SIMULATION AND PERFORMANCE ANALYSIS OF SOLAR PV-WIND HYBRID ENERGY SYSTEM USING MATLAB/SIMULINK

B.Kanagasakthivel
Research Scholar
Kalasalingam University
Tamilnadu, India
sakthieee33@gmail.com

Dr.D.Devaraj
Professor,EEE
Kalasalingam University
Tamilnadu, India
deva230@yahoo.com

***Abstract*--This paper presents, a stand-alone hybrid Solar PV-Wind energy system for applications in isolated area. The wind and solar PV system are connected to the common load through DC/DC Boost converter. The modeling and simulation of hybrid system along with the PI controllers are done using MATLAB/SIMULINK. The performance of the hybrid system is evaluated under different wind speeds and different irradiation levels Simulation results show that the proposed hybrid system has the potential to meet the electricity demand of an isolated area.**

Keywords-- Renewable energy, photovoltaic, Wind energy conversion system, hybrid energy system, inverter

I. INTRODUCTION

Renewable energy sources have received greater attention during the past few decades and considerable efforts have been made to develop efficient renewable energy conversion system. The major goals of these approaches are to have reduced environmental damage, conservation of energy, exhaustible sources and increased safety. The renewable energy systems can be used to supply power either directly to a utility grid or to an isolated load. The stand -alone system find wider applications in isolated areas which are far away from the utility grid [2].

PV and Wind energy system are the most promising renewable energy technologies. A Photovoltaic (PV) system consists of a PV array, DC-DC converter, DC-AC Inverter and load. The development of suitable algorithms to control the power converter is essential, for the efficient operation of the PV system. The use of the power control mechanism, called Maximum Power Point Tracking (MPPT) in a PV system, leads to an increase in the efficiency of operation of solar modules. The MPPT is basically an operating point matching between the PV array and the power converter. Because of the non-linear P-V and I-V characteristics of the PV array, and the consequences of varying environment conditions, particularly irradiation and temperature, tracking the correct Maximum Power Point (MPP) is a challenging task.

Using the information provided (MPP current or voltage) by MPPT, the duty cycle of the DC-DC converter is adjusted using PI controller to match the MPP, which in turn forces the converter to extract the maximum power from the PV array. Development of suitable control strategies to improve the steady state as well as dynamic performance of DC-DC converter in terms of reaching its equilibrium condition, smoothly and quickly is necessary for the efficient operation of the PV system. The inverter convert DC power into AC power at desired voltage and frequency.

Wind power is another most competitive renewable technologies and, in developed countries with good wind resources, onshore wind is often competitive with fossil fuel-fired generation. Wind power generation has experienced a tremendous growth in the past decade, and has been recognized as an environmental friendly and economically competitive means of electric power generation. The wind energy system generates power in the form of AC with different voltage and frequency levels in case of variable speed operation. Solar energy system generates power in the form of dc voltage, the level of which varies depending on temperature and irradiation levels. Both these systems require power electronic interface for inter-connection with the grid.

The integration of different energy sources and energy-storage systems have been one of the new trends in renewable energy technology,[10]. Stand-alone wind with Solar Photovoltaic is known as the best hybrid combination of all renewable energy systems and suitable for most of the applications taking care of seasonal changes. They also complement each other during lean periods, for example additional energy production by wind during monsoon months compensate less output generated by solar. Similarly, in the post winter months when wind is dull, solar photovoltaic (SPV) takes over. This work proposes a solar PV and Wind generation based hybrid renewable energy system. The wind and solar systems are inter-connected with individual DC-DC converters and connected to the storage battery. The output of DC-DC converters is sent to an external H-Bridge inverter to supply ac power to load. MATLAB/SIMULINK is used to simulate the system and to evaluate its performance of the system.

II. PROPOSED HYBRID SYSTEM

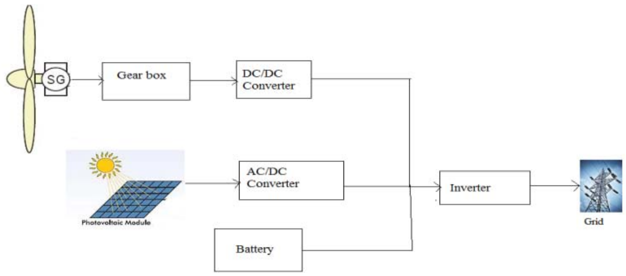

Fig 1 : Schematic diagram of Proposed Hybrid Energy System

The proposed hybrid energy system consists of a PV array and Induction generator-driven Wind energy conversion system meeting a common load. The PV system consists of PV arrays and corresponding DC/AC converter modules. Generally, according to the sunlight conditions, the maximum power point tracking control mode is adopted for PV system, which aims to maximum utilization of solar energy [4]. A H-Bridge inverter is used to connect the load to the hybrid system. Batteries are used to store the power when the power production exceeds the demand. The supply from the battery is needed during peak hours when power demand is higher than the production.

III. MODELLING OF VARIOUS RENEWABLE ENERGY SYSTEMS:

This section presents the mathematical models of energy sources namely, Solar PV, Wind and power electronic converters used in the proposed hybrid energy system

A. Modeling *of Photovoltaic System :*

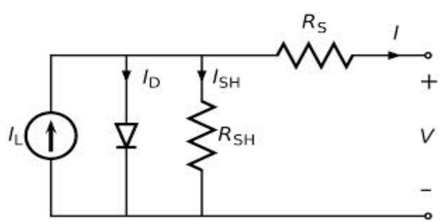

Fig 2 : Model of Solar PV cell

The PV system consists of PV arrays and corresponding DC/AC converter modules. When exposed to sunlight, photons which have energy greater than the band gap energy of the semiconductor are absorbed and create some electron hole - pair proportional to the incident radiation. The equations of the output current is given by

$$I = I_{PV} - I_D \qquad (1)$$

Where

$$I_D = I_0[exp\frac{V}{AV_T} - 1] \qquad (2)$$

Then equation (1) becomes

$$I = I_{PV} - I_0[exp\frac{V}{AV_T} - 1] \qquad (3)$$

The I-V characteristics of a solar cell is given by

$$I = [\exp(\frac{V+I*R_s}{I_{PV}-I_0*V_T}) - 1] \qquad (4)$$

$$P = V\ \{I_{sc} - I_0[\exp\left(\frac{V}{AV_T}\right) - 1]\} \qquad (5)$$

I_{pv} is the current generated by the incident of light, I_0 is the diode reverse bias saturation current, $V_T = \frac{N_{S*K*T}}{Q}$ is the thermal voltage of PV module having Number of cells (NS) connected in series; Rs starting resistance, Isc is the short circuit current, q is the electron charge; K = 1.38x10^{-23} is the Boltzmann constant; T is the temperature of the p-n junction and A = 2 is the diode ideality factor. The output of the current source is directly proportional to light falling on the cell. Naturally PV system exhibits a non-linear Current - Voltage (I-V) and Power - Voltage (P-V) characteristics which vary with the radiant intensity and cell temperature. The dependence of power generated by a PV array with changing atmospheric conditions can readily be seen in the I-V and the P-V characteristics of PV arrays.

B. Modeling of Wind System

The wind turbine rotor consists of two or three blades mechanically coupled to an electric generator. The power captured by the wind turbine is given by the relation

$$P_{\omega} = \frac{1}{2} C_p \rho . A . {V_{\omega}}^3 \qquad (6)$$

Where ρ is the air density, which is equal to 1.225 kg/m^3, C_p is the power coefficient, V_w is the wind speed in (m/s) and A is the area swept by the rotor in(m^2).

The amount of aerodynamic torque T_w in (N-m) is given by the ratio between the power extracted from the wind P_ω and turbine rotor speed W_w in (rad /s) as follows

$$T_w = P_{\omega w_\omega} \qquad (7)$$

C. Modeling of Battery:

The storage capacity of the battery at any given time (t) is expressed as

$$C_{bat\,(t)} = C_{bat(t-1)} + P_{pv(t)} + P_{wg(t)} - P_{load(t)}.\eta_{cad}\,\Delta t.\eta_b \qquad (8)$$

Where $C_{bat\,(t)}$ and $C_{bat(t-1)}$ is the available battery capacity at time (t) and (t-1).P_{pv} is power generated by Photovoltaic system , P_{wg} is power generated by wind turbine generator, $P_{load\,(t)}$ is power consumed by load t, t is simulation step (Δt = 1hrs), η_{cad} is efficiency of AC/DC converter and η_b is battery charging efficiency which depends upon charging current and may vary from 0.65 - 0.85. When wind alone cannot meet the power demand but combining with PV can, i.e., $\eta_{inv} P_{wg}(t) + Ppv(t) \geq P_{load\,(t)}$. The excess power if available is used in charging the battery. Battery storage capacity in such case is given by:

$$C_{bat}(t)\ C_{bat}\ (t-1)\left(P_{pv}(t)\ \left(\frac{P_{load}(t)-P_{\omega g}(t)}{\eta_{inv}}\right)\right)\Delta t.\eta_b \quad (9)$$

D. DC-DC Boost Converter :

DC-DC boost converter is a most efficient topology which ensures good efficiency along with low cost. A DC-DC boost converter is connected next to full-wave bridge rectifier to raise the voltage of the diode rectifier. Figure 3 shows the arrangement of the DC-DC boost converter circuit. A capacitor C1 is connected across rectifier to lessen the variation the rectified AC output voltage waveform from the bridge.

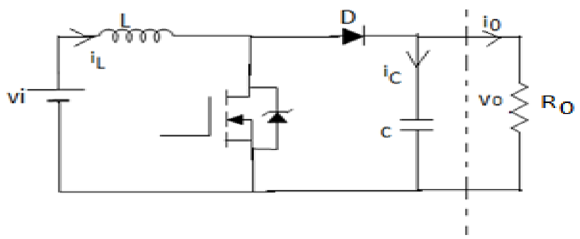

Figure : 3 . DC-DC Boost converter circuit

The model of the boost converter is needed to simulate and analyze the behavior. The input and output voltage of the boost converter under an ideal condition can be written as

$$V_{i=}\ V_0 * (1-D) \quad (10)$$

where V_i is the input voltage, V_0 is the output voltage and D is duty cycle . Given the value of D, it is possible to find the minimum values of inductance and capacitance using the equations given below:

$$L_{min} = \frac{(1-D)D\ R_0}{2f} \quad (11)$$

$$C_{min} = \frac{DV_0}{V_r R_0 f} \quad (12)$$

Where, V_r is the ripple voltage, R_0 is the output resistance and f is the switching frequency. An important consideration in DC-DC converters is the use of synchronous switching which replaces the flywheel diode with a power IGBT with low "on" resistance, thereby reducing switching losses. This is achieved by using a Pulse Width Modulation (PWM) switched mode control design or PWM. The PWM performs the control and regulation of the total output voltage . If the semiconductor device is in the off-state, its current is zero, and hence, its power dissipation is zero. If the device is in the on-state, the voltage drop across it will be close to zero, and hence, the dissipated power will be very small.

E. Three Level H- Bridge Inverter:

Figure 4 shows the a-phase of a Cascaded H - Bridge inverter utilizing two three level cells. The b - and C- phases are identical to the a-phase. The H - Bridge inverter is designated according to the voltage levels.

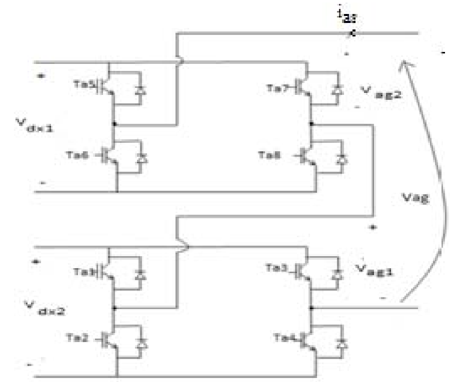

Fig : 4 Cascaded 3/3 H states Inverter

In terms of the general mathematical description, it can be noted that p = 2, n1 = 3, and n2 = 3. If the dc voltage of each cell is set to the same value $(V_{dx1} = V_{dx2} = E)$ when V_{dx1}, V_{dx2} are inverter input voltage., then the resulting inverter can operate with five voltage levels, and two output voltages V_{ag1}, V_{ag2} and V_{ag} is the total H-Level inverter output voltage. Table I shows the zero and positive voltage levels obtainable from this inverter as well as the voltage levels from the individual H - bridge cells. The positive levels of E and 2E are possible output voltages as well as 0. Due to the inverter symmetry, it is also possible to have negative output voltages of -E and -2E for a total of five voltage levels. Table II shows the zero and positive switching states for the case where $V_{dx1=}2$ and $V_{dx2} = 2E$. In condition $V_{ag} = E$ it`s the direction of i_{as} to avoid current flowing into the positive terminal of a rectifier source.

TABLE I:
CASCADED 3 STATES
$(V_{dx1} = V_{dx2} = E)$

V_{ag}	V_{ag1}	V_{ag2}
0	E	-E
	0	0
	-E	E
E	E	0
	0	E
2E	E	E

TABLE II:
CASCADED 3 STATES
$(V_{dx1} = 2\,V_{dx2} = 2E)$

V_{ag}	V_{ag1}	V_{ag2}
0	0	0
E	0	E
	2E	-E
3E	2E	E

IV. SIMULATION RESULTS

A hybrid system consisting of 1.5MW and 150Wp Solar PV system is simulated . The parameters of the Wind turbine and Solar PV system are given in Table III and IV. The subsystem of the Wind and Solar PV system are given in Fig 5 and 10 respectively. The load is connected to the hybrid system through an inverter with the rating of 1.3 MVA. PWM with carrier frequency of 1000 Hz is given across the gate circuit of the H-Bridge inverter. Figure 14. shows the developed MATLAB/Simulation model of hybrid renewable energy system. First the system is simulated with wind and Solar alone and the performance of the individual generators are evaluated. Next the performance of the hybrid system is evaluated under different load conditions.

Case I : Wind alone **:**

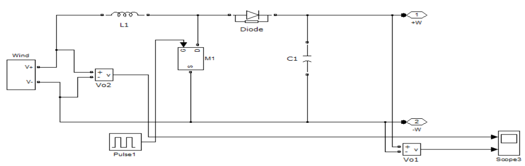

Fig: 5 .Simulink diagram of wind turbine subsystem

Table III : Parameters of Wind turbine

Parameters	Blade Radius	No of Blades	Air Density	Rated Wind speed	Cut-in speed	Cut-out speed
Rating	38m	3	0.55kg/m^3	12m/s	4m/sec	25m/sec

Figure 6 shows the Simulation waveform of Time vs. Wind speed characteristics for various speed wind turbine. Figure 8 and 9 shows the Rotor speed and Electromagnetic torque and output voltage waveforms against time. Figure 9 shows the output voltage of wind energy system

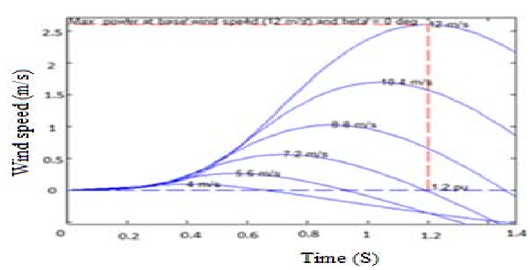

Fig 6: Time vs. Wind speed characteristics

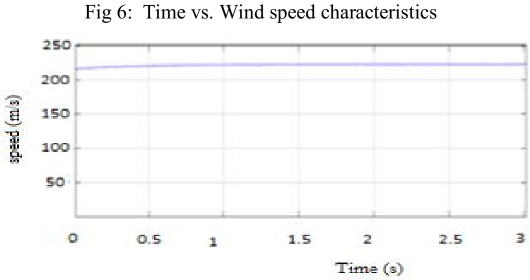

Fig 7 : Time vs Rotor Speed in wind system

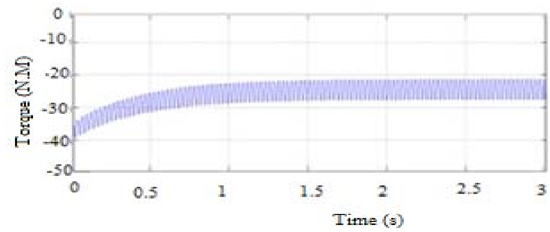

Fig 8 : Time vs Torque in Wind System

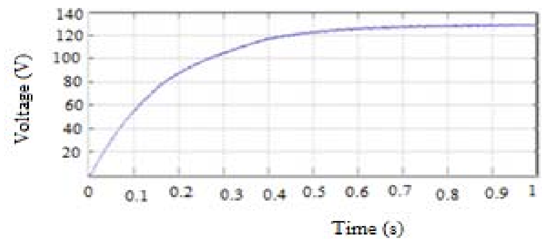

Fig : 9. Output voltage of Wind Energy System at 12 m/s

Case II : Solar PV alone :

Next the modeling and simulation of solar PV alone system has been carried out using MATLAB/SIMULINK. The system consists of solar photovoltaic module with 18 solar cells and DC-DC converter. If 18 solar cells are connected in series to get the desired voltage, the PV system output voltage is 36V and current will be 4.6 A

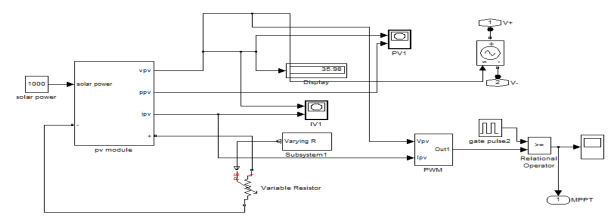

Fig : 10. Photovoltaic subsystem

Table IV : Parameters of Photovoltaic Module

Maximum Power	Maximum Voltage	Temperature Coefficient
150 W	35 V	25ºC

The solar photovoltaic module generates the DC voltage under different solar temperature and irradiations The energy supplied by the modules does not have the constant values, and it as fluctuates according to the intensity of solar photovoltaic rays and temperature as shown in the fig 12.

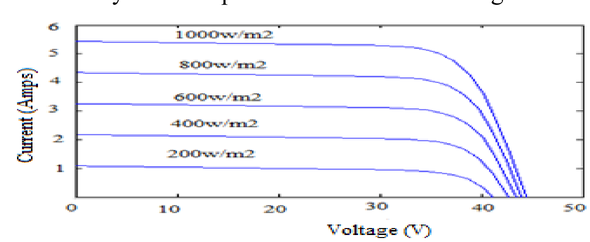

Fig 11. Voltage vs. Current characteristics at Irradiance G = 1 W/m^2, 0.8 W/m^2, 0.6 W/m^2,0.4W/m^2,0.2 W/m^2

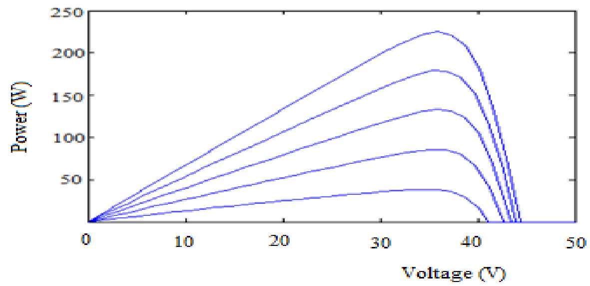

Fig 12. Power vs Voltage at Irradiance G = 1 W/m^2, 0.8 W/m^2, 0.6 W/m^2,0.4W/m^2,0.2 W/m^2

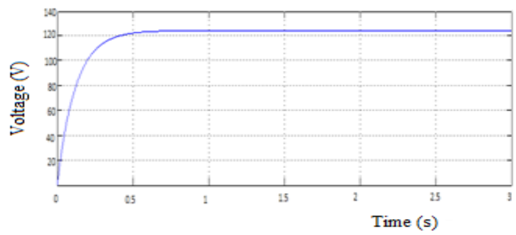

Fig 13. Output voltage of Photovoltaic System at 1000 W/m^2

Figure 12 shows the voltage-current waveform of photovoltaic array model for different solar irradiation with temperature 25ºc. The Voltage vs Current and voltage-power output characteristics of a Photovoltaic module at irradiation G = 1 W/m^2, 0.8 W/m^2, 0.6 W/m^2,0.4W/m^2,0.2 $W/m^2$and temperature 25ºc is shown in fig 11 and 12. It is observed that the temperature and irradiation changes mainly affect the PV system output voltage and output current [3].

Case III : Hybrid System :

In this case both wind and solar PV system are used to meet the demand DC/DC Boost converter is combined with multilevel inverter to get the output voltage of 230V. Figure 14, shows the hybrid system with wind turbine model, synchronous generator model, power converter, PV system and control blocks. The Capacitor value of interface rectifier is 6000µH. The Resistance (R) Load on the hybrid system is 500Ω. The hybrid system is operated with wind at 14m/s, and Solar PV system with irradiation level such as G = 0.8 W/m^2. The output voltage of the hybrid system is shown in Figure 15.

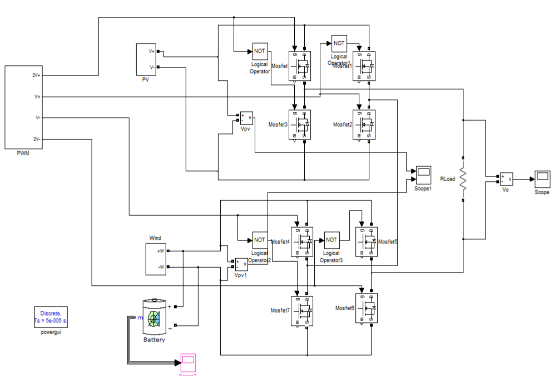

Fig : 14 MATLAB/SIMULINK model of Hybrid system

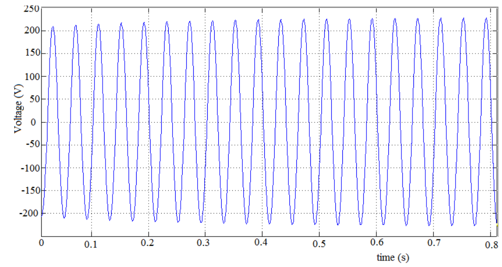

Figure 15. Time vs Output voltage of wind (14 m/s) and Solar PV (800 W/m^2)

V. CONCLUSION:

This paper has described a hybrid energy system with variable speed wind generation, photovoltaic system along with power electronic interface under stand-alone mode. Computer simulation was conducted using MATLAB/SIMULINK. In the stand-alone mode the performance of the system is evaluated for various wind speeds and various irradiation levels. Due to variations in wind speed and solar irradiation AC voltage varies. Battery system is used to maintain the balance between the source and load. In hybrid system, 14 m/s in wind system and 800 W/m^2 in solar PV system performance has been analyzed. This system is expected to meet up electricity demand in a remote area. The performance of the developed system is evaluated in MATLAB/SIMULINK platform and the results are presented.

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