Operation and Control of Off-Grid Hybrid Standalone System

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ABSTRACT
This paper focuses on the development of the model for optimal management and operation of hybrid stand-alone wind-solar energy generation system. The proposed hybrid system consists of wind turbine with variable speed permanent-magnet synchronous generator, solar system with mechanical tracker and a system for storing energy during wind speed, solar output and load variations. This system is used to regulate the fluctuations in the power output and to meet the power demand in conditions of blackout. The Mechanical MPPT tracker is used to get the maximum power output from the PV solar subsystem. The off-grid operation is demonstrated and the bus voltage is maintained constant by using the merging pattern of the DC bus. The load demand is always met because both the subsystems are complementing each other without any interruption. The experimental results are demonstrated through the MATLAB simulink. A prototype was developed to verify the performance of the proposed system.

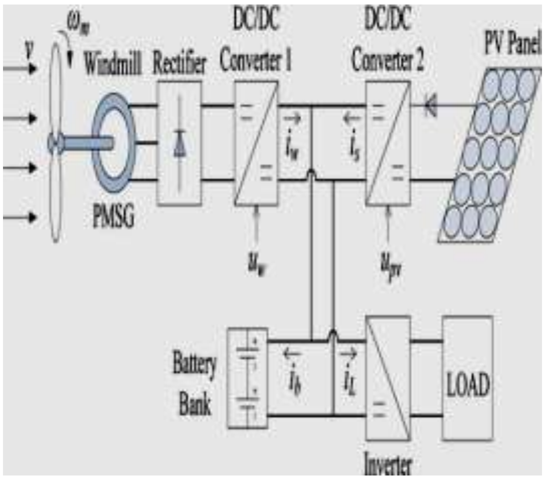
Keywords
MPPT, PV panel

1. INTRODUCTION
Renewable sources of energy in India are natural resources that can be replenished naturally at a rate faster than its speed of consumption. Wind power is one of the renewable, clean, cost free sources of energy for power production. Photovoltaic (PV) power is another promising clean energy source since it is globally available and harnessed without using rotational generators. Standalone solar photovoltaic and wind systems cannot provide continuous source of energy, as they are seasonal. For example, during non-sunny days, standalone solar photovoltaic energy system cannot provide reliable power. The standalone wind system cannot provide constant load demand due to fluctuations in the wind speeds throughout the year. Combining these two intermittent sources and by incorporating Mechanical MPPT tracker, the system's power transfer efficiency and reliability can be improved significantly. As a result, energy storage systems are used for continuous and reliable operation. In a recent survey, Indian government has proposed to generate 20000 MW grid-based solar power,2000 MW of off-grid solar power by the year 2020. For the five year plan (2012-2017) the government has set a target of adding 18.5 GW of renewable energy sources of which 11 GW would be wind energy. However, achieving such goals require reliable operation and integrated generation using both the wind and solar energy system. Various features for improving the performance are included in this study to get better efficiency.

To minimize the cost and to improve the power quality various wind turbines have been developed. Based on the rotational speed, turbines can be classified into fixed speed, limited variable speed and variable speed. Based on the power regulation, these can be divided into stall control and pitch control. Based on the drive train, it is classified into geared drive and direct drive. During 1980's and 1990's SCIG with multiple-stage gearbox is used for fixed speed stall control wind turbines.[5] After 1990's variable speed control is used due to increased power level more than 1.5MW.The generator system consists of DFIG with multiple-stage gearbox and power electronic converters. Since 1991, to reduce the failure of gearbox and to lower maintenance problems, direct drive wind turbine system is used. Direct drive generator rotates at low speed, because the rotor is directly connected on the hub of the rotor blades. The benefits of direct drive PM machines such as the elimination of the excitation losses, reduction of the weight of active material, increased efficiency, no additional power supply for the field excitation, higher reliability, and higher power to weight ratio [2]. Due to recent development in permanent magnet materials, especially Nd-Fe-B, high efficiency PM generators are used [3].In [1], model predictive control have been developed for the optimal management and operation of the hybrid system but no special focus is provided to improve the efficiency of solar output.The objective of the present work is to develop a standalone wind-solar hybrid energy generation systems with maximum power point tracking and merging pattern of the bus to improve the generated power and efficiency in order to meet the power demand at varying operating conditions. The proposed model is shown in Fig.1. The implementation of the mechanical MPPT tracker is to perform power flow control and to harness the maximum power from the PV panels. Hence, this hybrid generation system forms a highly independent generation system from day to night.

2. WIND TURBINE MODELLING
The mechanical power generated for the wind turbine is given in equation

$$P_{mech}=0.5\rho A V_w^3\, C_P(\lambda, \beta) \quad (1)$$



The mechanical power depends on the wind speed (V_w) and the power coefficient (C_P) which is a function of the tip speed ratio (λ), and the pitch angle (β), Air density (ρ) and swept area (A). The λ is defined as the ratio of tip speed to the wind speed.

Rated speed of the wind turbine is calculated from the below equation:

$\lambda * V_w / R = \Omega_t$ (2)

Where R is the rotor radius, Ω_t is the rotational speed of the wind turbine. A non linear relationship between C_P and λ for different values of β is shown in Fig.2.

C_P reaches maximum value for a given pitch angle β for λ_{opt}. The C_{Pmax} and λ_{opt} vary with pitch angle. These two parameters decreases as the pitch angle increases.

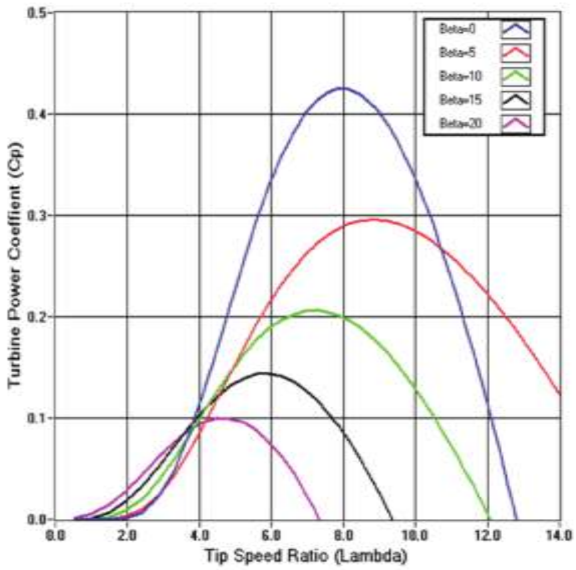


Fig.2. C_P v_s λ for different values of β

The tip speed ratio assumed as the optimum value, depending on the wind speed, gives the optimum turbine speed (Ω_{opt}) through equation(2). The optimum torque and the maximum active power are given by the expressions (3) and (4).

$T_{opt} = K_{opt}\, \Omega_{opt}^2$ (3)

$P_{opt} = T_{opt}\, \Omega_{opt} = K_{opt}\, \Omega_{opt}^3$ (4)

Where,

$K_{opt} = 0.5 \rho \pi R^5 C_{Pmax} / \lambda opt^3$, (5)

$C_{Pmax} = C_P(\lambda opt, 0)$ (6)

It is shown that the relation between the torque and the wind turbine speed in the optimum point follows a quadratic function, whereas the relation between the power and the wind turbine speed is a cubic function.

3. STANDALONE WIND-SOLAR SYSTEM CONFIGURATION

3.1 Wind subsystem model

The proposed standalone wind-solar power system supplies single phase to consumers. A wind turbine cannot completely extract the power from wind. Generally, only 59% of the wind power could be utilized by wind turbine. The wind turbine rotor is connected to the wind generator, which converts the mechanical energy into electrical energy. The generator ac voltage is converted into dc voltage through an ac/dc converter. The rectifier converts the generator ac voltage to the dc voltage, while the boost converter provides the required level of constant dc voltage. The voltage should be maintained constant for various wind speeds. When the wind speed is too high, the excess power supplied by the wind turbine is stored in the battery. When the wind speed is low, the solar energy and energy from the battery bank will satisfy the demand.

3.2 Modeling of PMSG

The dynamic model of PMSG is derived from the two-phase synchronous reference frame in which the *q*-axis is 90◦ ahead of the *d*-axis, with respect to the direction of rotation. The electrical model of PMSG in synchronous reference frame is given by (1)

$di_d/dt = -(R_a/L_d).i_d + \omega_e(L_q/L_d)i_q + (1/L_d)v_d$

$di_q/dt = -(R_a/L_q)i_q - \omega_e((L_d/L_q)i_d + (1/L_d)\Psi_{PM}) + (1/L_q)v_q$ **(7)**

where subscripts *d* and *q* refer to the physical quantities that have been transformed into the *d–q* synchronous rotating reference frame; R_a is the armature resistance; ω_e is the electrical rotating speed which is related to the mechanical rotating speed of the generator as $\omega_e = n_p \cdot \omega_g$, where n_p is the number of pole pairs; and ψ_{PM} is the magnetic flux of the permanent magnets. The electromagnetic torque can be derived, as shown in [23], to be

$T_e = 1.5 n_p[(L_d - L_q)i_d i_q + \psi_{PM} i_q]$. **(8)**

If the PMSG is taken without rotor saliency (where $L_d = Lq = L$), Then (7) can be rewritten as

$di_d/dt = -(R_a/L)\, i_d + \omega_e i_q + (1/L)v_d$

$di_q/dt = -(R_a/L)i_q - \omega_e(i_d + (1/L)\Psi_{PM}) + (1/L)v_q$ **(9)**

and the electromagnetic torque can be regulated by *iq* as

$T_e = 1.5 n_p \psi_{PM} i_q$. ***(10)***

3.3 Solar Subsystem

The solar subsystem composed of PV panel and DC-DC Boost converter. The solar subsystem is connected to the DC bus through dc/dc converter. In this subsystem, converter is used to get required voltage. Thus the converter controls the operating point .Here we use the MPPT technique to track the maximum power obtained at all time. The DC-DC converter is used to boost the voltage obtained in solar panel. This is given to the dc bus, so that the voltage is maintained constant. When the solar power generation exceeds the demand, it is sent to the battery bank to store the excess power. When the generated power is less than the demand battery bank supplies the required power to the load. The PV panel used is of polycrystalline type and have black coating to improve the insolation of sunlight on the panel. It consists of 12 cells of 0.5 V each. More cells can be connected to increase the voltage capacity. The efficiency of the panel is calculated as follows:

$$\text{Efficiency}= P_m/(G*A_c) \qquad \textbf{(11)}$$

Where,
P_m = cell power output at its maximum power point.

G = irradiance (the amount of light input) In W/m^2

A_c = surface area of the solar cell.

The multi junction solar panel has more conversion efficiency because they convert more of the light spectrum to electricity. these are nothing but the stack of individual single junction cells in descending order of band gap(E_g).The Gallium arsenide material is preferred because they have a efficiency of 35%.

3.4 Boost converter model

The unidirectional boost converter is connected between the battery and the rectifier. The block diagram is shown in Fig. 3 shows the simplified model of the boost converter. The voltage relationship between the primary and secondary sides is given by (12)

$$V_{out}=V_{in}/(1-D) \qquad \textbf{(12)}$$

where D is the pulse-width modulation (PWM) modulation factor. When $V_{in} \geq V_{out}$, the boost converter is not working, and the current provided by the generator is channelled through the bypass Schottky diode which will be placed across the inductor and diode. From equation (12), it is assumed that there is no power loss in the converter.

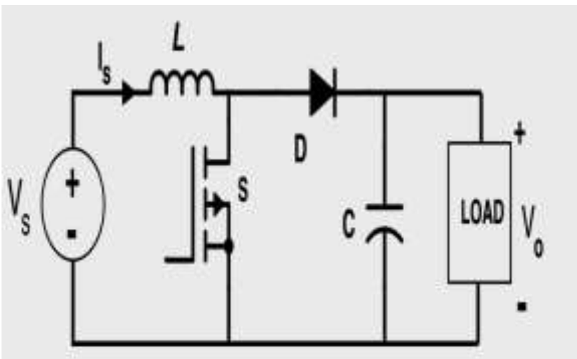


Fig. 3 simplified model of the boost converter

3.5 MPPT

To obtain maximum power from solar panel, maximum power point tracking is used. Depending up on the insolation and temperature, the MPPT control adjusts the position of the panel to transfer the maximum power and bringing the operating points onto the “maximum power curve”. A PI controller is used to implement the MPPT function, which provides the reference power for the boost converter, based on the temperature measurements. The MPPT control block diagram is shown in Fig.4

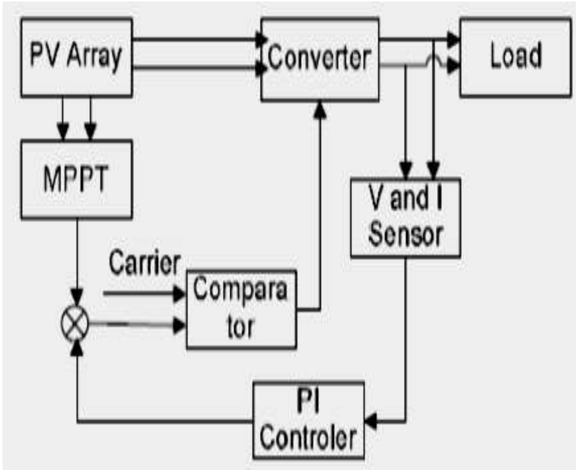


Fig.4 control block diagram of MPPT

The mechanical tracker presented here is of single axis type. It consists of DC geared motor, LDR, Motor driver board, solar panel. The dc geared motor module consists of dc motor of 12 V and gear system which is controlled by motor driver circuit –L293D, They have high torque at relatively low shaft speed. LDR sensor is a photo resistor whose resistance decreases with increasing incident light intensity and it exhibits photo conductivity. As the light falls on PV panel the resistance of the LDR decreases and it conducts current, which in turn makes the motor to rotate to change the direction of the PV panel according to the incident light which falls on it, Hence maximum power is obtained from the solar subsystem. During night time the panel comes to its initial position, and the motor rotation is damped.

3.6 Energy storage system

The energy storage system consists of single-phase MOSFET inverter and a bank of LABs (Lead Acid Battery) of 12v each. Each Labs are connected in series to provide the desired value of the inverter battery voltage. The rechargeable lead acid batteries are preferred as they have a longer life time, can withstand cold, heat, vibrations, shock. The battery bank is used to supplement the power in times of shortage to supply the demand i.e., it will be used when the wind speed is lower or insolation is not sufficient. When the generation is greater than the demand, the excess power is parallelly charged in to the battery. When the generation is lesser than the demand, the power needed is satisfied by discharging the battery. Both the wind and solar subsystem share the same battery bank for energy storage.

4. BLOCK REPRESENTATION OF THE HYBRID SYSTEM.

The kinetic energy of the wind turns the turbine blades around the hub of the rotor creating mechanical energy. The Permanent magnet synchronous generator converts it in to electrical power where an rectifier is included to convert in to DC power and boosted using DC-DC boost regulator. Using the MPPT control, maximum power is tracked from the solar panel and the respective DC voltage is given to DC-DC boost converter for boost operation. The DC is maintained constant by merging pattern of the DC bus and therefore maximum voltage from the two subsystems is available across the bus. The charging of battery is done simultaneously while supplying the load. The block diagram is shown in Fig 5.

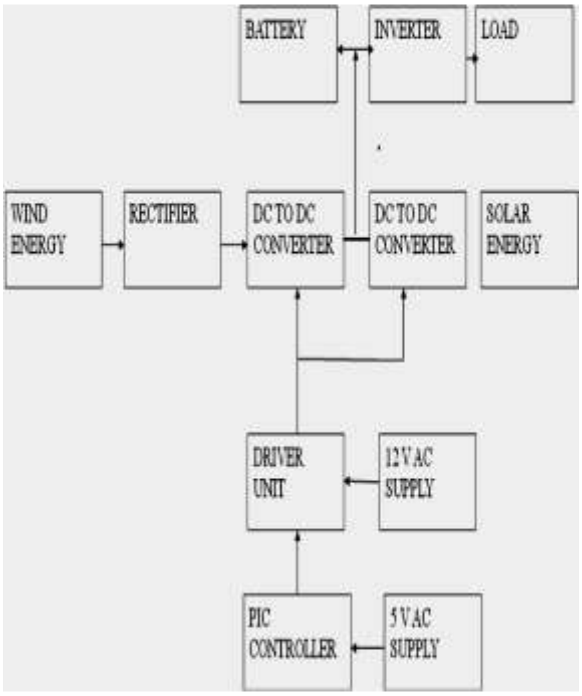


Fig.5 Block diagram of entire system.

The PIC controller is used to provide firing signals to both the converters which requires a voltage input of about 5- 7volts. The inverter used here is of single phase type. Further study can be included in using the Multilevel inverters to reduce harmonic contents in the output of the both the subsystem and to improve the efficiency.

5. RESULTS AND DISCUSSIONS

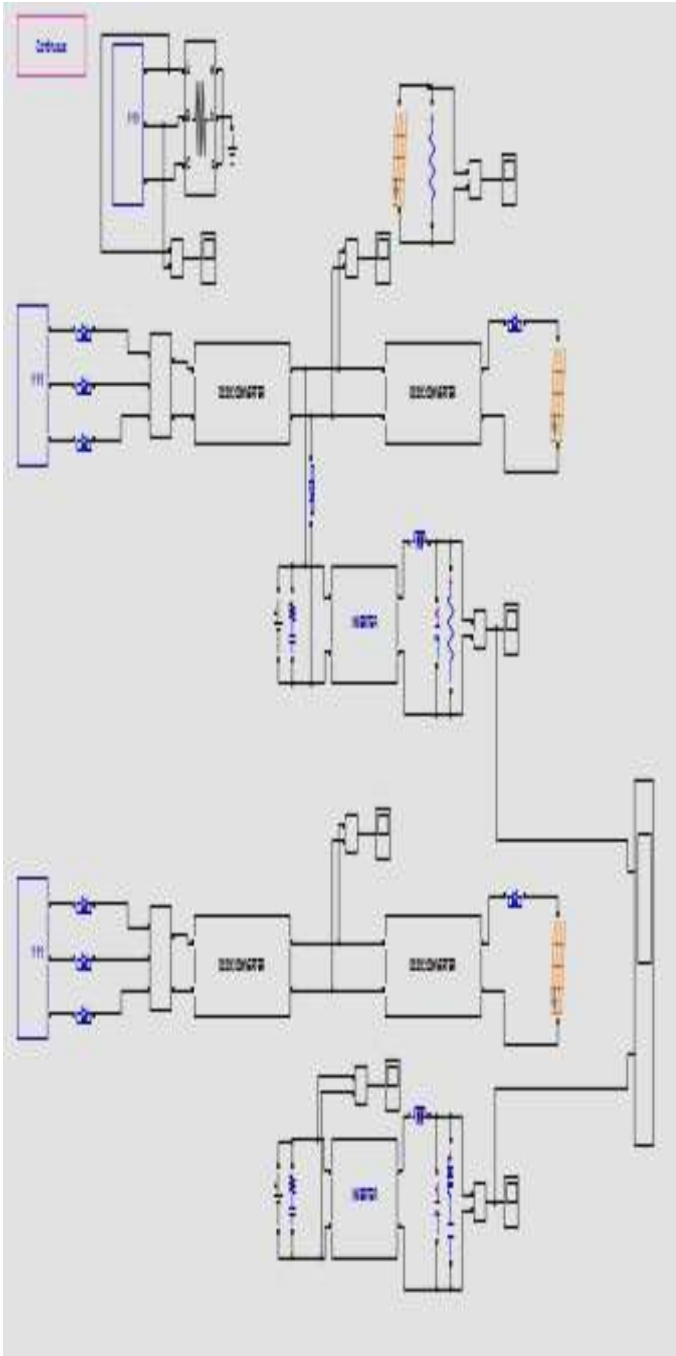


Fig.6 Simulation of hybrid system

The system is simulated in matlab(simulink) and various graphs are plotted for exihibiting the behaviour of the system.PMSG is used to demonstrate the operation of wind subsystem where the mechanical energy is converted in to electrical energy.simulation diagram is shown in Fig 6.

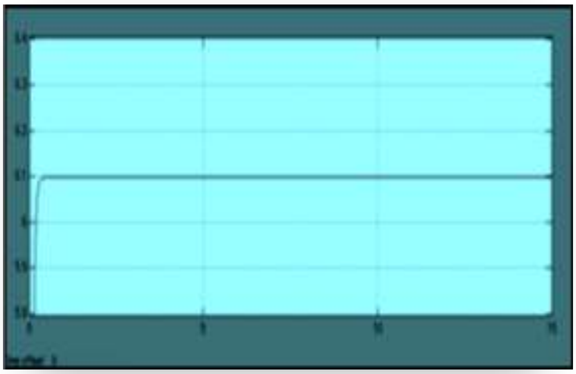


Fig.7 solar ouput

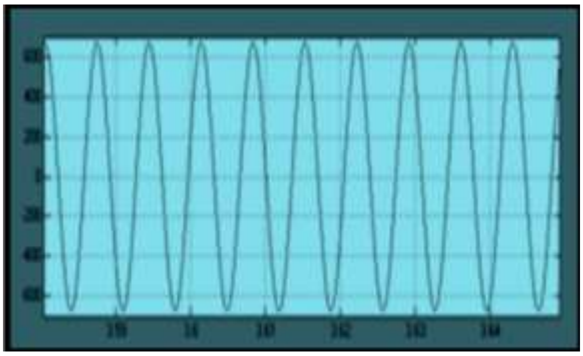


Fig. 8 Wind output

The features of the proposed operation strategy is examined through insufficient and sufficient generation. When there is an insufficient generation battery bank will supply the power stored during excess generation. fig.7,fig.8 shows the variation of solar and wind subsystem output as a function voltage and time. The solar panel is represented with an output voltage of 6.1 V(fig 7) (more number of cells can be connected to get maximum voltage as per the requirements). The base mechanical output power of the proposed model of wind turbine is 8.5KW. The output voltage is represented in fig.9 which is around 700V.The bus uses merging pattern to get the maximum voltage and bus voltage is maintained constant which is around 800V for the above system. The battery stores the energy generated and load of around 800V is connected with an inverter on the input side which is supplied by the battery.

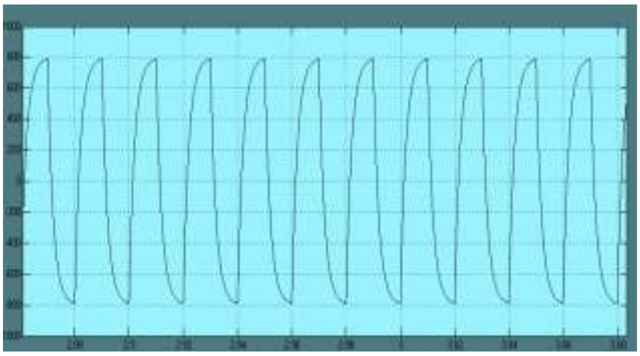


Fig.9 Output on load side

Further study will be focused on reduction of inrush current on load side. This can be accompanished by placing the LC filters following the inductor.The optimisation techniques for reduction of filter size and cost shall also be focused.

6. CONCLUSION

In this work supervisory control of the standalone wind-solar energy subsystem. MPPT technique is used to track the maximum energy generated from the solar subsystem at all the time. The excess power generated is sent to the battery bank to satisfy the load demand when the generation is minimum. This system satisfied the load demand during all conditions. Future work will include the investigation to reduce the inrush current at the load side and large time span behavior of the hybrid wind-solar generation system taking into account information of future weather forecast, and investigation of the performance of the system under the condition that the future power demand is unknown.

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