Comprehensive evaluation of PV-Wind Hybrid system using MATLAB/Simulink

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Abstract - The model is useful for simulation of a hybrid PV-wind system connected to load and grid are implemented and the results of simulation are presented. Here p-v model, wind model are implemented with Matlab/simulink. Useful for power applications and also helpful in research work.

Index terms — PV model, Wind Model, Hybrid system.

Nomenclature

- $I_{pv,cell}$: current generated by incident light
- $I_d$: Shockley diode equation
- $I_0$: Reverse saturation current
- $q$: Electron charge
- $T$: Temperature of p-n junction
- $a$: Diode ideality constant
- $I_0$: Saturation current of array
- $V_t$: Thermal voltage or array
- $N_s$: Cell connected in series
- $N_p$: Cell connected in parallel
- $R_s$: Equivalent series resistance
- $R_p$: Equivalent parallel resistance
- $I_{sc}$: Short circuit current
- $V_{oc}$: Open circuit voltage
- $(O,I_{sc})$: Short circuit point
- $K_v$: Voltage coefficient
- $K_i$: Current coefficient
- $P_{max,m}$: Maximum power
- $P_{max,e}$: Maximum experimental power from data sheet
- $(V_{oc},0)$: Open circuit point
- $(V_{mp,imp})$: Maximum power point
- $I_{pv,n}$: Light generated current at nominal condition at $(25^0C$ and $1000\ W/m^2)$
- $T$: Actual temperature
- $T_n$: Nominal temperature
- $G$: Solar irradiance
- $W_T$: Wind turbine
- $T_W$: Torque wind turbine
- $P_W$: Power wind turbine
- $V$: Mean wind speed
- $C_P$: Power coefficient
- $C_Q$: Torque coefficient
- $\lambda$: Tip-speed ratio
- $\Omega_{WT}$: WT rotor speed

Introduction - Hybrid power systems consist of a combination of renewable energy sources such as: photovoltaic (PV), wind generators, hydro, etc., to charge batteries and provide power to meet the energy demand, considering the local geography and other details of the place of installation. These types of systems, which are not connected to the main utility grid, are also used in stand-alone applications and operate independently and reliably. The best applications for these systems are in remote places, such as rural villages, in telecommunications, etc. The importance of hybrid systems has grown as they appeared to be the right solution for a clean and distributed energy production. It has to be mentioned that new implementations of hybrid systems require special attention on analysis and modeling. One issue is determined by the variable and unpredictable character of energy supply from renewable sources. A major importance for the theoretical study of hybrid systems, based on renewable energy (photovoltaic, wind, hydroelectric systems), is the availability of models, which can be used to study the behavior of...
hybrid systems, and most important, software simulation environments.

**PV-cell modelling**-With the rapid development of study on solar cells, many models are presented to describe the characteristics of solar cells. This method helps us to construct the circuit model of pv cell. Computer simulation seems to reduce the tests for solar cells. This model accepts irradiance and temperature as environmental parameters as input variables, simulate the I-V characteristics of solar cells.

**Fig-a, P-V Cell, P-V Module, P-V Array**

combine to form PV module, no of module combine to form PV array.

**Fig-b, P-V Cell model-Circuit Diagram**

Shunt diode ideality factor is set to achieve the best curve match.

Series resistance \((R_s)\): gives a more accurate shape between the maximum power point and the open circuit voltage.

Temperature dependence of the reverse saturation current of the diode is \((I_d)\).

Temperature dependence of the photo-generated current is \((I_{pv})\). Current source: proportional to the light falling on the cell in parallel with a diode.

The photovoltaic array can be simulated with an equivalent circuit model based on the photovoltaic model given below,

\[
I\_{PV} = I_{PV,cell} - I_{0,cell} \left[ \exp \left( \frac{qV}{akT} \right) - 1 \right] 
\]

\[\text{....1}\]

Fig-c, characteristics I-V curve of a practical PVA device and the three remarkable points: short circuit \((0,I_{SC})\), maximum power point \((V_{mp},I_{mp})\) and open circuit \((V_{oc},0)\).

The I-V characteristic of the ideal photovoltaic cell is

\[
I = I_{PV,cell} - I_{0,cell} \left[ \exp \left( \frac{qV}{akT} \right) - 1 \right] 
\]

\[\text{....1}\]

The light generated current of the photovoltaic cell depends linearly on the solar irradiation and is also influenced by the temperature is given by

\[
I_{PV} = \left( I_{PV,n} + K_I \Delta T \right) \frac{G}{G_n} 
\]

\[\text{....2}\]

The diode saturation current \(I_o\) and its dependence on the temperature may be expressed by
\[ I_0 = I_{0,n} \left( \frac{T_n}{T} \right)^3 \exp \left[ \frac{qE_g}{aK} \left( \frac{1}{T_n} - \frac{1}{T} \right) \right] \]

where \( E_g \) is the bandgap energy of the semiconductor (\( E_g \approx 1.12 \) eV for the polycrystalline Si at 25°C), and \( I_{o,n} \) is the nominal saturation current. \( V_t = NskT/q \) is the thermal voltage of the array with \( Ns \) cells connected in series. \( I_{o,n} \) is the nominal saturation current, with \( Vt,n \) being the thermal voltage of \( Ns \) series-connected cells at the nominal temperature \( T_n \).

\[ I_{0,n} = \frac{I_{oc,n}}{\exp \left( \frac{V_{oc,n}}{aV_{r,n}} \right) - 1} \]

Maximum experimental power from datasheet

\[ P_{max,e} = V_{mp} \left[ \frac{I_{pv} - I_0}{\exp \left( \frac{q}{kT} \frac{V_{mp} + R_s I_{mp}}{aN_i} \right) - 1} \right] - \frac{V_{mp} + R_s I_{mp}}{R_p} \]

For any value of \( R_s \) there will be a value of \( R_p \) that makes the mathematical I-V curve cross the experimental (\( V_{mp}, I_{mp} \)) point.

\[ R_p = \frac{V_{mp} \left( V_{mp} + I_{pv} R_s \right)}{V_{mp} I_{pv} - V_{mp} \exp \left( \frac{q}{kT} \left( \frac{V_{mp} + R_s I_{mp}}{aN_i} \right) \right) + V_{mp} I_0 - P_{max,e}} \]

Mathematical model of PV-array

\[ T_{WT} = \frac{V_{mp} \left( V_{mp} + I_{pv} R_s \right)}{V_{mp} I_{pv} - V_{mp} \exp \left( \frac{q}{kT} \left( \frac{V_{mp} + R_s I_{mp}}{aN_i} \right) \right) + V_{mp} I_0 - P_{max,e}} \]

Wind-Turbine modeling- The WT converts wind energy to mechanical energy by means of a torque applied to a drive train. A model of the WT is necessary to evaluate the torque and power production for a given wind speed and the effect of wind speed variations on the produced torque. The torque \( T_{WT} \) and power \( P_{WT} \) produced by the WT within the interval \([V_{min}, V_{max}]\), where \( V \) is the mean wind speed, are functions of the WT.
blade radius R, air pressure, wind speed and of coefficients CQ and CP.

\[ T_{wt} = \frac{1}{2} \, p \, p \, R^3 \, Cq(\lambda, \theta) \, V^2 \]  
\[ P_{wt} = C_p(\lambda, \theta) \, P_v = \frac{1}{2} \, \rho \, R^2 \, C_p(\lambda, \theta) \, V^3 \]  

CP is known as the power coefficient and characterizes the ability of the WT to extract energy from the wind. CQ is the torque coefficient and is related to CP according to

\[ C_q = \frac{C_p}{\lambda} \]  

Here, \( \lambda \) is the tip-speed-ratio,
\[ \lambda = \frac{W_{wt} \, R}{V} \]  

Where \( \omega_{WT} \) is the WT rotor speed.

### Mathematical model of wind turbine

![Mathematical model of wind turbine](image)

**Inputs and Outputs of wind turbine**

**Generator speed (pu)**
Simulink input of the generator speed in pu based on the nominal speed of the generator.

**Pitch angle (deg)**
Simulink input of the pitch angle.

**Wind speed (m/s)**
Simulink input of the wind speed in m/s.

**Tm (pu)**
Simulink output of the mechanical torque of the wind turbine, in pu of the nominal generator torque. The nominal torque of the generator is based on the nominal generator power and speed.

### Matlab model of Hybrid PV-Wind turbine System

![Matlab model of Hybrid PV-Wind turbine System](image)

**Simulation results**

![Simulated IV curve of PV-array](image)
in phase voltage. As we know due to non linear load a lot of harmonic distortion occurs in supply system, due to non linear load harmonic component occurred in voltage waveform of different phases

The simulation model allows studies such as:

- renewable energy sources electrical parameters (powers, voltages, currents etc.)
- renewable energy sources constructive parameters (blades length and number of wind turbine, PV panels’ number)
- voltage and frequency control (control algorithms)
- electrical energy conversion (type of DC/AC conversion)
- Consumer modeling and control.
- Power quality distortion phenomena and analysis.
- Renewable energy availability.

Conclusions

The full mathematical models for PV array modules were fully developed including the inherently nonlinear I-V characteristics and variations under ambient temperature and solar irradiation conditions. Grid connected renewable photovoltaic dynamic control strategies were digitally simulated and validated, using matlab/simulink/simpower system software environment. From the results obtained above, the following are the salient conclusions that can be drawn from this paper. A novel of PV/Wind HEPS modeling and simulation problems by using Matlab/Simulink environment has been proposed. By this we can interface two or more types of

Simulated PV-curve of pv-array

Phase to phase inverter voltage

THD analysis at 50(Hz)

Result Analysis

It can be seen a voltage waveform distortion caused by electronic devices — inverters used for energy conversion in DC/AC module, shows harmonic distortion
electrical power generation sources and based on optimization we can run the plant as per our need. In further work to that fuel cell, battery can also be added so that in night time when solar power is unavailable the fuel cell and battery can act as a backup source of power.

References


