Simulation of Standalone PV/Wind Hybrid System

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Abstract

The paper presents a model of stand-alone photovoltaic /wind turbine hybrid system. The system consists of photovoltaic array, wind turbine, asynchronous (induction), generator, controller converter and dc bus. The system is implemented using MATLAB/ SIMULINK software. The solar irradiation decides the power from PV system. Hence maximum power point tracking algorithm is used to track maximum power from the sun .Presence of sun is intermittent so wind energy conversion system is connected with photovoltaic system. Thus an integration of sun and wind forms the PV /WT hybrid system .The output from this hybrid system is DC. This DC is supplied to DC bus and to DC loads. The inverter can be used to convert DC to AC and to AC loads.

1. Introduction

A life without electricity is a life without vision. The developed world around us will become a dark world. The scarcity of electricity is due to depletion of fossil fuel and increase in demand because of industrial development, consumer consumptions and life style. In-order to compensate the shortages in energy, a solution must be sort out and should meet the energy demand. The best solution is to take up the renewable energy sources and the most easily available and advantageous among these is the power from sun and wind. The conversion of solar and wind energy into power is possible due to tremendous advancements in power electronics. Solar energy is present throughout the day but the solar irradiation from sun changes due to intensity of sun and the shadows of clouds. Similarly wind energy alone can supply large loads but its presence is unpredictable. Thus both of this energy sources are not constant, they are intermittent. Hence both the sources are combined to improve the efficiency of the system and the output can be maintained to the required level. When the output power is in excess, it can be stored in battery bank and can be used later to supply loads.

As the power from the PV panel is variational, Maximum Power Point Tracking is used to track maximum power from sun. The Perturb and Observe algorithm is used normally for tracking MPP as it is easy to implement. In P & O algorithm, the voltage of the cell is increased and if the power output increases, the voltage is increased continuously till the power output starts to decrease. When the power output decreases, the voltage of the cell is to get maximum power. This procedure is continued till the maximum power is reached. There will be an oscillation of power output at the MPP.

The WECS model consist of wind turbine, pitch angel control, permanent magnet synchronous generator (PMSG) and the converter. The general types of generator are induction generator (IG), synchronous generator (SG), doubly fed induction generator (DFIG), squirrel-cage rotor, induction generator (SCIG), wound rotor induction generator (WRIG), and permanent magnet synchronous generator (PMSG). The PMSG is used for small power generation and DFIG is used for large power generation. Hence PMSG is used for standalone systems and DFIG is used for grid connected WECS system. The model of PMSG is given in d-q model. Mostly PMSG based systems are used without the gear box. Thus cost and weight of nacelle is reduced.

This paper presents the modelling and simulation of standalone PV/WT hybrid system using MATLAB/SIMULINK. It includes the design of PV panel with equation and includes the equation that forms the wind turbine. The two systems are combined to operate individually and simultaneously. Finally the simulated result of the hybrid system is presented.

2. Components of Standalone PV System

2.1. PV Cell

A PV (photovoltaic) cell is a semiconductor device that converts light energy to electrical energy by photovoltaic effect. If the energy of photon (light) is greater than the band gap then the electron is emitted and the flow of electrons creates current. However a PV cell is different from a photo-diode. In a photodiode light falls on the n-channel of the semiconductor junction and it gets converted into current or voltage signal but a PV cell is always forward biased.

2.2. PV module

Usually a number of PV modules are arranged in series and parallel to meet the requirements of energy. PV modules of different sizes are commercially available (mostly sized from 60W to 170W).

2.3. PV Modelling

A PV array consists of several PV cells in series and parallel connections. It is the combination of many PV modules. Parallel connections are responsible for increasing the current of the module whereas the series connection is responsible for increasing the voltage in the array. A solar cell can be modelled by a current source and an diode which is inverted is connected in parallel to it. It has its allowable series and parallel resistance. Series resistance is due to the blocking in the path of flow of electrons from n junction to p junction and parallel resistance is due to the leakage current.

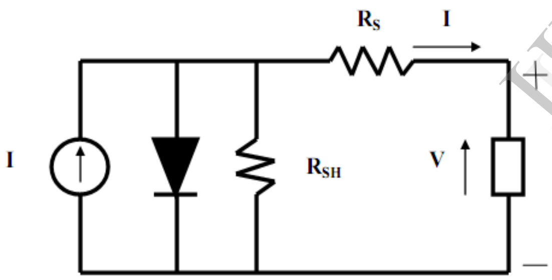

Fig.1 Single diode model of a PV cell

The output current from the PV array is

$I = I_{sc} - I_d$ (1)

$I_d = I_o\,(eqV_d/kT - 1)$ (2)

where I_o is the reverse saturation current of the diode, q is the electron charge, V_d is the voltage across the diode, k is Boltzmann constant (1.38 * 10-19 J/K) and T is the junction temperature in Kelvin (K).

From equation 1 and equation 2

$I = I_{sc} - I_o\,(eqV_d/kT - 1)$ (3)

By suitable approximations,

$I = I_{sc} - I_o\,(eq((V+IR_s)/nkT) - 1)$ (4)

where, I is the photovoltaic cell current, V is the PV cell voltage, T is the temperature (in Kelvin) and n is the diode ideality factor.

In this paper PV model is built and implemented using MATLAB/SIMULINK to verify the output characteristics of the PV module. In this model, the inputs are the solar irradiation and cell temperature; the outputs are the photovoltaic voltage and current. The PV panel characteristics are given in figure 2. The current-voltage and power-voltage relationship is given in the PV characteristics.

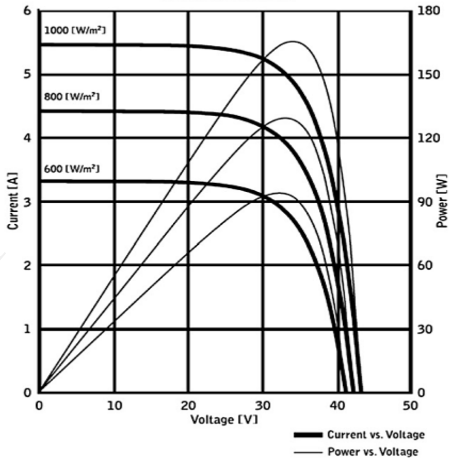

Fig.2 Current, Power vs Voltage Characteristics

2.4. Perturb and observe algorithm

In Perturb and observe (P&O) method, the MPPT algorithm is based on the calculation of the PV power and the power change by sampling both the PV current and voltage. The tracker operates by periodically incrementing or decrementing the solar array voltage. This algorithm is summarized in table I.

TABLE I Summary of hill-climbing and P&O algorithm

Perturbation	Change in Power	Next Perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

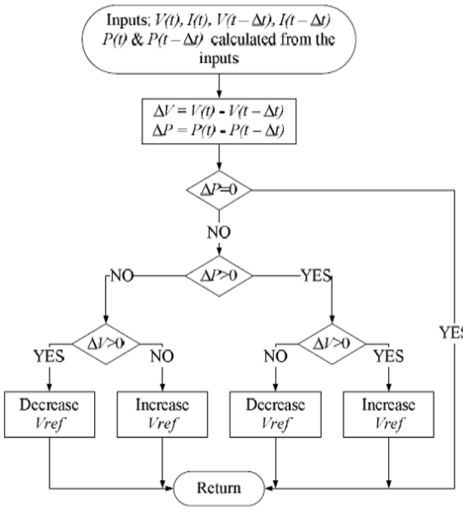

Fig.3 Flow chart of Conventional P&O technique

The algorithm works when instantaneous PV array voltage and current are used, as long as sampling occurs only once in each switching cycle. The process is repeated periodically until the MPP is reached. The system then oscillates about the MPP. The oscillation can be minimized by reducing the perturbation step size. However, a smaller perturbation size slows down the MPPT.Fig.3 shows the flow chart of conventional P&O technique. To overcome the problem of this slow response in reaching to MPP, a new algorithm has been developed so that MPP can be reached faster compared to that of conventional P&O.

2.5. Boost Converter

The maximum power point tracking is basically a load matching problem. In order to change the input resistance of the panel to match the load resistance (by varying the duty cycle), a DC to DC converter is required. It has been studied that the efficiency of the DC to DC converter is maximum for a buck converter, then for a buck-boost converter and minimum for a boost converter but as we intend to use our system either for tying to a grid or for a water pumping system which requires 230 V at the output end, so we use a boost converter.

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. In a boost converter, the output voltage is always higher than the input voltage. When the switch is turned-ON, the current flows through the inductor and energy is stored in it. When the switch is turned-OFF, the stored energy in the inductor tends to collapse and its polarity changes such that it adds to the input voltage. Thus, the voltage across the inductor and the input voltage are in series and together charge the output capacitor to a voltage high than the input voltage.

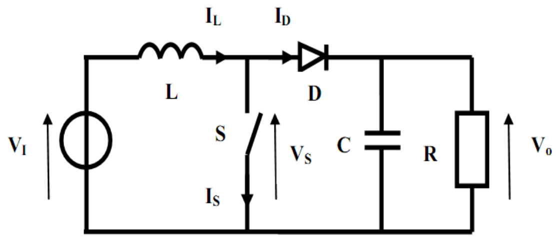

Fig.4 Circuit Diagram of a Boost Converter

The basic principle of a Boost converter consists of 2 distinct states. In the On-state, the switch S (see first figure in two configurations) is closed, resulting in an increase in the inductor current. In the Off-state, the switch is open and the only path offered to inductor current is through the fly back diode D, the capacitor C and the load R. This result in transferring the energy accumulated during the On-state into the capacitor.

3. Components of Standalone Wind Turbine System

Wind turbine is applied to convert the wind energy to mechanical torque. The mechanical torque of turbine can be calculated from mechanical power at the turbine extracted from wind power. The model of wind turbine is based on the steady-state power characteristics of the turbine. The output power of the turbine is given by the following equation.

$$P_m = \frac{1}{2} \rho A v^3 C_p(\lambda,\beta) \quad (5)$$

where ,*Pm: Mechanical output power of the turbine(W)*

C_p: Performance coefficient of the turbine

ρ: Air density (kg/m3)

A: Turbine swept area (m2)

v: Wind speed (m/s)

λ: Tip speed ratio of the rotor blade tip speed to wind speed

β: Blade pitch angle (deg)

The pitch angle, β, refers to the angle in which the turbine blades are aligned with respect to its longitudinal axis.

$$\lambda = R\,\omega_b / v_w \qquad (6)$$

where , R = turbine radius

ω_b = angular rotational speed

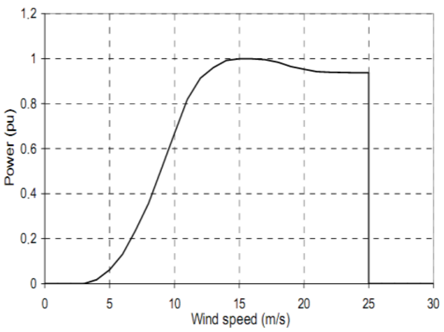

Fig.5 Power curve of the wind turbine

The wind energy conversion system consists of the wind turbine which collects the wind from the atmosphere and converts the power of wind into mechanical energy which is an input to the generator. The generator converts this mechanical energy into electrical power. The output from generator is three phase AC, this is converted into DC by the three phase full converter. The DC is given to the DC bus and then to DC loads. The power curve of the wind turbine is depicted in Figure 5. The power curve has an upper limit for the output power, which is equal or near the rated power (i.e., 1pu).

4. Block Diagram of the Proposed System

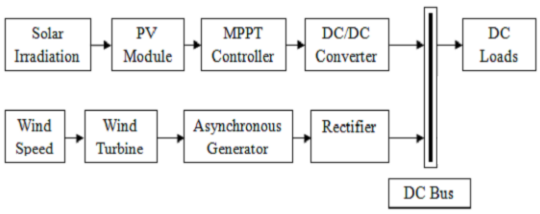

Fig.6 Block Diagram

The block diagram consists of solar irradiation as input to PV module, Maximum Power Point Tracking (MPPT) to track maximum power from sun and a boost converter which is a DC-DC converter. This DC output is given into DC bus. The wind speed is given as input to wind turbine. It converts the kinetic energy of moving air into mechanical energy that can be either used directly to run the machine or to run the generator. The output from generator is a three phase output which is given as input to the rectifier. This AC is converted into DC by the rectifier and connected to DC bus. The DC power can be used directly for DC loads.

5. Simulation model and results of standalone PV/WT hybrid system

5.1. Photovoltaic System

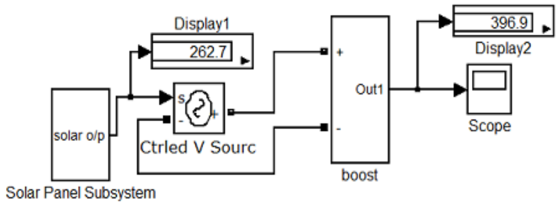

Fig.7 PV System and Boost Converter used for DC Power Generation

The model of the PV module was implemented using a Mat lab program. The model parameters are evaluated during execution using the equations listed below in this paper. The program calculates the current I, using typical electrical parameter of the module ($I0$, $V0$).

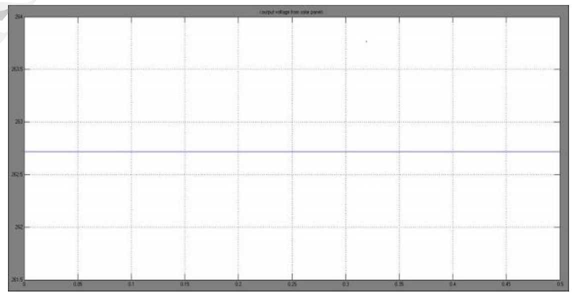

Fig.8 Output Voltage Waveform from PV Panel

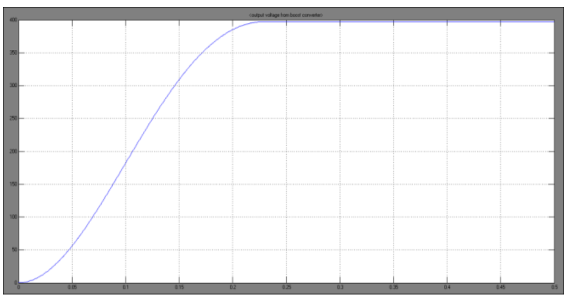

Fig.9 Output Voltage Waveform from Boost Converter

The output from PV system is DC. This DC output is of magnitude 263 V DC. This DC output is given to the Boost Converter (DC-DC converter). The DC output voltage from solar and boost is having a magnitude of 397V DC.

5.2. Wind Energy Conversion System

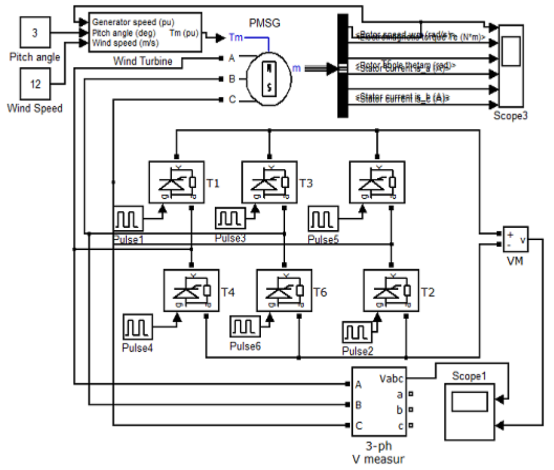

Fig.10 Wind Energy Power Generating System used for DC Power Generation

Wind Energy is conversion of kinetic energy (i.e. energy of motion of the wind) into mechanical energy that can be utilized to generate electricity. The wind blows against the blades and they rotate about the axis. The rotational motion is converted to energy by wind turbines because wind turbines produce rotational motion. Wind energy is readily converted into electrical energy by converting the mechanical energy by the electrical generator. The AC output from wind energy system is converted to DC by rectifier. The output from rectifier is a DC output. This can be connected to DC loads.

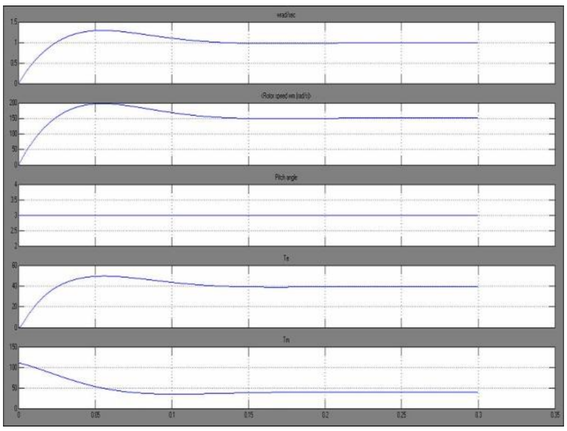

Fig.11 Simulated Waveform from WT & Generator

Wind energy is readily converted into electrical energy by converting the mechanical energy by the electrical generator. The output from generator is a three phase AC output. The magnitude of the output voltage is 430V AC. The AC output voltage is given to the rectifier and the rectifier converts the AC into DC. The amplitude of DC is 430V DC.

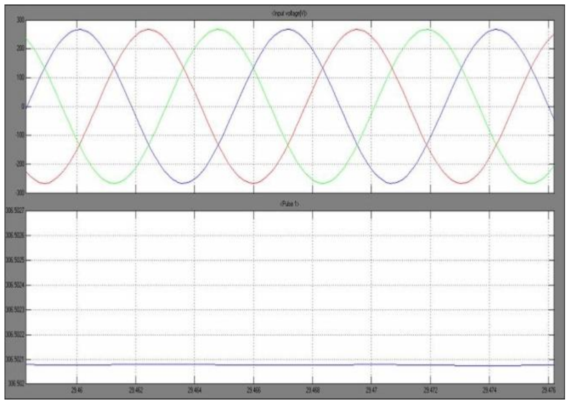

Fig.12 Waveform: Time(s) vs Output Voltage from Asynchronous Generator(Vph) and DC Output Voltage from Rectifier(V_{out})

5.3. Overall Simulated Model of Standalone PV/WT Hybrid System

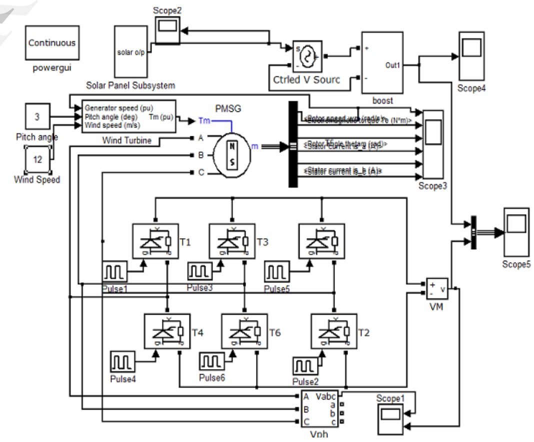

Fig.13 Overall System of Standalone Solar/Wind Hybrid Power

The solar irradiation is given as input to PV system. The PV system converts this irradiation into DC power the DC power is supplied to boost converter to get smooth and required DC. This DC is connected to DC bus and from DC bus the power is used by DC loads. The wind speed is converted to mechanical energy by the wind turbine. The wind turbine is connected to generator. The generator converts the mechanical energy into electrical energy. The output from generator is a three phase AC output. This AC is converted into DC by rectifier. Thus the DC output is supplied to DC loads through DC bus.

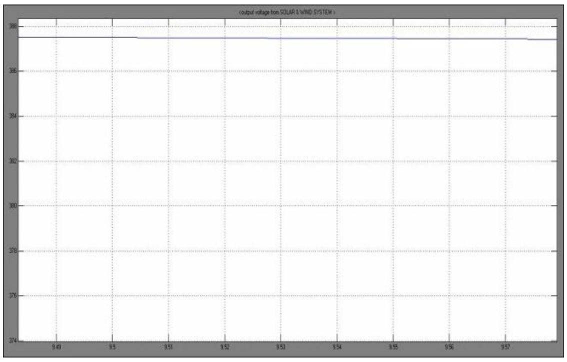

Fig.14 DC output from Standalone Solar/Wind Hybrid Power

The output from PV system is DC. The DC output is given to the Boost Converter (DC-DC converter). The DC output voltage from solar and boost is having a magnitude of 397V. Wind energy is readily converted into electrical energy by converting the mechanical energy by the electrical generator. The output from generator is an three phase AC output. The magnitude of the output voltage is 430V AC. The DC output obtained is of 430 V DC. The output obtained from overall system is a DC output of magnitude 430V. This DC is given to the DC bus and is supplied to DC loads. Mostly this type of system is used in remote areas where the reach of electricity from grid is very difficult. This type of standalone solar/wind power system is used for street lighting using LEDs.

6. Conclusion

In this paper, a standalone PV/WT hybrid power system is designed and modeled for remote area power applications. The developed algorithm comprises system components and an appropriate power flow controller. The model has been implemented using the MATLAB/SIMULINK software package, and designed with a dialog box like those used in the SIMULINK block libraries. The available power from the PV system is highly dependent on solar radiation. To overcome this deficiency of the PV system, the PV module was integrated with the wind turbine system. The dynamic behaviors of the proposed model were examined using 72 cell PV panel and with PMSG wind energy conversion system. The output acquired from the simulation of hybrid system is of 430V magnitude DC. This DC can be converted into AC by inverter and can be connected to grid in future.

7. References

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