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Modeling of PV and Wind for Microgrid Application

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Abstract—This paper studies the modeling of PV and wind for microgrid application. Solar energy and wind energy are interminable and reliable renewable energy sources which become more and more popular among assiduous power system researchers. For efficient operation of microgrid, it is necessary to achieve maximum conversion efficiency of these renewable energy resources and this can be made possible by integrating DC-DC converter with maximum power tracking (MPPT) algorithm. In this work, a single diode photovoltaic cell is modeled in MATLAB and validated the performance using the standard datasheet. Similarly, a wind turbine is also modeled interfaced using dc to dc converter.

IndexTerms—Microgrid, MPPT, Photovoltaic (PV), single diode photovoltaic cell. DC-DC converter,

I. INTRODUCTION

Due to depletion of fossil fuel resources, generation of power from renewable energy become inevitable. Photovoltaic and wind resources has gaining more potential to mitigate exacerbated increasing energy demand. High installation cost and low efficiency of photovoltaic (PV) cells has bolstered the maximum power extraction from the PV cell [1-2] indispensable. However, it is censorious in using maximum power point tracking (MPPT) algorithms, but the system's reliability can be improved and power transfer capability of the system gets increased significantly.

The system which directly transforms sunlight into electricity is called Photovoltaic system. Some of the applications of PV devices like lighting applications and DC motors etc. However, recent developed applications may need converters to maintain voltage and current regulation, to manage the power flow in grid-connected systems, which is mainly used to find the maximum operating point of the device. Hence, to provide good MPPT control for the system it is indeed to provide better mathematical model for both PV device and WECS and that could be useful in the dynamic analysis of converters, also finds application in tracking maximum power in the operating curve of PV and Wind. Several researcher has provided many mathematical models for PV system.

In this study, the single diode model is considered because it provides better tradeoff between simplicity and accuracy. Many researchers have used this mathematical model in their work mostly with the circuit comprised of current source in parallel with diode.

As stated earlier in order to improve the performance of the solar panel and wind turbine Maximum Power Point Tracking algorithm is necessary. There are many different algorithms are available to track maximum operating point (MPPT) they are Perturb and Observe (hill climbing) method, Incremental conductance algorithm, Fractional Short Circuit Current method, Fractional Open Circuit Voltage method, Fuzzy logic Control, Neural Network control algorithm, etc. From the above algorithms the most commonly used algorithms are Perturb and observe (P&O) algorithm and Incremental conductance algorithm because of their simplicity and lesser time consumption for tracking maximum point [4]. Since PV characteristic curve and power coefficient curve of wind turbine depends on weather conditions, the curve may change abruptly for varying weather conditions (irradiance level). Since the curve changes the maximum operating point also changes continuously. P&O algorithm it takes perturbation in voltage and tracks MPP. As weather condition changes, MPP also changes due to perturbation rather than that of irradiance and that may sometimes ends up in calculating wrong MPP [11].

Hence, the above drawbacks can be overcome by Incremental Conductance method, as the algorithm uses only two instants of voltage and current to calculate maximum operating point. As a result, performance gets improved but also the complexity gets increased and therefore, the installation cost of panel is increased. So it is necessary to improve performance without affecting the simplicity. This paper deals with the modeling of PV and wind, in order to study the control strategy with the microgrid in MATLAB.

II. PV MODELING

Generally an ideal photovoltaic cell can be represented by connecting ideal current element in parallel with the diode. The equivalent circuit of an ideal PV cell is shown in Fig 1.

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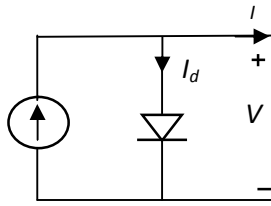


Fig.1 Equivalent circuit of an ideal PV cell

The mathematical model for PV cell is represented as follows and in this Shockley ideal diode equation is considered and the final equation is as follows

$$I_d = I_0 \left[\exp \frac{qV_d}{V_{TH}} - 1 \right] \quad (1)$$

Where

I_d = Diode current

I_0 = Reverse saturation current

V_d = Diode Voltage

V_{TH} = Thermal voltage

The thermal voltage is defined as the characteristic voltage that relates the electrical current and the electrostatic potential across p-n junction in semiconductors. It may be expressed as given below.

$$V_{TH} = \frac{nkT}{q} \quad (2)$$

Where

k = Boltzmann constant ($1.3806503 \times 10^{-23}$ J/K)

q = Charge of an electron ($1.6021765 \times 10^{-19}$ C)

T = Absolute temperature

n = Ideality factor of diode ($n=1$ for ideal diodes and $1 < n < 2$ for non-ideal diodes)

The fundamental equation of the ideal PV cell can be written as below. The light generated current is denoted by I_{pv} [3,5]

$$I = I_{pv} - I_d \quad (3)$$

$$I = I_{pv} - I_0 \left[\exp \frac{V}{V_{TH}} - 1 \right] \quad (4)$$

However, equation (4) may fails to give the accurate voltage – current characteristic curve for practical PV array. Practically, PV arrays is the combination of many PV cells and it demands the inclusion of additional parameters for the ideal PV equation.

In practical case, ideal PV characteristic is not possible there may be drop because of two parameters series resistance (R_s), and the parallel resistance (R_p) which are considered for practical case. For a practical PV device, the diode is always a non-ideal one. So, the ideality factor will never be one. It will be a value ranging between 1 and 2. The ideality factor is a measure of how closely the diode follows the ideal diode equation. But in a practical case, there may cause deviation in the behavior of the ideal diode.

By considering the above discussed effects parameters, the equivalent circuit for a practical PV cell can be modified as shown below in Fig 2.

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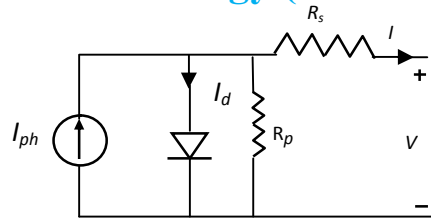


Fig.2 Practical model of a PV cell

By considering series and parallel resistance in PV model gives the modified version of the single diode PV model with R_s . By considering this parameter causes the curve to match with open circuit characteristics with the test data for a wide range of varying solar irradiance. The parallel resistance, R_p takes leakage current of the diode into consideration. This R_p decides the slope of the I - V characteristics curve in the fixed current region. Hence the final current equation of the single diode model with R_s and R_p can be given by equ(5)

$$I = I_{pv} - I_o \left[\exp \frac{q(V + IR_s)}{N_s n k T_c} - 1 \right] - \left[\frac{V + IR_s}{R_o} \right] \quad (5)$$

From above it is clear that saturation current I_o depends on the temperature coefficient of open circuit voltage, K_v , and the temperature coefficient of short circuit current, K_i . The photon generated current, of the PV cell is proportional to the solar irradiation and also depends on the temperature. The photon generated current is calculated as:

$$I_{pv} = \left[I_{sc} + K_i (T_c - T_{rf}) \right] \frac{G_c}{G_{rf}} \quad (6)$$

And the saturation current I_o is calculated as

$$I_o = \frac{I_{sc} + K_i (T_c - T_{rf})}{\exp \left[\left(\frac{V_{oc}}{N_s} \right) + K_v q (T_c - T_{rf}) / n k N_s T_{rf} \right]} - 1 \quad (7)$$

Using equations(6) and (7) a single-diode PV can be modeled with series resistance and parallel resistance and this is used to make analysis of the MPPT algorithm. It has been found that in computational representation this model is accurate and fast for PV. The mathematical model is simulated for varying irradiance with constant temperature of 25°C and for varying temperature with constant irradiance of 1000W/m² in MATLAB/Simulink and checked the performance curve with KC200GT datasheet [8] as shown in Fig.4 and Fig. 5.

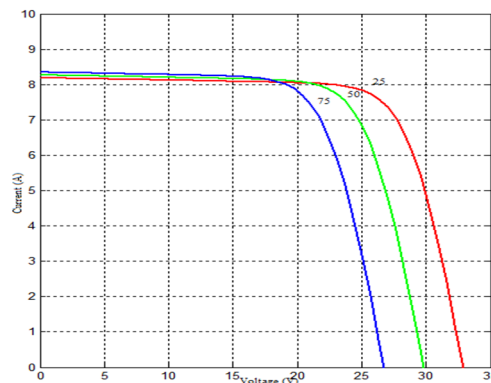


Fig.4 I-V characteristics for varying temperature at fixed irradiance level (1000W/m²)

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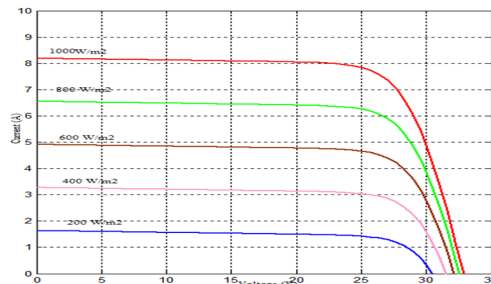


Fig.5I-V characteristics for varying irradiation levels at fixed temperature (25°C)

From the simulated curves shown in Fig.5 it is seen that if irradiation level is decreased current also decreased but by increasing irradiation level current level also improves and maximum operating point also gets improved as well for varying irradiation level and MPPT plays role in finding different maximum operating point for different irradiation level hence by incorporating MPPT control, panel operates at the maximum power point for different weather condition and in this obtained PV characteristic has perfect agreement with KC200GT datasheet curve for varying irradiation level and also for different temperature at constant irradiation. By using this model, highly absolute results are obtained in case of open circuit condition as well as in short circuit condition. Even though the computation time is more for this model, it is more precise since it considers the practical solar cell behavior.

III. WIND TURBINE MODELING

The main component of wind energy conversion system (WECS) are wind turbine, generator and power converter. The mechanism of capturing power from wind called rotor or wind wheel. The theory of capturing energy from wind stream, and the performance of WECS can be represented by means of torque-speed and power-speed characteristics. The wind turbines can generate mechanical power from the availability of wind power which in turn fed to the electrical generator to generate electrical power. When wind passes through the blades, it generates lift force and exerts a torque. At the inner side of the nacelle the rotating blades turns a shaft then goes into a gearbox. The gearbox is used to improve the rotational speed for the operation of the generator and utilizes magnetic fields to convert the rotational energy into electrical energy.

The power coefficient (C_p) is defined as capability of the rotor to extract the mechanical power extracted by the rotor over the power contained in the undisturbed air stream. It is more important parameters, which affects the power availability in the wind and power transferred to the wind turbine rotor. Albert Betz calculated the maximum theoretical value of C_p based on the elementary momentum theory. This has been expressed in [9].

$$m = \rho_{\text{air}} A V_{ws} \quad (8)$$

Where m is mass flow in kg/s, ρ_{air} is the air density in kg/m³, V_{ws} is wind speed in m/s, and A is the area, which air passes through in m².

The power coefficient is expressed as:

$$C_p = \frac{P_{\text{Mech}}}{P_o} = .5 \left[1 - \left(\frac{V_{w2}}{V_{w1}} \right)^2 \right] \left[1 + \frac{V_{w2}}{V_{w1}} \right] \quad (9)$$

Where P_{mech} is the mechanical power extracted by the converter in W, V_{w1} and V_{w2} are the undisturbed wind speeds before and after the converter in m/s, respectively, and P_o is the power contained in wind $P_o = \frac{1}{2} \rho_{\text{air}} V_{w1}^3 A$ (10)

C_p in equation (9) is a function of $\frac{V_{w2}}{V_{w1}}$, which reaches its maximum value when $\frac{V_{w2}}{V_{w1}} = 1/3$. By substituting this value in the equation (9), $C_p = 16/27 = 0.593$. This means that even for an ideal converter only less than 60% of wind energy can be extracted by the converter.

This performance of wind turbine can be characterized by its rotor torque and power, versus speed curves. Power coefficient or

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torque coefficient, for any wind turbine, which is important to be known to allow the calculation of the power and torque captured and produced by its rotor. These two coefficients are functions of the tip speed ratio which is given by

$$\lambda = \frac{\text{Tangential velocity of the rotor blade tip}}{\text{wind speed}} = \frac{R_r \omega_{wt}}{V_{ws}} \quad (11)$$

Where R_r is the radius of rotor in m, ω_{wt} is the speed of rotor in rad/s, and V_{ws} is the wind speed in m/s. Equations (12) and (13) express the power captured by the rotor and the average rotor torque, respectively

$$P_{wt} = \frac{1}{2} \rho_{air} C_p \lambda V_{ws}^3 A \quad (12)$$

Where P_{wt} is the power captured by the rotor in W, $C_p(\lambda)$ is rotor power coefficient, ρ_{air} is the air density in kg/m³, and A is the swept area of rotor in m².

$$\tau_{wt_{av}} = \frac{1}{2} \rho_{air} C_t(\lambda) V_{ws}^2 A R_r \quad (13)$$

Where $\tau_{wt_{av}}$ is in Nm, $C_t(\lambda)$ is the rotor torque coefficient, and R_r is the rotor radius in m. The $C_p(\lambda)$ curve as presented in for a 3-bladed, fixed pitch, small wind turbine is shown in Fig. 6.

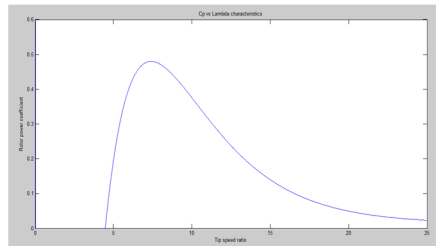


Fig. 6 Torque coefficient (C_p) versus tip speed ratio (λ) Curve

IV. CONCLUSION

Due to increasing energy crisis, renewable energy sources is gaining more and more popularity and due to high availability nature solar and wind power is gaining more importance among researchers, so it is indeed to provide a precise mathematical modeling for both PV and wind and this paper emphasizes the importance of an accurate PV and wind modeling in Simulink. These model can be subsequently used for the study of control strategy in microgrid and to develop MPPT algorithm.

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