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Comparative Analysis of Output Power of PV/Wind Hybrid Boost Converter System with PI, PI with Fuzzy, FLC and ANFIS based MPPT Techniques

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ABSTRACT: Solar PV gives nonlinear I-V and P-V characteristics. As a result, it is difficult to transfer the maximum power from source to load. In order to overcome this drawback, in this article a soft computing based Maximum Power Point Tracking (MPPT) Techniques are used to track MPP. Here PV and Wind energy conversion systems are connected to common DC-bus. The PV and Wind power systems are interfaced with unidirectional DC-DC converter. The P&O along with PI, Fuzzy, PI with Fuzzy and ANFIS based MPPT controllers are employed to the PV/Wind Hybrid system to extract the peak power of the system. The advantages of soft computing MPPT techniques are easy design and high accuracy. A 500W PV system and a 500 W Permanent Magnet Synchronous Generator (PMSG) based Wind Energy Conversion System (WECS) are implemented for its simplicity and high efficiency. DC load of 700W and Battery Energy Storage System (BESS) is also connected to the DC Bus. The PV/Wind and hybrid power is compared with battery power at different irradiation and wind speed conditions. The BESS is charged and discharged through a bidirectional converter in order to support the standalone hybrid system in spite of variable power generation.

Keywords: ANFIS controller, bidirectional converter, fuzzy logic controller, PV system, WECS.

I. INTRODUCTION

Now a days all the countries are focusing on renewable energy resources instead of nonrenewable energy sources to reduce the environmental pollution caused by fossil fuel burning [1]. The PV and wind power generations are the best choice for hybrid system combination to form smart standalone grid [2]. The reliability of solar and wind energy is highly depending upon the climatic changes and unpredictable in nature. Thus, it causes serious concern of grid integration. To overcome the issue, need of hybridization of renewable sources and energy storage is viable option to extract quality power from renewable based generation [3, 4].
The hybrid renewable energy power generation consist of variable renewable energy and storage elements combination based on the availability and need [5]. The hybrid energy system can be of standalone or grid connected system. The standalone system is generally termed as the micro-grid which meets the demand of local loads which is equipped with the power electronics interface to ensure proper load sharing [6]. The standalone system requires a high rating and sufficient energy storage device to cope with the variable power generated by the renewable sources. The grid connected system of the hybrid renewable system is the extension of the micro-grid. The ratings of the energy storage device can be minimized since the grid provide a sufficient backup to low power generation. Since, the renewable based generation is highly non-linear in nature; the grid compatibility is the major concern. The regulation such as voltage, frequency and harmonics must strictly adhere to the policy to ensure better utilization of source and protect the loads connected to the system. Thus, an efficient control strategy is required to integrate the renewable sources to the grid [7, 8].
In this paper, a hybrid PV-Wind based renewable energy is considered as the source. The output of the PV and wind system is connected to the boost converter in order to maximize the voltage to match the DC-bus voltage. The hybrid system is connected to the common DC-bus system which also consists of the battery storage system connected through the Bi-directional DC-DC converter to provide both charging and discharging operation. The common DC bus system (360V) is utilized in this article in order to integrate the PV and wind source along with energy storage system. The boost converter of the system is controlled using the MPPT methodologies. The main objective of the paper is to generate the maximum power output by the operation of Boost converter by soft switching controllers along with the MPPT Techniques. Ensure the proper charging of the battery during excess power generation and to discharge during low power production. The constant DC link voltage for the DC bus system is also an important parameter of the proposed topology. The I-V and P-V curves of PV cell and the power verses speed characteristics of wind turbine are shown in Fig. 1 and 2 respectively.

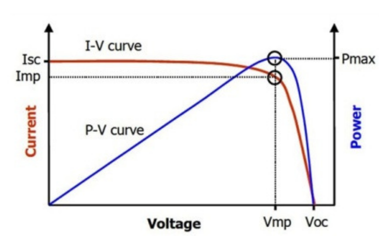

Fig. 1. I-V & P-V Characteristics of PV Cell with variable irradiation.

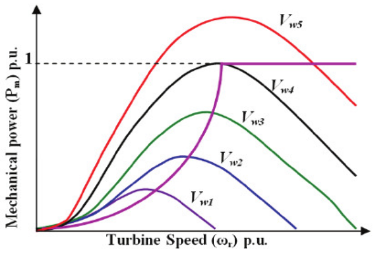

Fig. 2. Wind turbine power characteristics at different speeds.

II. HYBRID SYSTEM OF PV AND WECS

The proposed hybrid system consist of 500W PV and 500W wind power generation systems which is shown in Fig. 3. In addition, a 1kW hybrid power system is considered for the analysis of the system. The design parameters and specifications are listed in Table 1. The battery parameters used in this study are also shown in Table.1.

The availability of both solar and wind energy sources is alternative to each other and to check the feasibility of the developed converter operation in both individual and simultaneous modes, the availability of the renewable energy sources are considered as follows. For the period 0 to 0.75 sec, the availability of wind source is 8 m/s and the PV irradiation are 600 W/m^2. Similarly, for period of 0.75 to 1.5 sec and 1.5 to 2.25 sec are wind velocity 10m/s with PV irradiation of 800 W/m^2 and wind velocity 12 m/s with 1000 W/m^2 respectively as shown in Fig.4 and 5.

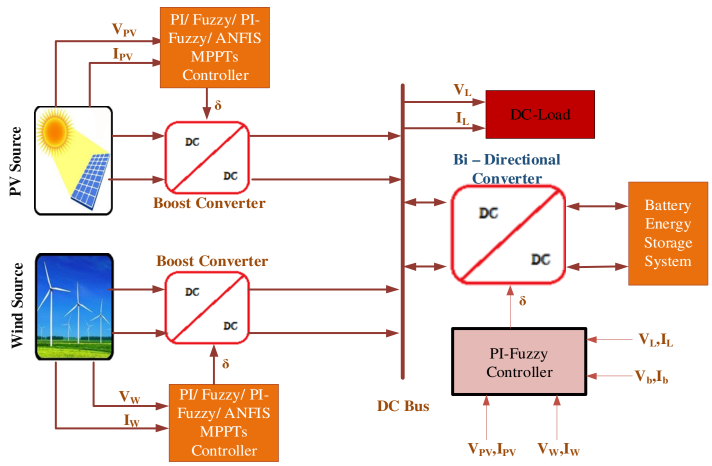

Fig. 3. Block diagram of proposed hybrid system.

Table 1: Hybrid system parameters.

Solar system		Wind System		Battery	
Variable	Value	Variable	Value	Variable	Value
VMP	48 V	Speed	12m/s	Type	Li-Ion
IMP	10.4A	Motor	500W	Voltage	48 V
Ns	8	No.of poles	5	—	—
Np	5	Inertia	11.9mkg/m2	—	—
Rp	360 Ω	Stator resistance	0.425Ω	Rated capacity	6.5 AH
Rs	0.18Ω	D-axis inductance	8.2mH	SOC at charge	30%
Cells in module	60	Q-axis inductance	8.2mH	SOC at discharge	80%

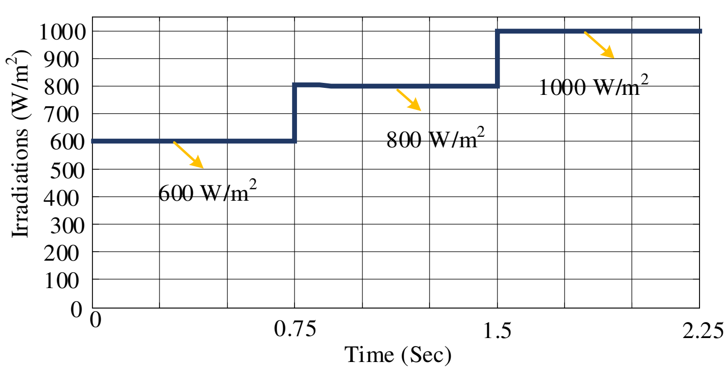

Fig. 4. PV Irradiance (W/m^2).

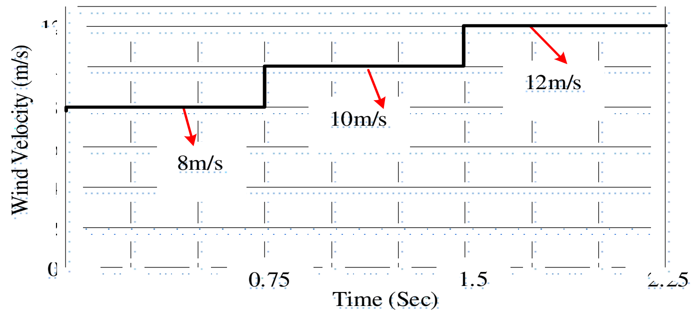

Fig. 5. Wind Speed (m/s).

III. APPLICATION OF MPPT TECHNIQUES FOR HYBRID PV AND WIND SYSTEM

The Perturb & Observe (P&O) in PV System and Tip Speed Ratio control in WECS are used in hybrid System along with PI Controller which produces duty cycle for DC-DC boost converter. The results are obtained when we replace normal PI controller with Fuzzy, PI Fuzzy and ANFIS Controllers.

A. PI based MPPT Technique

The proposed topology consists of PI based MPPT controller strategy for both PV and Wind generation. Fig. 6 shows the PI controller based MPPT for PV System and Fig. 7 shows PI based MPPT for wind turbine. In PV system, the voltage corresponding to maximum power is maintained where as in wind energy system the turbine is rotated at optimum angular speed to extract the maximum power in hybrid system [9]. The DC voltage and power obtained using PI based MPPT strategy employed for hybrid system are shown in Fig. 8 and 9. In PV system P&O algorithm is employed to obtain the V_{ref} and tip speed ratio control method is used to obtain the I_{DCref} in MPPT of wind turbine.

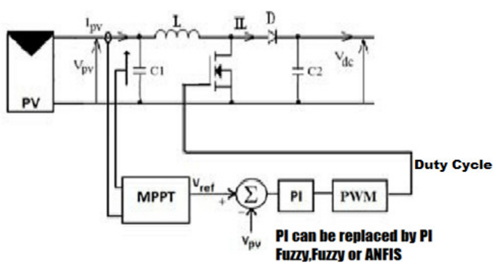

Fig. 6. PI based MPPT for PV System.

The output of PI Controller is derived as,

$$u(t) = K_p.V_i(t) + K_i \int V_i(t)d(t) \qquad (1)$$

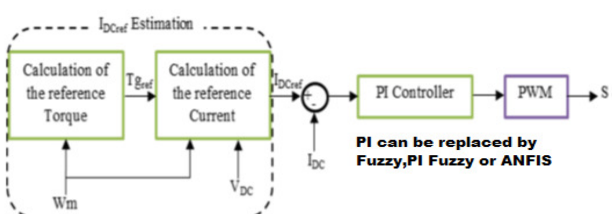

Fig. 7. PI based MPPT technique for WECS.

In this work, the PI controller is used in a current loop, to control the duty cycle of the switch S (Fig. 7) and to extract maximum power from the variable speed wind turbine. The error between the reference current IDC ref and measured current IDC is used to vary the duty cycle of the switch S to regulate the output of the Boost converter and the generator torque through a PI controller. The PI controller gains are calculated from the transfer function of the boost converter.

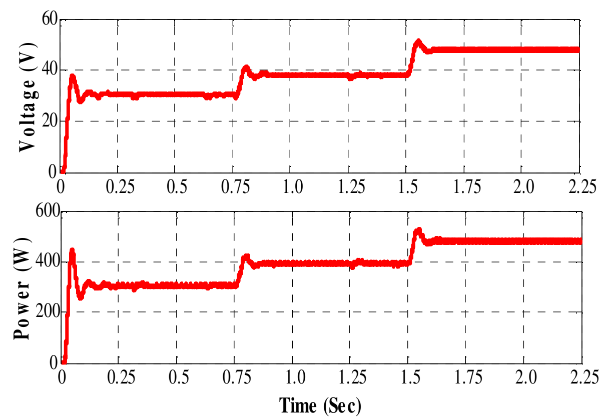

Fig. 8. PV System Output Voltage, Power.

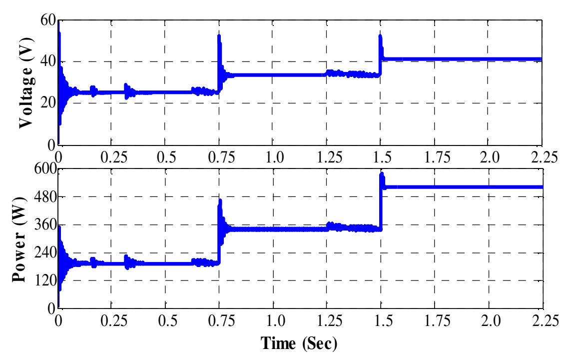

Fig. 9. Wind System Output Voltage and Power.

B. FLC based MPPT for PV, Wind and Hybrid System

The MPPT tracks the new modified MPP in its corresponding curve whenever temperature and/or insolation variation occurs. The MPPT is used for extracting the maximum power from the solar PV in order to transfer to the load. A DC-DC converter acts as an interface between the load and the module [10].

The MPPT is changing the duty cycle to keep the transfer power from the solar PV module to the load. Maximum power point tracking system uses dc to dc converter to compensate the output voltage of the solar panel to keep the voltage at the value which maximizes the output power.

The FLC examines the output PV power at each sample (time n), and determines the change in power relative to voltage (dp/dv). If this value is greater than zero the controller change the duty cycle of the pulse width modulation (PWM) to increase the voltage until the power is maximum or the value (dp/dv) =0, if this value less than zero the controller changes the duty cycle of the PWM to decrease the voltage until the power is maximum as shown in Fig. 1. The FLC has two inputs which are: error and the change in error, and one output (duty ratio) (see in Fig. 10, 11 and 12) feeding to the pulse width modulation to control the DC-DC converter. The two FLC input variables error E and change of error ∆E at sampled times n defined by:

$$E(n) = \frac{P(n)-P(n-1)}{V(n)-V(n-1)} \quad (2)$$

$$\Delta E(n)=E(n)-E(n-1) \quad (3)$$

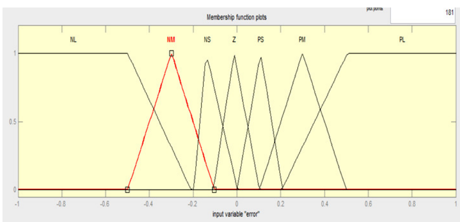

Fig. 10. Input-1: error E.

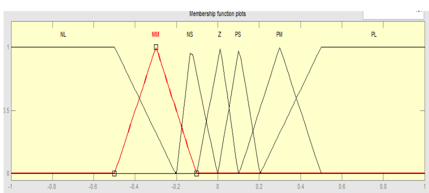

Fig. 11. Input-2: change in the error (∆E).

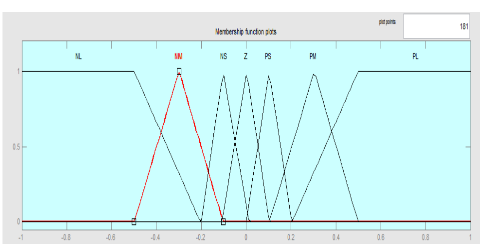

Fig. 12. Output membership function (duty ratio) of FLC.

Table 2: Rule Base for Output Duty Ratio.

E / ∆E	NB	NS	ZE	PS	PM	NB	PB
NB	PB	PB	ZE	NB	NB	PB	NB
NS	PM	PM	ZE	NM	NM	PB	NB
ZE	PM	PS	ZE	NS	NM	NB	NB
PS	ZE	ZE	ZE	ZE	ZE	ZE	ZE
PM	NM	NS	ZE	PS	PM	NB	PB
NB	NM	NM	ZE	PM	PM	NB	PB
PB	NB	NB	ZE	PB	PB	NB	PB

The fuzzy values are: NB (negative big), NS (negative small), ZE (zero), PS (positive small) and PB (positive big) (see in Table 2). The output fuzzy sets are then identified using a fuzzy implication method, which is a max-min method. The trapezoidal and triangular membership functions of the FLC are used. The centroid (center of gravity) defuzzification method was also implemented. Depending on the wind speed, the MPPT controller adjusts the power transferred, bringing the turbine operating point so onto the maximum power curve as shown in Fig. 2. The converter control the system did not allow obtaining maximum power over the entire range of wind speeds, but only from 3 to 6 m/s, due to current limitations introduced by the motor inverter which emulated the wind turbine. A FLC regulator is used to implement the MPPT function, which provides the reference power for the boost converter, based on the wind speed measurements (vp.u) and the turbine generator speed (ωp.u). The proposed FLC is shown in Fig. 13. Its input variables are: change in mechanical power (∆P), change in rotating speed (∆ω). The output variable is the change in dc reference current (∆I*).

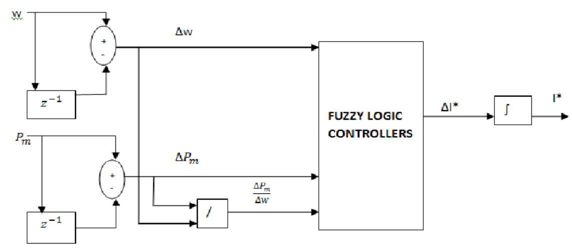

Fig. 13. MPPT of Wind using FLC.

The MPPT – FLC has to extract the maximum available power from the wind by increasing or decreasing the reference rectified PMSG current. Changing the PMSG current changes the PMSG torque, which will modify the rotating speed. In the steady state, if the operating point is on the left side of MPP on the curve shown in Fig. 2, to attain the optimum power operating point, the controller has to decrease the reference current and, as a result, the rotating speed increases. In this way the operating point will shift to the right to a higher power point. In the other case, when the operating point is on the right side of the maximum power point, the reference current needs to be raised. In this way the speed will fall and the operating point will shift to the left, to an upper power point. These input and output variables are normalized according to the system behavior in order that the FLC block to be universal for other wind turbine systems. The FLC algorithm is characterized by if then rules similar as shown for PV system.

C. PI based Fuzzy MPPT in PV and Wind Hybrid System

Here the Proportional gain (k_p) and integral(k_i) constants of PI controller are estimated by using Fuzzy controller with the rule base [11]. The voltage error (E) and change in voltage error(∆E) are applied as inputs for PV System where as current error and change in current error are taken as inputs in Wind system as shown in Table 3. The gain and integral constants are outputs of PI fuzzy Controller. The membership function of inputs and outputs of PI fuzzy controller are shown in Figs. 14-17.

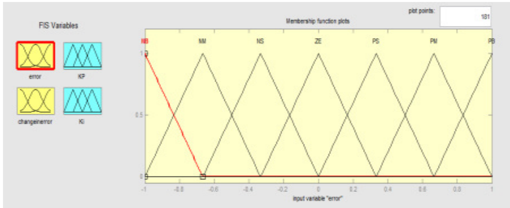

Fig. 14. Input 1: Voltage error (E).

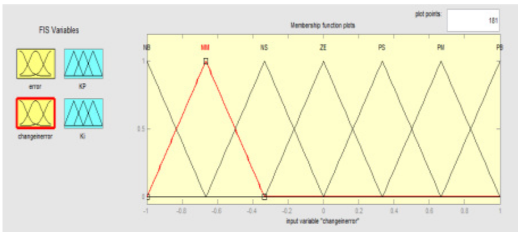

Fig. 15. Input 2: change in the Voltage error (ΔE).

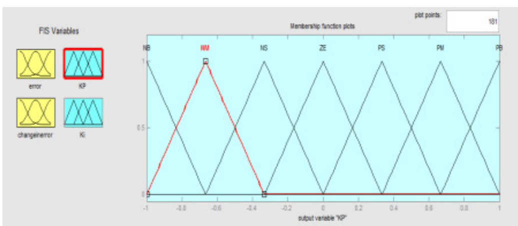

Fig. 16. Output ki.

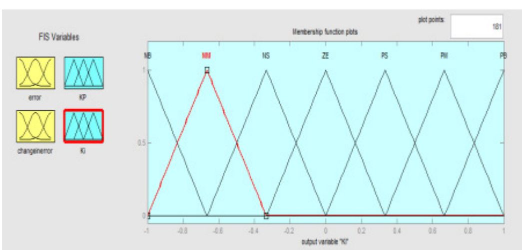

Fig. 17. Output kp.

The block diagram of PI Fuzzy controller for Wind System is shown in Fig. 18. In this paper, the PI Fuzzy controller used to generate the duty cycle to control the power electronic switch in the boost converter in order to achieve the maximum power point. The inputs to the PI Fuzzy are error E(n) and change in error ΔE(n) as given in Equations (4) and (5) respectively. Output is the duty cycle D that is fed to the switch of the DC-DC boost converter. The membership functions are shown in Fig.19.

$$E(n) = I_{DCref} - I_{DC} \quad (4)$$

$$\Delta E(n) = E(n) - E(n-1) \quad (5)$$

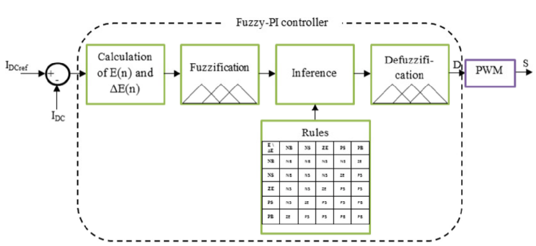

Fig.18. Operation of PI Fuzzy MPPT Controller for WECS

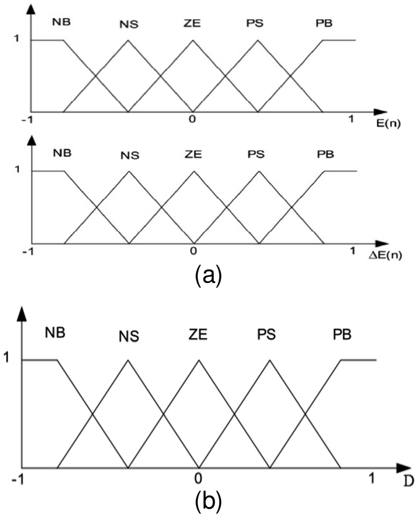

Fig. 19 (a) Membership functions for current error E(n), change in the current error ΔE(n); (b) Duty Cycle.

Table 3: Fuzzy control rule-base for duty Cycle.

E/ΔE	***NB***	***NS***	***ZE***	***PS***	***PB***
NB	NB	NB	NS	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PB
PB	ZE	PS	PS	PB	PB

D. ANFIS MPPT for PV and Wind Hybrid System

The fuzzy logic controller in the basic form has some limitations such as large time consumption in making decisions, a bit difficult to implement in hardware and there is a compromise between agreeability and accuracy [12]. To overcome this ANFIS controller is used. The wind generator speed and actual speed are the input data to the ANFIS and the output of the ANFIS controller is the duty cycle for the boost converter switch in order to track appropriately. In PV system Irradiance and Temperature are taken as inputs to ANFIS Controller where as in Wind system ref speed and actual speed of generator are taken as inputs. In this work, the PI controller is used in a current loop, to control the duty cycle of the switch S (Fig. 20, 21) and to extract maximum power from the variable speed wind turbine.

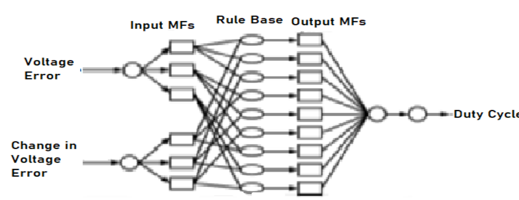

Fig. 20. Structure of ANFIS for PV system.

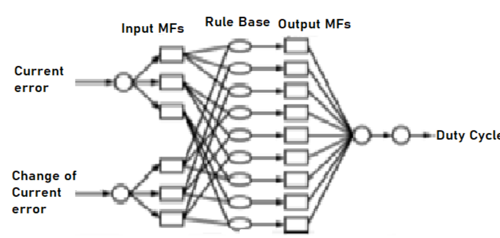

Fig. 21. Structure of ANFIS for Wind System.

IV. OPERATION OF DC-DC BIDIRECTIONAL CONVERTER BETWEEN DC BUS AND BATTERY STORAGE SYSTEM

Throughout the entire system the DC-DC Bi-directional converter is operated with PI Fuzzy controller both for charging and Discharging of Battery Storage system based on Power difference (∑PG-PD) and state of charge (SOC) of Battery. The inputs to Fuzzy PI Controller are Power difference and SOC of Battery and the output is Duty cycle of DC-DC Bidirectional Converter. The Fuzzy PI controller giving firing pulses is shown in Fig. 22. Battery is charged when Hybrid system output is more than Load. And also, the battery is discharged into DC Bus when total generation is less than load. It backs up the hybrid system two hours without PV and Wind generation. In order to reduce the complexity in switching non-isolated Bidirectional converter is employed in present paper.

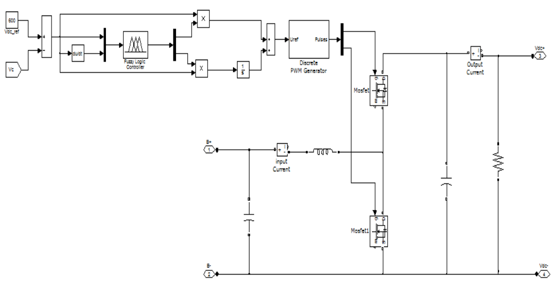

Fig. 22. Operation of DC-DC Bi-directional Converter (Charging & Discharging) with Fuzzy.

V. SIMULATION RESULTS

The overall DC link Power of the hybrid system with PI and PI Fuzzy are shown in Fig. 23. The DC link voltage of 380 V is constant for the variable irradiance and wind velocity. The rated power of 1 kW is achieved by combining the both sources.

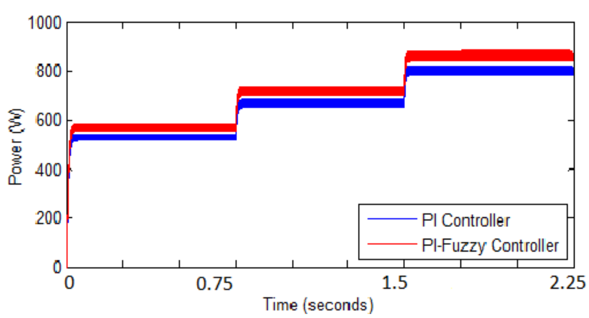

Fig. 23. Total Generation of hybrid system with PI & PI-fuzzy (DC Link Power).

The Fig. 23 shows the DC link power of hybrid system under different solar irradiation and wind speed data, the PI –Fuzzy based MPPT algorithm gives the at most efficiency of hybrid system when compare to the conventional PI MPPT controller. The battery source is connected to the DC bus using Bi-directional DC/DC converter. The battery storage system is charged when the load demand is low and there is excess power whereas, the battery supports the DC bus system when the load demand is high. The load demand of 700W is considered for this study.

Now the Boost converter is controlled by Fuzzy Logic Controller (FLC) and Adaptive Neuro Fuzzy Inference System (ANFIS) controller for the best results than PI controller. The simulation results are shown by Figs. 24 and 25 respectively.

The Fig. 24 shows the DC link power of hybrid system under different solar irradiation and wind speed data, the ANFIS based MPPT algorithm gives the at most efficiency of hybrid system when compare to the conventional FLC MPPT controller. The battery source is connected to the DC bus using bi-directional DC/DC converter. The battery is charged when the load demand is low and there is excess power whereas, the battery supports the DC bus system when the load demand is high. The load demand of 700W is considered for this study.

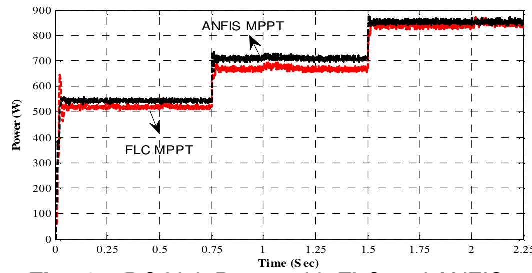

Fig. 24. DC Link Power with FLC and ANFIS Controllers.

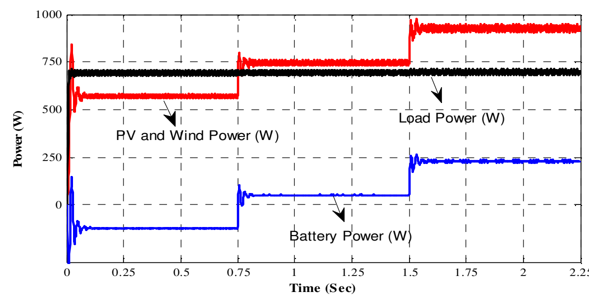

Fig. 25. Hybrid system output with Power Sharing.

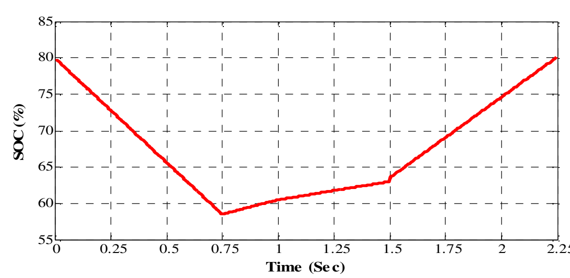

Fig. 26. SOC of lithium ion battery.

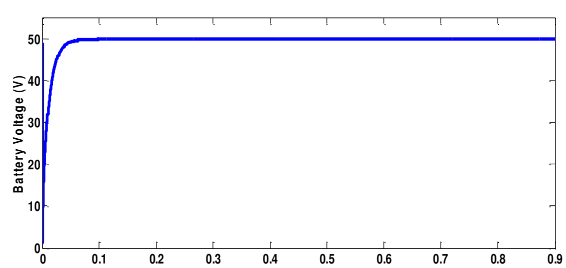

Fig. 27. Battery voltage.

The Fig. 25 shows the power sharing between the renewable energy sources and battery energy system to meet the load demand of 700 W throughout the time period from 0 to 2.25 sec as per the consideration of renewable energy sources input.

The state of charge (SOC) of the battery is shown in the Fig. 26 Since the sources employed in this research are alternative in nature, a fuzzy logic-based battery management system is used in order to reduce the response time and manage the charging and discharging time of the battery intelligently. The battery voltage during the wide operating region is shown in Fig. 27.

The proposed 1 kW hybrid system outputs with PI, FLC, PI Fuzzy and ANFIS controllers are compared in Table 4. The ANFIS based MPPT controller system yields the best results compared to the other controllers.

Design and implementation of ANFIS based MPPT control scheme with open loop boost converter is presented. The simulation of proposed control scheme is done using MATLAB software package and the operation is investigated under varying weather conditions. Simulation results reveals that ANFIS based MPPT control scheme is effective and efficient to track maximum available power from PV module under varying weather conditions and also varying wind velocities in Wind Turbine. Particularly at low irradiance level and wind speeds, maximum output power can be tracked without producing oscillations.

Table 4: Comparative table of hybrid system with different controllers.

Hybrid PV and wind 1 kW system			
Time (sec)	0-0.75	0.75-1.5	1.5-2.25
irradiations	600 W/m2	800 W/m^2	1000 W/m^2
Velocity	8 m/s	10 m/s	12 m/s
Voltage (V)	380	380	380
Hybrid generation with PI (W)	524	662	811
Load (W)	700	700	700
Battery Power (W)	176	38	-111
Hybrid system generation with FLC Controller	552	708	856
Load Demand (W)	700	700	700
Battery Power (W)	148	-8	-156
Hybrid system generation with PI - FLC Controller	559	717	874
Load Demand (W)	700	700	700
Battery Power (W)	141	-17	-174
Hybrid system generation with ANFIS Controller	563	728	889
Load Demand (W)	700	700	700
Battery Power (W)	137(Discharging)	-28 (Charging)	-189 (Charging)

VI. CONCLUSION

The developed 1 kW hybrid System with battery storage system is designed in MATLAB/Simulink environment. The performance of the outlined system is validated in consideration of different solar and wind input under different time durations with the constant 700 W load power demand. A PI-Fuzzy based battery management system is implemented in the system to charge and discharge battery based on the availability of solar and wind power. A comparative study has been done in maximum power extraction from renewable energy sources with PI, FLC, PI FLC and ANFIS controllers.

The ANFIS controller gives the much higher output power efficiency of 88.9 % compare to the PI-Fuzzy controller which is 87.4 %. And PI-Fuzzy controller gives much higher efficiency than normal Fuzzy controller which is 85.6%. Normal Fuzzy Controller gives much higher efficiency of 85.6% than PI Controller which has 81.1%. The effectiveness of load shared between renewable energy sources and battery are also presented.

VII. FUTURE SCOPE

The future scope of the work is the application of optimization based MPPT techniques for PV, Wind and hybrid power generation systems for extracting and transferring the maximum power from source to load.

Conflict of Interest. No conflict of interest.

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