HYBRIDIZATION OF SOLAR WIND RENEWABLE POWER SYSTEMS USING MODELING AND SIMULATION

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ABSTRACT

The modeling, simulation and control strategy of a hybrid power system (HPS) integrating a wind energy conversion system (WECS) and a solar photovoltaic system (SPV). The model includes wind turbine, photovoltaic panels, permanent magnet synchronous generator (PMSG), power converters and maximum power point tracking (MPPT) controllers. A supervisory control unit, designed to execute maximum power point tracking (MPPT), is introduced to maximize the simultaneous energy harvesting from overall power generation under different climatic conditions. Two contingencies are considered and categorized according to the power generation from each energy source, and the load requirement. In PV system Perturb & Observe (P&O) algorithm is used as control logic for the Maximum Power Point Tracking (MPPT) controller and Hill Climb Search (HCS) algorithm is used as MPPT control logic for the Wind power system in order to maximizing the power generated. The dynamic behavior of the proposed HPS is examined under different conditions based on wind speed variation and solar radiations. The developed HPS consists of a 50 W photovoltaic panel and 300 W wind turbine. The resultant model offers a good strategy to ensure power reliability under all conditions using renewable energies. A Simulink model of the proposed Hybrid system with the MPPT controlled Boost converters and Voltage regulated Inverter for stand-alone application is developed in MATLAB.

Key words: wind, power, solar, photovoltaic, reliability, Boost converters, Voltage regulate

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1. INTRODUCTION

Renewable energy sources (RES) such as Solar, Wind, Geothermal, Tidal, Hydro etc. are inexhaustible by nature. The RES have been found promising towards building sustainable and ecofriendly power generation. Due to the limitation of conventional resources of fossil fuels, it has compelled the evolution of hybrid power system. Therefore, new ways to balance the load demand is by integrating RES into the system. Hybrid system enables the incorporation of renewable energy sources and transfers the dependency on fossil fuels, while sustaining the balance between supply and demand. The significant characteristic of hybrid power system includes, system reliability, operational efficiency.

The hybrid power system enables to overcome the limitations in wind and photovoltaic resources since their performance characteristics depends upon the unfavorable changes in environmental conditions. It is probable to endorse that hybrid stand-alone electricity generation systems are usually more reliable and less costly than systems that depend on a single source of energy. On other hand one environmental condition can make one type of RES more profitable than other. For example, Photovoltaic (PV) system is ideal for locations having more solar illumination levels and Wind power system is ideal for locations having better wind flow conditions. Moreover, both wind and solar systems are non-linear systems with a maximum point called maximum power point (MPP). To reach this MPP, a maximum power point tracking (MPPT) controller should be applied. Many techniques were proposed and published in the literature. For RES especially the variable speed wind energy conversion systems, Permanent Magnet.

Synchronous generator (PMSG) is gaining popularity. PMSG have a loss free rotor, and the power losses are confined to the stator winding and stator core. A multi-pole PMSG connected to power converter can be used as direct driven PMSG in locations with low wind speed there by eliminating the gearbox which adds weight, losses, cost and maintenance. A gearless construction of wind conversion system represents an efficient and reliable wind power conversion system. In a PV system, a solar cell alone can produce power of 1 to 2 watt. The solar cell is modeled by two diode model.

The solar cells are connected in series and parallel to form a PV panel or module. The PV modules are connected in series and parallel to form a PV array in order to generate appropriate amount of power.

These techniques include but not limited to increment conductance, constant voltage method, constant current method,

curve-fitting, steepest descent, perturb and observe (P&O), fuzzy logic (FL), artificial neural network (ANN). The selection between these methods is based on the cost, the complexity, the accuracy, the convergence speed and the applicability [4]. The method used in this paper for the solar power is the P&O technique which is one of the most used MPPT algorithms, because of its easy implementation. For the wind energy system, Tip Speed Ratio (TSR) control method is adopted because of its good performance with fast response and high efficiency.

Thus a PV system consisting of PV array, Maximum Power Point Tracking (MPPT) boost converters, and Wind power system consisting of wind turbine, PMSG, rectifier and MPPT boost converter is integrated into Solar Wind hybrid power system (SWHPS). The efficiency and reliability of the SWHPS mainly depends upon the control strategy of the MPPT boost converter. The solar and wind power generation cannot operate at Maximum power point (MPP) without proper control logic in the MPPT boost converter. If the MPP is not tracked by the controller the power losses will occur in the system and in spite of wind and solar power availability, the output voltage of the hybrid system will not boost up to the required value. The

output voltage of the PV and Wind power generation are quite low as compared with the desired operating level. So, this output voltage is brought to desired operating value of 220V using Boost converter with MPPT controller at each source.

The control logic of the MPPT controlled boost converter for the Wind power generation and PV based generation are selected on the basis of ease of implementation and robustness of the Hill Climb Search (HCS) and Perturb & Observe (P&O) algorithm respectively. To ensure power reliability, many scientists recommend to not using one intermittent power source such as solar or wind but suggest the integration of both of them working either together or alternatively. That was named hybrid power system. Many investigations have been conducted in hybrid power system. M.Natsheh and A. Albarbar proposed a hybrid power system based on wind and solar energy. S. Kumar and V. K. Garg presented a hybrid solar-wind system with storage fuel cell in India. C. Marisarla and K. R. Kumar introduced a hybrid wind and solar energy system with battery storage for an isolated system. However, these solutions can't fully ensure continuous power supply since the wind speed and sunshine are unpredictable and the battery energy can sometimes be insufficient.

This work proposes a hybrid power system which consists in the integration of three renewable energy sources composed of wind, solar and biodiesel energies as well as a storage battery in order to increase the power stability and reliability. Finally, the simulations results are presented and discussed. This deals with the simulation and control of (PV/wind) hybrid systems. Study of modeling and simulation on the entire PV/wind/battery hybrid system is carried out under MATLAB/Simulink environment.

2. MATERIALS METHODS

2.1. Hybrid Power System

The proposed hybrid power system consists of PV panels, wind turbine, dc-dc converters and DC load. The schematic representation of the system is shown in Fig. 1 and the electrical rated powers of all components used in this study are as follow: the wind turbine is 300 W, the solar panel is 50W and the DC load is 300W.

2.1.1. Solar Photovoltaic System

Modeling and Design of PV Module

Solar module is composed of several cells mounted in series and/or in parallels. When mounted in series, the total voltage is the sum of every cell voltage and the current keeps the same. On contrary, when mounted in parallels, the current is the sum of every cell current and the voltage keeps the same. Our solar module includes 36 cells mounted in series.

The considered equivalent circuit of solar cell is depicted in Fig. 2. It consists of photocurrent, diode, shunt resistor and series resistor. The used mathematical model of the solar cell is based on the photovoltaic current equation as follow

$$I_{pv} = I_{ph} - I_s \left(\exp \frac{q(V + R_s I)}{AKT} - 1 \right) - \frac{V + R_s I}{R_{sh}}$$

Where, I_{ph} is the photonic current, I_s is the saturation current dependent on cell temperature, q is the electric charge (1.6×10^{-19} Coulombs), K is Boltzmann's constant (1.38×10^{-23} J/K), T is the cell's absolute temperature, A is the idealizing factor, R_s is the series resistance, R_{sh} is the shunt resistance, V is the cell output voltage. The photocurrent I_{ph} mainly depends on solar

radiation and cell temperature described in the following equation. Furthermore I_s is the cell's reverse saturation current specified as below

Figure 1 Equivalent circuit of an ideal and practical PV cell.

Figure 3 Equivalent circuit of PV module.

$$I_{ph} = (I_{sc} + K_i(T - 298)) \frac{G}{1000} \quad (2)$$

Where, I_{sc} is the short-circuit current, K is the current coefficient temperature, G is the current irradiance in (W/m^2) and 1000 is the irradiance at standard operating conditions.

Figure 4 Proposed hybrid power system

$$I_s = \frac{I_{sc} + K_i \Delta T}{\exp\left(\frac{V_{oc} + K_v \Delta T}{AV_t}\right) - 1} \quad (3)$$

Where, V_{oc} is the voltage open circuit, K_v is the voltage coefficient temperature, ΔT is the temperature at standard operating conditions and $V_t = NKT/q$ where N is cells number.

Solar Photo voltaic Control System

The proposed PV model is PWX500 and its specifications are shown in table 1. The PY system is a non-linear system with a MPP. In order to maintain the system working at the MPP, a boost converter is inserted between the PY and the load. The P&O algorithm is adopted to tune the duty cycle of the boost converter to keep the PY system at the maximum point. The working principle of this algorithm is that a slight perturbation is introduced to the system which changes the module power. If the power increases due to the perturbation, then the perturbation is continued in that direction. After the peak power is reached, the power at the next instant decreases and hence after that the perturbation reverses. When the steady state is reached, the algorithm oscillates around the peak point. The P&O algorithm flow chart is shown in Fig. 3 and the adopted SPV system in Fig. 4.

The power flow of the dc-dc converter is controlled by varying the on/off duty cycle of the converter. The average output voltage is determined by the equation

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D} \quad (4)$$

Where, D is the duty cycle, V_{out} is the dc-dc converter output voltage and V_{in} ($V_{in} = V_{pv}$) is the input voltage. The SPV system was simulated with a variable solar irradiance and the results are presented below. Fig. 5-a displayed the solar irradiance profile and in Fig. 5-b and Fig. 5-c, it is shown that the PV output power and the voltage V_{pv} respectively vary according to the irradiance profile. Between 4 and 6 seconds, the SPV operates at its rated output power which is around 50 Watt 1000 W/m^2 .

Fig. 6 clearly demonstrates that the SPV output power oscillates around its maximum power for each irradiance. The irradiances applied are 200 W/m^2 , 400 W/m^2 , 600 W/m^2 , 800 W/m^2 and 1000 W/m^2 . The oscillation is illustrated by a cloud of points around the MPP respectively. The peak is reached at 1000 W/m^2 with power oscillation around 50 W.

Figure 5 Solar cell equivalent circuit

Table 1 Solar Panel Characteristics

Parameters	Values
Solar panel power P_{mp} (W)	50
Current at maximum power I_{mp} (A)	2.9
Voltage at maximum power V_{mp} (V)	17.2
Short-circuit current I_{sc} (A)	3.2
Open circuit voltage V_{oc} (V)	21.6
Nominal cell temperature N_{oct} ($^{\circ}$ C)	25
Temperature coefficient of I_{sc} (K_i ($^{\circ}$ K))	1.46×10^{-3}
Temperature coefficient of V_{oc} (K_v ($^{\circ}$ K))	-79×10^{-3}
Cells number N_s	36

Figure 6 Perturb and observe algorithmflow chart

Figure 7 Solar photovoltaic power system

2.2. Wind Energy Conversion System

2.2.1. Modeling and Design of WECS

The wind energy conversion system is presented in Fig. 7 and the wind turbine characteristics in Table.

The WECS converts the wind kinetic energy into electrical energy. The actual mechanical power provided by wind turbine is given by the equation:

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

Where, ρ is the air density, A is the swept area of the rotor blade, it is equal to πR^2 , v is the wind speed, and $C_p(\lambda, \beta)$ is the power coefficient. The power coefficient determines the efficiency of the wind turbine depending on the Tip Speed Ratio λ and the pitch angle (β). λ stands for the ratio between turbine speed and the wind speed. It is given by the equation

$$\lambda = \frac{\omega R}{v} \quad (6)$$

Where, ω is the turbine angular speed, R is the turbine blade radius. $C_p(\lambda, \beta)$ depends on the wind turbine characteristics.

$$C_p(\lambda, \beta) = 0.5176 \left(\frac{116}{\lambda} - 0.4\beta - 5 \right) e^{-\frac{21}{\lambda}} + 0.0068\lambda \quad (7)$$

Where,

$$\frac{1}{\lambda} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1 + \beta^3} \quad (8)$$

Theoretically, the wind turbine maximum power coefficient is 0.593 which is called the limit of Betz, but the practical range is between 0.2 and 0.4.

2.2.2. WECS Control System

The wind turbine is a non-linear system; therefore it does not always work in optimal condition. In order to keep it working at maximum condition, a MPPT controller is used. The tip speed ratio (TSR) technique is adopted. The process to get the maximum power of the wind turbine goes as follows.

Figure 8 SPV with variable irradiance:

(a) solar irradiance profile, (b) output power, (c) reference voltage

Figure 9 Maximum power points with irradiance variation

The optimum power of the wind turbine is given by the following equation considering the optimal tip speed ratio (λ^{opt}) and $\beta=0$.

$$P_{eol}^{opt} = \frac{1}{2} \rho C_p (\lambda^{opt}) A V^3 \quad (9)$$

Taking into account the WECS efficiency η , the output optimum power is calculated as below

$$P_{out}^{opt} = U_{out} I_{out}^{ref} = \eta P_{eol}^{opt} \quad (10)$$

Where, I^{ref} is the output reference current. From equation (10), the reference current is obtained by

$$I_{out}^{ref} = \frac{\eta P_{eol}^{opt}}{U_{out}} \quad (11)$$

To maximize the output power, we need to control the output current that is the inductor current for which voltage is given by

$$U_L(t) = L \frac{dI_{out}}{dt} \quad (12)$$

From this equation, we obtain the output current equation

$$I_{out}(p) = \frac{1}{L.p} U_L \quad (13)$$

A PI controller is used to regulate this output current. The regulation method is illustrated in the Fig. 9.

To get the PI controller parameters, the following closed-loop transfer function was used.

$$G(p) = \left(K_p + \frac{K_i}{p} \right) \frac{1}{L.p} = \frac{K_i}{L} \frac{pT_i + 1}{p^2} \quad (14)$$

The WECS output power is analyzed with an input variable wind speed. In Fig. 9-b, we observe that the output power varies according to the wind speed profile displayed in Fig. 9-a.

In addition, Fig.10 proves that the output current follow the input reference current in order to extract the maximum power from the wind turbine.

Figure 10 Wind energy conversion system

Table 2 Wind Turbine Characteristics

Parameters	Values
Rotor diameter (m)	2.2
Number of blades	3
Rated output power (W)	300
Power max output (W)	450
Speed wind minimal start (m/s)	3
Rated wind speed (m/s)	8
Speed wind operation (m/s)	3~25
Security wind speed (m/s)	40

2.3. Energy Sources Coupling and Control Strategy

The WECS and SPV work simultaneously as primary Hill Climb Search MPPT algorithm for wind turbine. The HCS algorithm for MPPT control logic sources. In normal conditions, the WECS and the SPV provide the power to the load.

The block diagram of PV-wind hybrid power system is shown in Fig. 8. The hybrid generations consist of Photovoltaic based generation and Wind Power Generation. A comprehensive mathematical analysis of the Hybrid generation will be discussed in this section.

Figure 11 Block diagram of PV-Wind hybrid system

Perturb and Observe MPPT Algorithm for PV array

Perturb and Observe (known as P&O) algorithm, shown in Fig .9, is used in this paper for maximum power tracking of PV array. This method involves perturbation of the voltage, V , and observing the change in power output, P . If the perturbation in one direction increases the power output of the PV array, then the same direction of perturbation is continued. Otherwise, the direction of perturbation is reversed. Thus, it is a continuous process of searching for the voltage on power V_s voltage (P-V) curve, which increases the power output of the PV array. This method is well described in the literature.

Figure 12 Description of P&O algorithm for MPPT

Figure 13 Sub-system implementation of MPPT control for Wind Power system

The inputs to the controller are voltage, current and speed of PMSG. Using the speed and voltage samples the reference current is calculated. It is compared with the current measured and the error is utilized to compute the duty cycle of the power electronic switch in boost converter which controls the operation of wind power generation at MPPT.

Voltage Regulated Inverter Design

The inverter plays a key role in the hybrid power generation. The load voltage, frequency is controlled and maintained constant using inverter in stand-alone operation. The proposed voltage regulated inverter maintains the output voltage and frequency constant irrespective of change in wind speed, solar irradiation levels and load condition. The rectified and boosted DC voltage from the PV, wind is applied as input to the inverter. The schematic diagram of Voltage regulated inverter is shown in Fig. 11.

Figure 14 Voltage Regulated inverter

3. HPS SIMULATION RESULTS AND DISCUSSION

The hybrid power system is simulated and analyzed according to two scenarios. The simulation is done within 20 seconds interval. Recall that the PV panel is 50W, the wind turbine is 300 W, and the rated load power consumption is 300 W. The WECS works during the first 4 seconds and stops working the rest of time and the SPV works for 5 seconds and stops working. The simulations results are presented and analyzed in this section.

Fig. 14-a and Fig. 14-b show the WECS output power and the SPV output power respectively.

The hybrid wind and solar output power is higher than the load power demand. As a result, the hybrid power system supplies power to the load during the complete simulation time despite the variation of the wind and solar power.

Figure 15 System response during the first case:
(a) WECS power, (b) SPV power (c) load power

Figure 16 System response during thesecond case,
(a) WECS power, SPY power, (c) load power

Figure 17. PV changing irradiation level

Figure 18 Wind speed changing level

Figure 19 Output current wind

Figure 20. Output Voltage wind

Figure 21 Power generation of the hybrid system undervarying wind speed and irradiation

4. CONCLUSION

The PV power generation branch characteristics are analyzed. Fig. 18 shows the voltage with MPPT controller under different irradiances. It verifies that the PV power generation branch can readily perform the MPPT and achieve the maximum output power at a given irradiance; fig 20, 21 shows the output current and voltage for the PMSG wind system with HCS algorithm MPPT controller.

It can be clearly observed that the MPPT controller plays a key role in the hybrid power system. In order to reduce the losses and to improve the efficiency and performance of the hybrid system a faster MPPT controller is required. In the first case with PI voltage regulated inverter the output voltage is unstable with disturbance in frequency compared to the FLC voltage regulated inverter shows in fig 23 and fig 25. The power flow in the second case provide the power efficiency and the advantage of fuzzy logic controller algorithm to control the inverter and the stability of system compared to the PI voltage regulated inverter.

Nature has provided ample opportunities to mankind to make best use of its resources and still maintain its beauty. In this context, the proposed hybrid PV-wind system provides an elegant integration of the wind turbine and solar PV to extract optimum energy from the two sources. It yields a compact converter system, while incurring reduced cost.

A hybrid power system integrating three renewable energy sources composed of wind and solar has been studied in this work. The proposed method includes P&O algorithm to achieve the solar panels maximum power extraction and TSR technique to obtain the maximum power from the wind turbine. The model shows that the load is always sufficiently supplied with power despite the variation of the wind speed and the solar irradiance. This hybrid system was analyzed through two scenarios based on the variation of the wind speed and the solar irradiance.

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