Modelling and Analysis of Photo Voltaic Cell Fed Seven Level Multi-String Inverter

A. Vinothkumar[1], S. Selvakumar [2], M. Vigneshkumar[3]

[1.] Assistant Professor, Department of Electrical and Electronics Engineering, P.A college of Engineering and Technology, Pollachi.
[2.] M.E (Power Electronics and Drives) student, P.A college of Engineering and Technology, Pollachi.
[3.] Assistant Professor, Department of Electrical and Electronics Engineering, P.A college of Engineering and Technology, Pollachi.

***Abstract* --There is strong trend in the photovoltaic (PV) inverter technology to use transformer less topologies in order to acquire higher efficiencies. This paper presents a single-phase seven level grid connected PV inverter with two reference signals that were identical to each other with an offset that was equivalent to the amplitude of the triangular carrier signal were used to generate PWM signals for the switches. Multistring inverter based system gives better voltage regulation and efficiency compare to the multilevel inverters. Seven level multistring inverter consists of two auxiliary switches and diodes. The inverter produces output voltage in seven levels V_{dc}, $V_{dc}/3$, $2V_{dc}/3$, 0,-$V_{dc}/3$,-$2V_{dc}/3$,-V_{dc}. The validity of the propose inverter is verified through simulation.**

Keyword - Pulse Width modulation (PWM), Photo Voltaic (PV) Source, Maximum Power Point (MPP).

I. INTRODUCTION

PV inverter, which is the heart of a PV system, is used to convert dc power obtained from PV modules into ac power to be fed into the grid. Improving the output waveform of the Inverter reduces its respective harmonic content and, hence, size of the filter used and the level of the Electromagnetic Interference (EMI) generated by switching operation of the inverter. In recent years, multilevel inverters have become more attractive for researchers and manufacturers due to their advantages over conventional three level PWM Inverters. They offer improved output waveforms, smaller filter size and lower EMI, lower Total Harmonic Distortion (THD).

II. CIRCUIT DESCRIPTION OF THE PROPOSED SYSTEM

The proposed single-phase seven-level multi-string inverter circuit is shown in Fig 1. It consists of three strings of DC - DC step up converter connected to common dc bus, an auxiliary circuit, and conventional full-bridge inverter configuration. Input sources, PV strings are connected to the inverter via dc-dc boost converters. The dc–dc boost converters are used to track the Maximum power point tracking (MPPT) independently and to step up inverter output voltage. The multi-string approach is adopted because each dc–dc converter can independently perform MPP tracking (MPPT) for its PV strings. This will compensate for mismatches in panels of like manufacture, which can be up to 2.5%. It further offers the advantage of allowing panels to be given different orientations and so open up new possibilities in architectural applications. Another advantage of multi-string configuration is that the mixing of different sources becomes possible, i.e., existing PV panel strings could be extended by adding new higher output panels without compromising the overall string reliability or performance [1]. Depending on the design, each converter module may be able to isolate its connected power source so that the wiring of series or parallel connection of these strings can be performed safely. The power-source converter connection is a safe low-voltage connection. The dc–dc boost converters are connected in parallel to avoid high dc-bus voltage, which will eventually increase the size of the capacitors and the inverter's cost. Therefore, only three capacitors with equal capacitance rating are used as the dc bus, and the other dc–dc boost converters are connected to this dc bus, as shown in Fig.1. A filtering inductance L_f is used to filter the current injected into the grid. The injected current must be sinusoidal with low harmonic distortion. In order to generate sinusoidal current, a sinusoidal PWM is used because it is one of the most effective methods.

A sinusoidal PWM is obtained by comparing a high-frequency carrier signal with a low-frequency sinusoidal signal, which is the modulating or reference signal.

The carrier has a constant period; therefore, the switches have constant switching frequency. The switching instant is determined from the crossing of the carrier and the modulating signal.

The table 2.1 gives the switching operation of the Seven Level inverter. The voltage levels in the truth table are V_{dc}, $V_{dc}/3$, $2V_{dc}/3$, 0, $-V_{dc}/3$, $-2V_{dc}/3$, $-V_{dc}$. The switching operation of the above voltage levels for the switches will be on (1) and off (0) according to the input need to be given. In Pulse width modulation technique the input can be given as in the table 1. The on and off can be done according the output required.

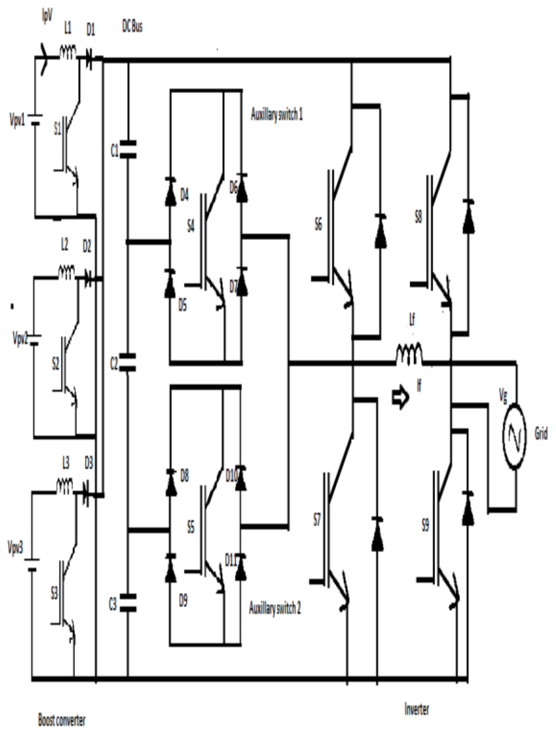
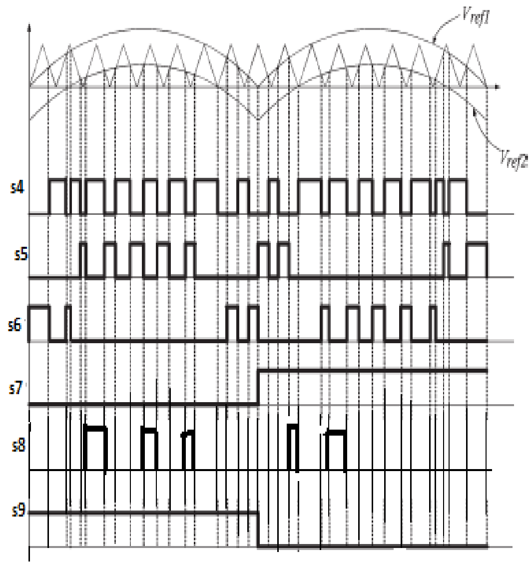


Fig.1. Circuit diagram of Multistring inverter

Voltage Levels	S1	S2	S3	S4	S5	S6
V_{dc}	0	0	1	0	0	1
$V_{dc}/3$	0	1	0	0	0	1
$2V_{dc}/3$	1	0	0	0	0	1
0	0	0	1	1	0	0
$-V_{dc}/3$	0	0	0	1	1	0
$-2V_{dc}/3$	0	1	0	0	1	0
$-V_{dc}$	1	0	0	0	1	0

Table 2.1 Truth table for the 7-level multistring inverter



III. PWM MODULATION

Modulation index M_a for a seven-level PWM inverter is given as,

$$M_a = \frac{A_m}{2A_c} \qquad (1)$$

Where,

A_c is the peak-to-peak value of carrier

A_m is the peak value of voltage reference V_{ref}.

As two reference signals are identical to each other, (1) can be expressed in terms of the amplitude of carrier signal V_c by replacing A_c with V_c, and $A_m = V_{ref1} = V_{ref2} = V_{ref}$ then,

$$M = \frac{V_{ref}}{2V_c} \qquad (2)$$

If $M > 1$, higher harmonics in the phase waveform is obtained. Therefore, M is maintained between zero and one. Here two reference signals V_{ref1} and V_{ref2} are compared with the carrier signal at a time. If V_{ref} exceeds the peak amplitude of carrier signal $V_{carrier}$, then V_{ref2} will be compared with the carrier signal until it reaches zero. At this point onward, V_{ref1} takes over the comparison process until it exceeds $V_{carrier}$. This will lead to a switching pattern, as shown in Fig 2. Switches S4–S9 will be switching at the rate of the carrier signal frequency, while S7 and S8 will operate at a frequency that is equivalent to the fundamental frequency. Table 1 illustrates the level of V_{inv} during S4–S9 switch on and off.

Section 4 illustrating the Simulink model of the PV cell is given in the appendix.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 2, February - 2014

IV. CHARACTERISTICS OF PV CELLS

A. Characteristics of PV cell at constant temperature

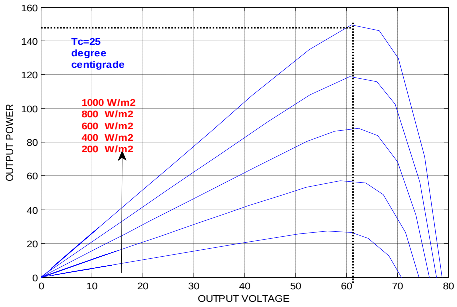


Fig.4. Power and voltage waveform at constant temperature for PV cells

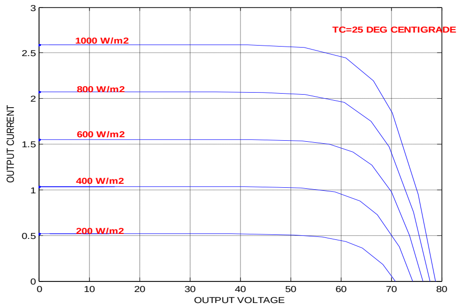


Fig.5. Current and voltage waveform at constant temperature for PV cells

B. Characteristics of PV cell at constant irradiance

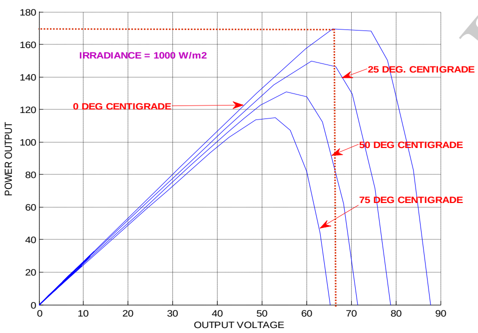


Fig.6. Power and voltage waveform at constant irradiance for PV cell

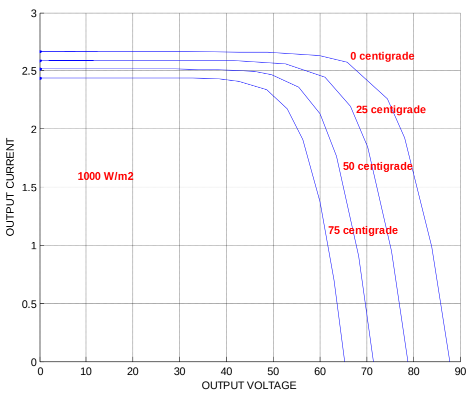


Fig.7.Current and voltage waveform at constant irradiance for PV cells

From the above characteristics (Fig.4, Fig.5, Fig.6, Fig.7) curves the power generation continuously varies along with two main factors, which are known as cell temperature and irradiance. In this work MPPT technique is used for finding the maximum output at various instant of time.

V. MAXIMUM POWER POINT TRACKING CONTROL (MPPT)

In order to operate the PV cells at the maximum power point, several techniques has been suggested in the literature .Some of them are,

(i) Look up table Method

(ii) Perturbation and Observation methods

(iii) Model based computation methods

(iv) Artificial intelligence techniques

Model based Computation methods are of two types they are,

a. Voltage based MPPT (VMPPT)
b. Current Based MPPT (CMPPT)

In this work focus is made on Current Based MPPT (CMPPT).The CMPPT method simplifies the entire control structure of the power conditioning system and uses an inherent current source characteristic of solar cell arrays. Therefore it exhibits robust and fast response under rapidly changing environmental conditions.

A. Current Based Maximum Power Point Tracking Control

The main idea behind current based MPPT is that the current at the maximum point I_{mp} has a strong relationship with the short circuit current I_{sc}. I_{sc} can either be measured on line under different operating conditions or can be computed from a validated model.

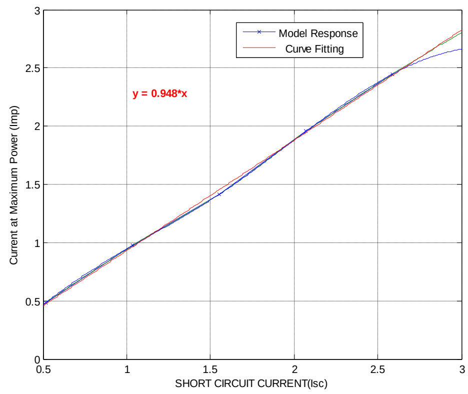


Fig.8. Current based control

Fig.8 represents the current based control scheme which gives the linear relationship between short circuit current I_{sc} and current at maximum power I_{mp} using curve fitting.

VI. SIMULINK MODEL OF SEVEN LEVEL INVERTER

The feasibility of the proposed approach is verified using computer simulations. A model of the seven-level inverter is constructed in MATLAB-Simulink software. A new strategy with reduced number of switches is employed. Cascaded H bridge 7 level inverter requires 12 switches to get seven level output voltage and with the proposed topology requirement is reduced to 6 switches. The new topology has the advantage of its reduced number of switching devices (switches) compared to conventional cascaded H-bridge multilevel inverter, and can be extended to any number of levels. The simulink model of seven level multi-string inverter is represented in the Fig.9

A. Simulation diagram of multistring inverter

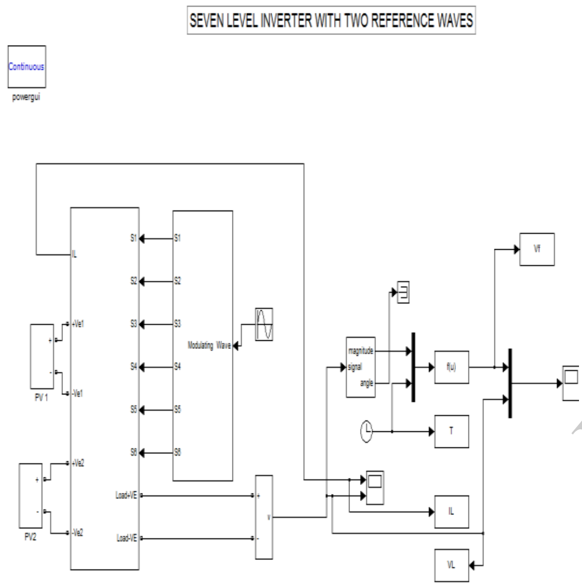


Fig.9. Simulink model of Seven level multi- string inverter

The above simulink model in Fig.9 could recreate the characteristic curves shown in Fig.6 and Fig.7 of section V when correctly inserted into the progam.

The life time of the PV panel depends on the environmental conditions at which the panel is installed. Aging effect is unavoidable but it can be minimized using anti-aging agents like ethylene vinyl acetate. This serve to improve the life time of PV panel to certain extent. The exact life time of the PV panel is unpredictable as it depends upon the field conditions and quality of manufacturing.

VII. RESULT AND DISCUSSION

A. Switching Pattern for the Single Phase seven-level inverter

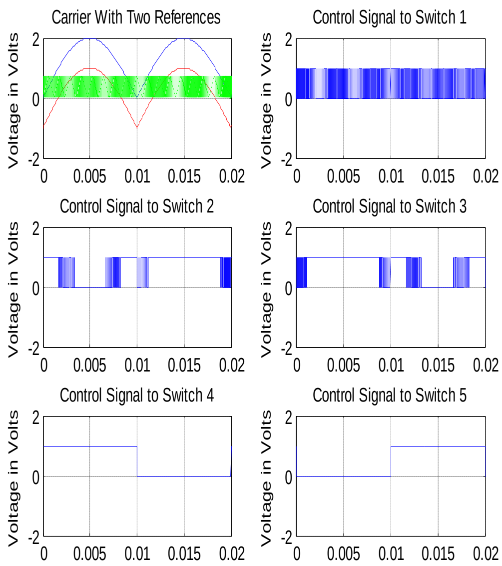


Fig.10. Switching pattern for seven level inverter

Fig.10 represents the switching pattern for seven level inverter. Here two reference signals V_{ref1} and V_{ref2} will take turns to be compared with the carrier signal at a time. If V_{ref} exceeds the peak amplitude of carrier signal $V_{carrier}$, then V_{ref2} will be compared with the carrier signal until it reaches zero. At this point onward, V_{ref1} takes over the comparison process until it exceeds $V_{carrier}$. This will lead to a switching pattern, as shown in Fig.10. Switches S4–S9 will be switching at the rate of the carrier signal frequency, while S7 and S8 will operate at a frequency that is equivalent to the fundamental frequency.

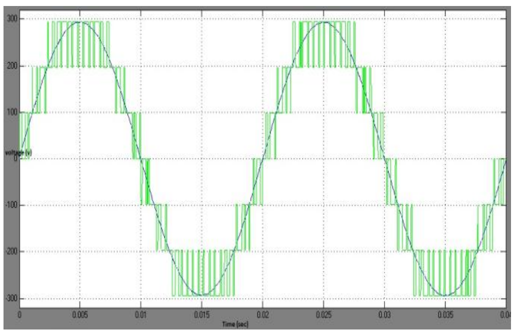


Fig.11 Simulation results for seven level inverter output voltages

$$(M \leq 0.5)$$

VIII. CONCLUSION

This paper has presented a single-phase multistring seven-level inverter for PV application. A novel PWM control scheme with two reference signals and a carrier signal has been used to generate the PWM switching signals. The circuit topology, control algorithm, and operating principle of the proposed inverter have been analyzed in detail. The configuration is suitable for PV application as the PV strings operate independently and later expansion is possible.

IX. SCOPE FOR THE FUTURE WORK

The proposed model is simulated using MATLAB.The simulation results indicate the functioning of the proposed model. The future work is to implement the proposed model in hardware. The proposed model can be improved by increasing the level of the inverter output.

REFERENCES

[1] N. A. Rahim and S. Mekhilef, "Implementation of three-phase grid connected inverter for photovoltaic solar power generation system," in *Proc .IEEE PowerCon*, Oct. 2002, vol. 1, pp. 570–573.

[2] S. B. Kjaer, J. K. Pedersen, and F. Blaabjerg, "A review of single-phase grid connected inverters for photovoltaic modules," *IEEE Trans. Ind. Appl.*, vol. 41, no. 5, pp. 1292–1306, Sep./Oct. 2005 .*Meeting*, Jul. 2000, vol. 2, pp. 1283–1288.

[3] J. Selvaraj and N. A. Rahim, "Multilevel inverter for grid-connected PV system employing digital PI controller," *IEEE Trans. Ind. Electron.*, vol. 56, no. 1, pp. 149–158, Jan. 2009.

[4] S. J. Park, F. S. Kang, M. H. Lee, and C. U. Kim, "A new single-phase five level inverter employing a deadbeat control scheme," *IEEE Trans, Power Electron.* vol. 18, no. 18, pp. 831–843, May 2003.

[5] Y. Liu, H. Hong, and A. Q. Huang, "Real-time calculation of switching angles minimizing THD for multilevel inverters with step modulation," *IEEE Trans. Ind. Electron.*, vol. 56, no. 2, pp. 285–293, Feb. 2009.

[6] S. Kouro, J. Rebolledo, and J. Rodriguez, "Reduced switching-frequency modulation algorithm for high-power multilevel inverters," *IEEE Trans. Ind. Electron.*, vol. 54, no. 5, pp. 2894–2901, Oct. 2007.

[7] G. R. Walker and P. C. Sernia, "Cascaded dc–dc converter connection of photovoltaic modules," *IEEE Trans. Power Electron.*, vol. 19, no. 4, pp. 1130–1139, Jul. 2004.

[8] R. Gonzalez, E. Gubia, J. Lopez, and L. Marroyo, "Transformerless single-phase multilevel-based photovoltaic inverter," IEEE Trans. Ind.Electron., vol. 55, no. 7, pp. 2694–2702, Jul. 2008.

[9] L. M. Tolbert and T. G. Habetler, "Novel multilevel inverter carrier-based PWM method," IEEE Trans. Ind. Appl., vol. 35, no. 5, pp. 1098–1107, Sep./Oct. 1999.

[10] V. G. Agelidis, D. M. Baker, W. B. Lawrance, and C. V. Nayar, "A multilevel PWM inverter topology for photovoltaic application," in Proc. IEEE ISIE, Guimaraes, Portugal, 1997, pp. 589–594.

[11] G. R. Walker and P. C. Sernia, "Cascaded dc–dc converter connection of photo voltaic modules," IEEE Trans. Power Electron., vol. 19, no. 4, pp. 1130–1139,Jul. 2004.

[12] Evaluation of DC-to-DC Converters Topologies with Quadratic Conversion Ratios for Photovoltaic Power Systems, Jean-Paul GAUBERT, Gwladys CHANEDEAU, IEEE2009

[13] Multi-string five-level inverter with novel PWM control scheme for PV Application, Nasrudin A.Rahim, IEEE, and JeyrajSelvaraj, IEEE transactions on industrial electronics,vol 57,n0.6,June 2010.

[14] S. Daher, J. Schmid, and F. L.M. Antunes, "Multilevel inverter topologies for stand-alone PV systems," IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2703–2712, Jul. 2008.

[15] Kaliamoorthy. M, Sekar R.M., and Rajaram.R, "A new single-phase PV fed five-level inverter topology connected to the grid" IEEE Trans.communication control and computing technologies.pages:196-203, 2010.

[16] S. Vazquez, J. I. Leon, L. G.Franquelo, J. J. Padilla, and J. M. Carrasco, ―DC voltage-ratio control strategy for multilevel cascaded converters fed with a single DC source, ‖*IEEE Trans. Ind. Electron*, vol. 56, no. 7, pp. 2513–2521, Jul. 2009.

[17] Srinath.K, Dr.P.Linga Reddy, "Matlab/simulink modelling of novel hybrid H-bridge multilevel inverter for PV application" International Journal of Modern Engineering Research., vol.2,issue.2,pp.149-153 March 2012.

[18] GeorgiosI.Orfanoudakis, Suleiman M.Sharkh and Michael A.Yuratich, "Analysis of DC-link capacitor losses in three-level neutral point clamped and cascaded H-bridge voltage source inverters."

[19] V.FernaoPires, J.F.Martins, D.Foito, Chen Hao, "A Grid Connected Photovoltaic System with a Multilevel Inverter and a Le-Blanc Transformer." International Journal of Renewable Energy Research., vol.2, No.1, 2012.

[20] K.Lakshmi Ganesh, U.ChandraRao, "Performance of Symmetrical and Asymmetrical Multilevel Inverters", International Journal Modern Engineering Research., vol.2, issue.4, July-Aug.2012 pp.2293-2302, ISSN: 2249-6645.

[21] D.PhaniDeepthi, Gandi.Vinaykumar. "A Novel Simplified Single-Phase and Three Phase Multi string Multilevel Inverter Topology for Distributed Energy Resources", International Journal of Engineering Research and Applications", vol.2, issue.3, May-Jun 2012, pp.661-665, ISSN: 2248-9622.

[22] Divya Subramanian, RebiyaRasheed, "Five Level Cascaded H-Bridge Multilevel Inverter Using Multicarrier Pulse Width Modulation Technique," International Journal of Engineering and Innovative Technology., vol.3, Issue.1, July 2013.

[23] R.Rajesh, M.Balasubramani, J.Gowrishankar, "Newly-Constructed Single Phase Multilevel Inverter for Distributed Energy Resources, "International Journal of Engineering and Technology, vol.5, no.2, Apr-May 2013, ISSN: 0975-4024.

[24] T.Singaravelu, M.Balasubramani, J.Gowrishankar, "Design and Implementation of Seven Level Cascaded H-Bridge Inverter Using Low frequency transformer with Single DC source," vol 5, no.3, Jun-Jul 2013, ISSN: 0975-4024.

[25] T.Porselvi and RanganathMuthu, "Seven-level Three Phase Cascaded H-Bridge Inverter with a Single DC Source," APRN Journal of Engineering and Applied Sciences, vol.7, no.12, Dec 2012, ISSN 1819-6608.

[26] A.Suga, K.EsakkiShenbagaLoga, "Single Phase Multi String Five Level Inverter for Distributed Energy Sources,"vol.2, no.4, April 2013, PP: 138-143, ISSN: 2325-3924.

[27] K.Lakshmi Ganesh, M.Balaji, K.Durgaprakash, "A Novel Simplified Single-Phase Cascaded Multistring and H-bridge Multilevel Inverter," vol.2, Issue.8, Aug.2013, ISSN: 2278-8875.

APPENDIX

SIMULINK MODEL OF PV CELL

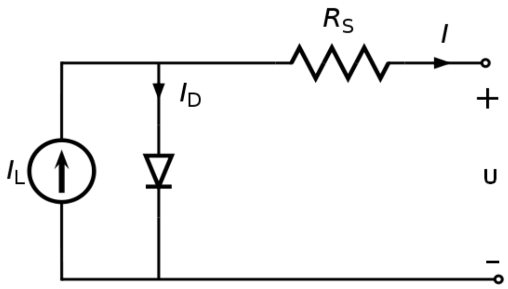


Fig.3 Line diagram of PV cell

$$I = I_L - I_D \quad (3)$$

Where,

I = Output Current in Amps

I_L = Photo Generated Current in Amps

I_D = Diode Current in amps

By Shockley equation, current diverted through diode is,

$$I_D = I_o\left[\exp\left(\frac{U + IR_s}{nkT/q}\right) - 1\right] \quad (4)$$

Where,

I_o = Reverse Saturation Current
n = Diode Ideality Factor
k = Boltzmann's Constant
T = Absolute Temperature
q = Elementary Charge

For silicon of 25^{0}C nkT/q =0.0259 volts=α,

$$I_D = I_o\left[\exp\left(\frac{U + IR_s}{\alpha}\right) - 1\right] \quad (5)$$

Substituting above equation in equation (3) we get,

$$I = I_L - I_o\left[\exp\left(\frac{U + IR_s}{\alpha}\right) - 1\right] \quad (6)$$

where $\alpha = nkT/q$ is known as Thermal voltage timing completion factor.

Photo generated current I_L is calculated by

$$I_L = \frac{\phi}{\phi_{ref}}\left[I_{L,ref} + \mu_{I,SC}\left(T_c - T_{c,ref}\right)\right] \quad (7)$$

Where,

ϕ = Irradiance (W/m^2)

ϕ_{ref} = reference irradiance (1000 W/m^2)

$I_{L,ref}$ = Light current at reference condition

T_c = PV cell temperature

$T_{c,ref}$ = Reference temperature

$\mu_{I,SC}$ = Temperature coefficient of the short circuit current (A/^{0} C)

Saturation Current I_o is given by

$$I_o = I_{o,ref}\left(\frac{T_{c,ref} + 273}{T_c + 273}\right)^3 \exp\left[\frac{e_{gap}N_s}{q\alpha_{ref}}\left(1 - \frac{T_{c,ref} + 273}{T_c + 273}\right)\right] \quad (8)$$

Where,

$I_{o,ref}$ = saturation current at the reference condition (A)

e_{gap} = band gap of the material (1.17eV for Si)

N_s = number of cells in series of the PV module

q = charge of the electron

α_{ref} = value of α at the reference Condition

Thermal Model of Photovoltaic Cell is

$$C_{pv}\frac{dT_c}{dt} = k_{in,pv}\phi - \frac{U \text{ x } I}{A} - K_{loss}\left(T_c - T_a\right) \quad (9)$$

Where,

C_{pv} = overall heat capacity of PV cell/Module
$k_{in,pv}$ = transmittance absorption product of PV cells
K_{loss} = overall heat loss coefficient
T_a = ambient temperature
A = effective area of PV cell/Module