Effect of Environmental Conditions on Single and Double Diode PV System : A Comparative Study

Ankit Gupta, Pawan Kumar*‡, Rupendra Kumar Pachauri*, Yogesh K. Chauhan*

*Electrical Engineering Department, School of Engineering, Gautam Buddha University
Greater Noida, Uttar Pradesh (India) – 201308

(guptaankit299@gmail.com, pawanthakurgrano@gmai.com, rupendra@gbu.ac.in, yogesh@gbu.ac.in)

‡Corresponding Author: Ankit Gupta, E-mail: guptaankit299@gmail.com

Received: 29.08.2014 Accepted: 04.10.2014

Abstract-In this paper, a single and a double/bypass diode based photovoltaic (PV) systems are designed in MATLAB/Simulink GUI environment based on mathematical modeling of above PV systems. A detailed comparative study of transient analysis for single and double/bypass PV systems has been done with a RL load. The effect of realistic conditions i.e. variable wind speed and irradiation level on single and double/bypass diode PV system is investigated, the obtained results show the satisfactory performance for realistic model of PV system.

Keywords—Solar photovoltaic system, Single diode PV system, Double/bypass diode PV system, Realistic PV system, Green energy.

1. Introduction

The utilization of electrical energy has increased all over the world due to its various advantageous features. The alternative energy sources are generally wind energy, solar energy, geothermal, biomass and hydro power, biodiesel made from vegetable crop etc. These are also called non-conventional energy sources [1].

A photovoltaic (PV) system directly converts solar energy into electricity. A PV array consists of a group of inter connected photovoltaic modules connected in series and parallel. An equivalent circuit model is commonly used to simulate the solar cell behavior under different operating conditions [2]. In this paper, the main parameters which explain solar cell model behavior such as photocurrent, saturation currents, series resistance, shunt resistance and curve fitting factor are accurately estimated.

PV array simulation models are developed using basic circuit equations of solar PV system. In [3] simulation and modeling of solar cells and PV modules with double/bypass diodes configuration, working under partially shadowed condition in Pspice environment, is presented. In [4] a single diode PV system is discussed. The effect of change in irradiation and module temperature is shown in [5] and a comparative study of single and two diode PV system is presented. The authors have compared the simulation results with manufacturer's data sheet to investigate model validity and accuracy. In [6] two models of PV system are implemented. Experimental and technical data of commercial panel is validated with the models. In [7-8] the main problems and existing solution concerning photovoltaic cells modeling are presented and it is concluded that the dynamic model of the PV cell is required in order to get a realistic picture of its working condition.

Authors [1-11] have discussed the model of various kinds of PV systems. Different kinds of solar PV systems i.e. single and double/bypass diode PV system have been simulated under variable solar irradiation level. But a comparative analysis of single and double/bypass diode PV system is not discussed. Also, no study is made to assess the performance of various PV systems under realistic conditions such as variable wind speed and temperature.

With the motivation of above literature review, novelty of this paper is to present comparative analysis of single and double/bypass diode PV system under standard and realistic environmental condition in detail. Several realistic conditions on wind and irradiation level are considered for the analysis.

2. System Description

The complete system can be divided into three main parts (a) Renewable energy generating sources (i) Single diode PV system (ii) Double/bypass diode PV system (b) Environmental conditions (i) Standard conditions (ii)

Realistic conditions (c) Load application. The schematic diagram of the complete system is shown in Fig. 1 as,

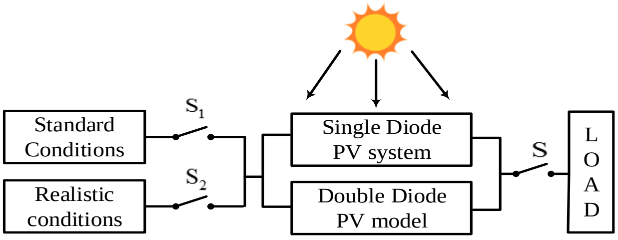


Fig. 1. Schematic diagram of proposed system.

2.1. Renewable Energy Generating Sources

2.1.1 Single diode PV system

The PV cell characteristics are strongly non-linear in nature. Its most referred equivalent circuit model is shown in Fig. 2. The related expression is given in Eq. 1. As shown in Fig. 2, I_{ph} stands for photovoltaic generated current, I_d is diode saturation current and R_S is series resistance of PV cell. PV array is a series and parallel combination of PV cells [4].

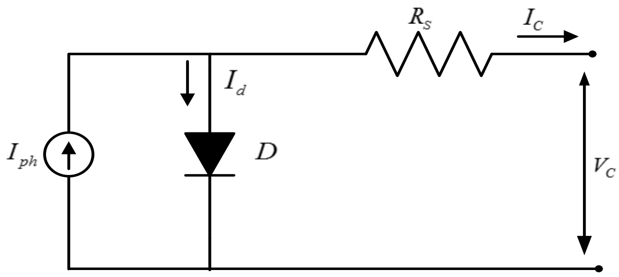


Fig. 2. Equivalent circuit of single diode PV cell.

The PV cell voltage (V_C) is function of photo current that is mainly determined by the load current and the solar temperature as,

$$V_C = \frac{AkT_C}{e} \ln\left(\frac{I_{ph} + I_o - I_c}{I_o}\right) - R_s I_c \tag{1}$$

The solar cell operating temperature T_C varies as a function of solar irradiation level S_C and ambient temperature T_{amb} affects the cell voltage V_C and cell output current I_C [4]. These effects are also implemented in the model by the temperature coefficients C_{TV} and C_{TI} for cell voltage and cell photo current respectively using Eq. 2 & 3 as,

$$C_{TV} = 1 + \beta(T_a - T_x) \tag{2}$$

$$C_{TI} = 1 + \frac{\gamma_T}{Sc}(T_x - T_a) \tag{3}$$

The effect of change in irradiation level (S_X) on the voltage and photo current can be expressed with the help of constants, C_{SV} and C_{SI}, which are the correction factors for changes in cell voltage V_C and photo current I_{Ph}. These are expressed in Eq. 4 & 5 as,

$$C_{SV} = 1 + \beta_T \alpha_S (S_x - S_c) \tag{4}$$

$$C_{SI} = 1 + \frac{1}{S_c}(S_x - S_c) \tag{5}$$

Where, S_C is the reference solar irradiation and S_X is new irradiation level at operating condition [4]. Using correction factors C_{TV}, C_{TI}, C_{SV} and C_{SI}, the new values of the cell voltage V_{CX} and photo current I_{phx} are given by Eq. 6 & 7 as,

$$V_{cx} = C_{TV} C_{SV} V_C \tag{6}$$

$$I_{phx} = C_{TI} C_{SI} I_{ph} \tag{7}$$

2.1.1 Double diode PV system

The two-diode model has one extra diode. It is also called seven parameter PV model. This model is more accurate than the single diode model especially in low level of irradiance. Here I_{D1} and I_{D2} are diode reverse saturation currents. Unfortunately, reverse saturation current, resistance and ideality factors are not available in PV panel data sheet, so some recursive and incremental methods are required to calculate these parameters.
The output voltage of PV is given in Eq. (8) as,

$$V_{cell} = \frac{AkT_C}{e} \ln\left(\frac{I_{ph} + I_{D1} + I_{D2} - I_C}{I_{D1} + I_{D2}}\right) - I_C\left(\frac{R_s \times R_p}{R_s + R_p}\right) \tag{8}$$

As the shunt resistance is very small, it can be neglected and other parameters can be calculated. A two diode electrical equivalent circuit used to estimate these parameters, is shown in Fig. 3 as,

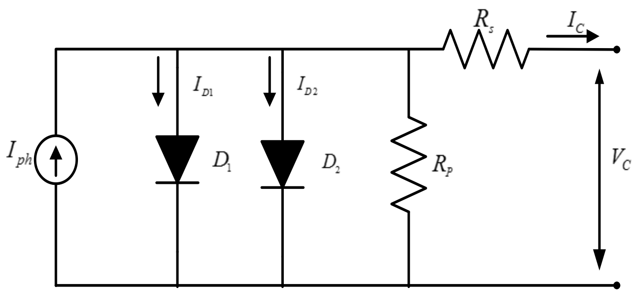


Fig. 3. Equivalent circuit of double diode PV cell.

The curve fitting factor A is used to adjust the I-V characteristic of the cell [6].

2.2. Environmental Conditions

In this paper two types of environmental conditions are taken into consideration which are discussed as follows.

2.2.1. Standard Conditions

The conditions used by the manufacturing companies to test a PV panel are called Standard Test Conditions (STC). The parameter values of the STC are summarized in Table 1. as,

Table 1. Standard test condition parameters

Standard Test Conditions (STC)	
Solar Irradiation, (S_C)	1000 watt/m^2
Cell Temperature, (T_{amb})	25°C
Wind Speed, (*W*)	1 m/sec
Air Mass, (*AM*)	1.5

Air mass is the optical path length through the earth's atmosphere for light from the celestial source. As it passes through the atmosphere, light is attenuated by scattering and absorption; the more atmosphere through which it passes, the greater the attenuation. An air mass of 1 is looking straight up from sea level at the sun when it is directly overhead.

2.2.2. Realistic Conditions

In this paper, single and double/bypass diode PV model are simulated for realistic environmental conditions. In order to achieve these conditions the thermal analysis of PV system is performed [7].

In above PV system models the temperature of module was linked only to solar irradiance level and the model was static [10-12]. In order to overcome these limitations a new relation in which the PV source temperature depends on solar irradiance, wind speed and ambient temperature of the module has been implemented. Moreover a dynamical model is obtained by evaluating the electrical constant. The temperature of PV module is given in Eq. (9) - (10) as,

$$T_{mod} = a_1.T_{amb} + a_2.S_C + a_3.W + a_4 \quad (9)$$

$$T_{mod} = T_{amb} + (b_1 + b_2.W + b_3.W^2) + G(b_4 + b_5.W + b_6.W^2) \quad (10)$$

Where, a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4, b_5 and b_6 are the constant values. The solar irradiation and wind speed varies in the range of 400-1000 watt/m^2 and 4-18 m/sec.

3. MATLAB/Simulink Model of PV Systems

3.1 PV system with Standard Test Conditions

3.1.1 Single diode PV system

The MATLAB/Simulink model of Single diode PV system under standard test conditions is shown in Fig. 4 as,

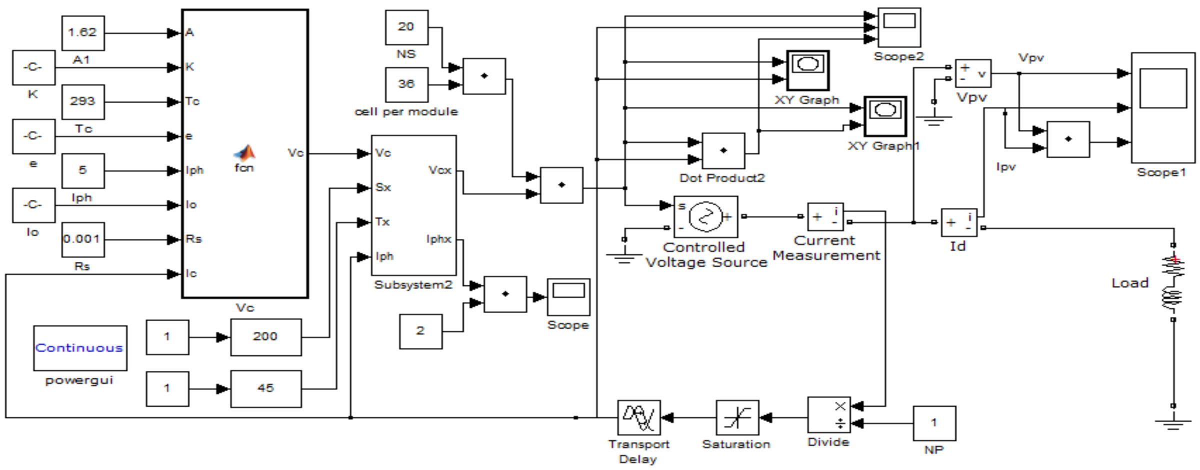


Fig. 4. MATLAB/Simulink model of single diode PV system under STC.

3.1.2 Double diode PV system

The MATLAB/Simulink model of Double diode PV system under standard test conditions is shown in Fig. 5 as,

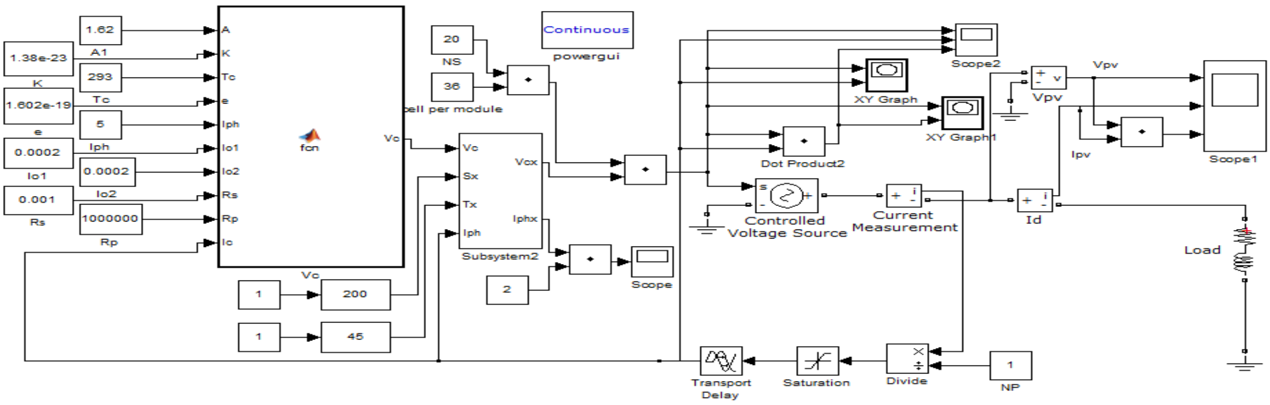


Fig. 5. MATLAB/Simulink model of double diode PV system under STC.

The modelled single diode and double/bypass diode PV panel have an operating voltage of 208 V and 212 V respectively. The solar irradiation (S_C) and temperature (T_{amb}) are taken constant according the STC. Here, a R-L load having value of 50 Ω and 0.02 H is considered.

3.2 PV System with Realistic Conditions

3.2.1 Single diode PV system

MATLAB/Simulink model of single diode PV system simulated under realistic environment are shown in Fig. 6 as,

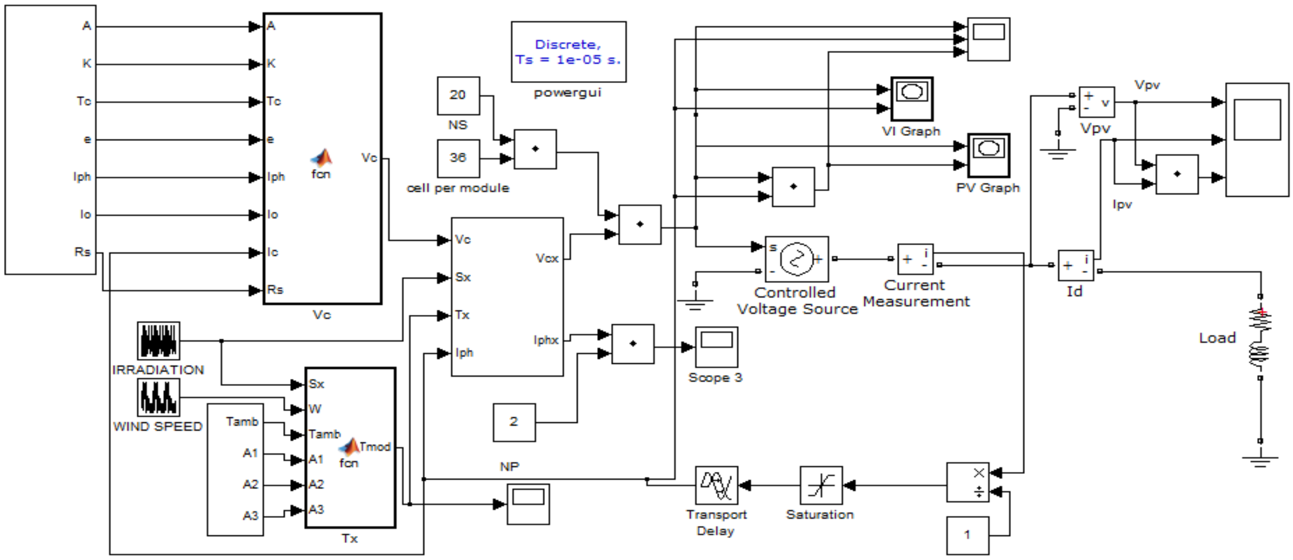


Fig. 6. MATLAB/Simulink model of single diode PV system under Realistic Conditions.

3.2.2 Double diode PV system

The MATLAB/Simulink model of Double diode PV system under realistic conditions is shown in Fig. 7 as,

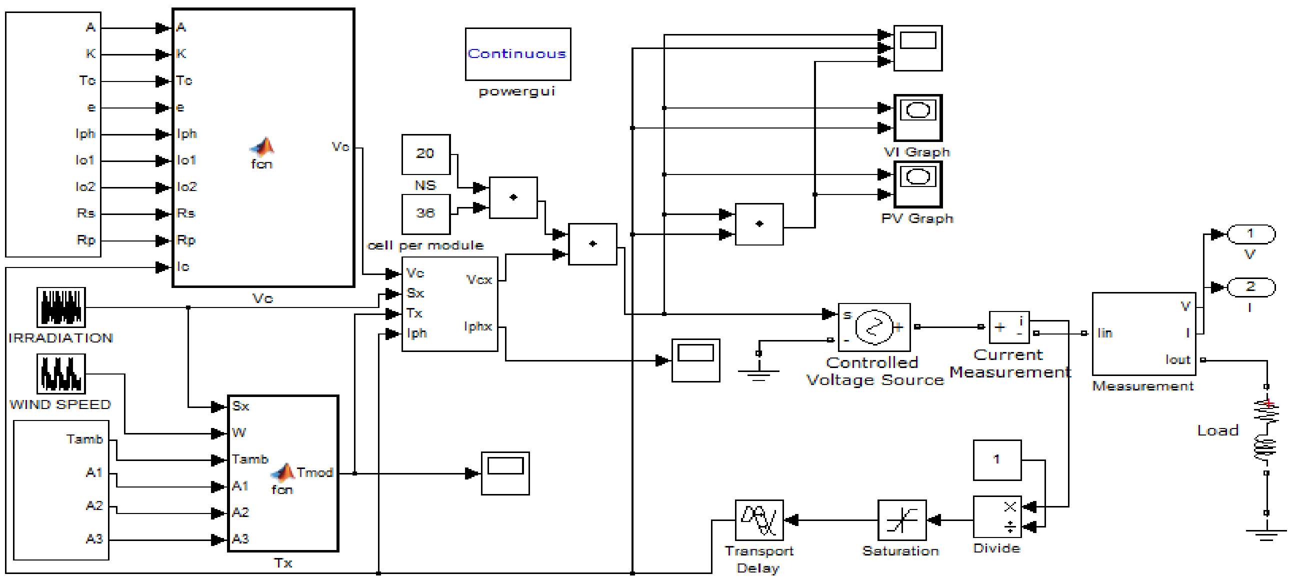
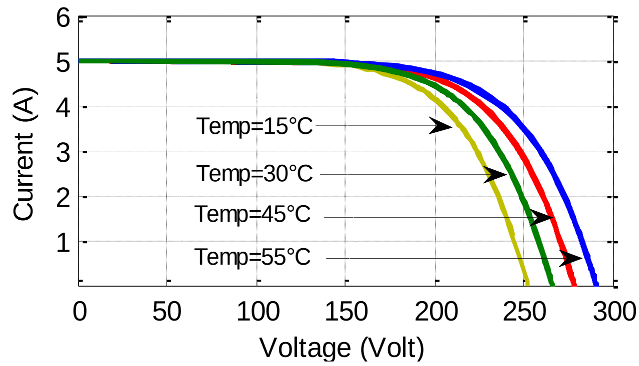


Fig. 7. MATLAB/Simulink model of double diode of PV system with Realistic Conditions.

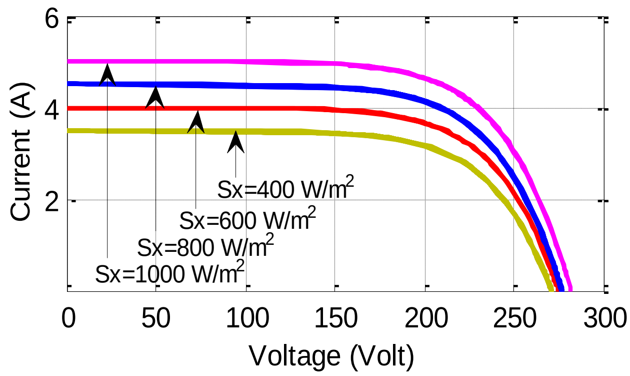
The modeled single and double/bypass diode PV panel have an operating voltage in the range 130-210 V. The solar irradiation (S_C) and temperature (T_{amb}) are taken variable in a considered range to show real time conditions. System is connected with a RL load of 50 Ω and 0.02 H.

4. Results and Discussion

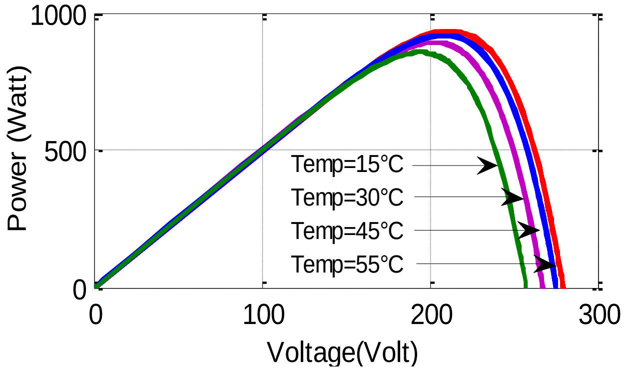
The typical P-V and I-V characteristic curves of the single diode PV system obtained from the simulation of above designed PV model (double/bypass have same characteristics) at different solar irradiation (S_C) and temperature (T) are shown in Fig. 8 (a) - (d) as,



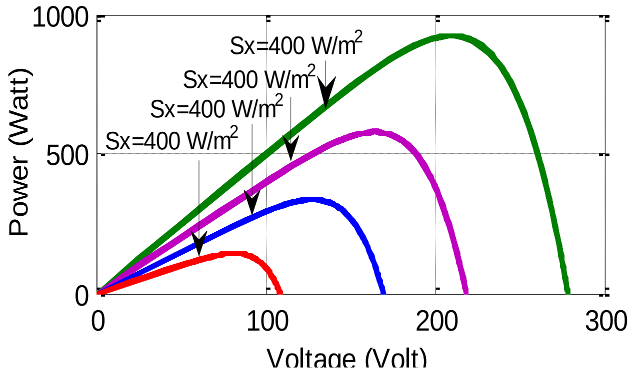
(a)



(b)



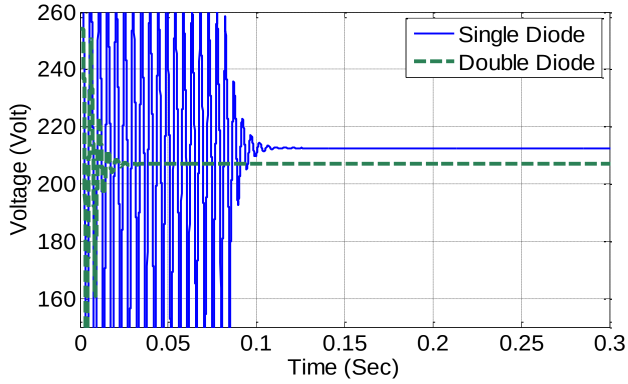
(c)



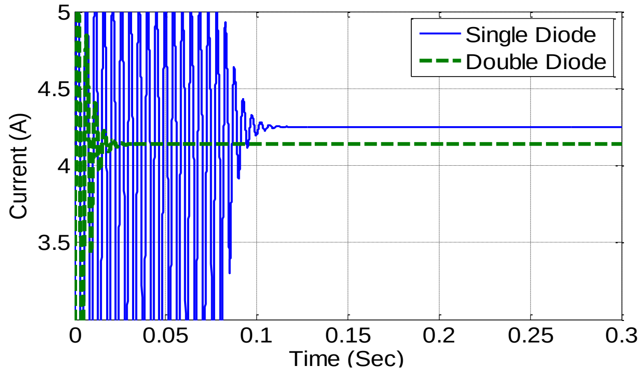
(d)

Fig. 8. (a)- (d) I-V and P-V Characteristics of single diode PV system at different temperature and irradiation level.

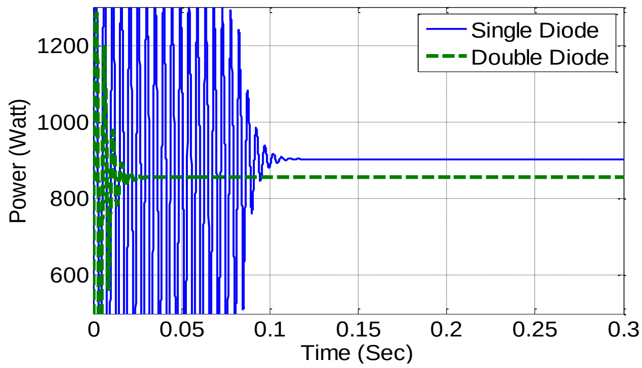
The comparative analysis of output voltage, current and power of single and double/bypass diode PV System under standard test conditions (STC) are shown in Fig. 9 (a) - (c) as,



(a)



(b)



(c)

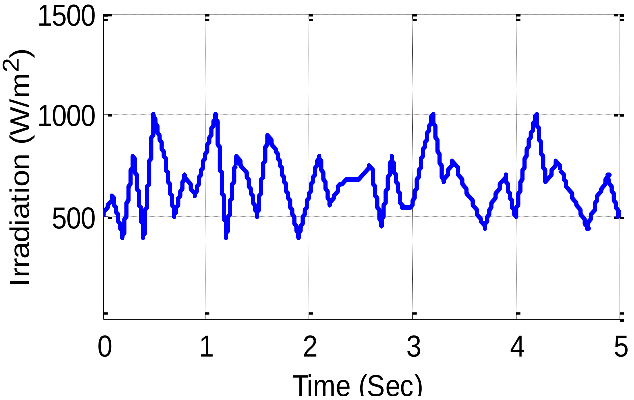
Fig. 9. (a)-(c) Comparison of output voltage, current and power of single and double diode PV system under STC.

From the above results it can be observed that there is a small voltage and current drop mainly due to the second diode in the double/bypass diode PV system but the transient stability and response time for voltage stabilization of the double/bypass diode PV system under standard test conditions (STC) is better than the single diode PV system. These transients are developed due to the inductive load connected to the system. The inductive loads are very common type of load. The same load is considered for both the PV models. The comparison of single diode and double/bypass diode PV system is shown in Table 2 as,

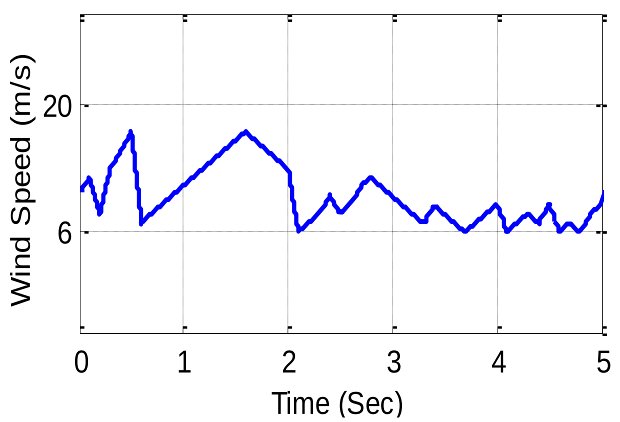
Table 2. Comparison of single and double/bypass diode PV system under various parameters.

Parameters	Single diode PV system	Double diode PV system
Voltage variation during transient state	140-280 V	155-266 V
Current variation during transient state	2.5-6.2 A	2.9-5.4 A
Power variation during transient state	400-1350 W	490-1270 W
Steady state Voltage	212 V	208 V
Steady state Current	4.35 A	4.23 A
Steady state Power	922.2 W	879.8 W
Steady state time	0.11 Sec	0.03 Sec

The single and double/bypass diode PV systems were simulated under realistic (variable) environment conditions. The comparative analysis of output voltage, current and power of single and double/bypass diode PV systems under variable solar irradiation (S_C) and variable wind speed (W) are shown in Fig. 10 (a) - (e) as,

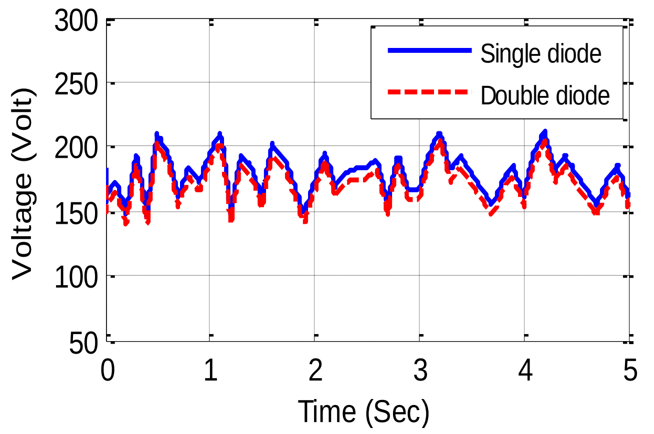


(a)

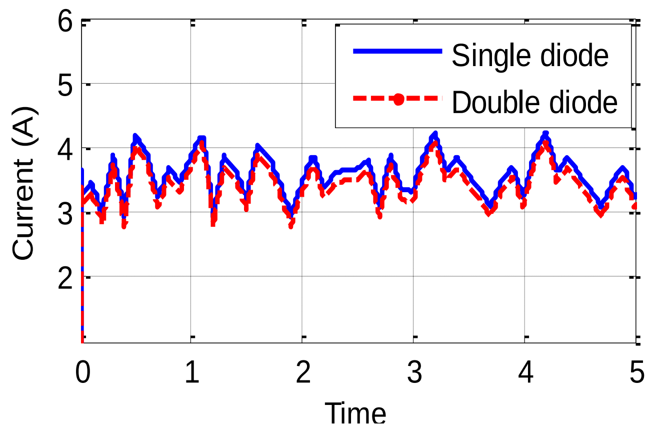


(b)

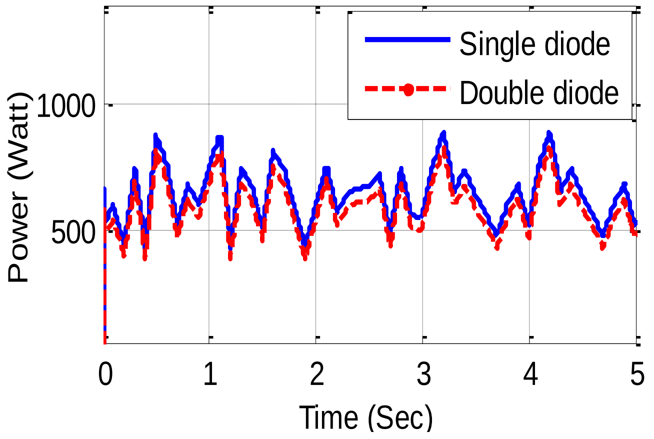
The irradiation level is varied in the range of (400-1000) watt/m^2 and wind speed is varies in the range of (6-18) m/sec. As shown in Fig. 10 (a) and 10 (b) respectively. Corresponding variation in voltage, current and power are depicted in Fig. 10 (c)-10(e) respectively.



(c)



(d)



(e)

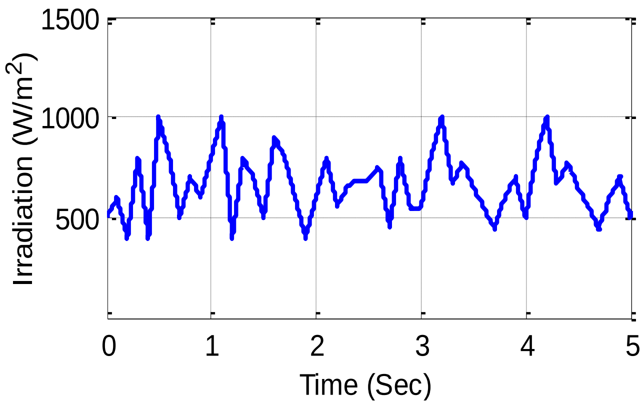
Fig. 10 (a)-(e). Variable irradiance and wind speed, output voltage, current and power of single and double/bypass diode PV system.

For the single and double diode PV system, the variation of voltage, current and power for the considered range of irradiation and wind speed is shown in Table 3 as,

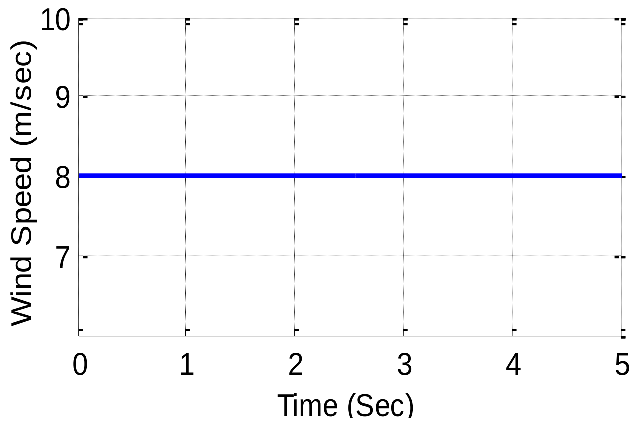
Table 3. Variation of parameters of single and double/bypass diode PV system.

Parameters (Range)	Single diode PV system	Double diode PV system
Irradiation	400-1000 watt/m^2	400-1000 watt/m^2
Wind speed	6-18 m/sec	6-18 m/sec
Voltage	142-212 V	145-208 V
Current	2.8-4.3 A	2.85-4.2 A
Power	397.6-911.6 W	413.25-873.6 W

The comparative analysis of output voltage, current and power of single and double/bypass diode PV systems under variable solar irradiation (S_C) and constant wind speed (W) are shown in Fig. 11 (a) - (e) as,

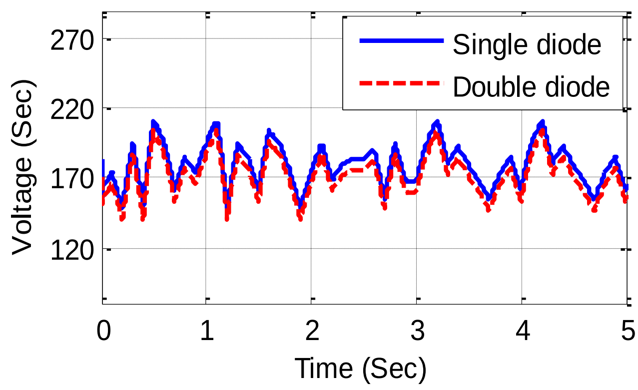


(a)

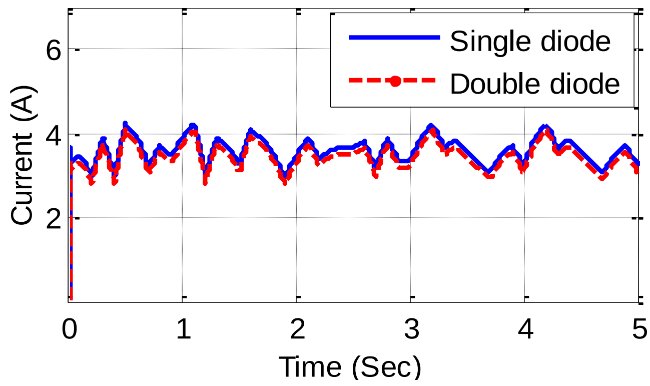


(b)

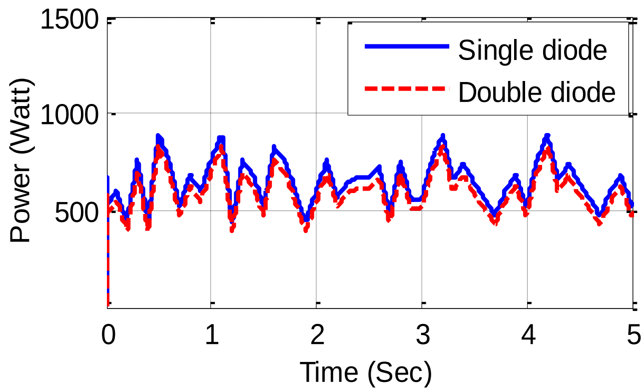
In this case, the irradiation level is varied in the range of (400-1000) watt/m^2 and wind speed is taken constant as 8 m/sec. as shown in Fig. 11 (a) and 11 (b) respectively. Corresponding variation in voltage, current and power are depicted in Fig. 11 (c)-11(e) respectively.



(c)



(d)



(e)

Fig. 11 (a)-(e). Variable irradiation, constant wind speed, output voltage, current and power for single and double/bypass diode PV system.

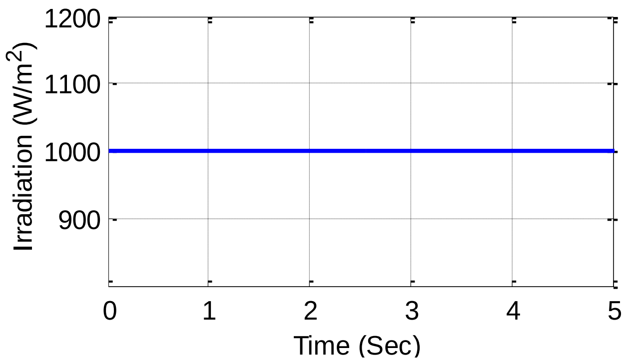
The variation of voltage, current and power can be observed for the single and double diode PV system for the considered variation of irradiation (S_C) and constant wind speed (W) is shown in Table 4 as,

Table 4. Variation of parameters of single and double/bypass diode PV system.

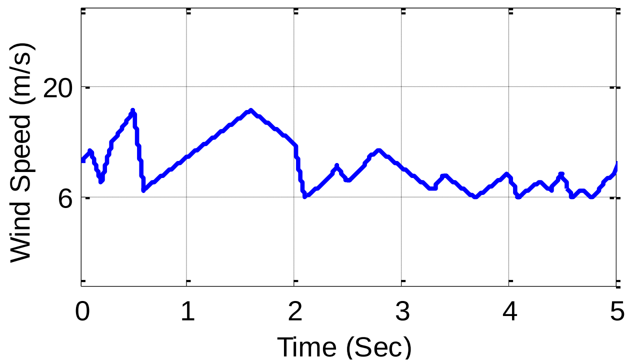
Parameters (Range)	Single diode PV system	Double diode PV system
Irradiation	400-1000 watt/m^2	400-1000 watt/m^2

Wind speed	8 m/sec	8 m/sec
Voltage	140-240 V	142-235 V
Current	2.5-4.15 A	2.65-4.10 A
Power	350-996 W	376.3-963.5 W

The comparative analysis of output voltage, current and power of single and double/bypass diode PV systems under constant solar irradiation and variable wind speed are shown in Fig. 12 (a) - (e) as,

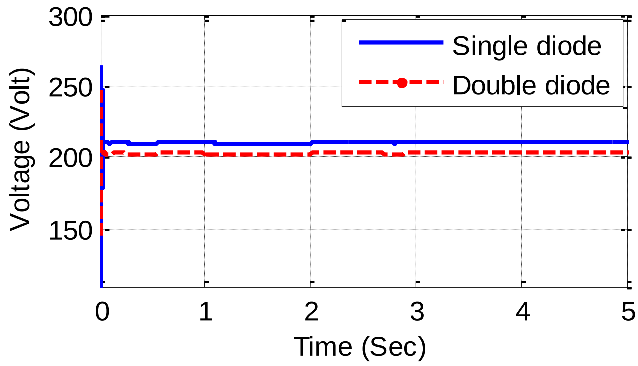


(a)

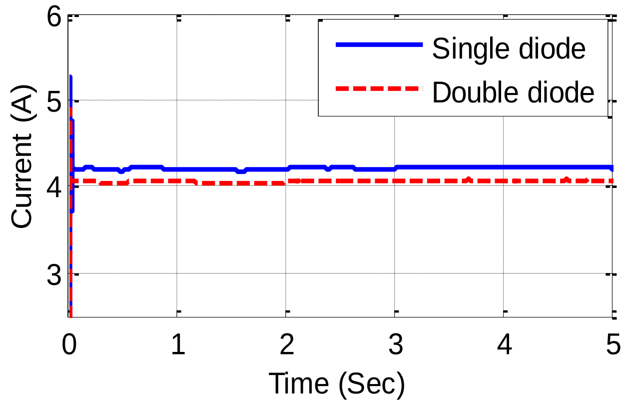


(b)

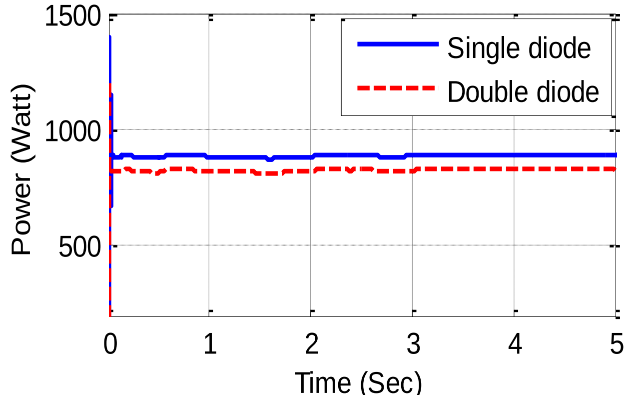
As it can be observed in Fig. 12 (a) and 12 (b) the irradiation level is taken constant as 1000 watt/m^2 and wind speed is varied in the range of (6-18) m/sec. respectively. Corresponding variation in voltage, current and power are depicted in Fig. 12 (c)-12(e) respectively.



(c)



(d)



(e)

Fig.12. (a)-(e) Constant irradiation and variable wind speed, output voltage, current and power of single and double/bypass diode PV system.

For constant irradiation and considered range of wind speed, the single and double diode PV system outputs in terms of voltage, current and power is shown in Table 5 as,

Table 5. Variation of parameters of single and double/bypass diode PV system.

Parameters (Range)	**Single diode PV system**	**Double diode PV system**
Irradiation	1000 watt/m^2	1000 watt/m^2
Wind speed	6-18 m/sec	6-18 m/sec
Voltage	206-208 V	201-203 V
Current	4.2-4.25 A	4-4.05 A
Power	865.2-884 W	804-822.15 W

From Table 3 - Table 5, it can be concluded that the dynamic response of double/bypass diode PV system under realistic conditions is better than the single diode PV system as the output of double/bypass diode PV system has less range of variation with respect to the variation in environmental conditions.

5. Conclusion

In this paper, the dynamic modeling of single diode, double/bypass diode and realistic PV systems has been carried out. A detailed comparative study and analysis of single and double/bypass diode PV system has been presented in terms of output voltage, current and power with transient analysis under standard and realistic environment conditions. The performance investigation on designed system has been compared and it can be concluded that the double diode PV system has less transients in the output voltage current and power for same condition of load. The effect of solar irradiation and wind speed on single and double diode PV system are shown on the PV outputs and it is observed that the effect of solar irradiation on output voltage, current and power is greater the wind speed. In the context of comparative study for both the PV systems, following objectives are achieved with satisfactory investigation as follows,

- MATLAB/Simulink modeling of a single and a double/bypass diode PV systems has been done.
- The comparative study of single and double diode PV system has been done in terms of transient analysis of the output voltage, current and power.
- The effect of variable wind speed and irradiation level on both the PV system is analyzed in terms of voltage, current and output power.
- The variation of irradiation level is much effective on the realistic PV system in comparison of the wind speed variation.
- The effect of series and parallel connection of PV cells on performance of single diode and double diode model based system may be considered as further work in this direction.

Appendix

Single diode PV system	
Series resistance, R_s	10^{-3} Ω
Output voltage, V_c	212 V
Output current, I_c	4.3 A
Reverse saturation current of diode, I_o	0.002 A
Series resistance, R_S	0.0001Ω
Shunt resistance, R_P	1000Ω
Double diode PV system	
Output voltage, V_c	208 V
Output current, I_c	4.2 A
Reverse saturation current of diode, I_{o1}	0.002 A
Reverse saturation current of diode, I_{o2}	0.002 A
Environmental temperature, T_{amb}	25°C
Temperature of the module, T_{mod}	10-55°C
Wind speed, W	6-12 m/s
Solar irradiation, G	0.4-1 KWatt/m^2
Constants	
Curve fitting factor, A	1.6
Electron charge, e	1.602×10^{-19} C
Boltzman constant, k	1.38×10^{-23} J/°K
α_S	0.2
B	0.004
γ_T	0.06
a_1	0.0624
a_2	0.7027
a_3	1.0078
a_4	0.5221
b_1	0.0223
b_2	0.4690
b_3	1.0184
b_4	0.0400
b_5	0.5532
b_6	1.1552

References

[1] R. K. Pachauri, and Y. K. Chauhan, “Assessment of Wind Energy Technology Potential in Indian Context,” International Journal of Renewable Energy Research, vol. 2, no. 4, pp. 773-780, Nov. 2012.

[2] S. Silvestre, A. Boronat and A. Chouder, “Study of Bypass Diodes Configuration on PV Modules,” Applied Energy, vol. 86, no. 9, pp. 1632-1640, Sept. 2009.

[3] R. K. Pachauri, and Y. K. Chauhan, “Hybrid PV/FC Stand Alone Green Power Generation: A Perspective for Indian Rural Telecommunication Systems,” in *Proc.* IEEE Conference on Issues and Challenges in Intelligent Computing Techniques (ICICT), 7-8 Feb. 2014 at Ghaziabad, pp. 807-815.

[4] I. H. Altas and A. M. Sharaf, “A Photovoltaic Array Simulation Model for Matlab-Simulink GUI Environment,” in *Proc. IEEE conference on Clean Electrical Power* at Capri, 21-23 May 2007, pp. 341-345.

[5] M. Seifi, A. B. C. Soh, N. I. Wahab, and M. K. B. Hassan, “A Comparative Study of PV Models in Matlab/Simulink,” International Journal of Electrical, Electronic Science and Engineering, vol. 7, no. 2, pp. 22-27, May 2013.

[6] J. A. R. Hernanz, J. J. Campayo, J. Larranaga, E. Zulueta, O. Barambones, J. Motrico, U. F. Gamiz and I. Zamora, “ Two Photovoltaic Cell Simulation Models in MATLAB/Simulink,” International Journal on Technical and Physical Problems of Engineering, vol. 4, no. 1, pp. 45-51, Mar. 2012.

[7] M. A. Stosovic, and D. Lukac, V. Litovski, “Realistic Modeling and Simulation of the PV System-Converter interface,” in *Proc. Small Systems Simulations Symposium* at Serbia, Feb. 2012, pp. 28-32.

[8] M. C. D. Piazza, A. Ragusa, M. Luna, and G. Vitale, “A Dynamic Model of Photovoltaic Generation Based on Experimental Data,” in *Proc. International Conference on Renewable Energies and Power Quality* at Spain, Mar. 2010, pp. 317-323.

[9] M. A. S. Masoum, H. Dehbonei, and E. F. Fuchs, "Theoretical and Experimental Analyses of Photovoltaic Systems with Voltage and Current Based Maximum Power Point Tracking," *IEEE Trans. on Energy Conversion.*, vol. 17, no. 4, pp. 514-522, Dec. 2002.

[10] C. Schwingshackl, M. Petitta, J.E. Wagner, G. Belluardo, D. Moser, M. Castelli, M. Zebisch and A. Tetzlaff,“ Wind Effect on PV Module Temperature : Analysis of Different Technique for an accurate estimation,” Enrgy Procedia, vol. 40, pp. 77-86, 2013.

[11] S. Mekhilef, R.Saidur, and M. K. Vestani,” Effect of Dust, Humidity and Air Velocity on Efficiency of Photovoltaic Cells,” Renewable and Sustainable Energy Reviews, vol. 16, pp. 2920-2925, 2013.