Modeling and MPPT Control of Hybrid WIND/PV/Fuel Cell Unit Energy Sources for Distributed Generation

D L Manoj Kumar [1] ,Dr. G.V.S.Krishna rao[2]

[1] *M.Tech scholar,Electrical Engineering,Andhra University,India*
[2] *Professor,Electrical Engineering,Andhra University,India*

***

Abstract - ***The renewable energy sources are gaining popularity day by day as the fossil fuels required for conventional electrical energy production are getting depleted. Hence a new hybrid topology formed by the integration of wind turbine, photo-voltaic cell and a fuel cell unit is proposed. This hybrid system consisting of these three sources is operated in parallel and any one of these sources can meet load demand depending on the availability from each source. Here the battery is provided as a regulating mechanism for ensuring continuous power supply to the load. This regulatory mechanism is done with the help of a battery controller. The battery controller action and the control action for the wind and the photovoltaic is discussed in this paper and the load sharing between these sources is explained with the help of simulated graphs. Here a load is taken that varies with time and the control topology mechanism is explained. This type of energy generation can be utilised for distributed generation.***

Key Words: *dc-dc buck boost converter, mppt tracking, pulse width modulated inverter control, pv array, wind turbine, PMSG(permanent magnet synchronous generator).*

1.INTRODUCTION

The world today is facing energy crisis as each and every aspect in present modernization is related to the generation of electric power. The main thing is that the conventional sources of energy are very limited in nature so the world is looking at the new sources for electrical energy production. Some studies reveal that the conventional energy sources may get exhausted in the near future. Also some of the conventional energy sources like coal and fossil fuels are not environment friendly.

So the research is being done on the generation of electrical power from non conventional sources of energy.

Some of the famous non renewable sources of energy are solar and the wind energy.

The generation of electric power from the above stated non conventional sources is somewhat relatively old. But the thing we are interested is that these sources are highly un-reliable. The main focus is to be laid to reduce the intermittent nature of these energy sources and allow continuous supply with minimum outages. There are many methods proposed in maintaining the continous supply to meet the load demand. The best among them is that is to provide a Battery energy storage system(BESS).By providing this one also has to ensure that these sources needed to be operated in such a way that the output from them should be maximum.

This paper deals with integration of wind turbine ,solar cell and a battery source to meet the load demand. The fluctuations in the power flow can be minimised by adopting a battery control scheme. The battery control scheme is explained here and the wind and the pv sources are operated at maximum power point by adopting perturb and observe algorithm.

The perturb and observe method is adopted because of its simplicity and accuracy, the load demand varies with time and the load sharing action is shown with the help of simulated graphs.

2. CONFIGURATION OF HYBRID SYSTEM

The proposed system consists of three energy sources i.e: wind,pv and battery are as follows

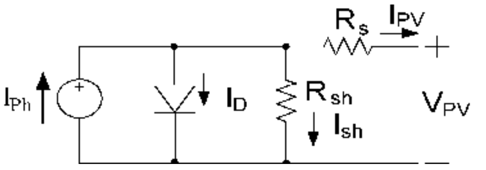
(i) Photo voltaic system - 9.5KW

(ii) Wind turbine - 8.5KW

(iii) Battery - 5 KW

2.1 PV array and its configuration

The photovoltaic cell is the basic component in a PV array. The combination of PV cells form a PV module and if these modules are integrated they form a array. The PV cell can be considered as an equivalent to a p-n junction diode as its function is nearly the same. When the sunlight is incident on the PV cell an electron hole pair is generated. These electrons cross the junction and thus electric field is created. This electric field results in the flow of electric current and which results in voltage across the PV array.



$$I_{PV} = I_{ph} - I_0(e^{\frac{q(V_{PV}+I_{PV}R_S)}{\eta kT}} - 1)$$

Here the series resistance R_s is very small and can be neglected and thus the above equation becomes

$$I_{PV} = I_{ph} - I_0\left(e^{\frac{qV_{PV}}{kT}} - 1\right)$$

where

I_{ph} - Photo current (A)

I_o - Diode reverse saturation current (A)

q -Electron charge = 1.6X10-19 (C)

k - Boltzman constant = 1.38X10-23 (J/K)

T - Cell temperature (K)

The power output of a solar cell is given by

$P_{PV} = V_{PV} * I_{PV}$

Where: I_{PV} = Output current of solar cell (A).

V_{PV}= Solar cell operating voltage (V).

P_{PV} =Output power of solar cell (W).

he power-voltage (P-V) characteristic of a photovoltaic

module operating at a standard irradiance of 1000 W/m2

and temperature of 25 ^{0}C is shown in Fig.1

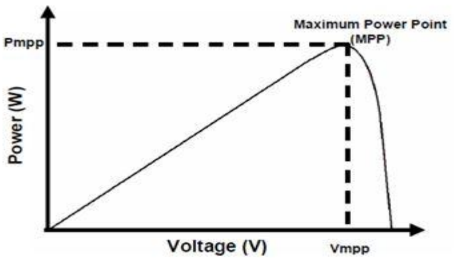


Fig. 1. Power-Voltage (PV) Characteristic of a PV Module

From the graph it can be observed that there is a particular point at which maximum power is obtained. This point is referred as maximum power point.

There are certain methods which can be useful to track this point and it is known as maximum power point tracking which will be explained later in this paper.

The P-V characteristics is dependent upon temperature and the value of irradiance.The graph below shows the variation of P-V characteristics with respect to irradiance. It is observed that as irradiance value increases the power output from a pv array increase.Hence it necessary that the solar panel receives maximum irradiance and to operate it near MPPT to obtain maximum output.

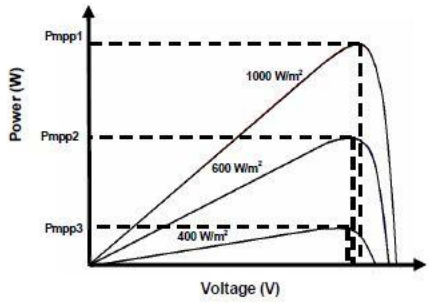


Fig. 2. Variation of P-V Characteristics of Photovoltaic Module

2. 2 Wind Turbine and its Configuration:

The wind turbine like pv cell cannot produce electric field that results in electric current. It produces the mechanical torque. Hence the turbine should be coupled to an generator that results in the production of electric current. The mechanical output from the wind turbine is given as follows

$$P^{M}_{MAX}=0.5*\pi*\rho*(C_P^{MAX}/\lambda^3_{OPT})\ \omega_M^3$$

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 air density are constant then then the output power is a function of power co-efficient of wind turbine(Cp). The speed tip ratio of wind turbine is given as

$$\lambda=(\omega R)/v$$

ω , R and v are the turbine rotor speed in “rad/s”, radius of the turbine blade in “m”, and wind speed in “m/s” respectively.

The C_p vs λ characteristics of a wind turbine is as follows.

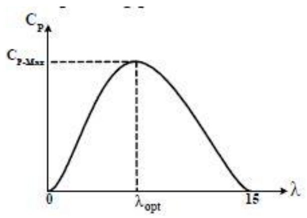


Fig 3: Power Coefficient vs. Tip-Speed Ratio.

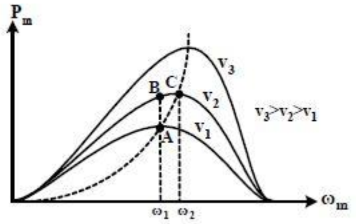


Fig. 4. Output Power vs. Rotor Speed for Three Different Wind Speeds

The above graphs show that as the wind speed increases there will be corresponding change in the output power. Similar to that of PV cell the wind has also a particular value of λ for power output from the turbine is maximum. This is termed as optimum value of λ denoted by $\lambda_{opt.}$. Fig. 4 shows that if the speed of wind is v1, then the maximum power could be captured when the rotor speed is ω1; in other words, the operating point of the system is point A, which corresponds to the maximum output power. Even if the wind speed changes from v_1 to v_2 if the rotor speed remains at w_1 then the operating point remains at B. This does not correspond to the maximum output power tracking. The maximum power tracking point is obtained at point c.

2.3. Fuel Cell System

A fuel cell consists of an electrolyte and two catalyst coated electrodes. The electrodes are a porous cathode and anode located on either side of the electrolytic layer.

Gaseous fuel (usually hydrogen) is fed continuously to the anode and the oxidant (i.e. oxygen from air) is fed to the cathode). Thus when hydrogen is fed to the anode, the catalyst in the electrode separate the negatively charged electrons of the hydrogen from the positively charged ions.

3. Maximum Power Point Tracking

As said earlier both the wind turbine and the photovoltaic array must be adjusted to operate at their point of maximum power. Many different maximum power point tracking (MPPT) algorithms like perturbation observation method, incremental conductance method have been developed and widely used for such systems. The perturbation observation method is adopted in this paper for both the wind turbine and the photovoltaic array for it simplicity and accuracy.

The algorithm starts by choosing an initial reference rotor speed for the wind turbine and an initial reference voltage for the photovoltaic array. The corresponding output powers of the two systems are measured. If this power does not correspond to their maximum powers, then their initial reference values are incremented or decremented by one step.

If this adjustment leads to an increase in their output powers then the next adjustment is made in the same direction and vice-versa. The above steps are repeated till the maximum power points of the wind turbine and photovoltaic array are reached.

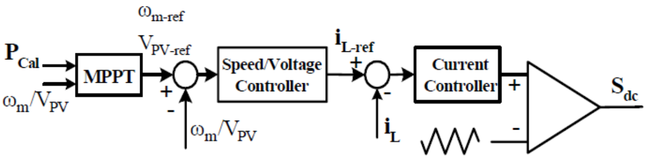


Fig 5:Control Topology of dc-dc Boost Converter for Max.

Power Point Tracking of Wind and Photovoltaic Sources.

The control topology for perturb and observe method is as shown in the above figure. Here a comparator is used to compare the values with ease without actually applying the MATLAB code.

3.1. Battery Control

The primary goal of the battery converter is to regulate the common dc-bus voltage. The battery load current rapidly changes according to changes in weather conditions and power command for grid inverter in dispatching or averaging mode of operation. Common dc-bus voltage must be regulated to stay within a stable region regardless of the battery-current variation. To do this, a modified hysteresis-control strategy is applied. The concept of this strategy is to regulate the common dc voltage within a specific band, for example, a hysteresis band. Therefore, the battery charger/discharger is controlled in such a way that the dc-bus voltage should not violate the specified upper and lower limits, V_{dc_up} and V_{dc_lw}.

A decision criterion for charging/discharging becomes the level of the common dc-bus voltage, and the battery buck–booster operates according to the scheme as below:

if $V_{dc} > V_{dc\text{-}up}$ then charging $V_{dc}^* = V_{dc\text{-}up}$

if $V_{dc} < V_{dc\text{-}lw}$ then discharging $V_{dc\text{-}lw} = V_{dc}^*$

if $V_{dc\text{-}lw} <= V_{dc} <= V_{dc\text{-}up}$ then no control(rest)

When the common dc voltage *Vdc* becomes larger than the upper limit, charging mode begins with the voltage command V^*dc equal to the upper limit and continues until the dc voltage reaches the limit. If V^*dc goes below the lower limit, then the voltage target is bound at the lower limit and the converter starts operating in boost mode. Accordingly, the battery-mode control block can be built.

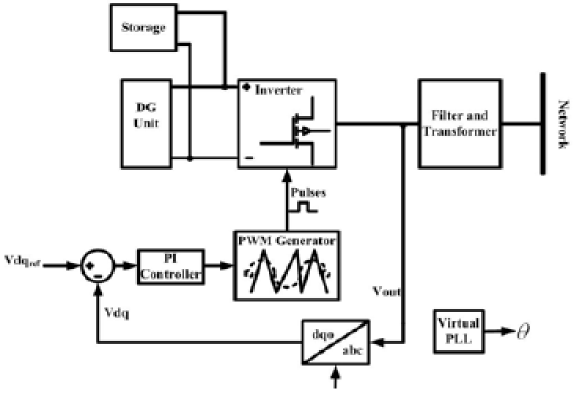
There is another reason for such hysteresis control other than voltage regulation of the dc bus. It is intended to protect the battery storage against excessive charging frequency and current variation. Not by bounding dc-bus voltage at a constant value but by allowing a hysteresis band; the battery can take a rest during the rest interval in Fig. 6. Energy that can be extracted or stored across the hysteresis band in a dc-bus capacitor ΔEC is described as follows:

$$\Delta E_c = 0.5 * C_{dc} * (V_{dc\text{-}up}^2 - V_{dc\text{-}lw}^2)$$

This energy gap is utilized for balancing PV, wind, and grid injection without use of the battery. Cdc is the capacitance of the common dc bus.

3.2. Vf Inverter Control

This controller has to act on the inverter whenever the system is in stand-alone mode of operation. In fact in this case it must regulate the voltage value at a reference bus A regulators work in order to keep the measured voltages upon the set points. Moreover the frequency is imposed through the modulating signals of the inverter PWM control by mean of an oscillator. A simple PI controller can regulate bus voltage in reference value with getting feedback of real bus voltage. Figure outlines this control strategy. In this case it is obvious that the DG unit should have storage device in order to regulate the power and voltage.



. Figure 6: Vf control scheme of inverter

SIMULATION:

The proposed simulink model as explained above consists of the three sources the wind turbine, PV array and the battery or fuel cell unit. To mitigate the power fluctuations a battery controller is provided. A dc -dc converter is also provided.

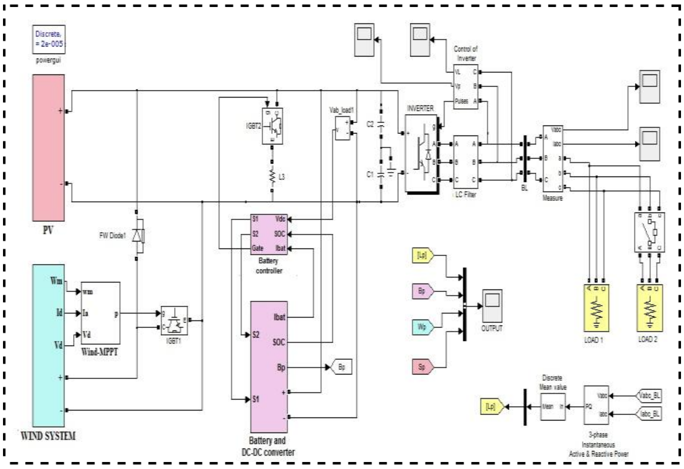


Fig 7 :overall simulink diagram of proposed model

An inverter is also present at the load side. The inverter is controlled with the help of pulse width modulator. The inverter acts as an interface between the dc side and the ac side. The main function of the inverter is convert the dc power produced from the three sources into ac power. These sources need to meet the load of 10 KW. An additional load of 5 KW is added by means of a circuit breaker. Then the load sharing action between these three sources is observed with the help of simulated graphs.

4.RESULTS:

The three sources are subjected to changes as explained in the table. The solar irradiance is varied as a step input and the wind turbine is made to attain its maximum speed after 0.5 secs. An additional load of 5 KW is added at the 4th second of operation of the hybrid system i.e ;the load is increased by 40%.

TABLE 1 Life Cycle Of Hybrid System

TIME	**Characteristics**
0-1s	1) Solar energy with full irradiance 2) Wind Turbine tends towards base speed of 12m/s after 0.5 s 3) Battery gives partial supply to load 4) Load is 10 KW
1-2s	1) Wind achieves 5.6 KW 2) Battery stores 5 KW
2-3s	1) Solar Energy Reduced by 15 % 2) Battery stores 3.5 KW
3-4s	1) Wind speed decreases by 25 % to 9m/s 2) Battery gives partial supply to load
4-5s	1) Load is increased by 40 % 2) Battery is responsible to overcome 40 % load demand
5-6s	Load demand comes to previous point

The load sharing action is explained with the help of following graphs.

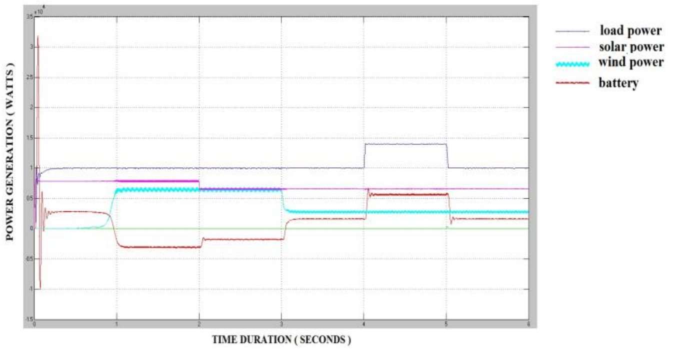


Fig 8 Load Sharing Action Performed by the the Hybrid Energy

This graph is explained with the help of table 2.

TABLE 2 Load Sharing Between Solar & Wind Systems Supported By Battery

TIME (sec)	LOAD (× 10^4) W	SOLAR (× 10^4) W	WIND (× 10^4) W	BATTERY POWER (× 10^4) W	BATTERY ACTION	REMARKS
$0-1$	1	0.92	0 (0-0.8 s)	+0.08	Supplying	G < L
		0.92	0.03 (0.8 s)	+0.05		
$1-2$	1	0.94	0.56	−0.5	Charging	G > L
$2-3$	1	0.78	0.56	−3.4	Charging	G > L
$3-4$	1	0.78	0.2	+0.02	Supplying	G ≤ L
$4-5$	1.4	0.78	0.2	+4.2	Supplying	G < L
$5-6$	1	0.78	0.2	+0.02	Supplying	G ≤ L

GRAPHS:

- The load demand to fulfill is 10 KW throughout the time scale except at 4 to 5 sec when it increases to 14 KW.
- Solar energy drops its irradiance to 15 % from 2 sec.
- Wind turbine initially rotating at 5m/s excels to base speed 12m/s after 0.5 sec. It's rotating speed is decreased to 25 % of its base speed.
- All these conditions are clearly observed in the below graph.

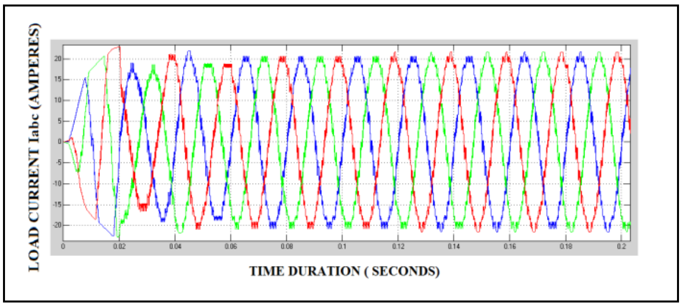


Fig 9 The load current supplied to the load is sinusoidal in nature as depicted in the simulation

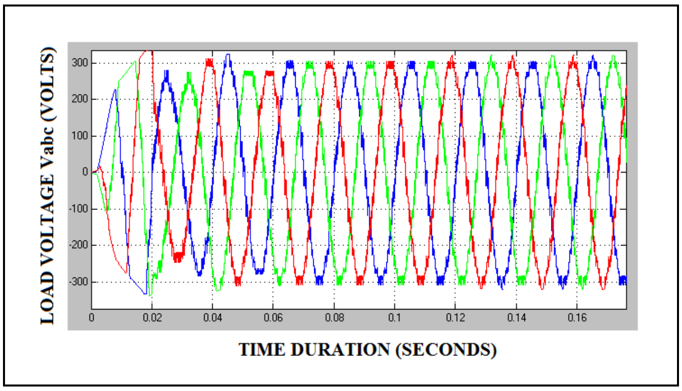


Fig 10 Three Phase Voltage Supplied To The Load By The Inverter

These results hence summarise the proposed model.

5. CONCLUSIONS

In this paper load demand is met by PV array ,wind turbine and battery. An inverter is used to convert output from solar and wind systems in ac output power. An additional load of 4KW is added by the circuit breaker. This whole mechanism is regulated by battery control. It uses bidirectional buck boost DC converter which charges and discharges according to the control signal. The final load voltages and current are obtained.

6. REFERENCES

[1] J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galvan, R. C. P. Guisado, Ma. A. M. Prats, J. I. Leon, and N. Moreno-Alfonso, “Power-electronic systems for the grid integration of renewable energy sources: a survey,” *IEEE Trans. Ind. Electron.*, vol. 53, no. 4, pp. 1002– 1016, Aug. 2006.

[2] L. N. Khanh, J.-J. Seo, T.-S. Kim, and D.-J. Won, “Power-management strategies for a grid-connected PV-FC hybrid system,” *IEEE Trans. Power Deliv.*, vol. 25, no. 3, pp. 1874–1882, Jul. 2010.

[3] Y. K. Tan and S. K. Panda, “Optimized wind energy harvesting system using resistance emulator and active rectifier for wireless sensor nodes,” *IEEE Trans. Power Electron.*, vol. 26, no. 1, pp. 38–50, Jan. 2011.

[4] J.-M. Kwon, K.-H. Nam, and B.-H. Kwon, “Photovoltaic power conditioning system with line connection,” *IEEE Trans. Ind. Electron.*, vol. 53, no. 4, pp. 1048–1054, Aug. 2006.

[5] J. Selvaraj and N. A. Rahim, “Multilevel inverter for grid-connected PV system employing digital PI controller,” *IEEE Trans. Ind. Electron.*, vol. 56, no. 1, pp. 149–158, Jan. 2009.

[6] J.J. Brey, A. Castro, E. Moreno and C. Garcia, "Integration of Renewable Energy Sources as an Optimised Solution for Distributed Generation," *28th Annual Conference of the Industrial Electronics Society 2002,* vol. 4, 5-8 Nov. 2002 T.-F. Wu, K.-H. Sun, C.-L. Kuo, and C.-H. Chang, “Predictive current controlled 5 kWsingle-phase bi-directional inverter with wide inductance variation for

[7]DC-microgrid applications,” *IEEE Trans. Power Electron.*, vol. 25, no. 12, pp. 3076–3084, Dec. 2010.

[8] R. D. Middlebrook, “Small-signal modeling of pulse-width modulated switched-mode power converters,” in *Proc. IEEE*, Apr. 1988, vol. 76, no. 4, pp. 343–354.

[9] M. T. Zhang, “Powering Intel Pentium 4 Generation Processors,” in *Proc. Intel Technol. Symp.*, 2001, pp. 215–218.

BIOGRAPHIES

Prof. Dr. G.V. Siva Krishna Rao received B.E., and M.Tech., degrees in Electrical engineering, from Sri Venkateswara Univerisity, Tirupathi, AndhraPradesh, and Ph.D degree from Andhra University AndhraPradesh, India. Since 1994 he has been with the Department of Electrical Engineering, Andhra University, where he is currently a Senior Professor. His research interests have been in Power Systems and Automation, Control Systems, HVDC, and High Voltage Engineering and their industrial applications.

Mr.D.L Manoj Kumar completed his B.Tech in Electrical Engineering under B.Tech+ M.Tech 5 year dual degree programme. Currently he is pursuing M.Tech with Specialization in Power System and Automation under the same programme in the Department of Electrical Engineering, AU College of Engineering, Andhra University, Andhra Pradesh, India.