ROLE OF POWER ELECTRONICS FOR MODELLING OF PV ARRAY IN PV SYSTEM

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ABSTRACT:

PV cell generates power at small voltage through high current. As a result, an appropriate power electronic interface is mandatory for grid-linked or standalone functions. This is attained by means of DC/AC inverter topologies through a step-up transformer or an arrangement of DC/DC converter in sequence by DC/AC inverter form multistage transfer for grid-connected/residential purposes. The distinct step electronic power converter gives superior efficiency, lesser element adds up and slight THD. A DC-DC boost up converter professionally changes DC voltage to superior voltage and is applied for maximum power tracking function to get highest power achievable from solar panel. The chapter evaluates the normally used MPPT techniques to find out which MPPT technique is mainly efficient, holds improved output power when associated to grid and fit for grid connected systems

1. INTRODUCTION:

Each PV panel is linked with a undo DC-DC converter to the general DC-link voltage as shown in fig 1. A meticulous MPPT technique is to be selected on the basis of factors such as cost, simplicity, highest output power, fast tracking under changeable atmospheric situation etc, the paper presents the modeling of a PV Module, PV arrays, DC-DC converter with suitable control and a simulation study on modeling of MPPT control of a grid related PV System

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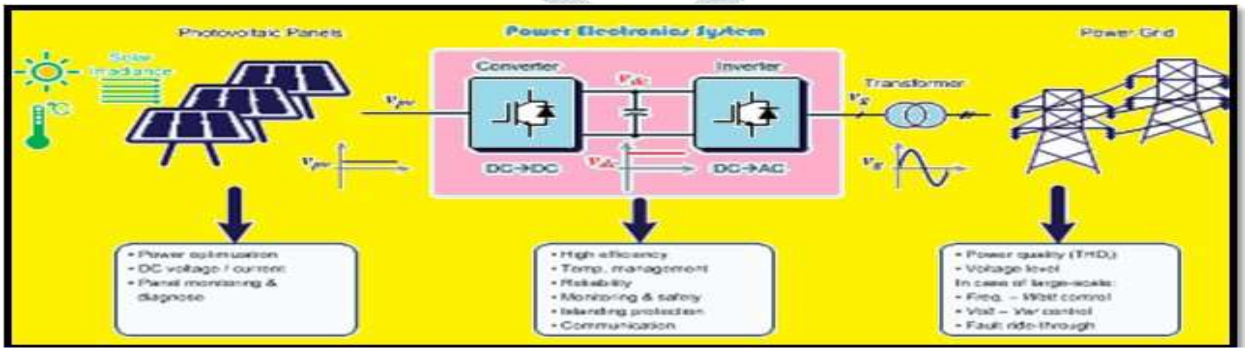


Fig. 1. Grid- connected PV system

Modeling of PV Array:

The model has, a nonlinear diode to account leakage current, a photocurrent source, shunt resistance and a series resistance to represent internal losses as given in Fig.2(a).

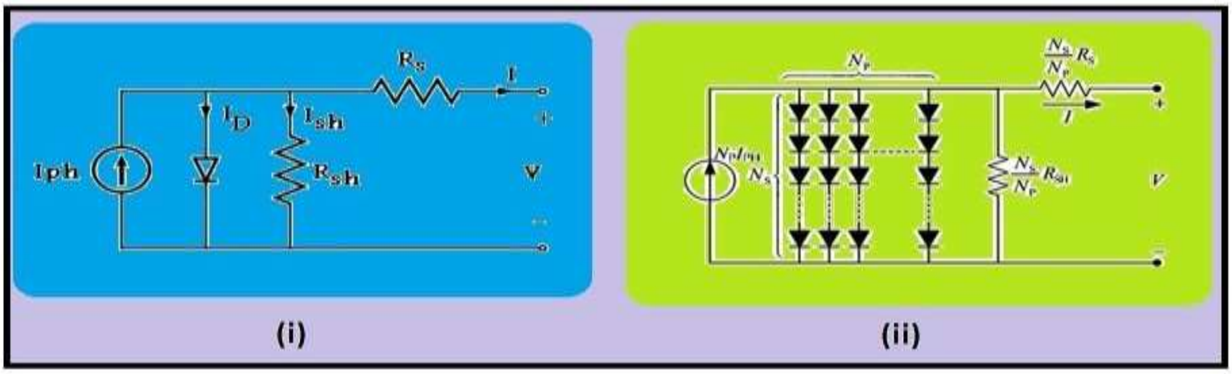


Fig.2: Single-diode circuit diagram of a (a) a PV cell (b} a PV Array

In single-diode circuit the relation between voltage and current is given as

$$I_L = I_{sc} - I_0 \times [\exp\left(\frac{q(V_0+I_L \times R_s)}{m \times k \times T}\right) -1] - \frac{V_0+I_L \times R_s}{R_{sh}} \qquad (1)$$

Were,

I_{sc} = Solar cell current; k = a constant (1.381 × 10-23);

q = Charge on electron (1.602 × 10-19 C);; m = ideality factor;

T = Absolute temperature of solar cell. Solar current depends on cell temperature and solar radiation as given.

$$I_{sc} = \{\frac{S}{S_{ref}}\} \times [I_{sc,ref} + K_i \; (T - T_{ref})] \qquad (2)$$

Where, S = Solar radiation (W/m2); K_i = The coefficient (temperature);

S_{ref}, T_{ref} = are respectively the solar radiations, absolute solar temperature at standard test;

Diode current varies by cell temperature as

$$I_d = I_d \times \left\{\frac{T}{T_{ref}}\right\}^3 \times \exp\left[\frac{q \times E_g}{A \times K} \times \left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \qquad (4.3)$$

Where, □□ = Diode current at standard conditions; Es = band-gap of semi-conductor (eV) depends on cell material. The combined circuit of solar panel is to be represented as shown in Fig.4.1(b).

$$I_L = N_p\, I_s - N_p \times I_s[\exp\{\frac{q}{m\times K\times T}(\frac{V}{N_s} + \frac{I\times R_s}{N_S})\} -1] - \frac{N_p}{R_{sh}}\{\frac{V}{H_s} + \frac{I\times R_s}{N_p}\} \quad (4)$$

Where, Ns and Np are respectively number of solar cell in series and parallel. All parameters used in circuit are given in the Table 4.1. To depict the I–V characteristic for the complete array the parameters are to evaluated in the ways as given below.

I_{tot} = □□I (5)

□□□□ = $N\,s$ □ (6)

□□,□□□ = □□/□ □□ (7)

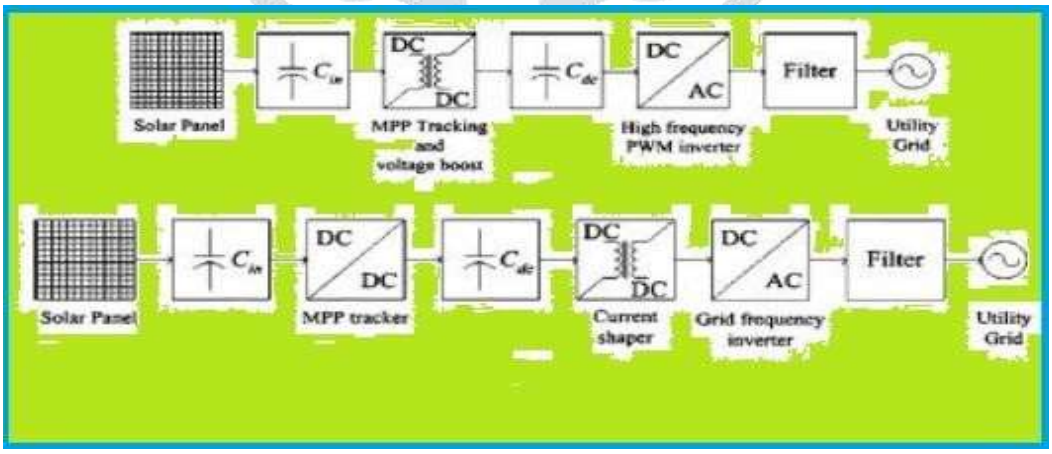
The output voltage of PV arrays will be increased when solar cells are connected in series and output current will increased when cells are connected in parallel. The expression is given as

□□□□ = □□ I (8)

$V_{tot} = N\,S$ V (9)

2. D.C-D.C Convertor:

The different configurations of PV array's connection with the utility grid is shown in fig 3 (a) It is tentative that the function of DC/DC converter is extremely significant amid the PV solar cell and DC/AC inverter to pick and choose up the voltage for improved voltage parameter and better effectiveness. So, by the philosophy of solar cell operations and necessities unusual switch mode DC-DC converter topologies like conventional boost converter, full bridge, push pull and half bridge, etc. projected by different authors are examined in [6]- [18].



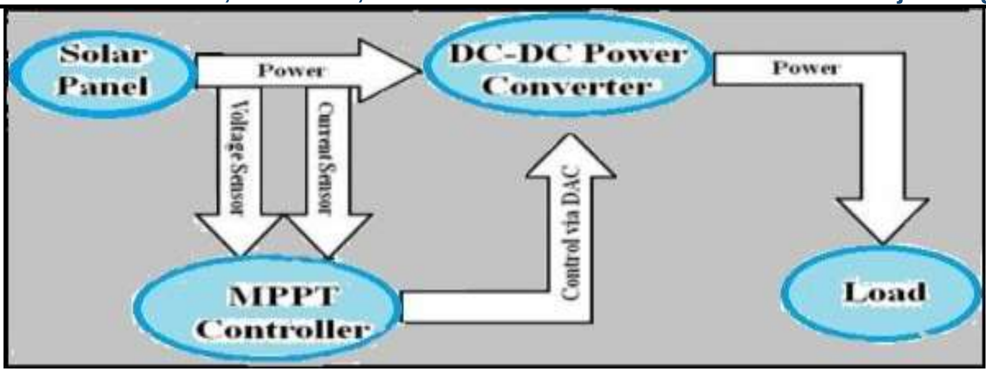


Fig 3 (a) Different connection configuration of PV arrays with utility grid.
(b) DC-DC Converter with MPPT Tracking algorithm

A assessment of various DC/AC inverter and DC/DC converter topologies on the basis of their shortcomings and benefit are explained in [27]. The key difficulty in push pull converter is that semi section of the transformer is not symmetrically wound, resultant in transformer diffusion at full load situation. The half bridge converter needs huge value of transformation ratio to go with the DC link voltage. Although the full bridge converter needs extra number of switches but it got an advantage of transformer turns ratio, reduced device current ratings and, voltage and current pressure across the switching devices. Though, simple boost converter provides advanced effectiveness and less constituent counts evaluating to other DC/DC converter topologies like as full bridge, push pull, and half bridge etc., that is recommended to interface PV cell system to grid.

Working principle of boost converter:

Boost converter has a diode, a capacitor, a diode, an inductor and a switch generally MOSFET, IGBT or BJT as shown in Fig. 4.4(i). The switch is preferred on the basis of rating of the converter and switching frequency. The inductor stores energy during switch ON mode (*Ton)* as shown in Fig 4.4(ii). During the period of switch OFF, the inductor current is not changed instantaneously, Hence it is not reduced to zero instantly [7]-[8].

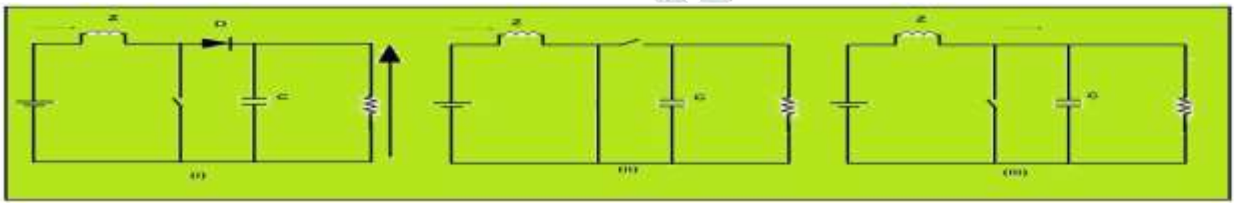


Fig 4 (i). Basic circuit of boost converter, (ii) *Switch in ON mode* (iii). Switch in OFF mode

$$Vo = Vpv + L(di/dt).$$

Like offers in Fig. 4 (iii) the current flows to diode and load. Once switch is in OFF mode, the voltage crossways load is $\square_0 = Vpv + L\,(di/dt)$. The energy stored in the inductor is delivered to the load. Through on period. the inductor current increases from $\square_2$ to $\square_1$. Once the switch is off, inductor current decreases from $\square_2$to $\square_1$

Through On, energy set to the inductor (L) is

$$\square_{\square\square} = V_{pv}(\frac{\square_1+\square_2}{2})\,\square_{\square\square} \qquad (10)$$

$\square_{\square\square}$ = (inductor voltage) (average current to inductor)

Where; V_{pv}: voltage output, Vo: Average voltage output,

T_{on}: Time duration of switching on, T_{off}: Time duration of the switching off

Through Off, period energy discharged by inductor (L) to the load is as given by:

$$\square_{\square\square\square} = (Vo - \square_{\square\square\_}) \left(\frac{\square_1+\square_2}{2}\right) \square_{\square\square\square} \quad (11)$$

Equation (4.10) and (4.11) are equal in a lossless system

$$\square_{\square\square}\left(\frac{I_1+\square_2}{2}\right) \square_{\square\square} = (Vo - \square_{\square\square\_}) \left(\frac{\square_1+\square_2}{2}\right) \square_{\square\square\square} \quad (12)$$

$$Vo = \square_{\square\square} \frac{\square\square\square}{\square\square\square\square} + \square\square\square\square \quad (13)$$

$$Vo = \square_{\square} \frac{\square}{\square\square\square\square}$$

$$Vo = \square_{\square} \frac{1}{1-\square} \quad (14)$$

Where, T = $\square_{\square\square}$ + $\square_{\square\square\square}$ and, D = $\frac{\square}{\square\square\square}$

D is called as duty cycle and the value of D is between 0 to 1 and voltage output changes between Vo to ∞, As the power on panel and load side is same

$$\square_{\square\square} V_{PV} = Io\ Vo \quad (15)$$

$$\square_{\square} = Io \frac{1}{1-\square} \quad (16)$$

3. Modes of operation of converter:

DC to DC boost converter activates in two dissimilar modes. The two modes are given as,

- Continuous conduction mode CCM
- Discontinuous conduction mode DCM [9]-[10].

Once the switch is in on state, converter will activate in continuous conduction mode (CCM) as presented in Fig. 5 (a). In this mode the inductor current never becomes zero. while the inductor current reduces to zero earlier the switch becomes in on mode, in that case the boost converter is assumed to be working in the discontinuous conduction mode (DCM). The inductor is discharged prior to the ending of entire sequence and it decreases to zero. All part of the phase is presented in Fig. 5 (b). This often happens at small loads

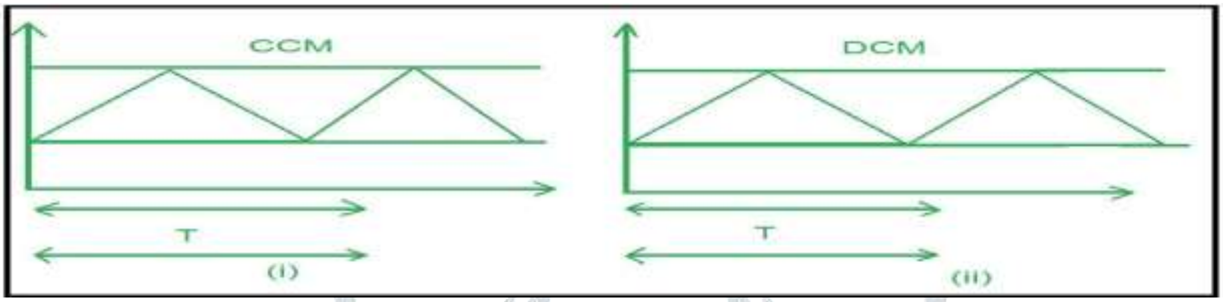


Fig. 5 Diagram of modes (a) C.C.M (b) D.C.M

Classification of Control Techniques:

By calculating the on–off instant of the switch in, output voltage of converter can be controlled [11]-[12]. There are two methods of controlling the on/off period of switch. They are: (*1) Time-ratio control, and* (*2) Current limit control.*

(1) Time-ratio control (TRC): Inside time-ratio control, the rate of Ton / *T* is changed. This is achievable in two ways.

(a) Constant frequency control or PWM control*:*

In this control, the on time (Ton) of the switch is changed however the time phase (*T*) is set sideways constant therefore, the frequency (*f*) is set reserved stable. This method is too supposed pulse-width modulation PWM technique.

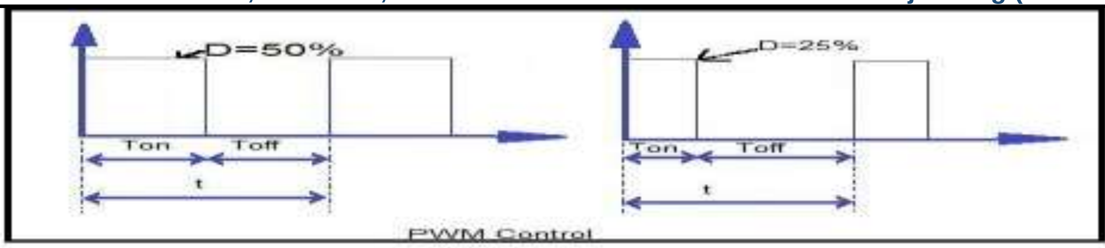


Fig. 6 PWM control.

(b) Variable frequency control:

In this method, the time phase is changed either, (i) ON- time , Ton is set aside stable or (ii) OFF-time, Toff is set aside steady as presented in Fig.7. This has some drawback as compared to PWM.

- The design of filter is very difficult in such system since, frequency differs more broad range.
- Since frequency varies more broad range, there are a chance of interferences.

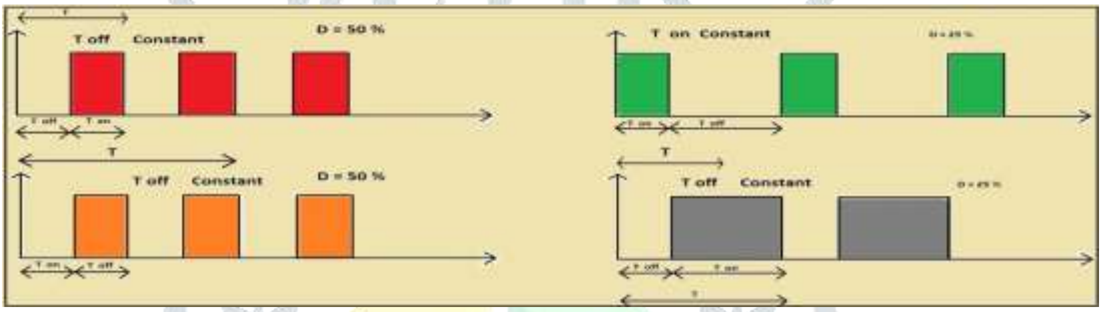


Fig 7 Variable speed control

(2) Current perimeter control or hysteresis controller:

In this method, load current is controlled between two limits by the Converter switch. As current go beyond a definite limit it freewheels and declines exponentially. Whilst, it attains the lower limit the converter is switched on [14-16]. The variations among maximum and minimum value of current settles the switching frequency as well. When the variation among maximum and minimum value of current is restricted to a minimum value then the ripple in the load current is to be decrease as illustrated in fig.8.

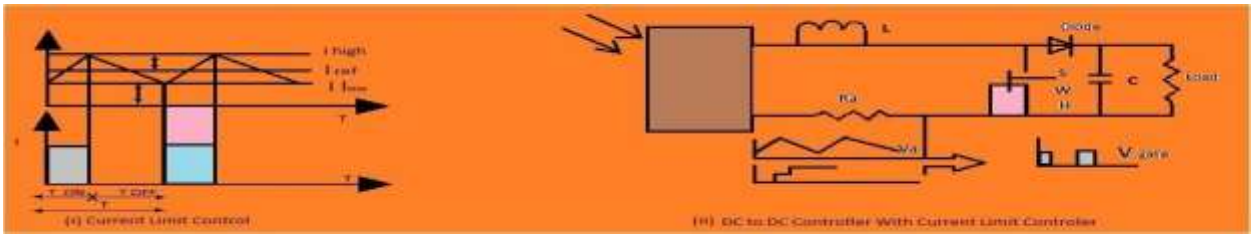


Fig.8 (i) Current limit control. (ii) DC Controller through current Limit Controller.

4. Modeling of Boost Circuit Control:

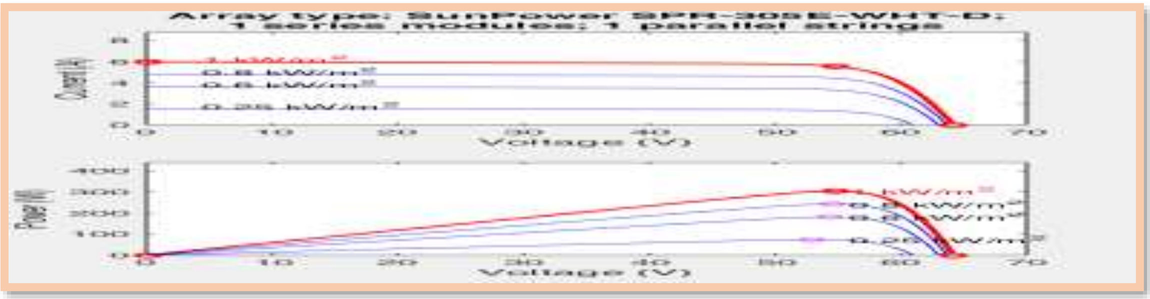
The output voltage of solar module is small. The boost circuit raises the level of low-voltage of PV array. A capacitor is fixed among solar panel and boost up circuit. The capacitor is utilized to reduce elevated harmonic frequencies.

5 Simulation analysis:

. A simulation study is carried out of a grid connected PV System. The Input to the solar system is irradiance and temperature. Highest Output currents and voltages are extracted from the solar panel to find out the output power. The design parameters of P-V module is presented in the table 1.

TABLE-1 Parameter of PV module

characteristics	Specifications
Power output	3840 W
Short circuit current	6 A
Open circuit Voltage	640 V
Voltage at maximum power point	5400 V
Current at at maximum power point	5.50
Temperature coefficient	0.008 A/C



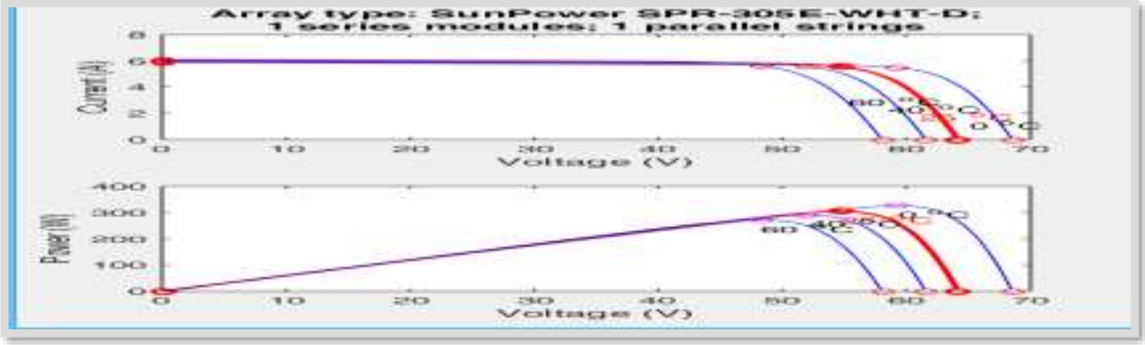


Fig 10 (a) Module’s I-V/PV graphs at variable irradiance and constant temperature

(b) Module's I-V/P-V graphs at variable temperature and constant irradiance

- Reference Module's I-V and PV graphs at variable irradiances and constant temperatures (25℃) is presented in Fig. 10 (a). The irradiance varies between (250 to 1000) W/m2 whereas temperature was set at 25 ℃. when the irradiance raises, at the same time current is enlarged. Even though, the Voltage, stay logically stable all through the irradiance choice.

- Reference Module's I-V and *P-V* graphs at variable temperatures (0,25, 40, 60 ℃) and constant irradiances (1000W/m^2) is illustrated in **Fig 10 (b)**. It is observed that lesser the temperature, the maximum power is higher and open-circuit voltage is also high. even though, a low temperature delivers a slightly lower short circuit current.

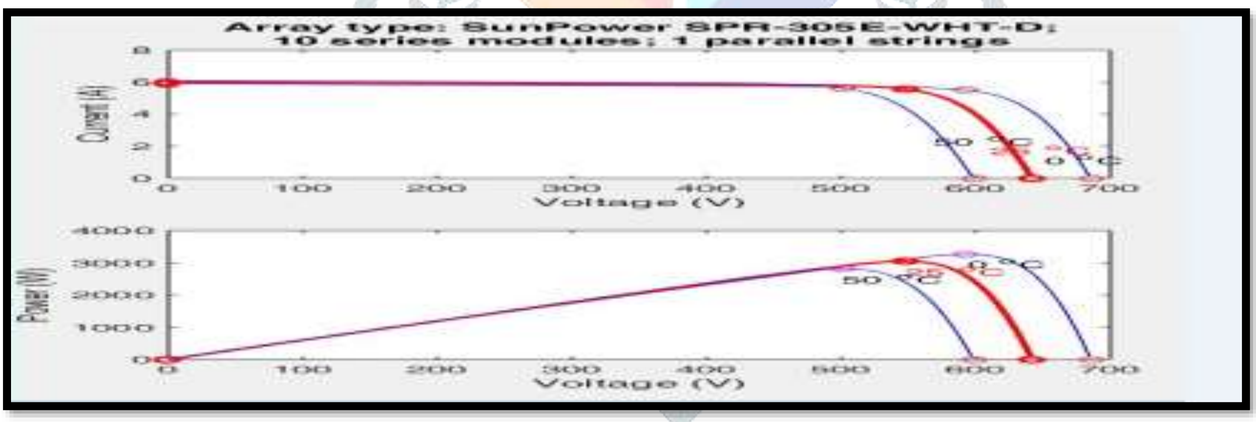


Fig: 11 (a) PV Array's I-V/P-V graphs at variable temperature and constant irradiance

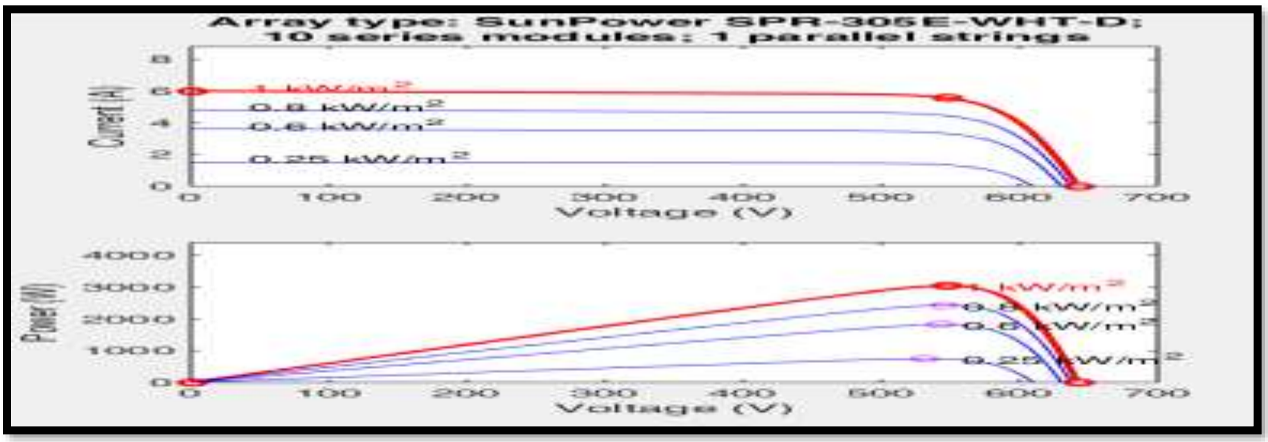


Fig 11 (b)) PV Array's I-V/P-V graphs at variable irradiance and constant temperature

- Reference Panel's *I-V and PV* graphs at unpredictable irradiances and stable temperatures (25℃) is shown in **Fig. 11 (a).** The irradiance varies between 250 -1000 W/m2 whereas temperature was set at 25 ℃. when the irradiance increases, at the same time current is increased. Although, the Voltage, stay realistically constant all through the irradiance series.
- Reference Panel's I-V and *P-V* graphs at unpredictable temperatures (0,25, 40, 60 ℃) and stable irradiances (1000W/m^2) is illustrated in **Fig 11 (b)**. It is observed that lesser the temperature, the maximum power is higher and open-circuit voltage is also high. Although, a low temperature delivers a slightly lower short circuit current.

Simulation summary:

The proposed incremental conductance controller with MPPT by means of boost converter to retain the stable output power of the load at the greatest point in variable irradiances, & constant temperatures and at variable temperatures & constant irradiances This controller was tested with MATLAB. The simulation consequence presented with incremental conductance controller shows that

i. At variable irradiances and constant temperatures when the irradiance increases, at the same time current is increased. Although, the Voltage, remained reasonably constant during the irradiance range.
ii. At variable temperatures and constant irradiances when that temperature is lesser, the maximum power is higher and open-circuit voltage is also high. Although, a low temperature delivers a slightly lower short circuit current.
iii. PV system involves less time (less than 0.7 ms) to attain the highest power.
iv. Improved power output and higher efficiency under normal and varying conditions.
v. The system shows improved dynamic performance and steady state performance for grid connected solar PV system simultaneously.

REFERENCES

1) J. Riatsch, H. Stemmler, and R. Schmidt, “Single cell module integrated converter system for photovoltaic energy generation,” Proceedings of Conference on European Power Electronics(EPE97), pp. 71–77, 1997.

2) J. Schoene, V. Zheglov, D. Houseman, J.C. Smith and A. Ellis, Photovoltaic's in Distribution Systems-Integration Issues and Simulation Challenges,” *in Power and Energy Society General Meeting (PES), IEEE*, 2013.

3) J. Solanki, S. K. Solanki and V. Ramachandran, “Steady State Analysis of High Penetration PV on Utility Distribution Feeder,” in *IEEE Conference*, 2012.

4) J. Widen, E. Wäckelgård, J. Paatero and P. Lund, “Impacts of distributed photovoltaic's on network voltages: Stochastic simulations of three Swedish low-voltage distribution grids,” *Electric power systems research*, vol. 80, pp. 1562-1571, 2010.

5) J. Yuncong, J. A. A. Qahouq, and M. Orabi, "Matlab/Pspice hybrid simulation modeling of solar PV cell/module," in *Applied Power Electronics Conference and Exposition (APEC), 2011 Twenty-Sixth Annual IEEE*, 2011, pp. 1244-1250.

6) Johann Hernandez, Nelson L. Diaz, and Gerardo Gordillo. Design-Dimensionin Model JohnWiles.PVMath.IAEINEWS, 2009. http://www.iaei.org/magazine/2009/01/pv-math/

7) K. Giannouloudis and E. Mulenga, "PV Systems and Applications," ENM-095: Sustainable Power Production and Transportation Scientific Paper, Gothenburg, 2014.

8) Kyocera, "High Efficiency Multicrystal Photovoltaic Module KD135GX-LPU ", Kyocera, Ed., ed. Northern Arizona, 2008.

9) Lijun Gao, Roger A. Dougal, Shingly Liu,and Albena P. Iotova, "Parallel-Connected Solar PV System to Address Partial and Rapidly Fluctuating Shadow Conditions," IEEE Transactions on Industrial Electronics, Vol. 56, No. 5,pp 1548- 1556, May 2009

10) Lidong Zhang, Lennart Harnefors and Hans-Peter Nee, "Power- Synchronization Control of Grid-Connected Voltage-Source Converters", IEEE transactions on power systems, vol. 25, no. 2, pp.809-820, may 2010.

11) LV Bin, CHE Yanbo and WANG Chengshan. Design of Grid-connected Photovoltaic System Using Soft Cut-in Control. International Conference on Geosciences, Power, Energy, & Industry Applications, pp 1-5, Sustainable Power Generation and Supply, Tianjin University, Tianjin, China, April 2009.

12) L. Rolim, D. Costa, M. Aredes. "Analysis and software implementation of a robust synchronizing PLL circuit based on the pq theory". IEEE Trans. Industrial Electronics, Vol. 53, No.6, pp. 1919-1926, 2006.M. Bollen och H. Fainan, "Integration of Distributed Generation in the Power System", Hoboken, New Jersey: John Wiley and Sons, Inc, 2011.

13) M. Calais, J. Myrzik, T. Spooner, and V. Agelidis, "Inverters for single-phase grid connected photovoltaic systems-an overview," Proceedings of 33rd IEEE Annual Power Electronics Specialists Conference (PESC 02), vol. 4, pp. 1995–2000, 2002.

14) M. G. Villalva, J. R. Gazoli, and E. R. Filho, "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays," Power Electronics, IEEE Transactions on, vol. 24, pp. 1198-1208, 2009