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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 resourceshasgaining more potential to mitigateexacerbated 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 censoriousinusing 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 sunlightinto electricity is called Photovoltaic system. Some of the applications of PV deviceslike lighting applications andDC motors etc. However,recentdevelopedapplicationsmay 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 bothPV 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 providedmany mathematical models for PV system.

In this study, the single diode model is considered because it providesbetter 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 inorder to improve theperformance of the solar panel and wind turbineMaximum Power Point Tracking algorithm isnecessary.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 fortracking 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 takesperturbation in voltage and tracks MPP. Asweather condition changes,MPPalso changes due to perturbation rather than that of irradiance andthat may sometimesends up in calculating wrong MPP[11].

Hence, the abovedrawbacks can be overcome byIncremental Conductance method, as the algorithm usesonly two instants of voltage and current to calculate maximum operating point. As a result,performancegets improvedbut 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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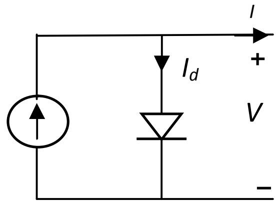

Fig.1 Equivalent circuit of an ideal PV cell

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 $(1.3806503*10^{-23}$ J/K)
q = Charge of an electron $(1.6021765*10^{-19}$ 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 theaccurate 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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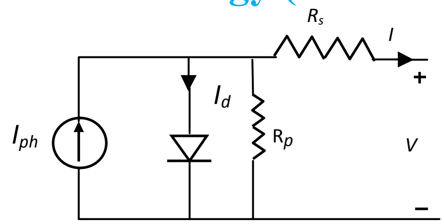

Fig.2Practical model of a PV cell

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 finalcurrent equation of the single diode model with$R_s$and $R_p$can be given by equ(5)

$$I = I_{pv} - I_o\left[\exp\frac{q(V + IR_s)}{NsnkT_c} - 1\right] - \left[\frac{V + IR_s}{R_o}\right] \qquad (5)$$

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:

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

And the saturation current I_o is calculated as

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

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 ofthe MPPT algorithm. It has been found that in computational representation this model is accurate and fast for PV.

Themathematical model is simulated for varying irradiance with constant temperature of 25^{o}Cand for varying temperature with constant irradiance of 1000W/m^{2}in MATLAB/Simulink andchecked the performance curve with KC200GT datasheet [8] as shown in Fig.4 and Fig. 5.

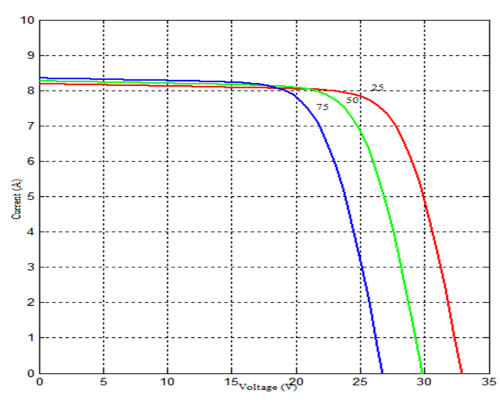

Fig.4 I-V characteristics for varying temperature at fixed irradiation level (1000W/m^2)

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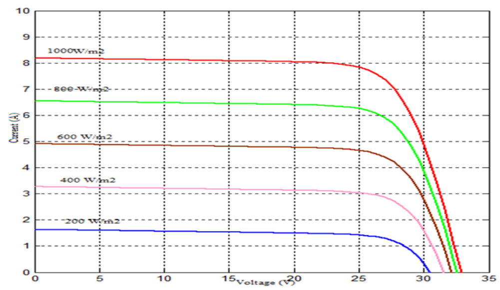

Fig.5I-V characteristics for varying irradiation levels at fixed temperature (25°C)

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 alsogets 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 timeismorefor thismodel, itismore 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. Themechanism of capturingpower 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 toimprove 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].

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

Where m is mass flow in kg/s, ρ_{air} is the air density in kg/m^3 ,V_{ws} is wind speed in m/s, and A is the area, which air passes through in m^2.

The power coefficient is expressed as:

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

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_0 is the power contained in wind $P_o = \frac{1}{2}\rho_{air} V_{w1} A$ (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

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

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

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

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/m , and A is the swept area of rotor in m.

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

Where τ_{wt_av} is in Nm,$C_p(\lambda)$ 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.

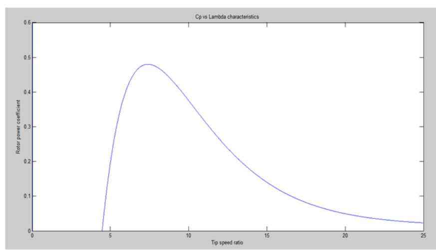

Fig. 6 Torque coefficient (C_P) versus tip speed ratio (λ) Curve

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 aprecise 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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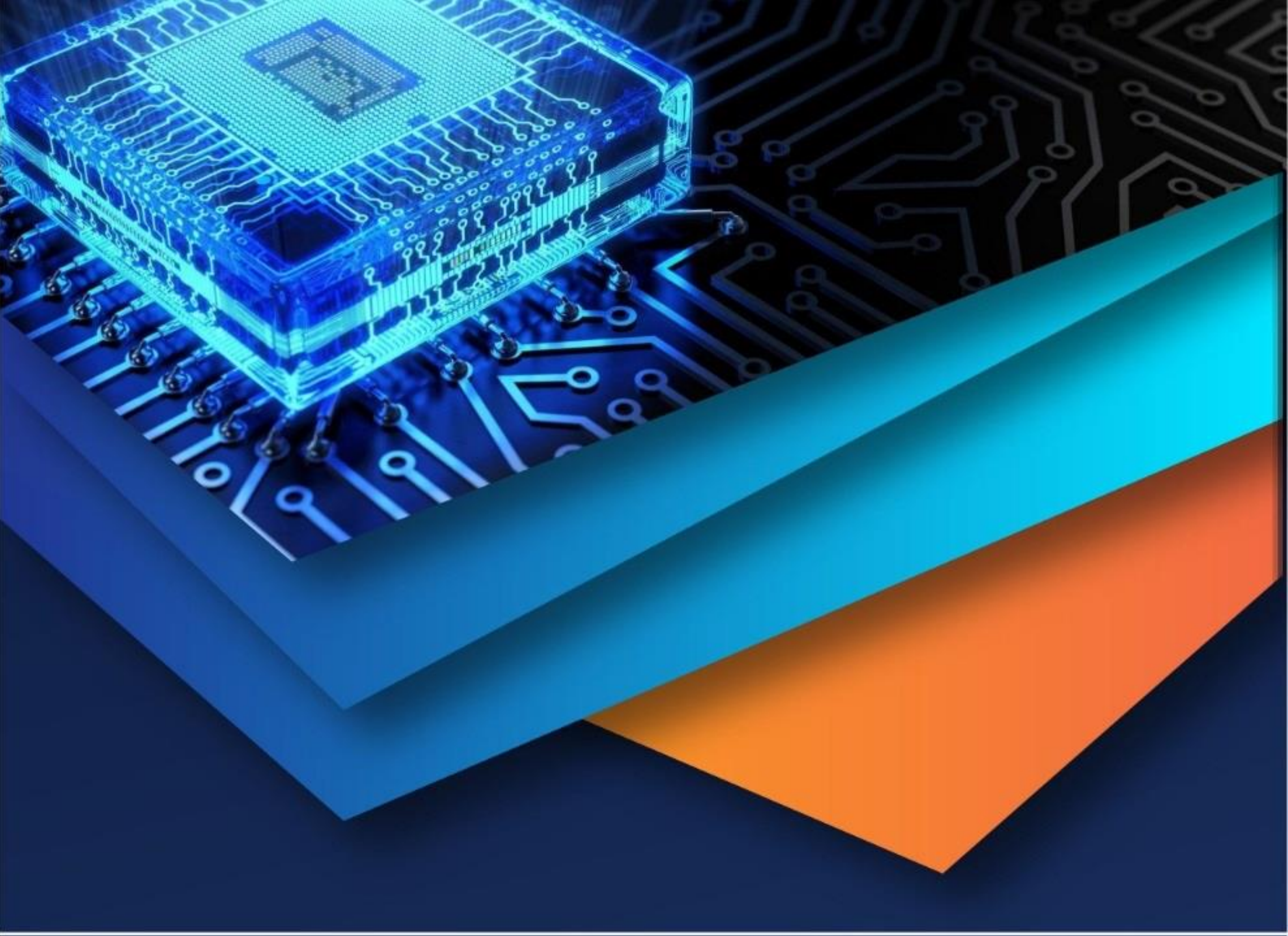

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