A MPPT Algorithm For Hybrid Photo-Voltaic And Wind Energy Conversion System

GUNDALA SRINIVASA RAO[1] NARESH CH[2] NARENDER REDDY NARRA[3]

Abstract

This paper proposes a hybrid energy conversion system combing photovoltaic and wind turbine as a small-scale alternative source of electrical energy where conventional generation is not practical. The hybrid system consists of photovoltaic panels, wind turbines and storage batteries. The wind and PV are used as main energy sources, while the battery is used as back-up energy source. Two individual DC-DC boost converters are used to control the power flow to the load. A simple and cost effective control with DC-DC converter is used for maximum power point tracking (MPPT) and hence maximum power is extracted from the wind turbine and the photo voltaic array. The modelling of hybrid system is developed in MATLAB- SIMULINK.

Keywords- *Renewable systems, PV panel, wind turbine, Maximum Power Point Tracking (MPPT)*

1. Introduction

With exhausting of traditional energy resources and increasing concern of environment, renewable and clean energy is attracting more attention all over the world to overcome the increasing power demand. Out of all the renewable energy sources, Wind energy and solar energy are reliable energy sources. However, the renewable energy generation has a drawback that the change of the output characteristic becomes intense because the output greatly depends on climatic conditions, including solar irradiance, wind speed, temperature, and so forth. In this paper, combining the photovoltaic generation with wind power generation, the instability of an output characteristic each other was compensated. Photovoltaic generation and wind generation use Maximum Power Point Tracker (MPPT). The Wind-solar complementary power supply system is a reasonable power supply which makes good use of wind and solar energy. This kind of power supply system can not only provide a bargain of low cost and high dependability for some inconvenient regions. In addition, the Wind/Solar complementary generation is more economical than a single PV or wind power generation in terms of both the cost and the protection of energy storage components. [5][6]

In stand- alone systems, sizing is extremely important since an adequate design lead to an efficient operation of the components with a minimum investment. So, the objective of this process is to achieve a system with the best compromise between the reliability and cost. However this is not easy because the resources and the load behave in a very random way. For this purpose, continuous effort to develop more attractive systems with lower-cost, higher-performance and multi-functions. [5][6]

Section 1 explains about the introduction to wind and solar energy, section 2 briefs about Solar Photo Voltaic System, section 3 briefs about wind energy conversion system, section 4 explains the proposed Hybrid Photovoltaic and Wind system, section 5 shows the simulation results of the hybrid system and finally Section 6 gives the conclusions and future scope of this work.

2. Modeling of Photo-Voltaic Energy Conversion System

The construction of PV cell is very similar to that of the classical diode with a p-n junction formed by semiconductor material. When the junction absorbs light, the energy of absorbed photon is transferred to the electron-proton system of the material, creating charge carriers that are separated at the junction. The charge carriers in the junction region create a potential gradient, get accelerated under the electric field, and circulate as current through an external circuit. The solar cell is the basic building of the PV power system it produces about 1 W of power. To obtain high power, numerous such cell are connected in series and parallel circuits on a panel (module), The solar array or panel is a group of a several modules electrically connected in series-parallel combination to generate the required current and voltage. The electrical characteristics of the PV module are generally represented by the current vs. voltage (I-V) and the Power vs. Voltage (P-V) curves. [1]

The equivalent circuit of solar cells shown in Figure.1, the radiation dependent V-I characteristic of N_s series cell and N_p parallel modules can be represented by:

$$I = nI_{SC} - N_P I_0 \left(exp \left[\frac{V_A + I_A R_S}{n N_S V_T} \right] - 1 \right) \qquad (1)$$

$$V = N_S \left(\frac{AKT}{q} \right) \left[\frac{N_p I_{sc} - I + N_p I_D}{N_p I_D} \right] - \frac{N_s}{N_p} I R_s \qquad (2)$$

Where I is output current of PV array(A), I_{SC} is short circuit current of PV module (A), I_0 is diode saturation current (A) , V_A is terminal voltage of PV array (V) , R_S is series resistance (Ω) , n is ideal constant of diode, V_T is thermal potential of PV module (V) , q is electron charge (C) , is k Boltzmann constant $\left({}^{J}/_{o_K} \right)$, A is p-n junction material factor and T is temperature (o_K) [1][2].

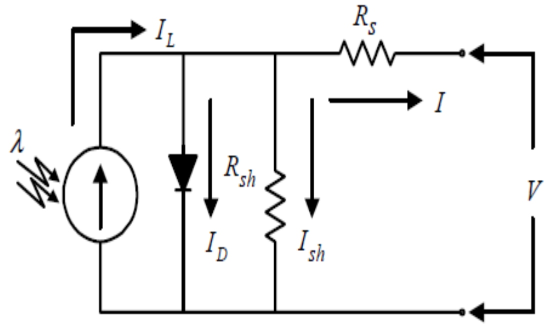

Figure 1 Equivalent circuit of PV module

Figure 2 Shows the I-V characteristics and Figure 3 shows the P-V characteristics of the photovoltaic module at different solar illumination intensities. The I-V characteristic of the solar PV decreases gradually as the voltage goes up and when the voltage is low the current is almost constant. The power output of the panel is the product of the voltage and current outputs. The PV module must operate electrically at a certain voltage that corresponds to the peak power point under a given operation conditions.[1]-[5]

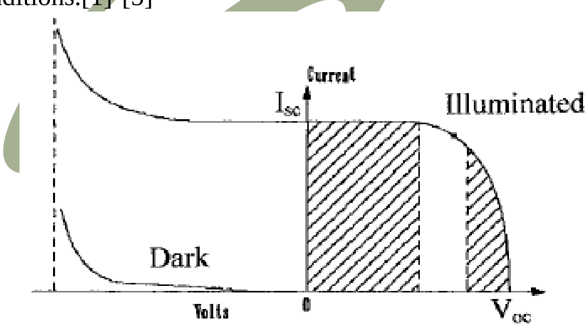

Figure 2. I-V characteristics of PV module

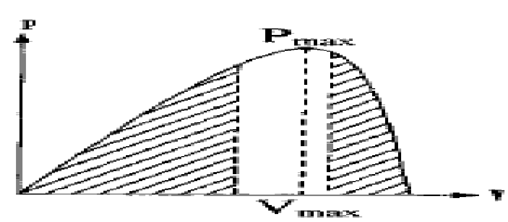

Figure.3. P-V characteristics of PV module

The PV array must operate electrically at a certain voltage which corresponds to the maximum power point under the given operating conditions, i.e. temperature and irradiance. To do this, a maximum power point tracking (MPPT) technique should be applied. Various MPPT techniques like look-up table methods, perturbation and observation (P & O) methods and computational methods have been proposed in the literature. The perturbation and observation (P&O)

method has been used in this work. If the array is operating at voltage V and current I, the operation point toward the maximum power point by periodically increasing or decreasing the array voltage, is often used in many PV systems. The advantage of this method is that it works well when the irradiation does not vary quickly with time, however, the P&O method fails to quickly track the maximum power points. In incremental conductance method the maximum power points are tracked by comparing the incremental and instantaneous conductance values of the PV array. Figure 4 presents the flow of the perturbation and observation technique implemented. [4][5].

For most PV modules, the ratio of the voltage at the maximum power point for different insulation levels to the open circuit voltage is approximately constant. Also, the ratio of the current at the maximum power point for different insulation levels to the short circuit current is constant. If the direction of the perturbation i.e an increase or decrease in the output voltage of a PV array results in a positive change in the output power, then the control algorithm will continue in the direction of the previous perturbation. Conversely, if a negative change in the output power is observed, then the control algorithm will reverse the direction of the pervious perturbation step. In the case that the change in power is close to zero (within a specified range) then the algorithm will invoke no changes to the system operating point since it corresponds to the maximum power point (the peak of the power curves). The MPPT technique proposed in this work makes use of a predetermined relationship between the operating voltage or current and the open circuit voltage/short circuit current to obtain MPPT at any operating conditions.

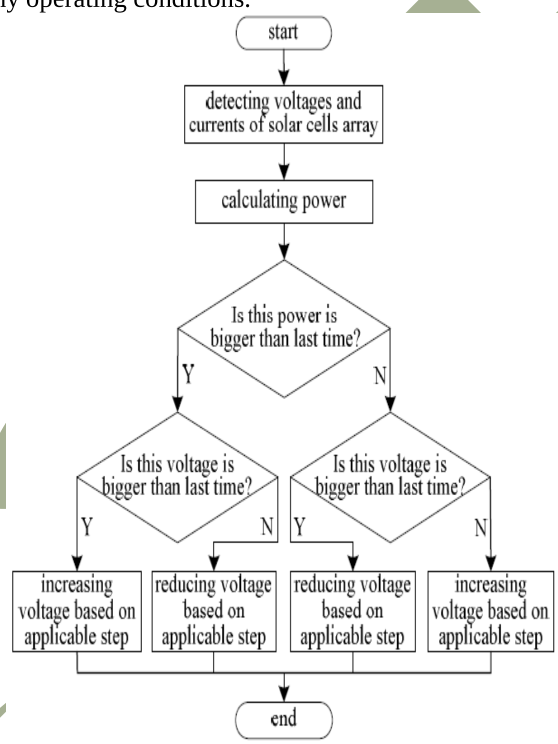

Figure 4. Flow chart of the MPPT technique

3. Modeling of Wind Energy Conversion System

The aerodynamic torque(T_m) and mechanical power (P_m) generated by a wind turbine is given by equation (3) and equation (4) respectively

$$T_m = \frac{1}{2} C_t(\lambda, \beta)\rho\pi R_r^3 V_w^2 \quad (3)$$

$$P_m = \frac{1}{2} C_p(\lambda, \beta)\rho\pi R_r^2 V_w^3 \quad (4)$$

Where P_m is the power in watts, ρ is the air density in g/m^3,C_P a dimensionless factor called power Coefficient, A_r the turbine rotor area in m^2($A_r = \pi R_r^2$, where R_r is the rotor blade radius), η_{gear} is and V_w the wind speed in m/s. The power coefficient is related to the tip speed ratio (λ) and rotor blade pitch angle $\boldsymbol{\beta}$ according to equation (5)

$$Cp(\lambda,\beta) = 0.73\left(\frac{151}{\lambda i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right)e^{\frac{-18.4}{\lambda i}} \quad (5)$$

Where

$$\lambda_i = \frac{1}{\frac{1}{\lambda - 0.02\beta} - \frac{0.003}{\beta^3+1}} \quad (6)$$

and

$$\lambda = \frac{\omega_r R_r}{V_w} \quad (7)$$

$$C_t = \frac{C_p}{\lambda}$$

In equation (7), ω_r is the angular speed of the turbine shaft. The theoretical limit for C_P is 0.59 according to Betz's Law, but its practical range of variation is 0.2-0.4. [8]

Power from the wind turbine, real and reactive power, is basically controlled by the wind-side converter and stalled by the wind blade. Below rated wind speeds, the real power from the wind generator is regulated to capture the maximum wind energy from varying wind speed. Reactive power generation is maintained at zero to minimize the thermal rating of the generator and the converter. Above rated wind speeds the maximum power control is overridden by stall regulation for constant power. In this study, the wind blade is assumed to be ideally stall regulated at rated power so that rotor speed can keep constant at rated speed under high wind speeds.

The typical turbine torque vs. rotor speed and power vs. rotor speed characteristics are shown in Figure.5 and Figure.6 respectively. The maximum power for different wind speeds is generated at a different rotor speeds. Therefore, the turbine speed should be controlled to follow the ideal TSR, with an optimal operating point which is different for every wind speed. This is achieved by incorporating a speed control in the system design to run the rotor at high speed in high wind and at low speed in low wind. If it is to be used for system control based on equation (7), the optimum speed of the rotor can be estimated as:

$$\omega_{opt} = \frac{TSR_{opt}V}{R} \quad (8)$$

Typical, small-scale, stand-alone, wind electric system is composed of a variable speed wind turbine, Squirrel cage induction generator and a diode bridge rectifier. In many small-scale systems, the dc system is set at a constant dc voltage and is usually comprised of a battery bank which energy storage, a controller to keep the batteries from overcharging; and a load. The load may be dc or may include an inverter to an ac system. Connecting a wind generator to a constant dc voltage has significant problems due to the mismatching the poor impedance matching between the generator and the constant dc voltage (battery), which will limit power transfer to the dc system. In response to these problems, researchers have investigated incorporating a dc–dc converter in the dc link. The power conditioning system which governs entire power control of the hybrid system. Figure 5 presents the proposed power electronic based interface, which is composed of a wind-side dc/ac converter, a PV-side dc/dc converter, a common dc capacitor and a grid-side inverter.[4][5]

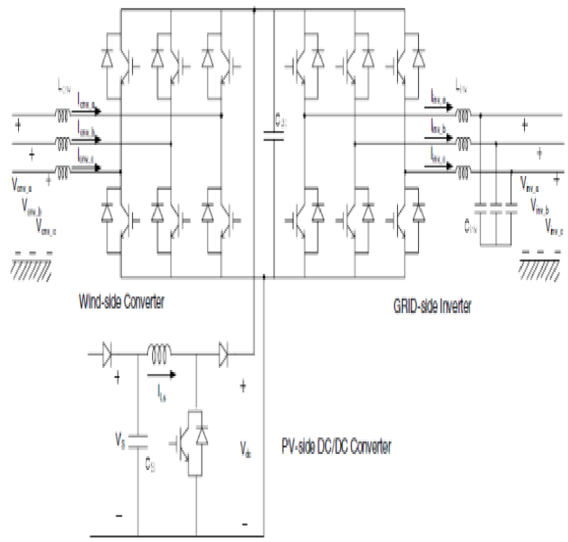

Figure 5 Power electronic interface of the hybrid system

Adjusting the voltage on the dc rectifier will change the generator terminal voltage and thereby provide control over the current flowing out of the generator. Since the current is proportional to torque, the dc–dc converter will provide control over the speed of the turbine. Control of the dc–dc converter can be achieved by means of a predetermined relationship between rotor speed and rectifier dc voltage to achieve maximum power point tracking or by means of a predetermined relationship between generator electrical frequency and dc-link voltage.

Using these methods the PV/WT hybrid generation system can supply almost good quality power. However, these methods have disadvantages that they require batteries, which are costly and the installation of dump load is not an efficient method to dissipate fluctuating power. Moreover, they can not guarantee certainty of load demands at all times especially at bad environmental conditions, where there is no power from the PV and WG systems.

4. Proposed Hybrid PV - Wind Energy Conversion System

The configuration of household hybrid wind and PV system is shown in Figure 6. This configuration is fit for stand-alone hybrid power system used in remote area. Wind and solar energy are converted into electricity and then sent to loads or stored in battery bank. The topology of hybrid energy system consisting of variable speed WT coupled to a permanent magnet generator (PMG) and PV array. The two energy sources are connected in parallel to a common dc bus line through their individual dc-dc converters. The load may be dc connected to the dc bus line or may include a PWM voltage source inverter to convert the dc power into ac at 50 or 60 Hz.

Each source has its individual control. The output of the hybrid generating system goes to the dc bus line to feed the isolating dc load or to the inverter, which converts the dc into ac. A battery charger is used to keep the battery fully charged at a constant dc bus line voltage. When the output of the system is not available, the battery powers the dc load or discharged to the inverter to power ac loads, through a discharge diode D_b. A battery discharge diode D_b is to prevent the battery from being charged when the charger is opened after a full charge. As depicted in the system configuration represented in Figure 6, the V_{dc} is fixed dc bus line voltage and the output dc voltage from each source is controlled independently for both generation systems to get maximum power point tracking.[4][5]

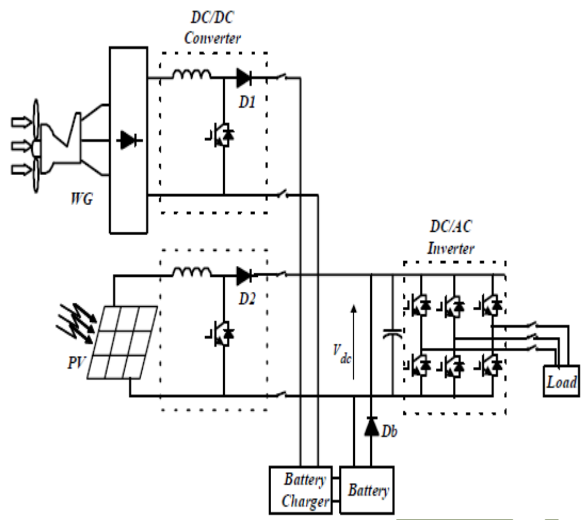

Figure 6 Equivalent circuit of Hybrid PV-Wind System

5. Simulation Results

Simulation of the hybrid wind and PV system is done in MATLAB/SIMULINK environment. In Hybrid Wind-PV System, PV system acts as a main source. In Wind Energy conversion system, wind speed is varied continously. PV and Wind systems are connected in parallel and the across this parallel combination, more than 30 V battery is connected which is in charging mode. If voltage across this parallel combination is less than 30 V, battery is in discharging mode. If battery is only present in the circuit, percentage semi-oxide concentration lineraly decreases and battery voltage rapidly decreases.

The main blocks in the simulink diagram are Wind turbine block , Squirrel cage Induction Generator block, PV model block, MPPT block, DC/DC converter block, Battery model and discrete PWM generator block. The Wind turbine with optimum power control and pitch angle control act as prime mover for induction generator. The external inputs to the turbine are wind speed and rotor speed. Optimum power is obtained from the Power-Speed characteristics and it depends upon the speed of the turbine. Rotor side converter is controlled by vector control and its main objectives are active and reactive power flow control and maximum power point tracking. The grid side converter (Front End converter) main objective is to regulate the DC link capacitor voltage and this converter controls the power flow between the DC bus and the AC side.

The simulation results of the dynamic performance, which validates the efficient MPPT of PV generation system when the irradiance changes dramatically are presented. The DC link voltage is shown in Figure 7.

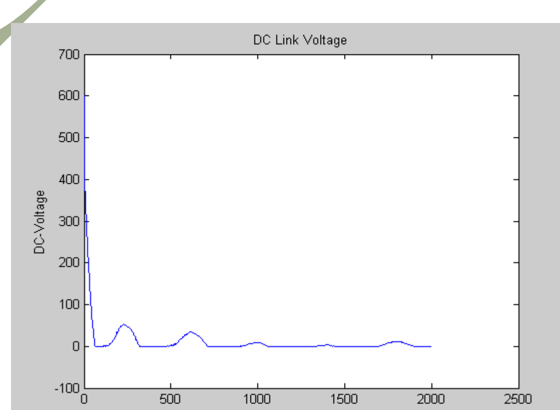

Figure 7 DC Link Voltage

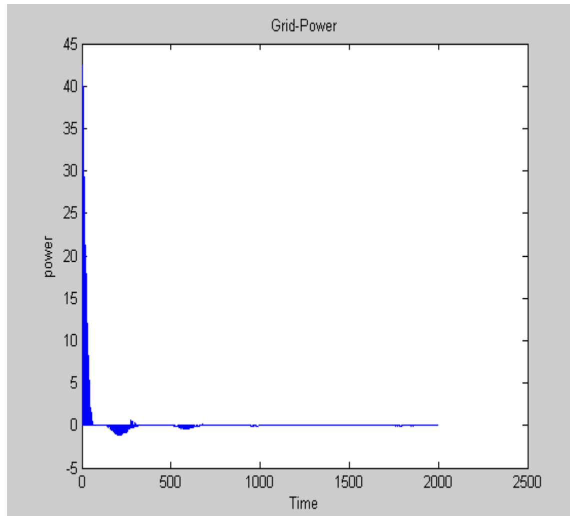

Figure 8 Power delivered to the grid

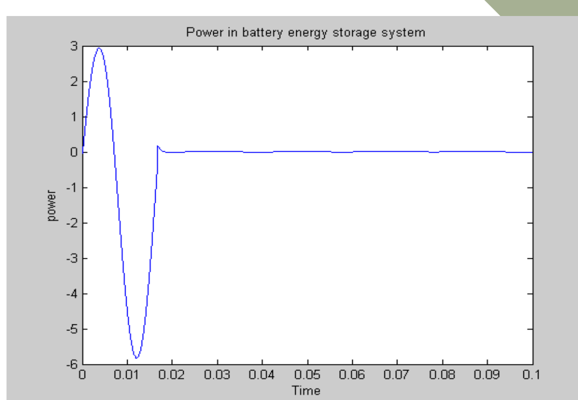

Figure 9. Power in Battery Energy Storage System

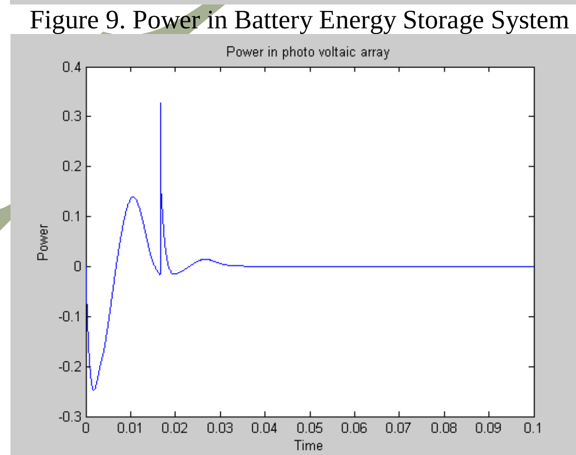

Figure 10 Power In Photo Voltaic Array

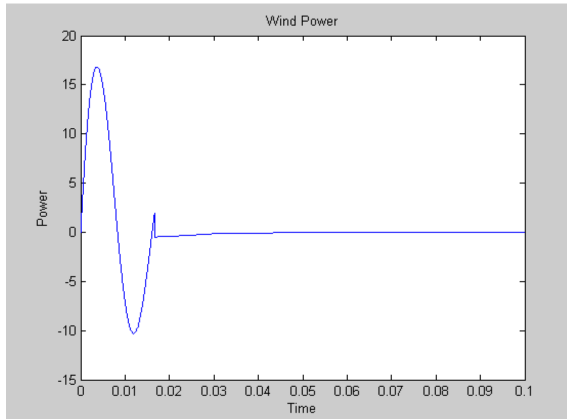

Figure 14. Power developed by Wind turbine

From the simulation results it is observed that the variations in output power are more in PV system because the voltage across PV module is changing rapidly whereas the variations in output power in wind energy conversion system is less because the voltage across wind system is almost constant and the battery voltage decreases exponentially and the battery current increases exponentially

6. Conclusions

A generalized PV model which is representative of the all PV cell, module, and array has been developed in MATLAB/SIMULINK .The proposed model takes sunlight irradiance and cell temperature as input parameters and outputs the I-V and P-V characteristics under various conditions. This model has also been designed in the form of Simulink block libraries. The masked icon makes the block model more user-friendly and a dialog box lets the users easily configure the PV model.

This paper describes renewable energy hybrid Wind-PV with battery energy storage system. In Hybrid Wind-PV System, PV system acts as a main source. A simple and cost effective maximum power point tracking technique is proposed for the photovoltaic and wind turbine without measuring the environmental conditions. This is based on controlling the photovoltaic terminal voltage or current according to the open circuit voltage or short circuit current and the control relationship between the turbine speed and the dc-link voltage is obtained using simple calculations. A complete description of the hybrid system has been presented along with its detailed simulation results which ascertain its feasibility. The power fluctuation of the hybrid system is less dependent on the environmental conditions as compared to the power generated of individual PV and WG systems. This power fluctuation has been suppressed using a battery in this project and it will be the subject of future work.

7. References

[1] L.-Q. Liu and Z.-X. Wang, "The development and application practice of wind-solar energy hybrid generation systems in China," Renewable and Sustainable Energy Reviews, no. 13, pp. 1504─1512, 2009.

[2] F. Valenciaga and P. F. Puleston, "Supervisor control for a stand-alone hybrid generation system using wind and photovoltaic energy," IEEE Trans. Energy Conversion, vol. 20, no. 2, pp. 398─405, June 2005.

[3] I. S. Kim, M. B. Kim, and M. J. Youn, “New maximum power point tracker using sliding-mode observer for estimation of solar array current in the grid-connected photovoltaic system,” IEEE Transaction on Industrial Electronics, vol. 53, no. 4, 2006, pp. 1027-1035.

[4] F. Valenciaga and P. F. Puleston, “Supervisor Control for a Stand- Alone Hybrid Generation System Using Wind and Photovoltaic Energy,” *IEEE Trans. Energy Conversion,* vol. 20, no. 2, pp. 398-405, June 2005.

[5] Nabil A. Ahmed and Masafumi Miyatake, “A Stand-Alone Hybrid Generation System Combining Solar Photovoltaic and Wind Turbine with Simple Maximum Power Point Tracking Control ”, IEEE Xplore 2006.

[6] Joanne Hui, Alireza Bakhshai and Praveen K. Jain, “ A Hybrid Wind-Solar Energy System: A New Rectifier Stage Topology”, IEEE Xplore 2010.

[7] Fernando Valencaga, Pablo F. Puleston and Pedro E. Battaiotto, "Power Control of a Solar/Wind Generation System Without Wind Measurement: A Passivity/Sliding Mode Approach", IEEE Trans. Energy Conversion, Vol. 18, No. 4, pp. 501-507, December 2003.
[8] Yi Goo, John N. Jiang, and Choon Yik Tang, "Nonlinear Control of Wind Power Generation Systems," 2009 IEEE Xplore.
[9] C. C. Hua and C. M. Shen, "Study of maximum power tracking techniques and control of dc-dc converters for photovoltaic power system," Proceedings of 29th annual IEEE Power Electronics Specialists Conference, vol. 1, 1998, pp. 86-93.
[10] J. A. Gow and C. D. Manning, "Development of a photovoltaic array model for use in power-electronics simulation studies," IEE Proceedings- Electric Power Applications, vol. 146, no. 2, 1999, pp. 193-199.
[11] W. D. Kellogg, M. H. Nehrir, G.Venkataramanan, and V. Gerez, "Generation unit sizing and cost analysis for stand-alone wind, photovoltaic, and hybrid wind/PV systems," IEEE Trans. Energy Conversion., vol. 13, no. 1, pp. 70–75, Mar. 1998.
[12] T. Senjyu, T. Nakaji, K. Uezato and T. Funabashi, "A hybrid System Using Alternative Energy acilities in Isolated Island," *IEEE Trans. Energy Conversion*, vol. 20, no. 2, pp. 406-414 June 2005.

GUNDALA SRINIVASA RAO[1] *is presently working as Assistant Professor in the department of Electrical & Electronics Engineering at Sri Venkateswara Engineering College, Suryapet. He has 4 years of teaching experience. He obtained master of technology in Power Electronics from Jawaharlal Nehru Technological University, Hyderabad, Andhra Pradesh, India.*

NARESH CH[2] *is presently pursuing his M.Tech in Power Electronics at Sri Venkateswara Engineering College, Suryapet, affiliated to Jawaharlal Nehru Technological University, Hyderabad, Andhra Pradesh, India.*

email: naresh.chilukamari@gmail.com contact: 9989968355

NARENDER REDYY NARRA[3] *is presently working as Assistant Professor in the department of Electrical & Electronics Engineering at Sri Venkateswara Engineering College, Suryapet. He has 8 years of teaching experience. He obtained master of technology in Power Systems (HVE) from Jawaharlal Nehru Technological University, Hyderabad, Andhra Pradesh, India.*