International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869, Volume-3, Issue-5, May 2015

Investigation of Two MPPT Techniques for Solar PV System-A Comparative Analysis

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Abstract- **Power quality monitoring and diagnosis is an important aspect in studies, which pertains to performance of a Photovoltaic (PV) system. With the growing popularity as alternative to conventional fuel, PVs are being increasingly employed for a wide range of applications. To be able to develop a complete solar PV power electronic conversion system in simulation, it is necessary to define a circuit based simulation model for a PV array in order to allow the interaction between a converter and the PV array. This research analyzes the role of Proportional Integral (PI) based controllers in the control systems for Voltage Source Converters (VSC). These PI controllers have been implemented for voltage and current systems for DC-AC converters. A double stage grid connected has been developed for the study in which manufacturer available data sheets of 100 kW solar PV array have been used. The PV array used has been operated under changing atmospheric conditions: solar radiation and ambient temperature. The Maximum Power Point Tracking (MPPT) technique is used to extract the maximum power from non-linear PV array. Two basic MPPT techniques have been implemented in this thesis: P&O and IC. A power quality comparison is carried out which analyzes the active and reactive power exchange among converter, load and utility grid. The MPPT technique has been built in DC-DC boost converter. In addition, harmonic analysis has been done using fast fourier technique in Matlab simulation for voltage and current.**

Index Terms- **Photovoltaic, maximum power, control, load, converter**

I. INTRODUCTION

Solar energy is one type of a non-conventional energy. It has been harnessed by humans since the ancient times using variety of technologies. Its radiation coupled with secondary resources such as wave and wind power, hydroelectricity and biomass, accounts for important non-conventional type of energy on earth. However, it has been seen that only a small fraction of the received solar energy is used [1]. Passive solar technologies include orientation of a building towards sun and selecting the materials with favorable thermal mass and light dispersing properties [2].

In [3] it is presented an approach which models the solar cell system with coupled multi-physics equations (PV, electro-thermal, and direct heating) within the context of the resistive-companion method in the virtual test bed computational environment. In [4] it is discussed that as Maximum Power Point (MPP) of PV power generation systems changes with changing atmospheric conditions (solar radiation and ambient temperature), it is important to correctly track the MPP in the design of efficient PV systems. In [5] it is presented that PV generators exhibit nonlinear *I-V* characteristics and MPP that vary with solar radiation.[6] proposed a novel MPPT technique which efficiently extracts maximum power from PV panels. In [7] it is discussed a dynamic process for reaching the MPP of a solar PV cell. The process tracks MPP nearly cycle-by-cycle during the transients. The information from natural switching ripple, instead of external perturbation is used to track the MPP. In [8] it is discussed that the MPPT is used in PV systems which maximize the PV array output power during changing ambient temperature and solar radiation. In [9] it is proposed a novel MPPT technique with a simple algorithm for PV power generation systems.

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II. SOLAR PHOTOVOLTAIC ARRAY MODELING

The important factors which affect the efficiency of a PV module are ambient temperature and solar radiation. The PV cell output voltage is a function of the photocurrent which is determined by load current depending on solar radiation level during operation, [10]. Figure 1, shows equivalent circuit of a solar PV cell which consists of a light generated current source, a single *p-n* diode representing the non linear impedance of *p-n* junction with R_s and R_p. The series resistance R_s accounts for any resistance in current path through semiconductor material, metal grid, contacts, and current collecting bus. The value of R_s is multiplied by the number of series-connected cells. The parallel resistance R_p is the loss associated with leakage current through parallel resistive path to the device.

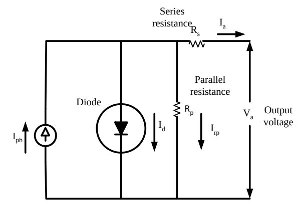


Figure 1 Single exponential model of single solar PV cell

The following equation gives output current [11] I_a of a PV array,

$$I_a = I_{ph}N_p - I_{rs}N_p e^{\{(\frac{q}{akT_c(\frac{V_a}{N_s}+\frac{I_aR_s}{N_p})}-1)\}} - \frac{N_p}{R_p}(\frac{V_a}{N_s}+\frac{I_aR_s}{N_p}) \quad \textbf{(1)}$$

where,

$$I_{ph} = [I_{sc} + K_i(T_c - T_x)\frac{S_c}{S_x}] \quad \textbf{(2)}$$

Another equation (3) gives the the PV cell output voltage,

$$V_a = \frac{akT_c}{q}\ln\left(\frac{I_{ph} + I_{rs} - I_a}{I_{rs}}\right) - R_s I_a \quad \textbf{(3)}$$

The above equation gives the output voltage of a single solar PV cell, which is multiplied by the number of PV cells connected in series to give full array voltage.

III. MODEL ANALYSIS WITH INCREMENTAL CONDUCTANCE MPPT TECHNIQUE

Figure 2 depicts the simulink diagram of incremental conductance MPPT technique in which PV current and voltage are the controlled variables. The initial duty cycle is assumed as unity for the DC-DC boost converter. The saturation block limits the signal range within the specified limits. Figure 3 shows the simulink diagram of boost converter control.

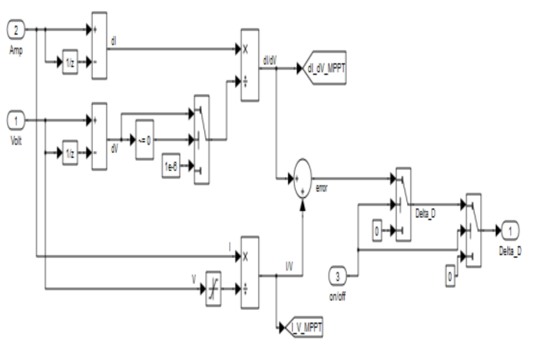


Figure 2 Simulink diagram of incremental conductance MPPT technique

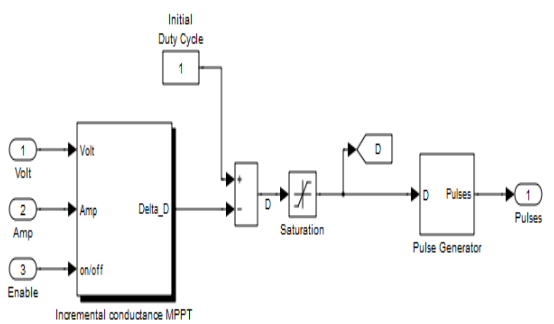


Figure 3 Simulink diagram of boost converter control

A. *Solar PV Computation Model*

According to the conducted literature survey, there are two types of solar PV conversion systems: single stage and double stage. As shown in Figure 4, the double stage Power Conditioning System consists of solar PV array, DC-DC boost converter and its MPPT control, along with Insulated Gate Bipolar Transistor (IGBT) based DC-AC converter with PI control. The grid voltage and current from bus no. 4 has been taken as the variables and given to the controller of DC-AC converter. In addition, the actual DC voltage to VSC is also to be controlled and maintained to track the reference MPPT voltage. The proposed system is tested at linear *RLC* load. Here, IC based MPPT technique has been implemented. The simulink tags for the measurement of voltage, current and power values are also shown. These values have been measured at VSC, load and utility grid side. Table I lists the specifications of each sub-system of the proposed simulink system. Table II lists the 100 kW PV module data-sheet specifications of manufacturer (Sun Power SPR-305-WHT) [12].

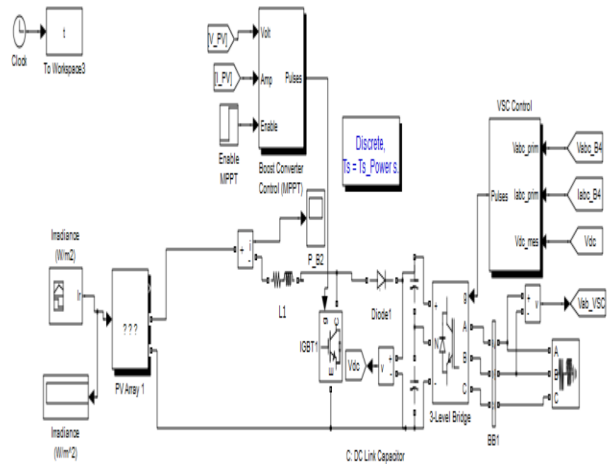


Figure 4 Simulink diagram of solar PV with connected load

Table I Specifications adopted for PV system

Parameter	specifications
DC voltage	200 V
Load (V_n, P, Q_l)	440 V, 82 kW, 22 kVAR
LC filter (L, C)	1500 μH, 30 μF
Current regulator gains (K_p K_i)	0.30, 57
DC voltage regulator gains (K_p, K_i)	6, 700
3-φ transformer nominal power and frequency	200 kVA, 50 Hz
Power and frequency	200 kW, 50 Hz

Table II: Specifications adopted for single PV array (Sun Power SPR-305-WHT) [12]

System name	Rating values
No. of cells per module	96
No. of series connected modules per string	5
No. of parallel strings	66
Module specifications under STC V_{oc}, I_{sc}, V_{mp}, I_{mp}	64.2 V, 5.96 A, 54.7 V, 5.58 A
Model parameters for one module R_s, R_p, I_{sat}, I_{ph}, Q_d	0.038 Ω, 993.5 Ω, 3.1949×10^{-8} A, 5.9602 A, 1.3
Maximum power	66×5×54.7×5.58 = 100.7 kW

IV. SIMULATIONS RESULTS AND DISCUSSION

In order to show the effectiveness of the proposed system, it has been tested at linear *RLC* load, where the total simulation time period is 0.3 s. The real and reactive power exchange has been demonstrated among PV-VSC, load and utility grid. The tracking behavior of actual DC link voltage around reference IC MPPT voltage has been presented. Finally, power quality evaluation study has been carried by measuring the THD at PV-VSC, load and utility grid side.

A. MODEL ANALYSIS WITH IC MPPT TECHNIQUE

Figure 5 (a)-(f) depicts the voltage and current waveform of VSC, connected load and utility grid. It has been observed that current starts flow from VSC at 0.05 s. It is found that the sine wave current flows through the connected load. Small harmonics are observed in the grid current waveform. These harmonics are due to the current injection by the semiconductor devices like wise IGBT based VSC.

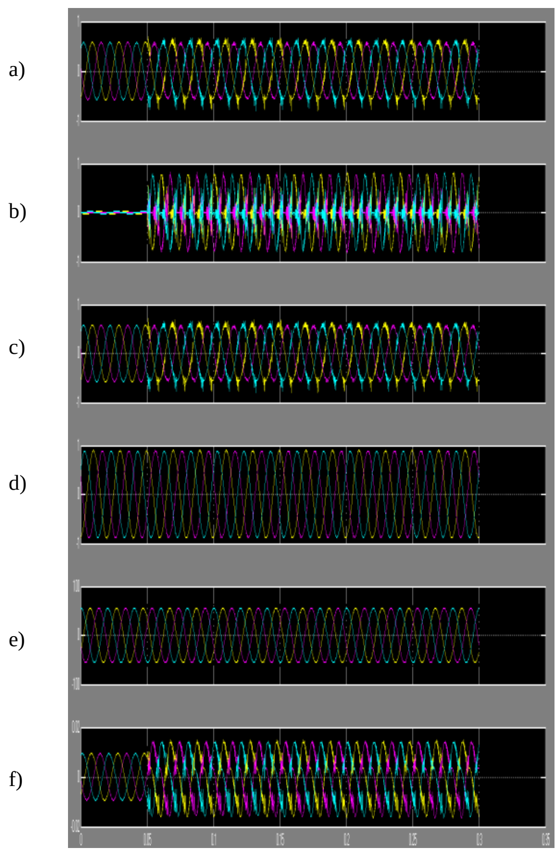


Figure 5 Waveform of a) VSC Voltage b) VSC Current c) Load Voltage d) Load Current e) Utility grid Voltage f) Utility grid Current

Figure 6 depicts the tracking of actual DC link voltage around the reference voltage of 200 V. It is possible to observe that actual behavior of DC link voltage to VSC is having more magnitude than the reference voltage. Small transients are started at 0.07 s, which can be controlled by the further tuning of PI based voltage and current controllers.

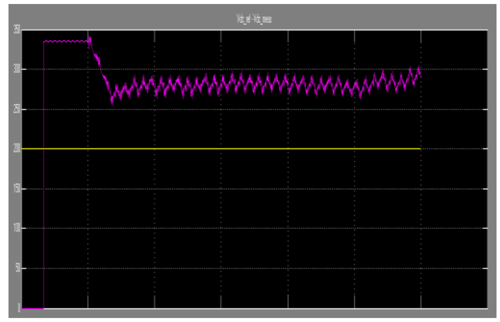
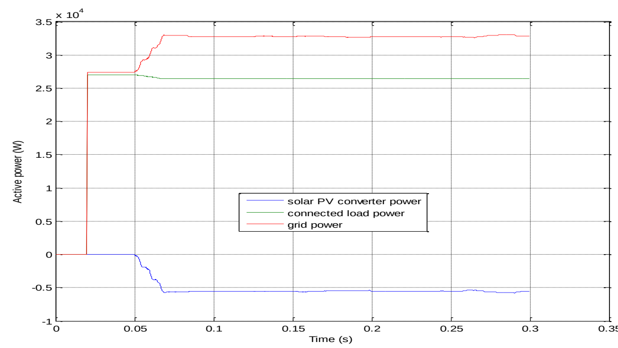
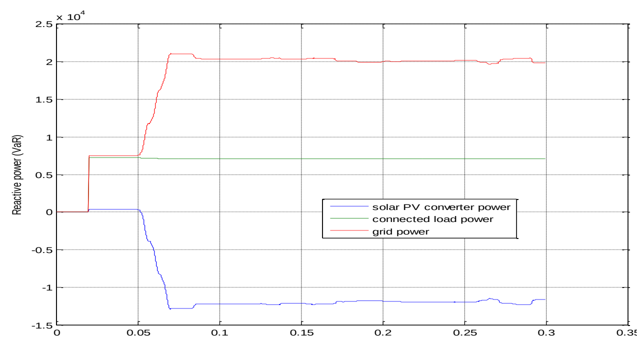


Figure 6 Change in actual DC link voltage with MPPT reference voltage

Figure 7(a) depicts the active power response, whereas Figure 7 (b) depicts the reactive power response of PV array through VSC, connected load and utility grid.



(a)



(b)

Figure 7 Waveform of a) Real power and b) Reactive power, with IC MPPT technique

In order to demonstrate the power quality evaluation of the proposed system, the THD measurement and its analysis is carried out with the FFT method. The THD values of load current and grid current are found to be 0.93 % and 28.94 %, respectively. Table III shows the complete THD analysis from where it is found that THD of converter current is 85.77 %. It is due to the fact that PV current flows through the VSC, which is a non-linear device.

Table III: Total harmonic distortion analysis

using IC MPPT

Parameter	THD (%)
DC-AC converter voltage	6.60
DC-AC converter current	85.77
linear-load voltage	6.60
linear-load current	0.93
Utility-grid voltage	0.22
Utility-grid current	28.94

B. MODEL ANALYSIS WITH P&O MPPT TECHNIQUE

In order to validate the results obtained in the previous chapter, this section presents the simulated results which have been obtained with P&O based MPPT technique. Figure 8 (a) depicts the waveform of VSC voltage which is sinusoidal and amplitude remains constant. Figure 8 (b) shows the waveform of VSC current whose value starts sine shape at 0.05 s. Figure 8 (c) depicts the waveform of load voltage whereas, Figure 8 (d) depicts the waveform of load current. Figure 8 (e) depicts the waveform of utility grid voltage and Figure 8 (f) depicts the waveform of utility grid current.

a)

b)

c)

d)

e)

f)

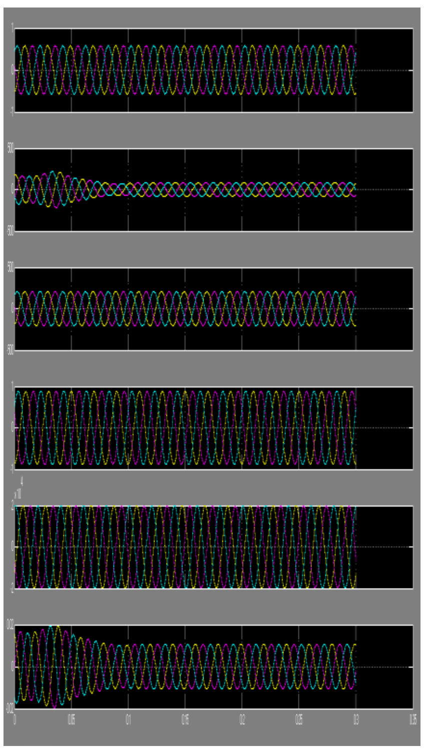
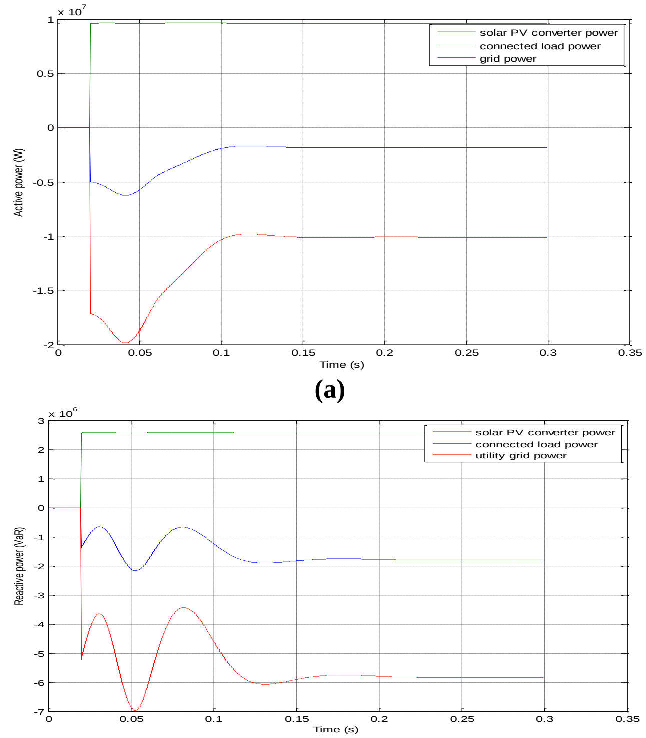


Figure 8 Waveform of a) VSC Voltage b) VSC Current c) Load Voltage d) Load Current e) Utility grid Voltage f) Utility grid Current

Figure 9 (a) depicts the waveform of active power for solar PV through VSC, load and utility grid. Figure 9 (b) depicts the waveform of reactive power from where it is clear that the VSC power and utility grid power are negative. Therefore, both are absorbing instead of generating the reactive power. The magnitude of reactive power depends upon the product of voltages of both utility grid and VSC, whereas the magnitude of real power depends upon the product of voltage and phase angle between grid voltage and VSC current.



(b)

Figure 9 Waveform of a) Real power and b) Reactive power, with P&O MPPT technique

Figure 10 depicts the behavior of actual DC link voltage around the reference MPPT voltage (200 V). It is possible to observe that after 0.05 s, the actual DC link voltage doesn't track the reference voltage. This shows that this P&O MPPT technique is not able to track the reference voltage under wide change of environmental conditions.

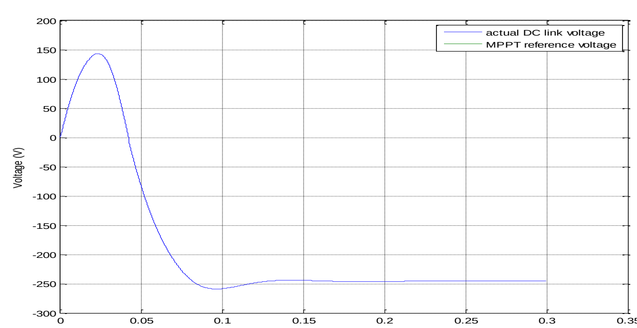


Figure 10 Change in actual DC link voltage with MPPT reference voltage

The THD values of load current and grid current are found to be 0.17 % and 5.26 %, respectively. Table IV shows the complete THD analysis from where it is found that THD of converter current is 4.53 %. It has been found to be lesser as compared to the value obtained with IC MPPT technique.

Table IV: Total harmonic distortion analysis using P&O MPPT

Parameter	THD (%)
DC-AC converter voltage	0.17
DC-AC converter current	4.53
linear-load voltage	0.17
linear-load current	0.17
Utility-grid voltage	0.01
Utility-grid current	5.26

V. CONCLUSION

This paper has discussed the system performance at P&O and IC based MPPT technique comparison for solar PV double stage grid connected system. It has been found that harmonic level is reduced by P&O MPPT for converter current and grid injected current. However, this MPPT is not able to track the reference MPPT voltage accurately. This validates that this MPPT is not able to operate under wide range of changing environmental conditions. The behavior of voltage and current levels of VSC, load connected and utility grid has also been discussed. Active and reactive power exchange among VSC, load connected and utility grid has also been highlighted.

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