SIMULATION OF GRID CONNECTED PMG WIND ENERGY AND SOLAR ENERGY SYSTEMS USING MPPT TECHNIQUES

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Abstract: Wind energy and Solar energy, are considered to be the main attributes of renewable energy for electricity generation, are growing with faster rate for the last two-three decades. This paper pertains to the study of a novel integration of wind energy from grid connected Permanent Magnet Synchronous Generator (PMSG) and solar energy systems. In order to extract maximum power from Wind energy and solar energy systems a novel technique, known as Maximum Power Point Tracking (MPPT) technique, has been adopted, in this paper.

Additionally, to maintain and sustain the continuity of supply to the load on demand at all times, the outputs of wind energy and solar energy are integrated suitably. For WEC, the overall operation is based on the estimation of the speed, that is basically a sensor-less rotor speed estimator, which in fact avoids all mechanical sensors. The rotor speed is so estimated, is used to control the turbine speed by maintaining the input dc quantities (Voltage and Current) for boost converter. Simulation studies of the proposed system are carried out using MATLAB / Simulink platform, and results are presented.

Key words: Energy system, BUCK-BOOST converter, Renewable energy, PMG of WECS, Photovoltaic system.

I. INTRODUCTION

With the gradual increase and continuing threat of global warming and the depletion of existing fossil fuel reserves, many are looking forward to sustainable green energy solutions to preserve the sources for the future generations. Other than hydro power, wind energy and pv energy are being considered to be the most renewable energy potential to meet the energy demands. Wind energy, by itself is capable to supply large amounts of power, but its presence is highly unpredictable, and depends on geographical locations and presence of tall structures. Similarly, solar energy is available throughout the day, but the solar irradiation levels vary, due to sun’s intensity and unpredictable shadows cast by clouds, birds, tall buildings, trees, etc. The common drawback of wind and solar systems, are their periodic nature that make them inconsistent. Hybrid renewable energy system utilizes two or more no of energy sources, usually wind power and pv array power. The main advantage of such hybrid system is that, when these two power production are used together, the reliability is enhanced at load side. Often, there is no sun, while there is intense wind. However, by combining both wind and solar systems power transfer, efficiency and reliability can be improved significantly. When any of the sources is unavailable or insufficient in meeting the load demands, the other energy source can compensate the deficit. Several hybrid wind and PV power systems are discussed in [2]. The proposed system consists of Wind turbine and solar PV module as inputs. Wind energy derived from PMSG connected to grid via buck-boost converter, followed by grid side converter. To extract maximum power output, special MPPT techniques are used. In this, Hill Climbing Search (HCS is employed for wind energy system [1]. For solar module another MPPT technique called Perturb and Observe (P&O) is used.[3]

II. PROPOSED SYSTEM ARCHITECTURE

The block diagram of the proposed architecture is shown in Fig. 1.
Wind turbine is coupled to PMSG, which is connected to uncontrolled three phase Diode Bridge, followed by Buck-Boost converter and Grid side converter. The DC/DC converter helps to maintain fixed DC output voltage with maximized output power by controlling the converter’s gate duty ratio by using PWM control, using MPPT technique (HCS). [4]-[5]

The solar photo-voltaic cell is connected to boost converter, to get high output voltage MPPT technique,  Perturb and Observe (P&O) is employed to extract maximum power. And this output voltage is fed to three phase inverter to convert DC voltage to AC grid voltage.

III. Wind Energy Conversion System (WECS)

A. Modelling of Wind Turbine

Wind turbine converts the wind energy, extracted through blades, to mechanical energy, which in turn, runs a generator to produce electrical energy. The power output of any variable speed wind turbine is given by [1],

\[ P_w = \frac{1}{2} \frac{m v_w}{t} = \frac{1}{2} \rho A \frac{d v_w^2}{t} = \frac{1}{2} \rho A v_w^3 \]  

(1)

where \( P_w \) is wind power (W), \( \rho \) is the air density (kg/m³), \( A \) is the area swept by the turbine blades (m²), \( d \) is the radius of the swept area of blades (m), \( D \) is the thickness of the parcel (\( D = v_w t \)) (m), \( m \) is the mass of air = air density * volume = \( \rho A d \) (kg) and \( v_w \) is the wind speed (distance/time) (m/s).

The mechanical power (\( P_m \)) generated is given by,

\[ P_m = P_w C_p(\lambda, \beta) = \frac{1}{2} \rho A v_w^3 C_p(\lambda, \beta) \]  

(2)

where \( C_p(\lambda, \beta) \) is the power coefficient function, \( \lambda \) is the tip speed ratio (TSR), and \( \beta \) is the pitch angle.

The power co-efficient is given by,

\[ C_p(\lambda, \beta) = C_1 \left( \frac{C_2}{\lambda} - C_3 \beta - C_4 \right) e^{-\frac{C_5}{\lambda^2}} + C_6 \lambda \]  

(3)

\[ \frac{1}{\lambda} = \frac{1}{\lambda + 0.08 \beta} - 0.035 \frac{1}{\beta^3 + 1} \]  

(4)

The power co-efficient is given by

\[ C_p = \frac{P_m}{v_w^3}; \quad C_p < 1 \]  

(5)

\[ P_m = C_p(\lambda, \beta) \frac{\rho v_w^3}{2} \]  

(6)

The generated \( P_m \) depends on \( C_p \), \( C_p \) is the ratio of actual power delivered by the wind turbine and the theoretical power available in the wind. \( C_p(\lambda, \beta) \) depends on TSR and pitch angle \( \beta \).

TSR refers to ratio of turbine angular speed over the wind speed, given by,

\[ \lambda = \frac{d \omega}{v_w} \]  

(7)

where \( m \) is the rotor speed.

The mechanical torque (\( T_m \)) for gearless WECS is given by,

\[ T_m = P_m \frac{d}{\lambda v_w} = \frac{1}{2} \rho A C_p(\lambda, \beta) \frac{R}{v_w} = \frac{P_m}{\omega} \]  

(8)

IV. SOLAR PV MODULE

The equivalent circuit of a PV cell is shown in Fig. 4. An ideal solar cell is modelled by a current source and a diode in parallel with it.
By applying Kirchoff’s current law, we get,
\[ I_{ph} = I_d + I_{RP} + I \]  
\[ I = I_{ph} - (I_{RP} + I) \]  
We get the following equation for the PV cell current
\[ I = I_{ph} - (I_o e^{(V + I/R_S) - 1}) + V + I_{RS}/R_p \]  
Where \( I_{ph} \) is isolation current, \( I \) is cell current, \( I_o \) is reverse saturation current, \( V \) is cell voltage, \( R_s \) is the series resistance, \( R_{sh} \) is the parallel resistance, and \( V_T \) is the thermal voltage.

V. DC – DC CONVERTERS

DC-DC converters are used to convert a DC voltage at one level to another level, often providing regulating output.

A buck-boost converter provides an output voltage that may be less than or greater than input voltage; the output voltage polarity is opposite to that of input voltage. This is also known as inverting regulator [8,12]. The circuit arrangement of buck-boost converter is shown in Fig. 4.1. In steady state, the output-to-input conversion ratio is the product of the conversion ratios of the two converters in cascade
\[ \frac{V_o}{V_b} = \frac{D}{1-D} \]  
Where \( V_o \) = Output DC voltage, \( V_b \) = Input DC voltage, \( D \) = Duty ratio

In the process of extraction of maximum power from wind, MPPT technique uses the duty ratio information, and the triggering pulses are generated.

VI. MPPT TECHNIQUES

Maximum power point tracking (MPPT) techniques are used to maximize the output power by tracking continuously the maximum power point (MPP).

Among various techniques, Hill Climbing Search (HCS) is used to extract maximum power for WECS. For solar PV module, Perturb & Observe (P&O) technique is used to extract maximum power from solar cell.

A. Hill Climbing Search

HCS is one of the simplest MPPT techniques where it requires power measurement only. This is based on perturbing the turbine shaft speed in small steps (\( \Delta \omega \)) and observing the resulting changes in turbine mechanical power increase or decrease. The various types of HCS techniques are; fixed, variable, and dual step size.

B. Perturb & Observe

In P&O method, the control adjusts the voltage by small amount from array and power will be measured. If power increases, adjustments will be done to maintain the power; this is P&O method. The only thing, this differs from HCS is in perturbation, in HCS it is on duty cycle and in P&O it is based on operating voltage of DC link between PV array and power converter.

VII. DC-AC INVERTER

A three phase inverter is used for DC-AC conversion. It is generally connected to grid, termed as Grid Side Converter (GSC).
A control technique called Voltage Oriented Control (VOC) is used for controlling the output voltages and current obtained from wind energy system. This technique includes double conversion of voltages, making use of transformation blocks (abc-dq) and current transformation to generate PWM output pulses to control inverter switches.

VIII. Simulation Results

The simulation for hybrid model of wind and solar energy systems using Matlab/Simulink platform (Version R12a) is carried out.

The parameters for PMSG and Wind turbine are given below (Table 1 [1])

<table>
<thead>
<tr>
<th>Wind Turbine Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power (MW)</td>
<td>2.3</td>
</tr>
<tr>
<td>Blade diameter (m)</td>
<td>71</td>
</tr>
<tr>
<td>Rated wind speed (m/s)</td>
<td>14</td>
</tr>
<tr>
<td>Number of blades</td>
<td>3</td>
</tr>
<tr>
<td>Turbine Inertia J (Kg.m²)</td>
<td>670</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PMSG Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power (MW)</td>
<td>2</td>
</tr>
<tr>
<td>Rated Voltage (V)</td>
<td>690</td>
</tr>
<tr>
<td>Rated Stator Frequency (Hz)</td>
<td>11.25</td>
</tr>
<tr>
<td>Number of poles P</td>
<td>30</td>
</tr>
<tr>
<td>Stator Winding resistance R_s (mΩ)</td>
<td>0.73051</td>
</tr>
<tr>
<td>d-axis Synchronous Inductance L_d (mH)</td>
<td>1.21</td>
</tr>
<tr>
<td>q-axis Synchronous Inductance L_q (mH)</td>
<td>2.31</td>
</tr>
<tr>
<td>Flux Leakage (Φ)</td>
<td>4.696</td>
</tr>
<tr>
<td>Stator Leakage Inductance L_s (mH)</td>
<td>1.2</td>
</tr>
</tbody>
</table>

The parameters of solar PV array are given in table 2

<table>
<thead>
<tr>
<th>Solar PV array Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power (W)</td>
<td>300</td>
</tr>
<tr>
<td>Open circuit voltage (V)</td>
<td>63.6</td>
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<tr>
<td>Short circuit current (A)</td>
<td>12.5</td>
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<tr>
<td>Optimum voltage (V)</td>
<td>42.4</td>
</tr>
<tr>
<td>Optimum current (A)</td>
<td>6.75</td>
</tr>
</tbody>
</table>

A. WEC system

The plot of wind speed of Wind turbine is shown above. For specified amount of time the speed of turbine is 14m/s till 1sec and after that it is 9m/s. Characteristics are flat.
For wind speed of 14m/s the torque is $4.8 \times 10^5$ N-m. After 1sec speed is changed to 9m/s, for this speed the torque is $2 \times 10^5$ N-m. During change of torque from $4.8 \times 10^5$ to $2 \times 10^5$ we can observe oscillations in the plot, during the interval of 1s to 1.2s, and these oscillations are due to rapid change wind speed from 14m/s and 9m/s.

The three phase voltages and currents are shown for the simulation time of 2sec. For the wind speed of 14m/s the currents are 2.2kA and for 9m/s it is 980A. The phase voltages Vabc are 600V.

### B. Solar PV system

![PV array power](image)

**Fig. 10 : Wind torque**

**Fig. 11 : Output power**

**Fig. 12 : Grid voltage and current**
The output of PV array is 600W.

The three phase voltages and currents are shown for the simulation time of 2sec. The current is 150A and the phase voltages Vabc is 600V.

C. Hybrid system

In this paper, simulation of grid connected PM wind energy system and Solar PV system using different MPPT techniques is carried out. MPPT technique is employed for wind energy system and another for solar. Hill climbing search (HCS) is employed for WECS. For solar energy system Perturb & Observe (P&O) is introduced. The results are verified using Matlab/Simulink platform.

REFERENCES


