I J C T A, 9(5), 2016, pp. 2517-2525

Modeling of An Efficient Hybrid Wind and PV System for DC Bus Voltage Regulation

P. Suresh* and D. Kirubakaran**

ABSTRACT

With the help of fossil fuels the electrical power cannot be generated for longer period of time as they will vanish soon. But the renewable energy sources such as Solar energy and Wind energy are complementary by nature. Using these natural resources to produce power will reduce the power demand on the conventional power generation sector. If any one of the sources is used it will not give a fruitful result as they will not be available all the day. So fusion of two sources for generating power can meet the demand effectively. Efficient hybrid power system (EHPS) is to reduce the amount of power consumed from the conventional power generation to charge the storage reserves present in the system. The EHPS comprises of Photovoltaic array, wind turbine, Permanent Magnet Synchronous generator (PMSG), controller and converter. The efficiency of the EHPS depends on the MPPT controller, which makes the Photovoltaic (PV) and wind power generation system to operate at its maximum power. In PV system Perturb & Observe (P&O) algorithm is used as control logic for the Maximum Power Point Tracking (MPPT) controller and Hill Climb Search (HCS) algorithm is used as MPPT control logic for the Wind power system in order to maximizing the power generated. This paper presents a comparative analysis of MPPT controller built using P&O for PV system and HCS for Wind power system, with MPPT controller implemented using Fuzzy Logic control (FLC) in the both the renewable sources in the hybrid system. The performance of the different implementation of MPPT controllers in the hybrid system are investigated in this paper in MATLAB, Simulink. The EHPS with the FLC based MPPT has shown to have a better, faster control as compared with the other controllers

Keywords: Hybrid power system; MPPT; FLC; Renewable energy; P & O; Wind;

1. INTRODUCTION

Renewable energy sources (RES) such as Solar, Wind, Geothermal, Tidal, Hydro etc. are inexhaustible by nature. The RES have been found promising towards building sustainable and eco friendly power generation. Due to the limitation of conventional resources of fossil fuels, it has compelled the evolution of hybrid power system. Therefore, new ways to balance the load demand is by integrating RES into the system. Hybrid system enables the incorporation of renewable energy sources and transferals the dependency on fossil fuels, while sustaining the balance between supply and demand. The significant characteristic of hybrid power system includes, system reliability, operational efficiency [1]. The hybrid power system enables to overcome the limitations in wind and photovoltaic resources since their performance characteristics depends upon the unfavorable changes in environmental conditions. It is probable to endorse that hybrid stand-alone electricity generation systems are usually more reliable and less costly than systems that depend on a single source of energy [2]. On other hand one environmental condition can make one type of RES more profitable than other. For example, Photovoltaic (PV) system is ideal for locations having more solar illumination levels and Wind power system is ideal for locations having better wind flow conditions [3].

For RES especially the variable speed wind energy conversion systems, Permanent Magnet Synchronous generator (PMSG) is gaining popularity. PMSG have a loss-free rotor, and the power losses are confined to

* Research Scholar, Dept. of Electrical and Electronics Engineering, St. Peters university, Chennai, India, *Email: suresh.au95@gmail.com*

** Research Supervisor, Research Scholar, Dept. of Computer Science & Engineering, St. Peters university, Chennai, India, *Email: kirubad@gmail.com*

the stator winding and stator core. A gearless construction of wind conversion system represents an efficient and reliable wind power conversion system. A multi-pole PMSG connected to power converter can be used as direct driven PMSG in locations with low wind speed there by eliminating the gearbox which adds weight, losses, cost and maintenance [4]. In a PV system, a solar cell alone can produce power of 1 to 2 watt [5].]. The solar cells are connected in series and parallel to form a array of PV panel or PV diode module.

Thus a EHPS is combination of PV array, Maximum Power Point Tracking (MPPT converters, and Wind power system consisting of turbine, PMSG, AC to DC system and MPPT boost converter. The MPPT boost converter determines the efficiency and reliability of the system. The solar and wind power generation cannot operate at Maximum power point (MPP) without proper control logic in the MPPT boost converter as the power losses will occur in the system and even though in the presence of wind and solar energy, the output voltage of the hybrid system will not boost up to the required value [7]. The output voltage of the PV and Wind power generation are quite low as compared with the desired operating level. So, this output voltage is brought to desired operating value of 220V using Boost converter with MPPT controller at each source. The control logic of the MPPT controlled boost converter for the Wind power generation and PV based generation are selected on the basis of ease of implementation and robustness of the Hill Climb Search (HCS) and Perturb & Observe (P&O) algorithm respectively. However, the Fuzzy logic controllers (FLC) have an advantage due to its robustness and simple implementation.

$$Ipv = I_{PH} - I_{D1} - I_{D2} - I_{SH} \quad (1)$$

FLC is simple to design as it doesn't require knowledge of the model but requires the information regarding the operation of the model. Henceforth in this paper the FLC based MPPT will replace the other MPPT controllers in the EHPS. A comparative analysis of the performance of the EHPS with different MPPT control logics is investigated in this paper. The performance of the EHPS implemented using MPPT control logic (HCS and P&O) is compared with the EHPS whose MPPT control logic is implemented using FLC and examined. In the following section modeling of the hybrid power system with the MPPT controlled boost converter will be discussed in detail.

2. HYBRID POWER SYSTEM MODELLING

Hybrid power system consists of different stages like power generation stage, converter / controller stage and the distribution stage. In this section, the dynamic simulation model of PV and wind turbine with

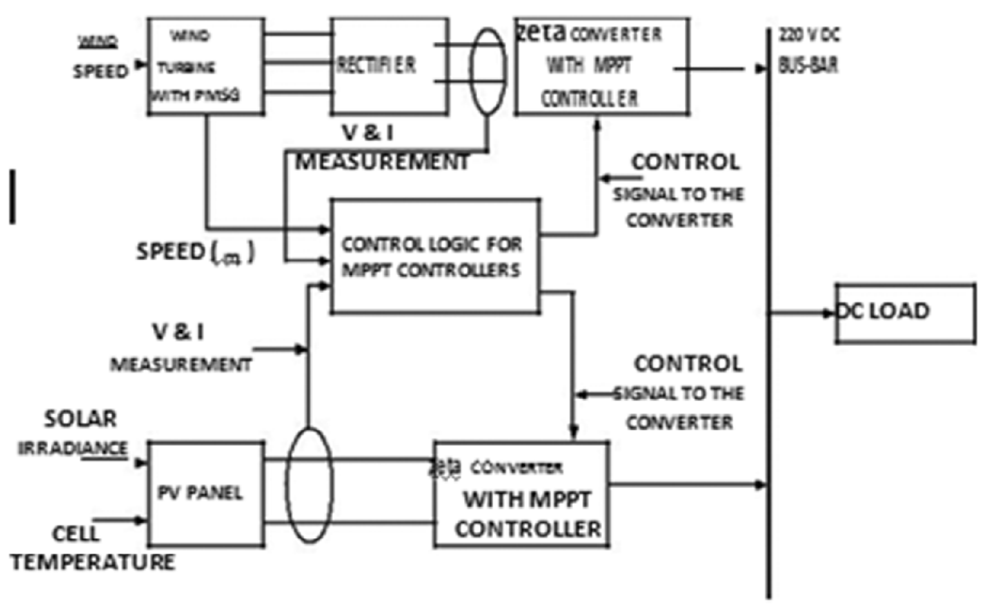

Figure 1: Block Diagram of Hybrid System

PMSG is described. The developed model consists of PV array, dc/dc boost converter to achieve the desired output voltage using P&O algorithm and wind turbine, PMSG, ac/dc diode rectifier, dc/dc boost converter with HCS MPPT controller. The block diagram of developed model is shown in Fig. 1.

2.1. Modeling of Photovoltaic modules in MATLAB, Simulink

General mathematical models of PV cell were proposed by various researchers [8-9]. A two-diode model of PV cell is selected whose equivalent circuit diagram is shown in Fig. 2. The mathematical model of two-diode PV cell performance is better as compared with the numerous models of single-diode model of PV cell and also under low illumination levels, two-diode model of PV cell exhibits better performance [10]. The two-diode PV cell shown in Fig. 2 consists of Photo-generated current (I_{ph}), two diodes with diode currents (I_{d1}, I_{d2}), Series Resistance (R_s), Shunt Resistance (R_p), output voltage (V) and PV current (I or I_{PV}). The relation between the output current and voltage can be obtained by using Kirchhoff's Current Law (KCL) [11]. where, I_{D1}, I_{D2} are the diode currents due to diffusion and are given by (2), (3).

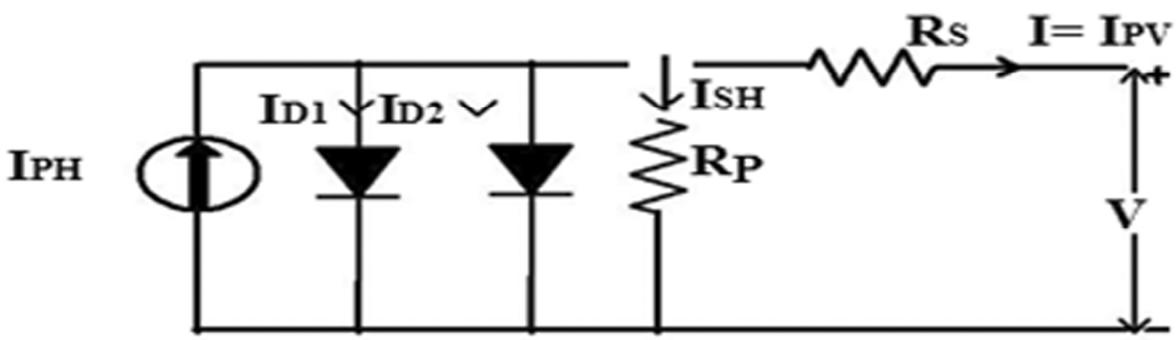

Figure 2: Equivalent circuit of two-diode model of PV cell

where, I_{s1}, I_{s2} are the reverse saturation currents of diode D_1, D_2, q is the charge on electron (1.602*10^{-19} C), V is the cell output voltage, N_1, N_2 are the quality factors of diode D_1, D_2, k is the Boltzmann constant (1.38*10^{-23}), and T is the junction temperature. The practical PV modules have the R_s and R_p as indicted in Fig. 2. These parameters are incorporated to build

$$I_{D1} - I_{s1} \frac{q.v}{N1.k.T} - 1 \quad (2)$$

$$I_{D2} - I_{s2} \frac{q.v}{N2.k.T} - 1 \quad (3)$$

the mathematical model of PV cell to replicate the practical PV cell. This is achieved by rewriting (2), (3) as (4), (5).

$$I_{D1} = I_{s1.} \frac{V + Rs.I}{N1.Vt} - 1 \quad (4)$$

$$I_{D2} = I_{s2.} \frac{V + Rs.I}{N2.Vt} - 1 \quad (5)$$

Where $V_t = \frac{Ns.k.T}{Rp}$ is the thermal voltage module and Ns is the number of series cells and current in shunt resistance is given by

$$I_{SH} = \frac{V + (Rs.Ipv)}{Rp} \quad (6)$$

Substituting (4), (5), (6) in (1) we get the relation between the voltage and current of the two diode equivalent of the PV cell as (7). Equation based implementation of the two-diode model is developed in MATLAB, Simulink as shown in Fig. 3 [12] in order to study the non-linear characteristics of PV Panel.

The equivalent circuit parameters are extracted from the manufacturer's data sheet. Table I shows the electrical parameters of the PV panel whose data is taken from the manufacturer data sheet [13].

In order to plot the current–voltage (I-V) and power–voltage (P-V) characteristics of two-diode model of PV panel a simple circuit is implemented in MATLAB, Simulink as shown in Fig. 4. The PV panel is simulated for different solar irradiance levels with the cell operating temperature kept constant at 25^{0}C.

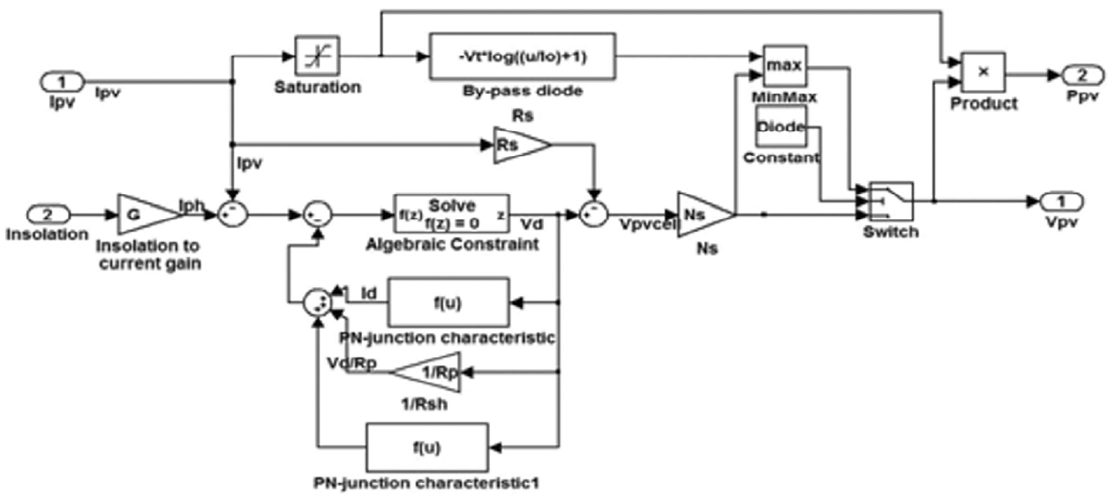

Figure 3: Sub-system implementation of two-diode model of PV Panel

Table 1
Electrical Parameters Of Sharp Nu-e245 (J5) From Data Sheet

Electrical Parameters	
Maximum Power (Pmax)	245 W
Voltage at Pmax (Vmpp)	30.5 V
Current at Pmax (Impp)	8.04 A
Short-circuit Current (Isc)	8.73 A
Open-circuit voltage (Voc)	37.5 V

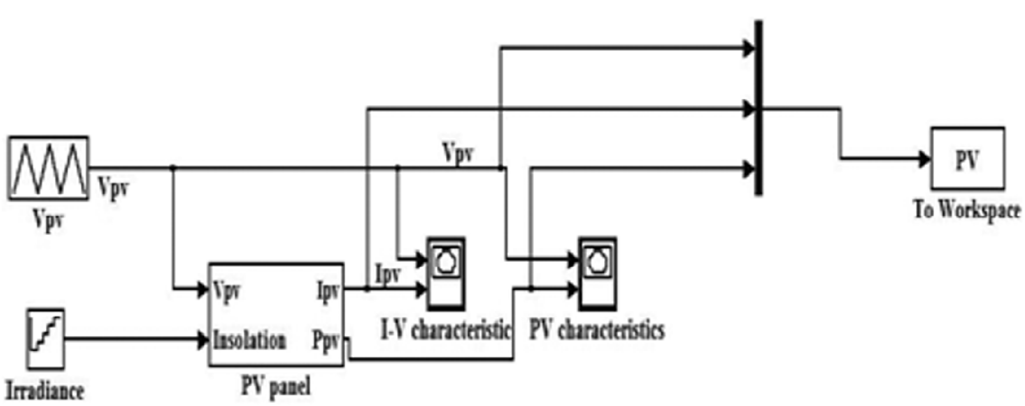

Figure 4: Simulink implementation of Two-diode model of PV panel

Fig. 5 shows the simulated I-V and P-V characteristics of two-diode model of PV panel developed in MATLAB, Simulink

In order to validate the simulated results a comparative analysis of electrical parameters obtained from the simulation of the two-diode model of PV panel under standard test conditions (STC) i.e. Solar irradiance of 1000 W/m^2, cell operating temperature at 25^{0}C are tabulated with the electrical parameters of manufacturer data sheet at STC as shown in Table II. We can analyze that the Simulink model of PV panel replicates the electrical behavior of practical model of PV panel in manufacture data sheet.

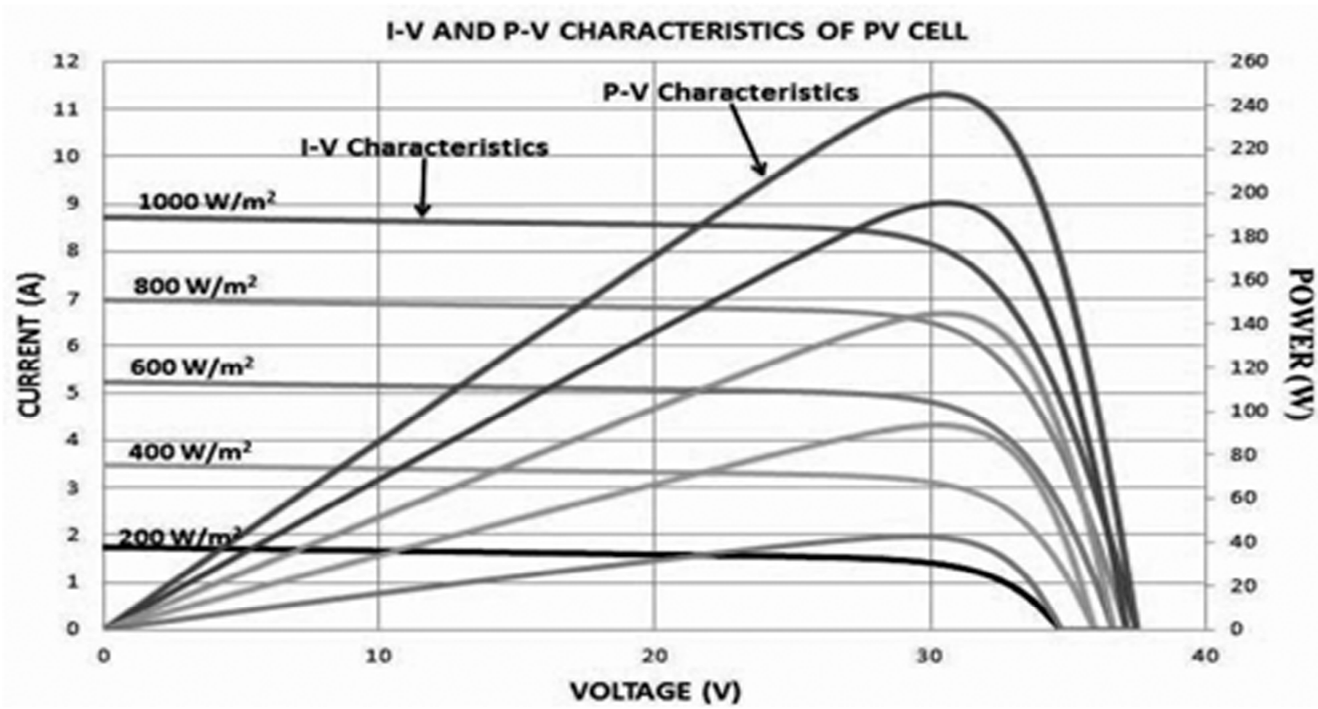

Figure 5: Simulated I-V characteristics of two-diode model of PV panel

Table 3
Electrical parameters of PV panel models at STC with manufacturer data sheet

Electrical Parameters	*Manufacturer Data-sheet*	*Two-diode model of PV Panel in Simulink*
Voc	37.5 V	37.5 V
Isc	8.73 A	8.729 A
Pmax	245 W	245.06 W
Vmpp	30.5 V	30.75 V
Impp	8.04 A	7.97 A

2.2. Modeling of Wind Turbine and PMSG in MATLAB, Simulink

Several studies have been reported regarding wind turbine and PMSG in the literature review [14-16]. The output power of the wind turbine is given by (8)

$$P_0 = \frac{1}{2}\rho A V^3 wind C_p \tag{6}$$

The power co-efficient of the turbine C_p is given by (7) where the values of the coefficients $C_1 - C_6$ and x depend on turbine type, is defined as the angle between the plane of rotation and the blade cross section chord, and is defined by (7)

$$\frac{1}{\beta}=\frac{1}{\theta+0.02}-\frac{0.035}{1+\theta 3} \tag{7}$$

where P_o is the mechanical power output of the turbine, C_p is the power coefficient of the turbine, is the tip speed ratio of the rotor blades, is the blade pitch angle, is the air density, A is the area of swept of turbine, V_{wind} is the wind speed. The power co-efficient of the turbine C_p is given by (9) the equation base modeling of PMSG in MATLAB simulink is implemented using the (8)-(10) the parameters os the PMSG under consideration are from [17].

3. MPPT CONTROL LOGIC IMPLEMENTATION

Fig. 6 shows the MPPT controlled boost converter common for PV and Wind based generation. For PV based generation the inputs to the controller are voltage and current samples, whereas for Wind power generation the inputs to the control are voltage, current and speed of the PMSG. A P&O algorithm is used as MPPT control logic for PV system, investigated in [18]. The voltage and current samples from the PV panel are given as the input to the MPPT control logic. Using this input the control logic which computes the duty cycle of the power electronic switch in the boost converter is controlled. Thus the MPP of the PV generation is continuously tracked by the MPPT control logic and the output of PV panel is boosted up to the desired value.

The HCS algorithm for MPPT control logic implementation for wind power generation system is shown in Fig. 7.

The inputs to the controller are voltage, current and speed of PMSG. Using the speed and voltage samples the reference current is calculated. It is compared with the current measured and the error is utilized to compute the duty cycle of the power electronic switch in boost converter which controls the operation of wind power generation at MPP.

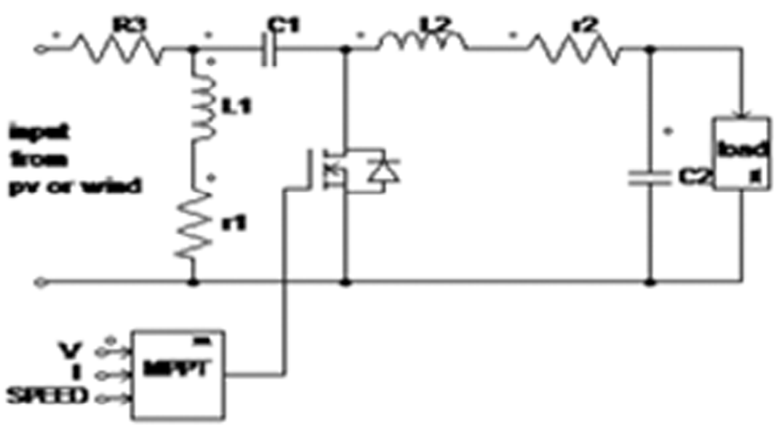

Figure 6: MPPT controlled ZETA converter for PV and Wind system

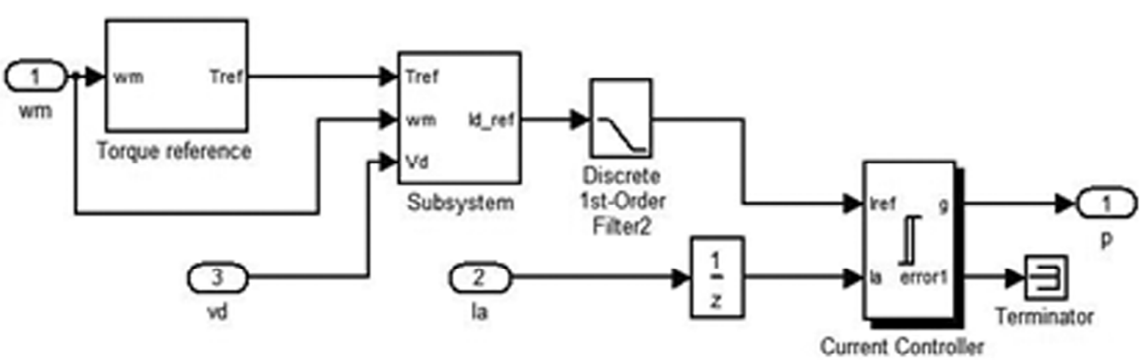

Figure 7: Sub-system implementation of MPPT control for Wind Power system

In the Fuzzy Implementation of P&O algorithm, a mamdani FLC is selected and the inputs of the FLC are error and change in error. They are computed by considering PV input current and voltage, and duty cycle has been calculated as output [19]. Fig. 8 indicated the sub-system implementation of P&O algorithm using FLC for MPPT control of PV based generation system. The rules for the mamdani FLC P&O implementation is tabulated as shown in Table III.

Table 4
Rule Base For Flc P&O Implementation

E	CE						
	NB	NM	NS	ZE	PS	PM	PB
NB	ZE	ZE	ZE	NB	NB	NB	NB
NM	ZE	ZE	ZE	NM	NM	NM	NM
NS	NS	ZE	ZE	NS	NS	NS	NS
ZE	NM	NS	ZE	ZE	ZE	PS	PM
PS	PM	PS	PS	PS	ZE	ZE	ZE
PM	PM	PM	PM	ZE	ZE	ZE	ZE
PB	PB	PB	PB	ZE	ZE	ZE	ZE

A Sub-system implementation of HCS algorithm using FLC as MPPT control for wind power generation system is shown in Fig.9.The Rule base for FLC implementation of HCS algorithm is tabulated as shown in Table IV. The generated duty cycle is to control the power electronic switch in the boost converter which tracks the MPP [20].

4. SIMULATED RESULTS AND DISCUSSIONS

The EHPS as shown in Fig. 1 is implemented in the MATLAB Simulink to feed a DC load of 220V, 3.1 KW with a PV based generation of 400W combined with a Wind based generation of 3 KW. The simulated results of EHPS with solar irradiation of 1000 W/m^2 and wind speed of 12 m/s are shown below. The EHPS is implemented with the MPPT controller build using HCS and P&O algorithm for wind and PV based generation respectively. These control logics are replaced by FLC and the comparative analysis of the

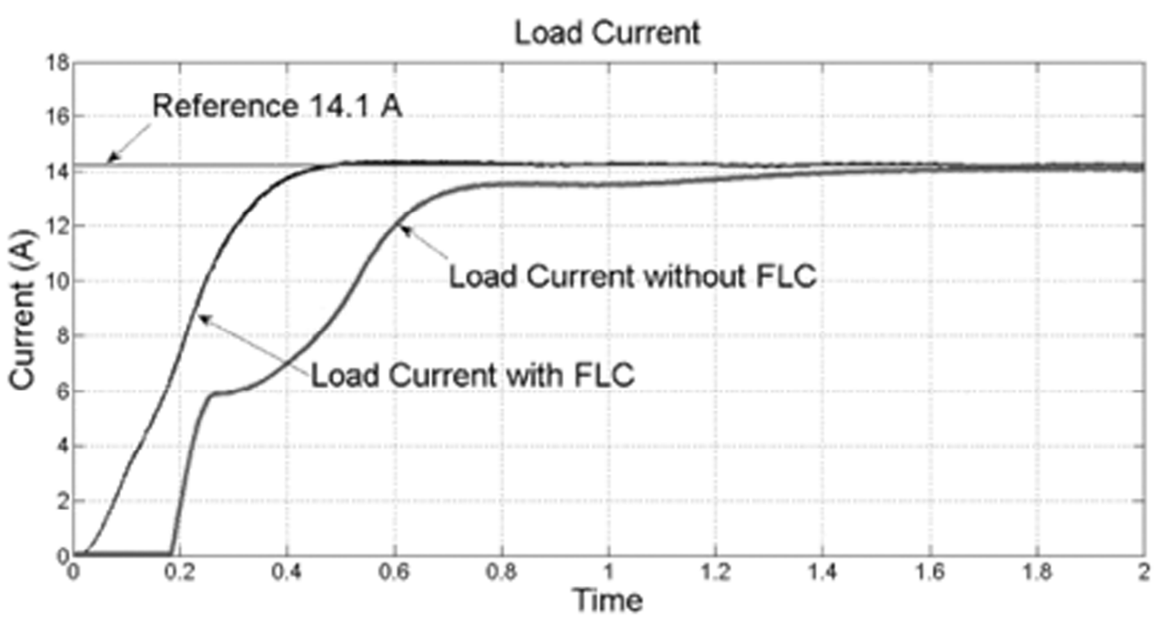

Figure 8: Simulated result of EHPS

simulated results with and without FLC are shown in Fig. 10-12.Fig.. It is seen that the load voltage profile improves when MPPT controller is implemented using FLC.

FLC boost up the load voltage to the desired value of 220V in 0.58s, whereas the system without FLC reaches the desired output voltage at 1.7s. From the Fig. 11 it can be observed that the system with FLC implemented MPPT control brings the load current to the desired value of 14.1A in 0.58s, whereas the system without FLC control reaches the desired output current at 1.7s.

In Fig. 10 it can be analyzed that the system with MPPT control using FLC brings the load power to the desired value of 3.1 KW in 0.58s, whereas the system without FLC reaches the desired output current at 1.7s. The load power profile has a significant improvement with FLC as compared with the other controller.

It can be clearly observed that the MPPT controller plays a key role in the hybrid power system. In order to reduce the losses and to improve the efficiency and performance of the hybrid system a faster MPPT controller is required. The hybrid system using MPPT controller with FLC serves the purpose.

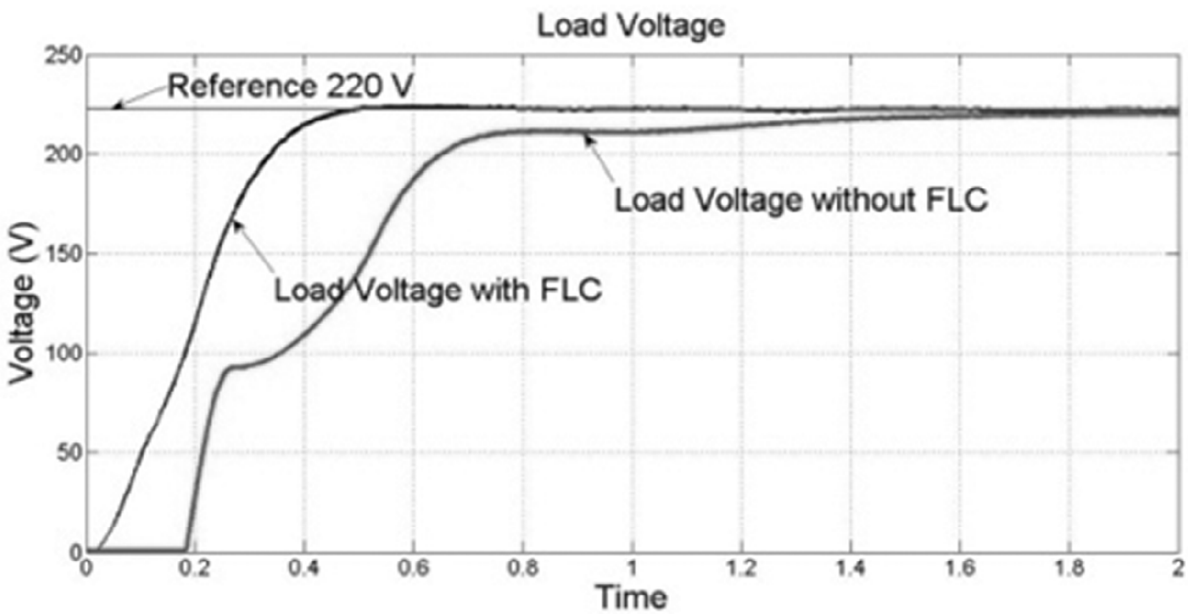

Figure 9: Simulated result of EHPS

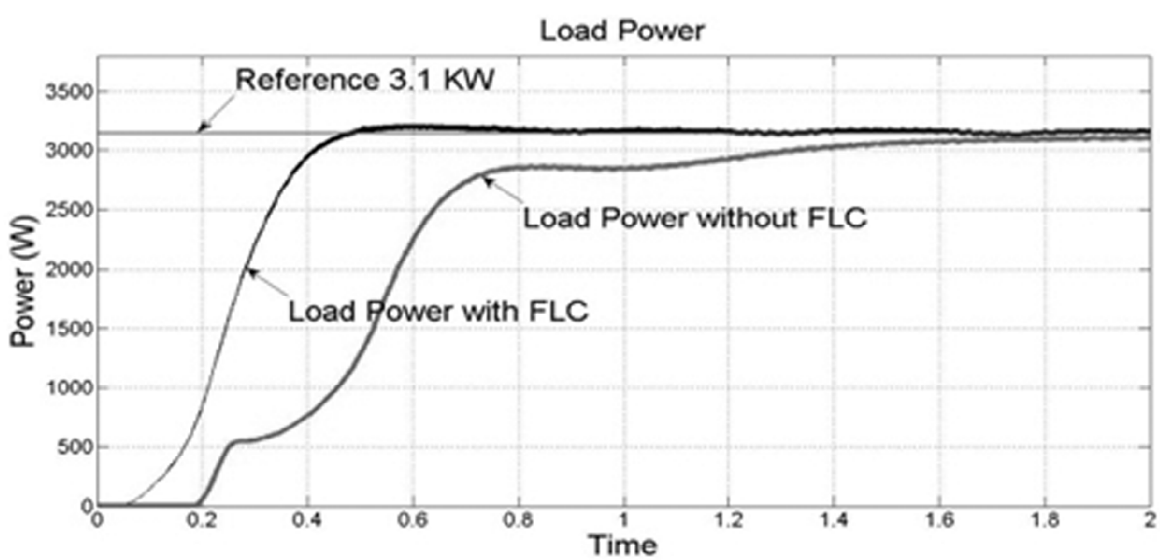

Figure 10: Simulated result of load power of EHPS

5. CONCLUSION

In this paper a comparative analysis of MPPT controller design in a EHPS is done. The MPPT controller plays an vital role in the hybrid system for improving the efficiency and reliability of the system. The losses are reduced by using MPPT controller. Here PV and Wind are operated at MPP in order to get a maximum efficiency. The MPPT controller with FLC has a much better performance as compared to the MPPT build using HCS and P & O methods.

The EHPS reaches the desired output voltage of 220 V, 3.1 KW in 0.58s with the MPPT controlled Zeta converter with FLC as compared with the 1.7s with the other implemented MPPT controllers. Here the system efficiency, reliability and performance of the system got improved by using the MPPT controller with FLC. In future it will be tested with real time data and comparing it with real-world scenario.

REFERENCES

[1] Natsheh, E.M.; Albarbar, A.; Yazdani, J., "Modeling and control for smart grid integration of solar/wind energy conversion system," 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies (ISGT Europe), pp. 1-8, 5-7 Dec. 2011.

[2] Bagen; Billinton, R., "Evaluation of Different Operating Strategies in Small Stand-Alone Power Systems," IEEE Transactions on Energy Conversion, vol. 20, no. 3, pp. 654-660, Sept. 2005.

[3] S. M. Shaahid and M. A. Elhadidy, "Opportunities for utilization of stand-alone hybrid (photovoltaic + diesel + battery) power systems in hot climates," Renewable Energy, vol. 28, no. 11, pp. 1741-1753, 2003.

[4] Goel, P.K.; Singh, B.; Murthy, S.S.; Kishore, N., "Autonomous hybrid system using PMSGs for hydro and wind power generation," 35th Annual Conference of IEEE Industrial Electronics, 2009. IECON '09, pp. 255, 260, 3-5 Nov. 2009.

[5] Salam, Z.; Ishaque, K.; Taheri, H., "An improved two-diode photovoltaic (PV) model for PV system," 2010 Joint International Conference on Power Electronics, Drives and Energy Systems (PEDES) & 2010 Power India, pp. 1,5, 20-23 Dec. 2010.

[6] Yuncong Jiang; Qahouq, J.A.A.; Orabi, M., "AC PV solar system distributed architecture with maximum power point tracking," IEEE 34th International Telecommunications Energy Conference (INTELEC), pp. 1-5, Sept. 30 2012-Oct. 4 2012.

[7] Yuncong Jiang; Qahouq, J.A.A.; Batarseh, I., "Improved solar PV cell Matlab simulation model and comparison," Proceedings of 2010 IEEE International Symposium on Circuits and Systems (ISCAS), pp. 2770-2773, May 30 2010-June 2 2010.

[8] Mahmoud, Y.A.; Weidong Xiao; Zeineldin, H.H., "A Parameterization Approach for Enhancing PV Model Accuracy," IEEE Transactions on Industrial Electronics, vol. 60, no. 12, pp. 5708-5716, Dec. 2013.

[9] Nikhil, P.G.; Subhakar, D., "An improved simulation model for photovoltaic cell," International Conference on Electrical and Control Engineering (ICECE), pp. 1978-1982, 16-18 Sept. 2011.

[10] Bal, S.; Anurag, A; Babu, B.C., "Comparative analysis of mathematical modeling of Photo-Voltaic (PV) array," 2012 Annual IEEE India Conference (INDICON), pp. 269-274, 7-9 Dec. 2012.

[11] A. V. Pavan Kumar; Alivelu M Parimi; K. Uma Rao, "A Comparative Study of Model Based Design of PV cell in MATLAB / Simulink / Simscape" International Journal of Advanced Trends in Computer Science and Engineering, Vol. 3, No. 1, pp. 37-42 (2014).