Chapter 5

Implementation of PV-Wind Hybrid Power system with FLC MPPT Controller for DC load using Real Time Data

5.1 Introduction

The mathematical modeling and Simulink implementation of PV based and Wind based generation in proposed hybrid power system as shown in Figure 5.1 were studied individually in the previous chapter. The performance of PV and Wind based generation feeding a DC load individually has been analyzed and the importance of MPPT algorithm in both the generation systems was investigated individually. The proposed MPPT controller operation was as desired when the environmental conditions and load were constant. The performance of the controller under varying conditions was not as desired and improvements in the control strategy are need to have a better voltage profile. In this chapter, the performance analysis of MPPT controlled boost converter of PV and Wind Hybrid power system feeding a DC load will be analyzed. A Fuzzy-based MPPT control logic is proposed to overcome the challenges faced in

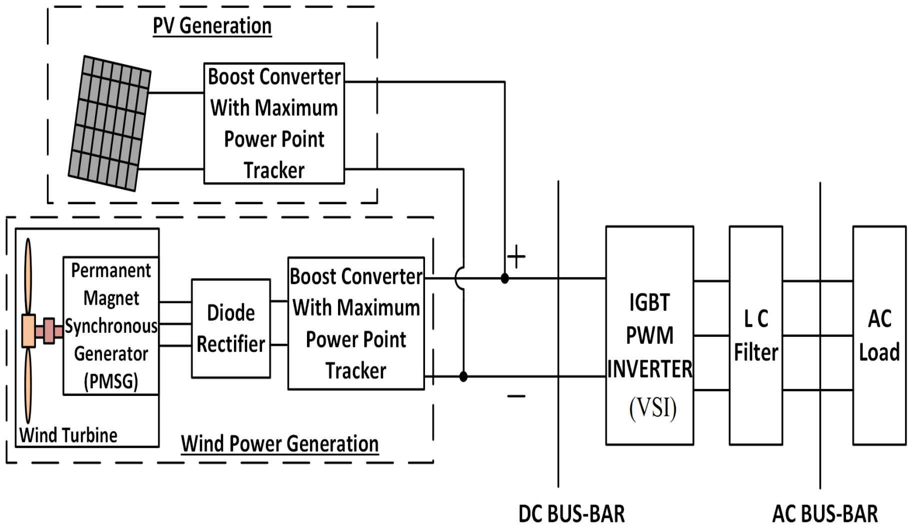

FIGURE 5.1: Block diagram of PV-Wind Hybrid Power System.

maintaining the load voltage profile constant under different conditions. The real-time data of Solar illumination and Wind speed measured at the location, BITS-Pilani, Hyderabad Campus is analyzed in this chapter. This real-time data is utilized to investigate the performance of the proposed Fuzzy control in the hybrid system.

THE gap between the electrical power generation and load demand is increasing exponentially and due to limitations of fossil fuels and an increase in carbon emission an alternate source of clean, green power generation is needed to bridge the gap. Renewable Energy Sources (RES) are the best alternative for the production of clean and green energy in order to bridge the gap and to limit the carbon emission. RES such as the wind, solar, fuel cell, nuclear etc. can utilize abundantly available natural resources to produce clean, green and safe energy which are a compliment by nature [228]. Among the RES the solar and wind power generation can be the potential choice of power generation for hybrid power system as the power generated from these sources have economical, environmental benefits to support the conventional power generation [229–231]. Small scale power generation is gaining importance due to recent development in small scale renewable energy generation techniques and to bridge the gap between energy generation and demand. Integration of different forms of renewable energy sources together can be the best alternative to reduce the utilization of a conventional source of generation, thereby reducing the carbon emission and environmental impact can be minimized [232, 233]. A Hybrid Power system is a combination of different forms of Renewable Energy Sources (RES). The RES like Fuel Cell, Wind, Photovoltaic (PV) etc. are integrated together to have a better eco-friendly solution for energy generation. Such generations are advantageous as the power generated from RES in the hybrid power system will be complementing the other source, thereby the storage reserves are reduced. They have low maintenance, increases reliability and efficiency of the system. In order to select RES for the stand-alone hybrid power system, the knowledge of environmental conditions is essential. In the location having rich solar irradiance level and moderate wind speed profile, the combination of PV-Wind hybrid power system with PV as the main source of generation and wind power as the complimenting source will be suitable and increase the reliability of the hybrid system [234]. The power generation from the wind and grid integrated wind power generation is well established and various techniques of power controller were proposed [235–242]. Several studies were reported on the stand-alone, grid-connected PV based generation and various MPPT controller techniques to control the power generated from PV and to extract maximum power out of the PV system [243–246]. However, a stand-alone system with PV-wind integrated generation is considered to be more economical as compared with a stand-alone system with a single source of RES generation [247]. Various researchers have worked on the PV-Wind integrated hybrid power system with respect to optimization, performance and control action in last few years [248] has investigated into a novel integration scheme of solar PV and wind power generation where the grid and rotor side converter are used to inject the PV power into the grid. Thereby giving a cost-effective solution by eliminating a dedicated power converter for PV power generation. The scheme investigated prevention on circulating power in sub-synchronous operation under the solar insolation. This improves the efficiency and stability of the system.

It has been observed that a number of researchers have worked on PV-wind hybrid power system in terms of improving the MPPT tracking algorithm, optimal placement of PV-wind or combination of RES sources, energy management system, and optimization. Under investigation of various topologies, the environmental conditions are assumed to be constant or simulated at Standard Test Conditions (STC). In order to simulate, evaluate the performances of a PV-Wind hybrid system for a particular location it is essential to analyze the solar irradiation levels and wind speed profile for that particular location. Few works were reported for north-east India, Rajasthan in India, Kenya, Nicosia, Cyprus and Nice, France etc. The researchers have concentrated on the modeling standalone hybrid power system and comparing the performance of the system for different locations, the optimal sizing coefficient of the hybrid power system, disaster management systems. From the literature review, it appears that no study has been carried out up till now regarding PV-wind integrated hybrid power system for a DC load for South-East India. With the above backdrop, a simulation study of PV-wind hybrid power system with the data of the wind and solar insolation recorded at the location has been carried out to examine the amount of power that can be extracted from the environmental conditions at the location.

Thus a PV system consisting of PV array, Maximum Power Point Tracking (MPPT) boost converters, and Wind power system consisting of a wind turbine, PMSG, rectifier and MPPT boost converter is integrated into Solar Wind hybrid power system (SWHPS). The efficiency and reliability of the SWHPS mainly depend upon the control strategy of the MPPT boost converter. The solar and wind power generation cannot operate at Maximum power point (MPP) without proper control logic in the MPPT boost converter. If the MPP is not tracked by the controller the power losses will occur in the system and in spite of the wind and solar power availability, the output voltage of the hybrid system will not boost up to the required value [249]. 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. 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 SWHPS. A comparative analysis of the performance of the SWHPS with different MPPT control logics is investigated in this paper. The performance of the SWHPS implemented using MPPT control logic (HCS and P&O) is compared with the SWHPS 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.

5.2 Proposed PV-Wind hybrid power system with DC Load

Hybrid power system consists of three different stages: the power generation stage, converter/controller stage and the distribution stage. In this section, the dynamic simulation model of PV and wind turbine with 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 Figure 5.2
The mathematical modeling of PV based generation is discussed in Section 3.2 and the mathematical modeling of Wind based generation is discussed in Chapter 4. The simulink implementation of P & O algorithm is subsection 3.4.5.1 and HCS algorithm in subsection 4.4.2.

The 400 W PV based and 2.7 kW wind based generations DC output are connected in parallel to from a common DC bus-bar of voltage 220 V. The PV-Wind hybrid power system is simulated under constant solar illumination of 1000 W/m^2 and wind speed of 12 m/s. The simulated load voltage, Current and Load power are shown in Figure 5.3.

From Figure 5.3 it can be comprehended that the time taken for the load voltage to reach the desired value is 1.7 sec. Similarly the load current and power follows the load voltage.

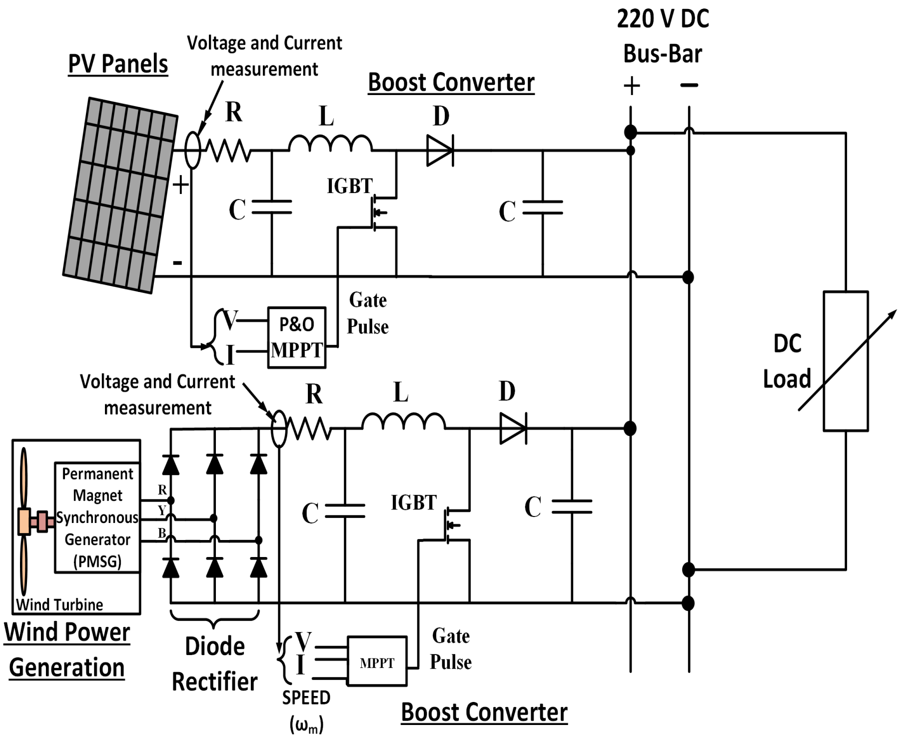

FIGURE 5.2: Block Diagram of PV-Wind hybrid Power system with DC load

5.3 Fuzzy Logic Controller (FLC):

5.3.1 Fuzzy implementation of P & O algorithm

The block diagram of Fuzzy Logic Controller (FLC) based Maximum Power Point Tracking (MPPT) controlled boost converter are shown in Figure 5.4 and Figure 5.5 for PV and wind generation respectively. The DC voltage from PV, Wind based generation are stepped up using boost converter and the output voltage can be computed as Eq. 5.1 [138].

$$V_s DT = (V_o - V_s)(1 - D)T \tag{5.1}$$

where

D = Duty cycle of the converter,

T = Total time period of the switching,

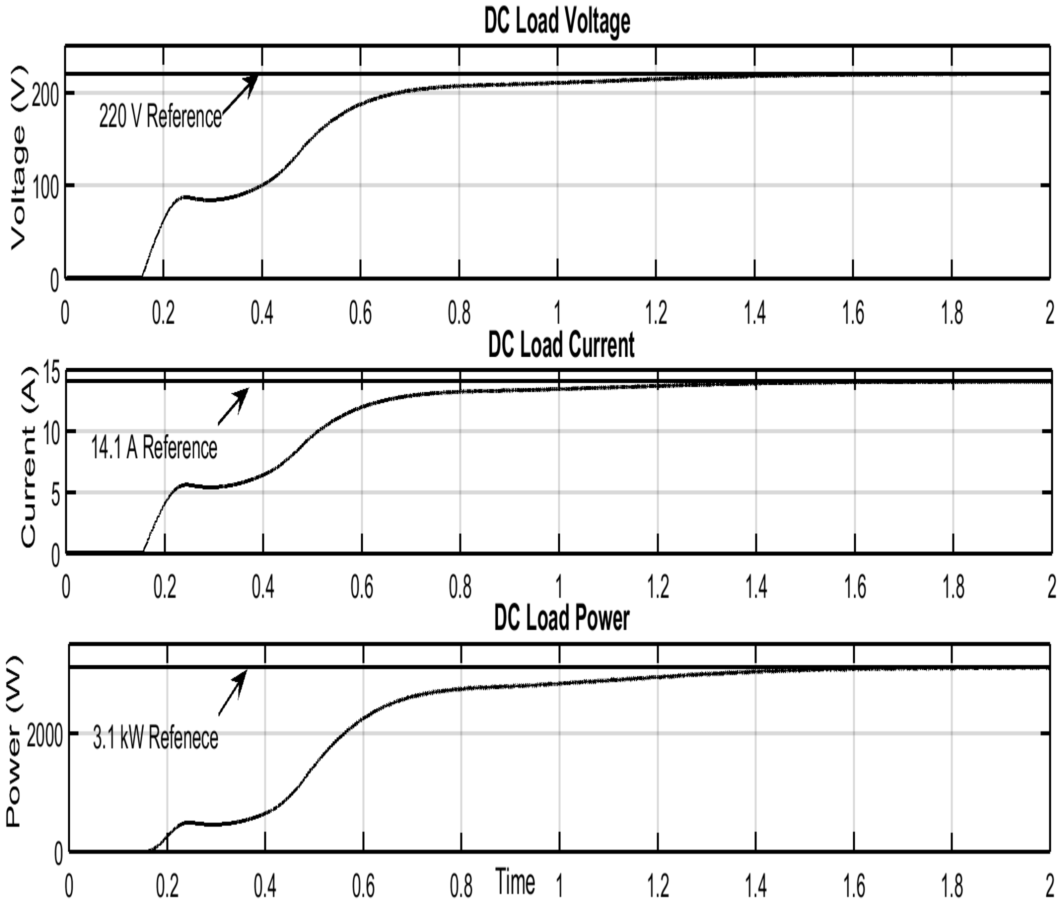

FIGURE 5.3: Simulated load Voltage, Current and Power of Hybrid power system

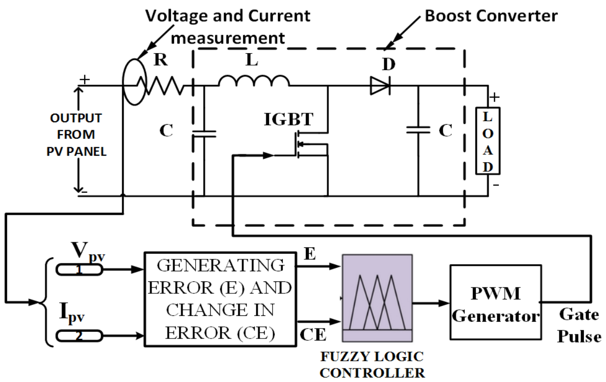

FIGURE 5.4: Block diagram of boost converter for PV generation

From which the boosted dc voltage can be expressed as (5.2)

$$\frac{V_o}{V_s} = \frac{1}{1-D} \tag{5.2}$$

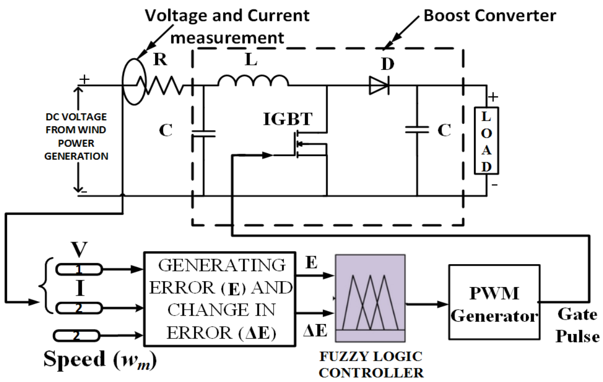

FIGURE 5.5: Block diagram of boost converter for Wind generation

5.4 Fuzzy Logic Control (FLC):

A fuzzy control system is a control system based on fuzzy logic. Fuzzy logic is a system that analyzes analog input to the control in terms of logical variables and are mapped as fuzzy sets which are continuous values between 0 and 1.

A fuzzy controller process can be divided into three main sections as shown in Figure 5.6. The first of these is the fuzzification, this uses defined membership functions to process the inputs and to fuzzify them. These fuzzified inputs are then used in the second part, the rule-based inference system. This system uses previously defined linguistic rules to generate a fuzzy response. The fuzzy response is then defuzzified in the final process: defuzzification. This process will provide a real number as an output.

The FLC analyses the control action depending on the states of the inputs. The inputs are first converted

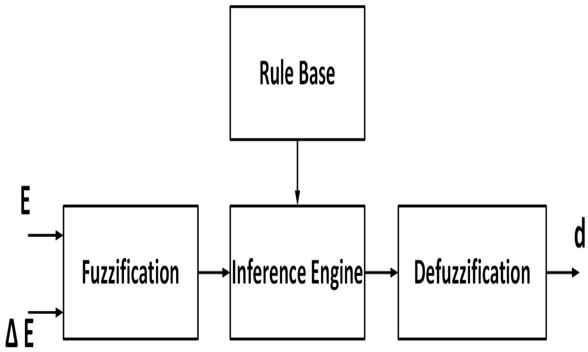

FIGURE 5.6: Basic elements of Fuzzy Logic Control

in fuzzy sets this process is known as fuzzification and the rule base is a set of if-then rules which contains all the information regarding the control parameters. Fuzzy inference engine has function of formulating logic decision based on the rule base. It will then transform the fuzzy rule base into fuzzy output. The defuzzification is the process to recover the real values from the fuzzy output. The reasons selecting Fuzzy controller are easy implementation, flexibility, tolerance of imprecise data, nonlinear functions can be modelled for arbitrary complex control, the ability to blend with the conventional control system, and the fuzzy is the based on natural communication.

5.4.1 Fuzzy implementation of MPPT algorithm

P & O algorithm As shown in Figure 5.4 the voltage(V), current (I) are sensed from the output of PV generation which are utilized to compute the control input to the fuzzy implementation of the P & O algorithm. The equations involved in subsystem implementation as shown in Figure 5.4 to calculating the error (E) and change in error (CE) are (5.3)-(5.8)

$$P = V \times I \tag{5.3}$$

$$\Delta V = V(x) - V(x-1) \tag{5.4}$$

$$\Delta I = I(x) - I(x-1) \tag{5.5}$$

$$\Delta P = P(x) - P(x-1) \tag{5.6}$$

$$E = \frac{\Delta P}{\Delta V} \tag{5.7}$$

$$CE = E(x) - E(x-1) \tag{5.8}$$

where (x) is for the current state of measured value and $(x-1)$ is for the previous state of measured value. The rule base of fuzzy logic implementation of P & O algorithm is shown in Table. 5.1. where

TABLE 5.1: Fuzzy rule base for P & O algorithm

E	CE						
	NB_{pv}	NM_{pv}	NS_{pv}	ZE_{pv}	PS_{pv}	PM_{pv}	PB_{pv}
NB_{pv}	ZE_{pv}	ZE_{pv}	ZE_{pv}	NB_{pv}	NB_{pv}	NB_{pv}	NB_{pv}
NM_{pv}	ZE_{pv}	ZE_{pv}	ZE_{pv}	NM_{pv}	NM_{pv}	NM_{pv}	NM_{pv}
NS_{pv}	NS_{pv}	ZE_{pv}	ZE_{pv}	NS_{pv}	NS_{pv}	NS_{pv}	NS_{pv}
ZE_{pv}	NM_{pv}	NS_{pv}	ZE_{pv}	ZE_{pv}	ZE_{pv}	PS_{pv}	PM_{pv}
PS_{pv}	PM_{pv}	PS_{pv}	PS_{pv}	PS_{pv}	ZE_{pv}	ZE_{pv}	ZE_{pv}
PM_{pv}	PM_{pv}	PM_{pv}	PM_{pv}	ZE_{pv}	ZE_{pv}	ZE_{pv}	ZE_{pv}
PB_{pv}	PB_{pv}	PB_{pv}	PB_{pv}	ZE_{pv}	ZE_{pv}	ZE_{pv}	ZE_{pv}

NB - Negative big, *NM*-Negative medium, *NS*-Negative small, *ZE*-Zero, *PS*-Positive small, *PM*-Positive medium *PB*-Positive big and suffix $_{pv}$-for PV based generation.

HCS algorithm As shown in Figure 3.9 the voltage (V), current (I) are sensed at the input of boost converter and speed (ω_m) of the PMSG is sensed and given as input to compute the control input to the fuzzy implementation of the HCS algorithm. The equations involved in subsystem implementation as shown in Fig. 5.5 to calculate error (E) and change in error (ΔE) are (5.3), (5.9)-(5.12).

$$\Delta P = P(k) - P(k-1) \tag{5.9}$$

$$\Delta\omega_m = \omega_m(k) - \omega_m(k-1) \tag{5.10}$$

$$E = \frac{\Delta P}{\Delta\omega_m} \tag{5.11}$$

$$\Delta E = E(k) - E(k-1) \tag{5.12}$$

where (k) is for the current state of measured value and ($k-1$) is for the previous state of measured value. The conditions to track the MPP are

$$\frac{\Delta P}{\Delta\omega_m} = 0, \qquad (\omega_m = \omega_{mpp}) \tag{5.13}$$

$$\frac{\Delta P}{\Delta\omega_m} > 0, \qquad (\omega_m < \omega_{mpp}) \tag{5.14}$$

$$\frac{\Delta P}{\Delta \omega_m} < 0, \qquad (\omega_m > \omega_{mpp}) \tag{5.15}$$

The rule base of fuzzy logic implementation based on MPP tracking conditions given by (5.13)-(5.15) is shown in Table. 5.2. Suffix $_w$ is for wind based generation.

TABLE 5.2: Fuzzy rule base for HCS algorithm

E	ΔE				
	NB_w	NS_w	ZE_w	PS_w	PB_w
NB_w	ZE_w	ZE_w	NB_w	NB_w	NB_w
NS_w	NS_w	ZE_w	NS_w	NS_w	NS_w
ZE_w	NS_w	ZE_w	ZE_w	ZE_w	PB_w
PS_w	PS_w	PS_w	PS_w	ZE_w	ZE_w
PB_w	PB_w	PB_w	ZE_w	ZE_w	ZE_w

The fuzzy implementation of MPPT algorithm is realized in MATLAB, Simulink. The DC output voltage from PV and wind based generation are boosted up to the desired level of 220 V and are kept constant at the desired level.

5.5 System Description and Simulation results:

The PV-Wind hybrid power system as shown in Figure 5.2 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 hybrid power system with solar irradiation of 1000 W/m^2 and wind speed of 12 m/s are shown below. A comparative analysis of the MPPT implementation done in section 3.4.5.1, Section 4.4.2 is compared with the Fuzzy implementation of MPPT algorithm.

Figure 5.7 gives the load voltage of the PV-Wind hybrid power system with and without FLC. It is seen that the load voltage profile has improved with the FLC implementation of MPPT as compared with the Simulink block implementation.

FLC boosts 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 Figure 5.8, it can be observed that the system with

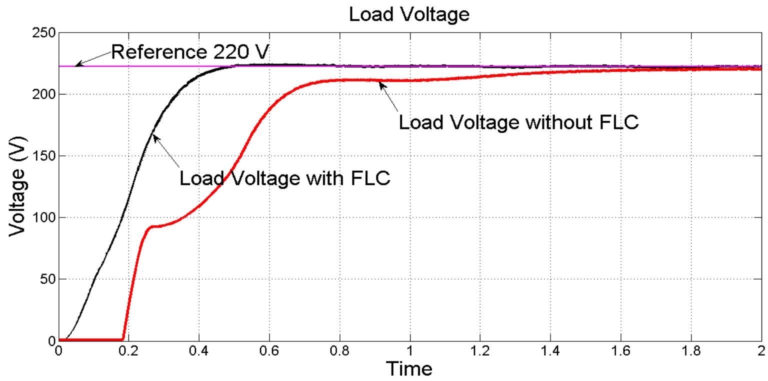

FIGURE 5.7: Simulated result of Load Voltage

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.

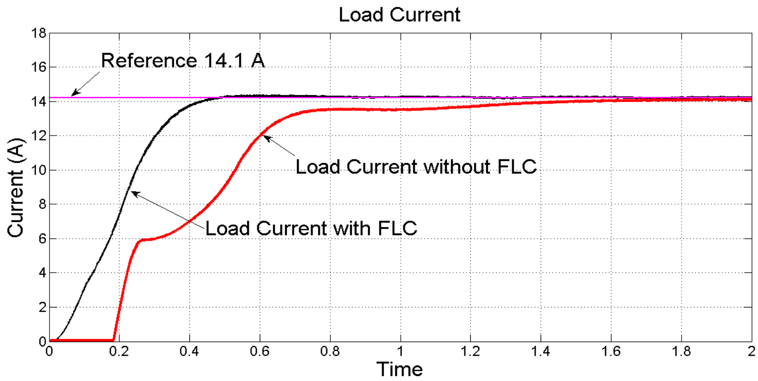

FIGURE 5.8: Simulated result of Load Current

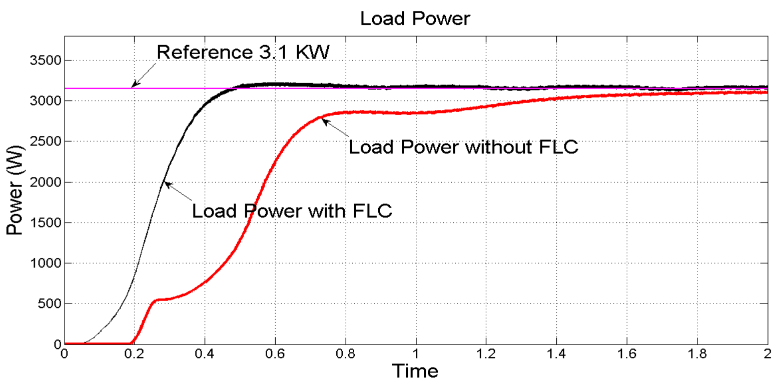

FIGURE 5.9: Simulated result of Load Power

From Figure 5.9 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. The FLC-based MPPT controller demonstrates enhanced performance over the MPPT implementation using Simulink blocks. Further, the performance of the PV-Wind hybrid power system with FLC MPPT controller will be analyzed under varying environmental and load conditions. The further section will discuss the real time data of solar and wind speed recorded at the location.

5.6 Measured data of Wind Speed and Solar Illumination at BITS-Pilani, Hyderabad Campus

The PV-Wind hybrid system has to be analyzed for the environmental conditions measured at the location. The Longitude and Latitude of the location are 17.54650 N, 78.57250 E the solar irradiation and wind profile for the location are measured using Weather Monitoring System (WMS) installed in the campus as shown in Figure 5.10.

The historical data of solar illumination and wind speed recorded at the said location is graphically represented from Figure 5.11 to Figure 5.18.

Figures 5.11 - 5.14 shows the graphical representation of solar irradiation level measured over a year at the location. From the solar irradiation plot, it is clear that the location has a good solar energy with maximum solar irradiations level touching 1500 W/m^2 with average solar irradiation level around 600 W/m^2. Figure 5.11 shows the graphical representation of hourly solar irradiance for the day it can be clinched that the location under consideration has a good solar irradiation level from 9 am to 6 pm with minimum irradiation of 400 W/m^2 and maximum value touching 1100 W/m^2.

Figures 5.15 - 5.18 shows the graphical representation of wind speed measured over a year at the same

FIGURE 5.10: Weather Monitoring Systems installed at BITS-Pilani, Hyderabad

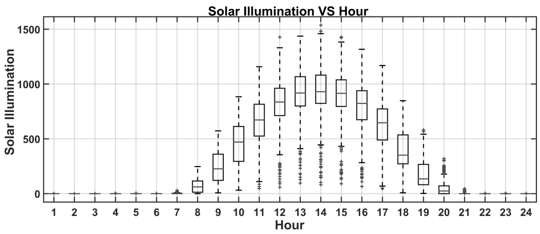

FIGURE 5.11: Solar illumination measured over a day

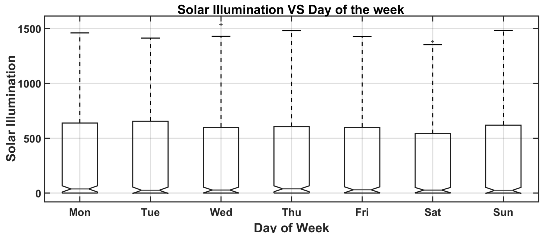

FIGURE 5.12: Solar Illumination measured over a week

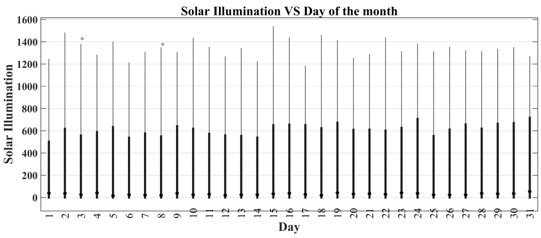

FIGURE 5.13: Solar illumination measured over a month

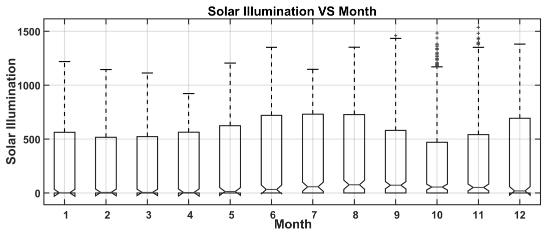

FIGURE 5.14: Solar illumination measured over a year

location. It can be projected that the wind profile is quite good for low wind speed generation with average wind speed above 3 m/s and with the average maximum wind speed of 12 m/s. It can be clearly comprehended from Figure 5.15 the hourly wind profile is quite good and from Figure 5.17 that the monthly average is above 3 m/s and touching 5 m/s and maximum wind speed is between 8 m/s to 14 m/s.

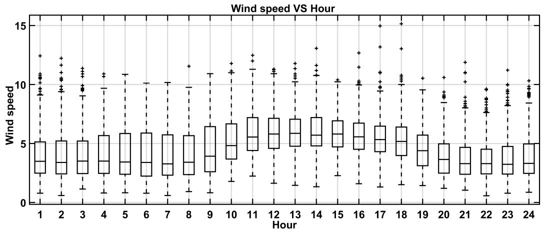

FIGURE 5.15: Wind Speed measured over a day

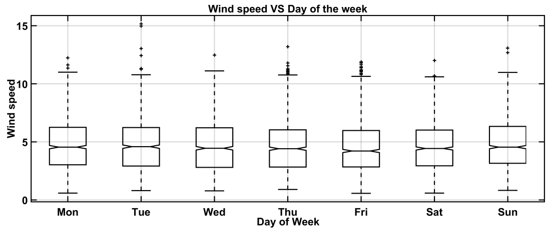

FIGURE 5.16: Wind Speed measured over a week

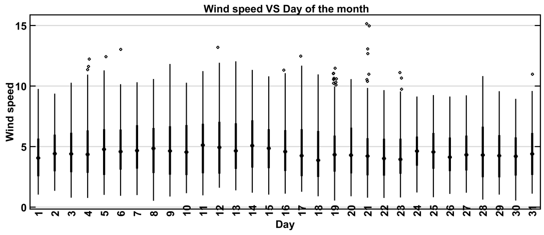

FIGURE 5.17: Wind Speed measured over a month

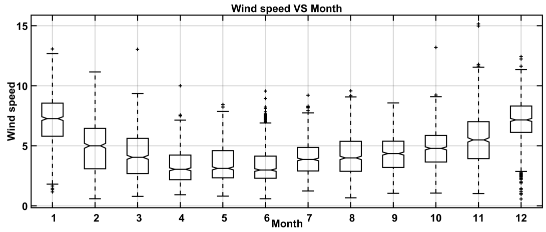

FIGURE 5.18: Wind Speed measured over a year

Utilizing this real-time data of solar irradiation and wind speed as shown in Figure 5.19, Figure 5.20 for the location to analyze the performance of the FLC controlled PV-Wind hybrid system for constant and variable DC load.

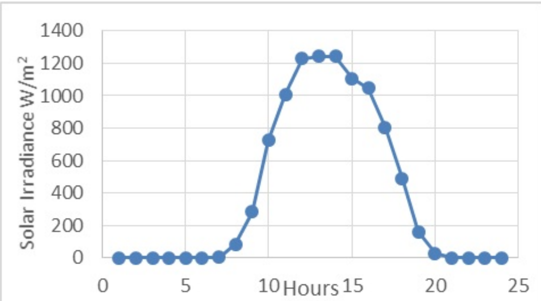

FIGURE 5.19: Hourly irradiation for a day

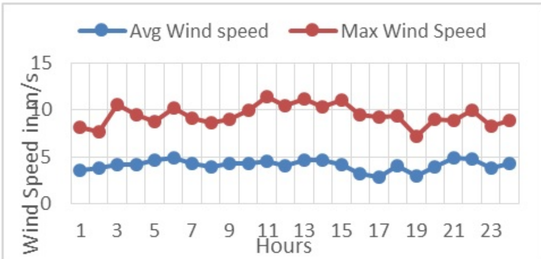

FIGURE 5.20: Hourly wind speed for a day

5.6.1 System Description and Simulation Results with measured Solar illumination and Wind speed data

Further scaling up the generation in the hybrid power system i.e. PV generation system is 3.4 kW and Wind power generation system is 3 kW and investigating the performance of the FLC-based controller. The PV-Wind hybrid system is simulated with the real-time data of solar irradiance and Wind speed measured at the location and is shown in Figure 5.19 and Figure 5.20. Using this real-time data as input to the PV-wind hybrid power is simulated for two sets of load conditions,

(i) Constant resistive load of 6 kW,

(ii) Varying resistive load of pattern i.e. the load is varied from 1000 W to 6500 W in steps.The controller action and the performance of the system to maintain constant output voltage are analyzed.

5.6.1.1 Constant Resistive load of 6kW with Real-time data of environmental conditions

The PV-Wind hybrid power system is simulated with the real-time data of solar irradiation and wind speed measured at the location with a constant load of 6000 W. The simulated results of the Load voltage, current, and Power measured at DC bus-bar are shown in Figure 5.21 - Figure 5.23.

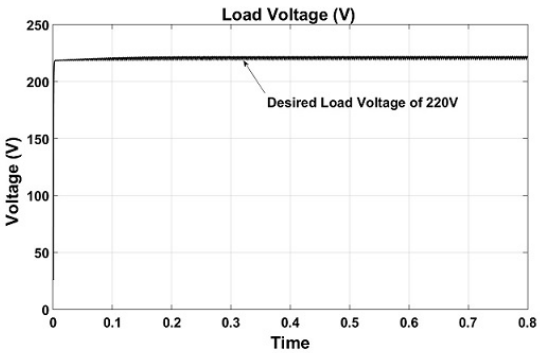

FIGURE 5.21: Simulated Load Voltage

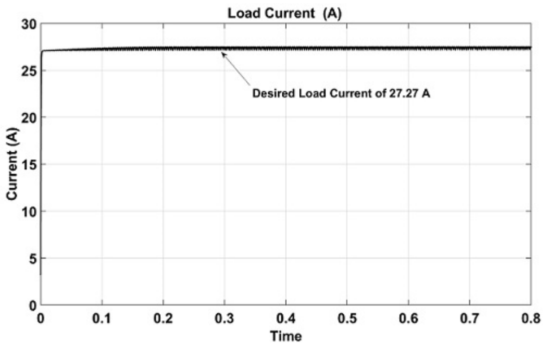

FIGURE 5.22: Simulated Load Current

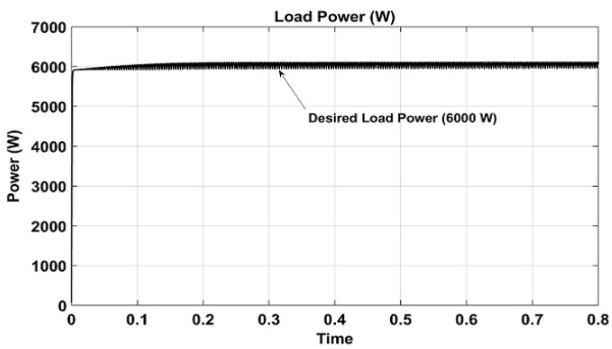

FIGURE 5.23: Simulated Load Power

From Figure 5.21 it can be clearly perceived that the output voltage of the PV-wind hybrid system is maintained constant at 220 V and the hybrid power system supplies desired load power of 6000 W as shown in Figure 5.23 at a constant voltage of 220 V and load current of 27.27 A as shown in Figure 5.22. The output voltage is maintained constant irrespective of varying wind speed and solar irradiation levels. The FLC implementation of MPPT algorithm for the PV-Wind hybrid system is working as anticipated. The output voltage reaches desired value of 220 V by 2.5ms.

5.6.1.2 Varying Resistive Load with the Real Time data of Environmental Conditions

The performance of the FLC controlled PV-Wind hybrid power system is investigated for the variable resistive load with the real-time data of solar illumination and wind speed. The simulated results of Load Voltage, Current and Power are graphically represented in Figure 5.24 – Figure 5.26.

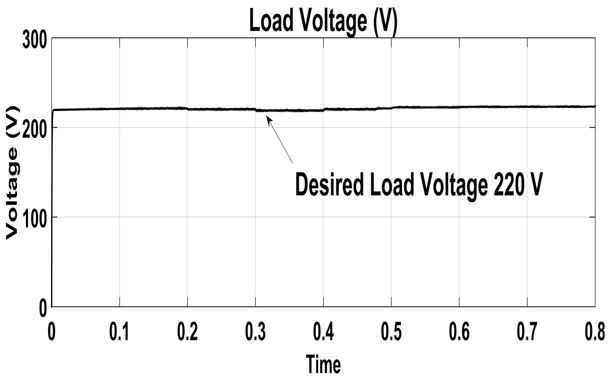

FIGURE 5.24: Simulated Load Voltage

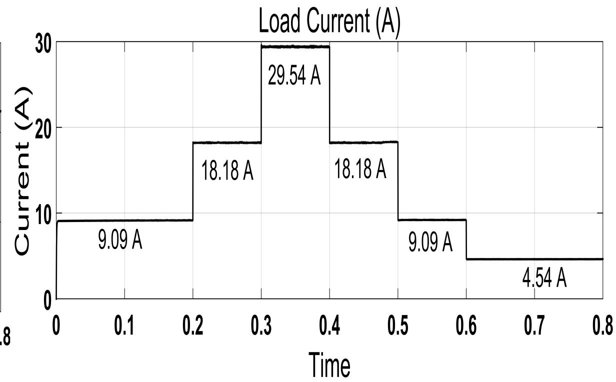

FIGURE 5.25: Simulated Load Current

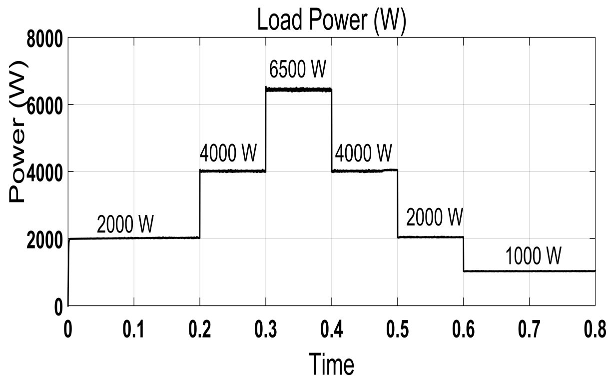

FIGURE 5.26: Simulated Load Power

From Figure 5.24 it can be comprehended that the output voltage is maintained constant at 220 V DC irrespective of change in solar irradiation, wind speed, and change in load. The controller designed worked as desired to maintain the output voltage constant irrespective of the change in environmental conditions and load. The simulated Load current and Power are graphically represented in Figure 5.25, Figure 5.26.

5.7 Summary:

In this chapter, a comparative analysis of MPPT controller design implementation of PV-Wind hybrid power is done. The MPPT controller plays an important role in the hybrid system in improving the performance and reliability of the system. Using MPPT controller the PV, the Wind is operated at MPP to harness the maximum power and to operate at maximum efficiency, thereby reducing the losses. The MPPT controller implemented using FLC has a much better performance as compared to the MPPT implementation using basic building blocks in Simulink for HCS and P & O for wind and PV generation respectively.

The hybrid system reaches the desired output voltage of 220 V, 3.1 kW in 0.58s with the MPPT controlled boosted converter build by FLC as compared with the 1.7s with the other implemented MPPT controllers. There the overall system efficiency, reliability, and performance of the system have improved by using the MPPT controller developed using FLC.

Further the real time data of the solar illumination and wind speed measured at the BITS-Pilani, Hyderabad Campus is analyzed. The PV-wind hybrid system when simulated with real-time data of solar irradiation and wind speed for a constant load the system performance has been analyzed. The output voltage reaches desired value of 220V by 2.5ms Similarly the load current and power follows the voltage. The output voltage is maintained constant at desired level. The PV-wind hybrid system when simulated with real-time data of solar irradiation and wind speed with the varying load the system performance and controller action has been analyzed. Under varying environmental conditions with the change in load, the controller was able to maintain the load voltage at desired level of 220V and their by meeting the load demand. The output voltage is maintained constant for load variation with a minimum load value of 1kW to a full load of 6.5 kW. Future work will be testing the system with real time data and comparing it with a real-world scenario.

The next chapter will focus on the short term and long term prediction of solar illumination and wind speed utilizing the historical data of the same recorded at the location.