Turbines" *IEEE trans on power electronics, vol. 26, no. 8, August 2011*

[11] Akie Uehara, Alok Pratap , Tomonori Goya , Tomonobu Senjyu, Atsushi Yona , Naomitsu Urasaki , and Toshihisa Funabashi , "A Coordinated Control Method to Smooth Wind Power Fluctuations of a PMSG-Based WECS" *IEEE trans on energy conversion, vol. 26, no. 2, June 2011*

[12] Changliang Xia, Zhiqiang Wang, Tingna Shi, and Zhanfeng Song "A Novel Cascaded Boost Chopper for the Wind Energy Conversion System Based on the Permanent Magnet Synchronous Generator" *IEEE trans on energy conversion, vol. 28, no. 3, September 2013*