Maximum Power Extraction Using Perturbation and Observation Algorithm in a Hybrid Energy System

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Abstract: Providing electric power to rural areas is a challenging issue for power system engineers due to their minimum total load demand. This paper provides an efficient method to provide Electrical Power to rural areas through a Grid connected Solar PV-Wind-Fuel cell hybrid system. Four fuel cells are connected in series for obtaining maximum value of power. Solar and Wind Power are continuously monitored and controlled using Perturbation and Observation (P&O) Algorithm. Along with this the Permanent Magnet Synchronous Generator(PMSG) which is used to drive the wind turbine. The Machine side Voltage Source controller(MVSC) which uses a composite sliding mode control to the wind speed and reduce the disturbance generated in the generator. A DC-DC boost converter is used for all the three types of generation i.e, Solar PV, Wind and Fuel cell. A Proportional-Integral (PI) Controller is used to control the Generated Voltage. The excessive generated voltage is sent to the Grid and used for Distributed Generation purposes. At the last, the Simulation results of each source are compared with the Hybrid Model.

***Index Terms* – DC-DC Boost Converter, Hybrid Systems, P&O Algorithm, PI Controller, MVSC, Composite Sliding Mode Control.**

I. INTRODUCTION

Currently, 14%of the total world population lack household electrical power, it may be isolated or rural areas. Both of these areas have less aggregate demand and hence their electrification becomes a challenge. However, many off-grid ventures have been developed to overcome this. Many sources like photo voltaic, wind, Biomass, and hybrid of these sources are used for generation of power as they sources are readily available in nature, their installation is cheap and they do not pollute environment as in the case of non-renewable energy sources[1] & [2].

A Composite Sliding Mode Controller (CSMC) is used in this paper for maximum power extraction. CSMC is comprised of two controllers namely Soft switch Sliding mode controller [3] which is used to observe disturbances and a Non-Singular terminal Sliding mode controller which acts as a speed controller. This controller is adapted for the extraction of wind power in a Solar PV-Wind hybrid system in an isolated area. Previous system used a Battery energy storage which stored the power when generation is leading the demand.[4] And it provides electrical power when generation is lagging the total demand, so that there is no black out of power in the isolated areas.[5] In this battery source has been replaced by the fuel cells. The Composite sliding mode controller extracts maximum wind power and this controller has the ability to reject any kind of disturbances. The peak solar power is harvested using Maximum Power Point Tracking.[6]

II. PROBLEM FORMULATION AND PROPOSED METHDOLOGY

Problem Formulation: In this paper, instead of off grid ventures, a grid connected Solar PV-Wind-Fuel Cell hybrid system has been developed supply a 30KW load to a rural area. Although wind and solar are the most promising sources of renewable energy in the generation field, they have limitations such as unpredictable availability and their intermittent nature. However solar and wind compliment each other in terms of availability and can be used as a hybrid system along with sources like battery which can supply power to the load when both the systems are not sufficient enough to supply power to the load. But there are chances, due to seasonal variations both the sources could not generate enough power that can be supplied to load or that could be stored in a battery. Hence, there are more chances of power cuts in that particular area.

Proposed Methodology:. To overcome this problem Fuel Cells have been used along with Solar and Wind. Fuel cells are more beneficial than a battery energy storage. Fuel cells generate electric power continuously as long as the fuel is supplied to it and besides it has high efficiency and causes no harm to the environment. In this particular case, four fuel cells have been connected in series to get the maximum power. MPPT algorithm specifically, improved Perturbation and Observation (P&O) algorithm has been used to keep both the wind and solar maximum power on point. The wind speed and the disturbances that are created due the PMSG are controlled by a Composite Sliding mode controller. Different structures must be developed to control wind and solar power. Anyhow, any such control is not required for fuel cells. The Block Diagram of the proposed methodology is shown in fig 1 and the description of its components is discussed in the further sections.

Solar and wind power are connected directly to a DC link. The voltage must be controlled at this link which uses a antiwindup PI controller. In this case, only active power is needed to control through the DC link voltage as the reference reactive power will be set to zero. After this a boost converter is used to boost up the voltage, after this point the boosted voltage is sent through a inverter and the DC voltage is converted to AC. At this point a dq controller is used to control active and reactive power.
The whole system description is discussed in the further sections.

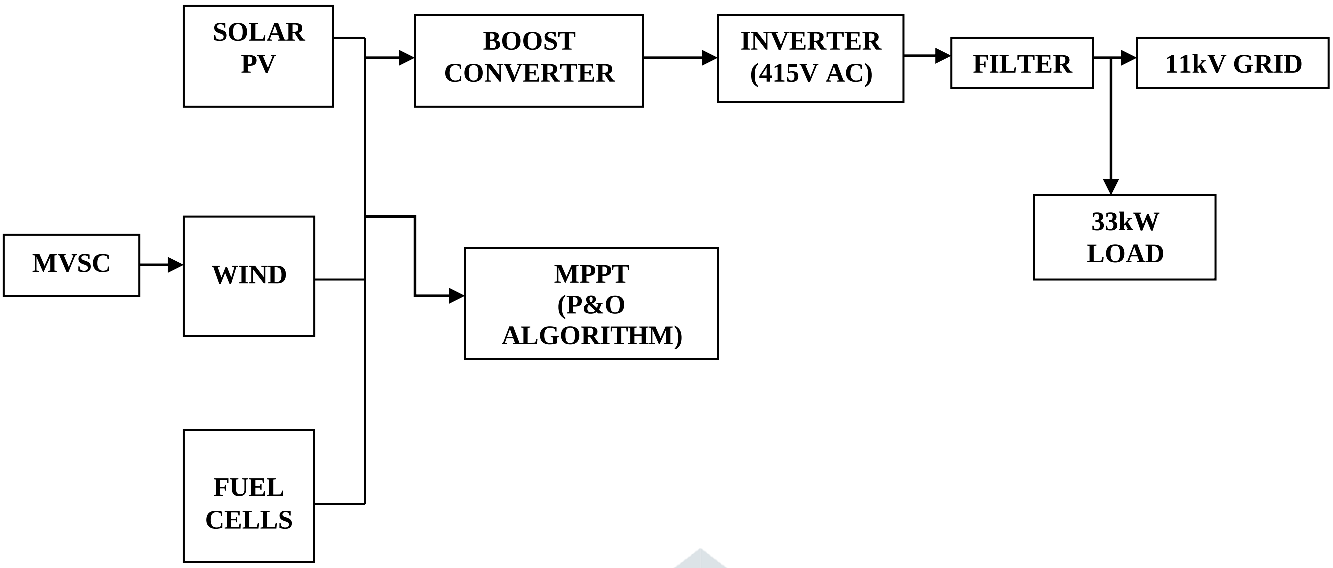

Fig. 1 Block Diagram of the Proposed Methodology

III. SYSTEM CONFIGURATION

As discussed in the previous section, three sources have been used as a hybrid source in the proposed system. The power output of each source is given below:

A. Solar: 25kW
B. Wind: 20 kW
C. Fuel Cells: 24kW

3.1 Solar PV Configuration

Solar cells are the necessary components of photovoltaic panels. Most of them are made up of silicon however other materials can also be used. The basic working phenomenon of solar cells is photoelectric effect: the capability of several semiconductors to translate electromagnetic radiation straightforwardly into electrical current [3].

A solar cell is mainly a p-n junction which is made up of two unique layers of silicon doped from a minimum quantity of impurity atoms: in case of n-layer, atoms having one additional valence electron, called donors, and in case of p-layer, with one fewer valence electron, called as acceptors.

A solar cell can also be represented using an electrical network as shown in Figure 2. Its current-voltage characteristics is given by the following equation (1):

$$I = I_L - I_O \left[e^{\frac{q(V-IR_S)}{AkT}} - 1 \right] - \frac{V-IR_S}{R_{SH}} \qquad (1)$$

where I and V : solar cell output current and voltage respectively,
I_O : dark saturation current
q : charge of an electron
A : diode quality (ideality) factor,
k : Boltzmann constant
T : absolute temperature and
R_S and R_{SH} : series and shunt resistances of the solar cell.
R_S : resistance offered by the contacts and the bulk semiconductor material of the solar cell.

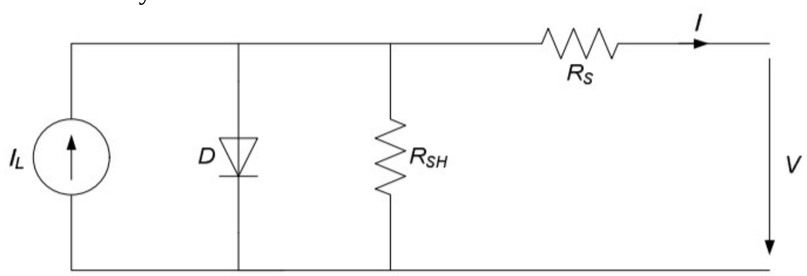

Fig 2: Equivalent Circuit of Solar Cell

A. Characteristic Curve of Solar Panel

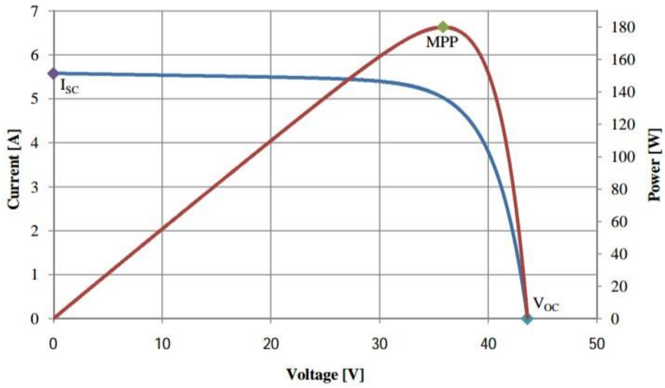

Fig 3. V-I Characteristics of Solar Panel

Two crucial points of the current-voltage characteristic can be noted out: the open circuit voltage V_{OC} and the short circuit current I_{SC}. The power generated at these points is zero.

B. Temperature and Irradiance Effect

Two vital factors that should be considered are irradiation and temperature. They stoutly affect the characteristics of solar modules. The consequence of the irradiance on voltage-current (V-I) and the voltage-power (V-P) characteristics is shown in Figure 4, where the curves are depicted in per unit, i.e. voltage and current have been normalized by using the V_{OC} and the I_{SC} correspondingly, in order to demonstrate better, the special effects of the irradiance on V-I and the V-P curves.

The short circuit current (I_{SC}) is directly proportional to photo generated current. Due to this reason voltage-current characteristic changes with the irradiation. In disparity, the outcome in the open circuit voltage is too small, as the reliance of the light generated current is logarithmic.

It can be seen in Figure 4 that the variations in the current is maximum than in the voltage. In practical systems, the voltage dependence on the irradiation can be neglected [10]. As its effect on both the parameters current and voltage is positive, i.e. both rise when the irradiation increases, same effect also implies on power. On the other hand temperature, affects only the voltage. This is shown in figure 5.

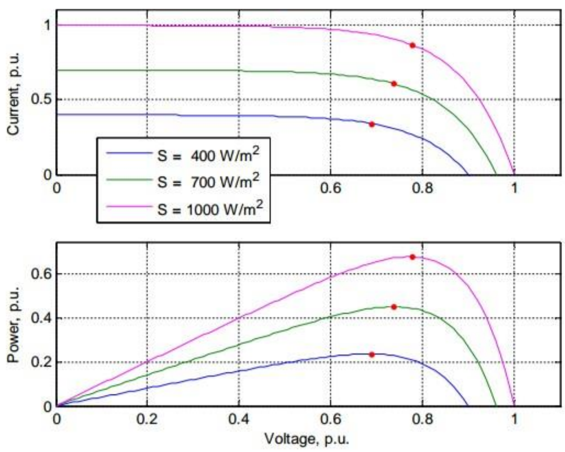

Fig 4. V-I and V-P Characteristics at Constant Temperature and Varying Irradiance

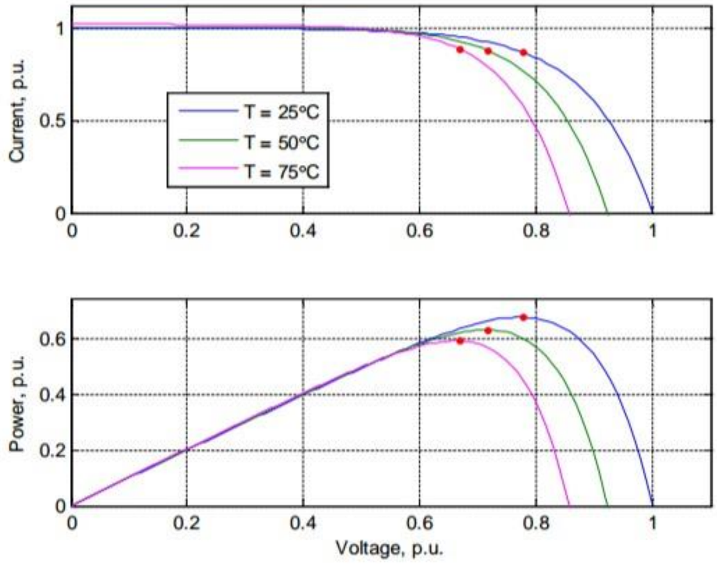

Fig 5. V-I and V-P Characteristics at varying Temperature and Constant Irradiance

3.2 Wind Energy Generating System

Unlike solar cells the wind turbine needs a driver to convert the mechanical energy of the wind to electrical power. Choosing a suitable generator and extraction techniques for achieving peak power, are the major issues for optimum operation of WEGS[4]. With respect to the lot of advantages described in the literature, PMSG with maximum number of poles, is much suitable option among the available generators for this purpose, as it eradicates the need of extra gearbox and slip rings. The mechanical output of the wind turbine can be written as follows:

$$P_{tur} = 0.5\rho\pi R_b^2 v_w^3 C_p\left(\lambda_{tsr}, \beta\right) \quad (2)$$

Where, ρ = Air density (Kg/m3) A = Swept area (m2) Cp= Power coefficient of the wind turbine V = Wind speed (m/s)

From the above equation if the wind speed, swept area and the air density are constant then output power is said to be a function of power co-efficient of wind turbine (Cp).

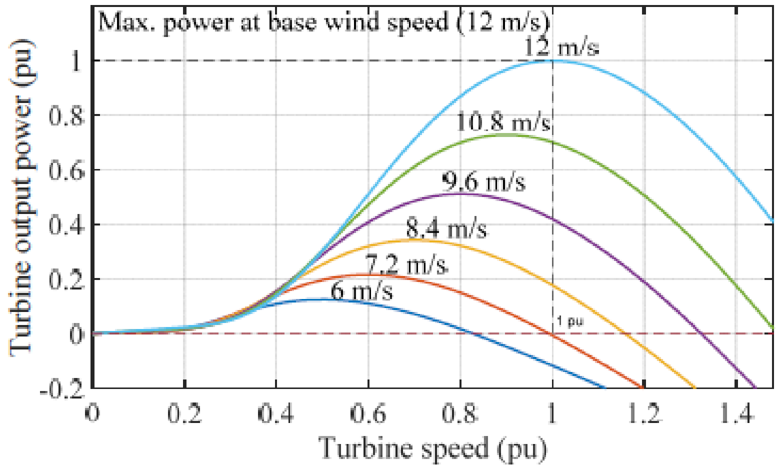

Fig 6: Speed Power Characteristics of Turbine (in per unit)

The Variable Speed Wind Turbine Generator performs efficiently when it is operated with fully controlled Voltage Source Controller (VSC) integrated along with suitable control logic. This design helps in extraction of optimal wind power in a definite range of wind speed using a shaft speed regulation, as compared with a design with an uncontrolled bridge rectifier along with a DC/DC boost converter. The conservative PI controller with maximum gain, improvises the system dynamics however it cannot improve steady state performance of the system. But, addition of small controller gain minimizes the dynamic response of system. Different adaptive, intellectual and robust techniques have been developed for PMSG based WEGS over conservative PI controller. These robust techniques have proved to be a appropriate choice for elimination of model uncertainties and the external disturbances. This technique known as Sliding Mode Controller(SMC) Technique is gaining a lot of attention among the various approached techniques . For SMC, selecting a sliding surface, reaching sliding mode gains are the basic requirements.

3.3 Fuel Cells System

A fuel cell is made up of an electrolyte and two electrodes coated with catalyst. A porous cathode and an anode forms the electrodes of a fuel cell which are located on either sides of electrolytic layer. Gaseous fuel (usually hydrogen) is supplied continuously to anode and oxidant (i.e. oxygen from air) is supplied to the cathode. Therefore when hydrogen is supplied to anode, the catalyst in electrode gets separated between the negatively charged electrons of hydrogen from and positively charged ions. In this case, addition of fuel cells acts as a backup generation when the other sources are unavailable.

IV. CONTROL TECHNIQUES

Controlling the generated Solar and Wind Power forms the crucial part of this work. Maximum power point tracking algorithm is used to control and keep the power at its maximum value. Perturbation and Observation algorithm is used for this purpose. Machine side Voltage Source Controllers (MVSC) and Load side voltage source controller (LVSC) are used for the extraction of maximum power which are described below:

4.1 Composite Sliding Mode Controller (CSMC) for MVSC

The schematic diagram of CSMC technique is shown in Fig. 7. The CSMC is used utilized in the MVSC for extraction of maximum power from WEGS by tracking reference shaft speed which is generated according to variable wind speed with an extra capability of disturbance reimbursement [5] & [6]. The SMC which has irregular switching control scheme with gain greater than the upper limit of lump disturbance of the system, that provides robustness in presence of parameter discrepancy and the lumped disturbances. But, it introduces chattering due to use of irregular signum function and the selection of high value of gain. The aforesaid problem can be dealt using online lumped disturbance estimator which uses a sliding mode observer. The observed disturbance can be then included in control loop as a feed-forward term. Hence, the chosen sliding mode gain in speed control loop must be higher than disturbance error that is very smaller from that of the preceding selected gain. This contributes to attain better performance with minimized chattering. As disturbance observer loop is very much advantageous, a CSMC is proposed. It is comprised of two controllers namely, Non-singular Terminal Sliding Mode Controller (NTSMC) based speed control loop and a Soft Switching Sliding Mode Observer (SS-SMO) based disturbance observer loop. As discussed in the previous section the controller section involves a dq controller which converts the 'abc' parameters as shown in the figure 6, and a two level, three phase hysteresis controller is also used to control the value of a current which reacts suddenly to any deviations in input signal and increases the value of gain. And a MPPT (P&O) algorithm is also used that records the value of input current and voltage and controls the value of duty cycle that avoids the intermittent nature of wind power and maintains the power at maximum value. The whole control system for controlling the wind speed is given in figure 7 below:

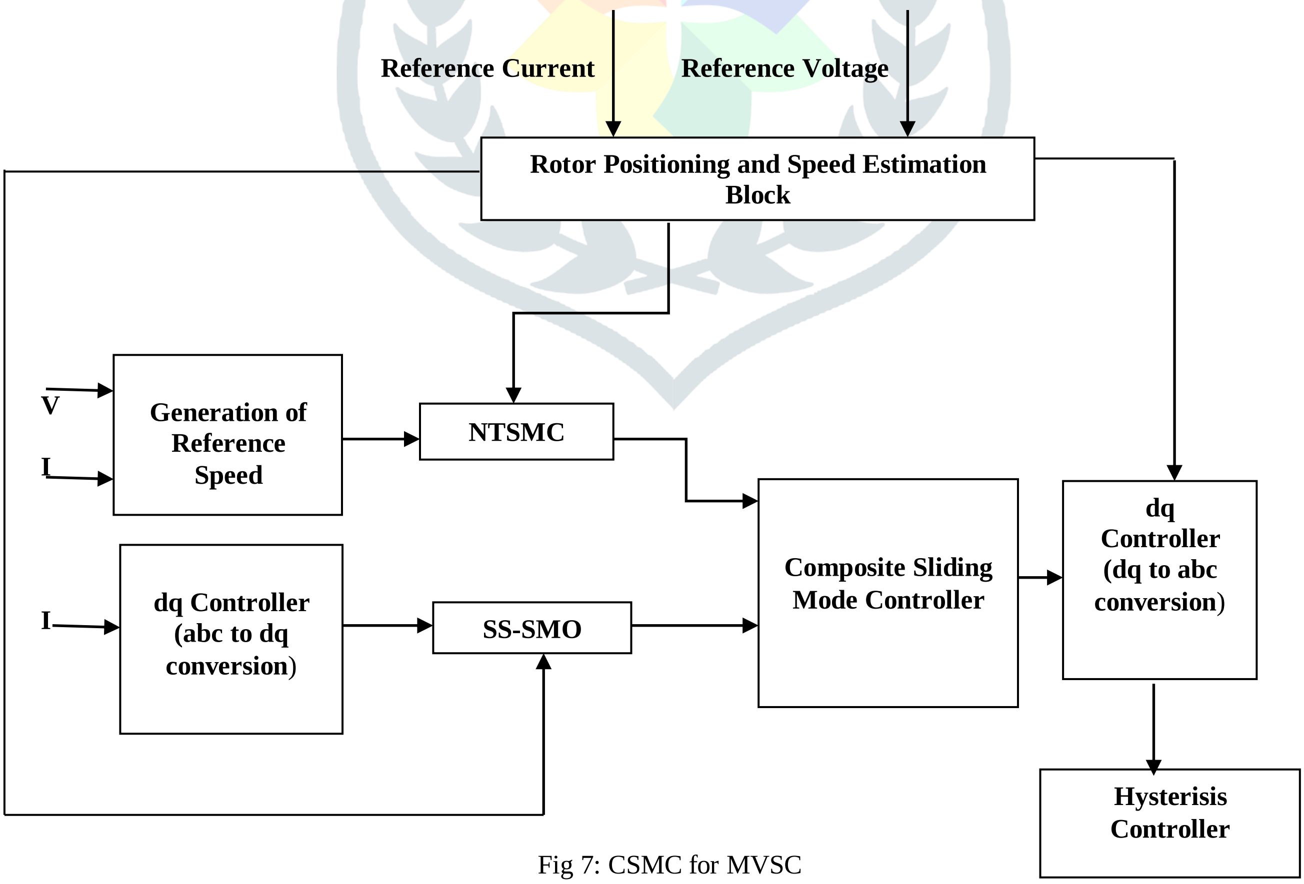

Fig 7: CSMC for MVSC

4.2 Perturbation and Observation

This algorithm is also known as 'Hill Climbing Method'. This MPPT technique records the PV array voltage (Vpv) and current (Ipv) as inputs and duty ratio is generated for boost converter switch as shown in fig 8. The whole operation of this algorithm is shown in the figure below [2]:

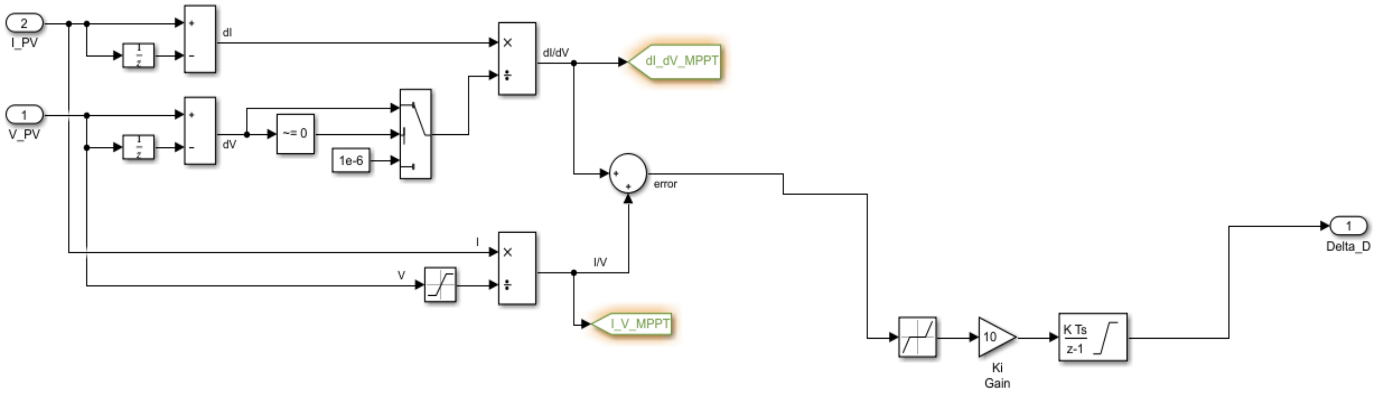

Fig 8: Simulation Model of MPPT Controller

V SIMULATION MODEL

The simulation model for the Grid Connected Solar PV-Wind-Fuel Cell Hybrid System is shown in the figure 9. The three various energy systems are connected at a common point as shown in fig 9. The MPPT's for solar and wind has been connected separately. The block MVSC, is the controller for the Variable Wind Speed which was discussed in section 4. Four Fuel Cells have been connected in series to a boost controller and connected to the same DC link which is followed by a 3 level inverter bridge and now this AC voltage is supplied to the filters to remove harmonics and from there the load and grid are connected. The main aim of this paper is maximum power extraction which is achieved by the various control techniques that have been discussed in the previous section. The power will be supplied first to the load and the excessive generation is sent to the grid which supplies it back to the load when the solar and wind fail to supply power to load due to their unavailability and since the fuel cells operate continuously, some power will always enter the grid and this power can be used for distributed generation purposes.

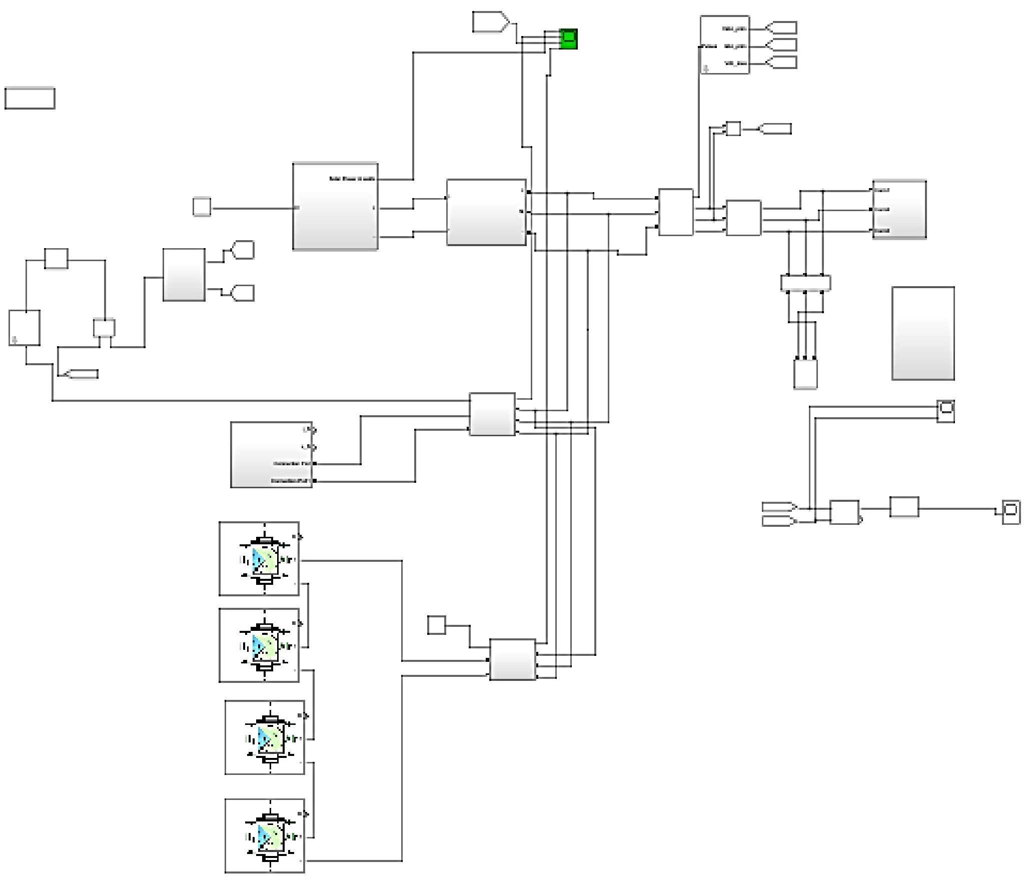

Fig 9: Simulation Model for the Grid Connected Solar PV-Wind-Fuel Cell Hybrid System

VI. RESULTS AND DISCUSSION

6.1 Simulation Result of Solar Power

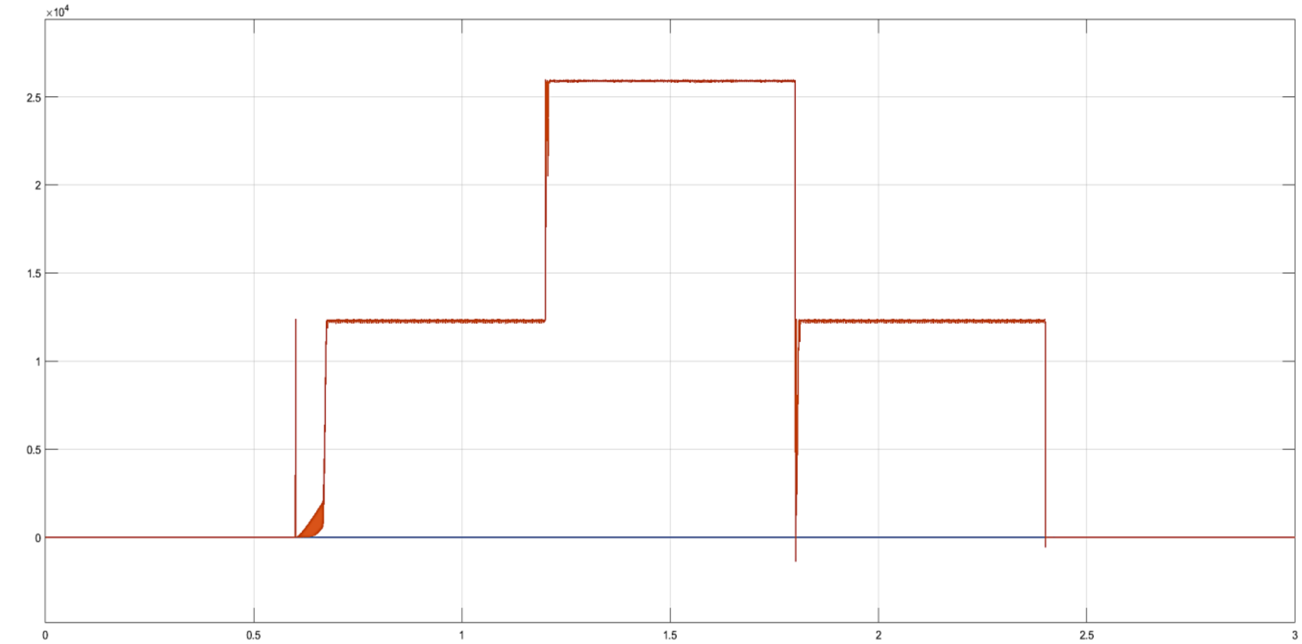

Fig 10 Simulation Result of Solar Panel

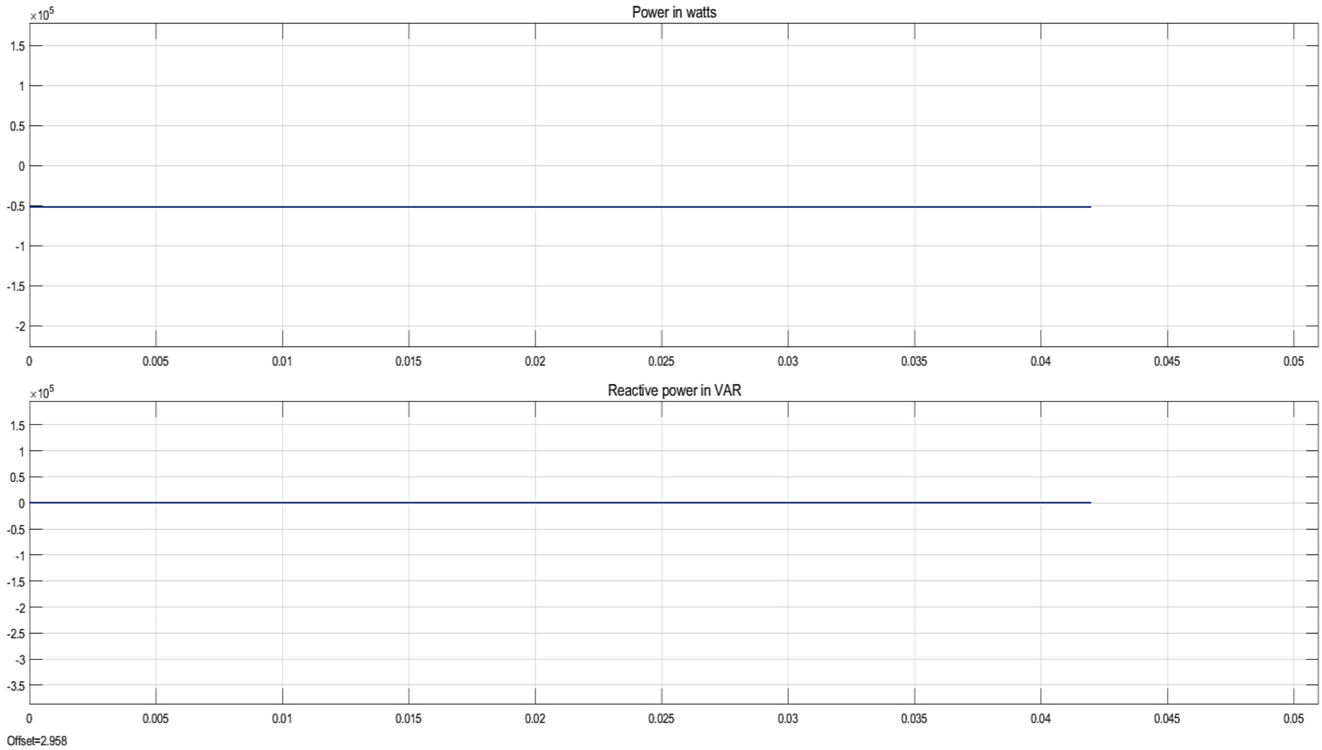

Fig 11. Simulation Result of Grid Power when only Solar is used

The total load that has to be supplied is 30kW. In figure 10, the output power of solar panel is shown whose maximum peak is 25kW. When only solar is used to supply the total load, during its unavailability the total load has to be supplied by the grid, that is total 30kW has to be supplied by the grid. When the generation is at peak, Solar Panel Supplies 25kW to the load and the remaining 5kW has to be supplied by the grid. This standalone system is intermittently available.

6.2 Simulation Results of Wind Power

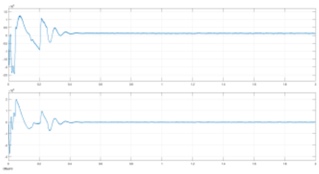

Fig 12. Simulation results of WEGS

Figure 12 shows the simulation result of WEGS. In the simulation figure shown above the first half is the simulation result of WEGS and second half is simulation result of grid. The graph in the negative section shows that the grid has to supply that amount of power to the grid. At its peak, wind supplies 20kW. In this case, the load sharing is same as that of solar and this system is also intermittently available.

6.3 Simulation Results of Fuel Cells

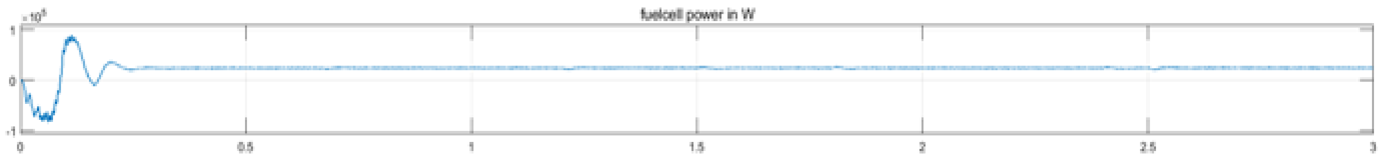

Fig 13. Simulation Result of Fuel Cells

Fuel cells are more advantageous than solar and wind systems as there are not intermittently available, they generate power continuously as long as the fuel is supplied. The simulation result of fuel cell is shown in fig 13. They generate 24kW continuously and the remaining 6kW is supplied by the grid.

6.4 Simulation Results of the Proposed System

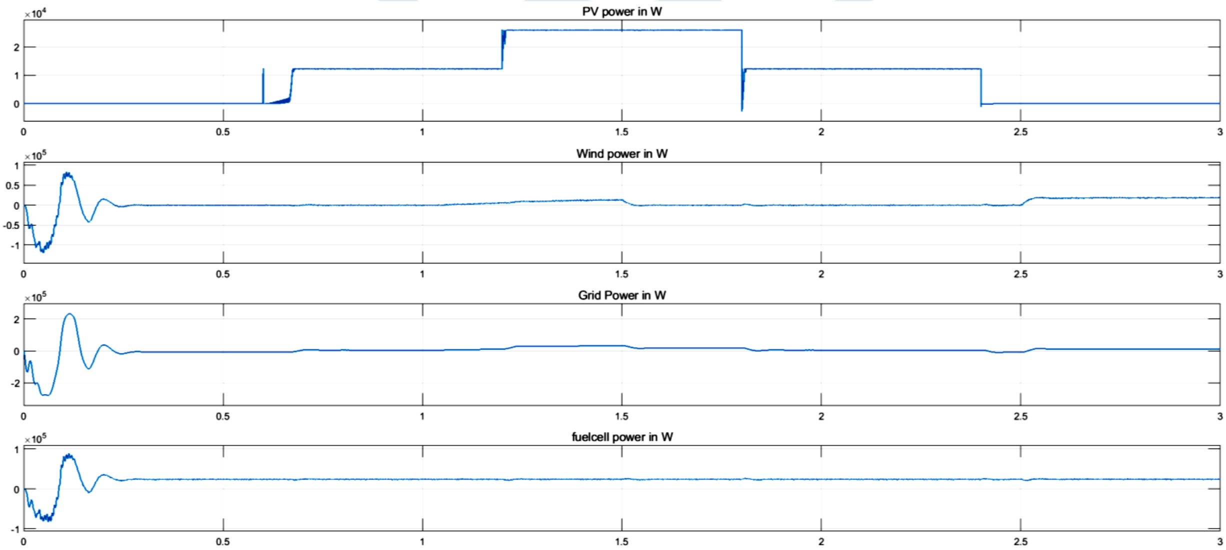

Fig 14. Simulation Result of Proposed System

When solar and wind are not available fuel cell and the grid are continuously supplying power as discussed in section 6.3. When wind is supplying around its peak that is, 20kW and the remaining power is supplied by fuel cell only, and the remaining 14kW that is, excessive generation of the Fuel Cell is sent to the Grid. When Solar is at it's peak as shown in the above fig 14, wind is supplying around 14kW, these two can supply the total load power and the remaining excessive generation which is around 30kW is sent to the grid and this excessive power can be utilized for Distributed Generation.

VII. CONCLUSIONS

In this paper, a Grid Connected Solar PV-Wind-Fuel Cell Hybrid System methodology has been proposed to electrify a rural area. The problems dealt with Solar and Wind Generating Systems have been explained in detail. A common DC link is maintained for regulation of generated voltage. Various others control technologies like P&O algorithm, Composite Sliding Mode Controller at the MVSC side have been used for the extraction of Maximum Power from these systems. All these technologies have been discussed clearly in this paper. Advantages of adding Fuel Cells to Solar PV-Wind Hybrid System have been mentioned in this paper. From the result section, it is evident that addition of fuel cells to renewable energy systems increases the reliability and efficiency of that system. Along with these advantages, this distributed generation system has economical benefits as the extra generated power can be sold back to the utility grid which can be used to electrify other areas.

REFERENCES

[1] M. M. R. Singaravel and S. A. Daniel, "MPPT with Single DC–DC Converter and Inverter for Grid-Connected Hybrid Wind-Driven PMSG–PV System," *IEEE Trans. Ind. Electr.*, vol. 62, no. 8, pp. 4849- 4857, Aug. 2015.

[2] M. Rezkallah, A. Hamadi, A. Chandra and B. Singh, "Design and Implementation of Active Power Control with Improved P&O Method for Wind-PV-Battery based Standalone Generation System," *IEEE Trans. Ind. Electr.*, vol. 65, no. 7, pp. 5590-5600, July 2018.

[3] X. Zhang, L. Sun, K. Zhao, and L. Sun, "Nonlinear speed control for PMSM system using sliding-mode control and disturbance compensation techniques," *IEEE Trans. Power Electr.*, vol. 28, no. 3,pp. 1358_1365, Mar. 2013.

[4] A. Merabet, K. T. Ahmed, H. Ibrahim; R. Beguenane, A. M. Y. M. Ghias,"Energy Management and Control System for Laboratory Scale Microgrid Based Wind-PV-Battery," *IEEE Trans. Sustain. Energy*, vol. 8,no. 1, pp. 145-154, 2017.

[5] V. Yaramasu, A. Dekka, M. J. Durán, S. Kouro and B. Wu, "PMSGbased wind energy conversion systems: survey on power converters and controls," *IET Electric Power Appl.*, vol. 11, no. 6, pp. 956-968, 2017.

[6] N. A. Orlando, M. Liserre, R. A. Mastromauro, and A. D. Aquila, "A Survey of Control Issues in PMSG-Based Small Wind-Turbine Systems," *IEEE Trans. Ind. Inform.*, vol. 9, no. 3, pp. 1211–1221, Aug. 2013.

[7] S. Li, M. Zhou and X. Yu, "Design and Implementation of Terminal Sliding Mode Control Method for PMSM Speed Regulation System," *IEEE Trans. Ind. Inform.*, vol. 9, no. 4, pp. 1879-1891, Nov. 2013.

[8] H. M. Al-Masri and M. Ehsani, "Feasibility Investigation of a Hybrid On-Grid Wind Photovoltaic Retrofitting System," *IEEE Trans. Ind. Appl.*, vol. 52, no. 3, pp. 1979-1988, May-June 2016.

[9] J. G. de Matos, F. S. F. e Silva and L. A. d. S. Ribeiro, "Power Control in AC Isolated Microgrids With Renewable Energy Sources and Energy Storage Systems," *IEEE Trans. Ind. Electr.*, vol. 62, no. 6, pp. 3490- 3498, June 2015.