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Research paper



Effect of DC-DC converter switching frequency on the performance of solar PV system

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Abstract

The performance of Photo Voltaic (PV) system depends on how effectively the impedance matching is maintained under climatic changes i.e. change in insolation and temperature. The Perturb and Observe (P&O) and Incremental Conductance (InC) type classical Maximum Power Point Tracking (MPPT) controllers with boost converter are used to maintain the desired impedance matching. The switching frequency of boost converter does play an important role in the overall performance of solar system. Due to the change in the switching frequency, various parameters such as settling time, peak over shoot, steady state response, MPPT voltage, MPPT current, maximum power and output voltage values are affected. The influence of these time domain specifications on the performance of the photovoltaic system with modification of above controllers is discussed in this paper. MATLAB/SIMULINK is used for simulation studies of solar PV system with modified InC and P&O controllers. The performance of the modified InC controller over P&O controller at different switching frequencies in transient, steady-state and dynamic responses, related to ripple, power loss, tracking speed and overshoot have been analyzed.

Keywords: *Impedance Matching; Incremental Conductance; Perturb and Observe; Photovoltaic System.*

1. Introduction

Solar power is the genesis for all forms of power. Its potential in India is enormous because the majority of the country's tropical land mass is located optimally for maximum solar irradiation. Research is still going on for improving the performance of solar panels, MPPT controllers and DC-DC converters. In India, solar power is a fast-developing industry due to enhanced solar framework with improved techno-economic policies and targeted to 100GW by 2022[1].

Integrated controller and Pulse Width Modulation (PWM) unit are the main section between the PV system and a power converter to transfer maximum power. The objective of the MPPT module is to identify the zero slope of the voltage-power (V-P) graph of the PV arrays. Researchers developed a huge number of MPPT systems over the last decade.Kamarzaman et al. [2], focus on both traditional and stochastic MPPT controllers in terms of tracking ability, design issues, system cost and response to climate change. Seyedmahmoudian et al. [3] discuss the effective tracking of global MPP under partial shading by AI-based methods. Karami et al. [4] compare several past and recent MPPT methods with respect to their merits and demerits. P&O [5-8] and InC [9-10] methods are commercial MPPTs developed in recent years. The duty cycle output of the module is fed to the PWM. The power converter included in this system consists of the buck [11], the boost [12], the buck-boost [13], the SEPIC converters [14] etc. The converter does the function of switching frequency pulses generated with the help of PWM.

At present mostly, the research is focused on MPPT systems, where comparison of the various techniques of MPP tracking are discussed [15-19]. The technology of tracking the peak power point is required to output the peak power from the PV systems. However, numerous crests are attained in the power-voltage (P-V) characteristic varying climatic conditions. In such situations, classical MPPT controllers may become inoperative due to its inability in global MPP detection. Many computational techniques like artificial neural network and fuzzy logic control can identify the global MPP. However, the feasibility of these methods is not good in real complex environment because they need suitable training and broad experience. Alternatively, these situations are handled properly by bio-inspired MPPT algorithms. However, the optimum selection of the switching frequency for DC/DC converter for the development of integrated PV MPPT system has not been explicitly discussed.

The purpose of the paper is to discuss a comparison of the PV module performance based on the effect of switching frequency of DC-DC converters, so that it may be possible to use optimum switching frequency. This paper is presented into four sections: Sections 2 presents the modeling of PV arrays and DC-DC converters. The results and observations are shown in Sections 3. At the end, conclusions are given in Section 4.

2. MPPT based PV system modeling

The main components of this system are

- Group of PV cells
- MPPT controller
- PWM - boost converter

2.1. PV module modeling

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The PV module model is the main element in simulating the solar PV system. Fig. 1 represents the basic diode electrical circuit PV module. The behavior of the module can be seen in Fig.2. The current equation of the PV module, Ipv, is obtained using Kirchhoff Laws, as shown in (1) [20]. This implicit equation is solved using a suitable numerical method.

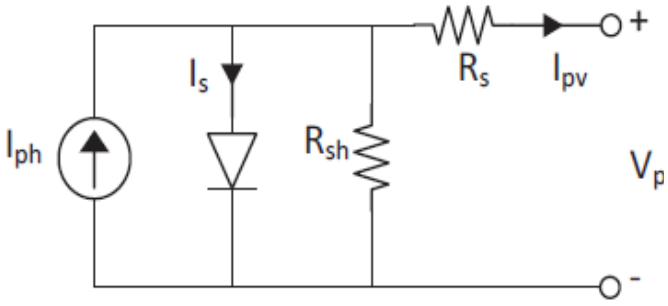


Fig. 1:.The Single Diode Model.

$$I_{pv} = I_{ph} - I_s\left(e^{\frac{(V_{pv}-I_{pv}R_s)}{AV_T}} - 1\right) - \frac{\left(V_{pv} - I_{pv}R_s\right)}{R_{sh}} \quad (1)$$

$$V_T = \frac{kT}{q}$$

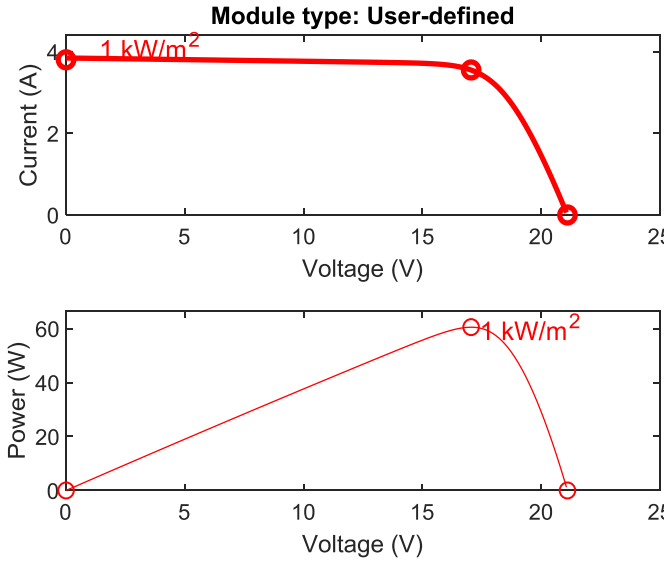


Fig. 2: V-I and P-V Characeristics.

Where I_{ph} represents the photon current, Is, the dark current saturation value, V_{pv}, the potential of the module, R_s the series resistance (Ω), A, the factor of ideality, V_T, the thermal voltage, k, Boltzmann constant, T the p-n junction temperature (K), q, the charge of electron, and R_{sh} the shunt resistance (Ω).

I_{ph} value is based on the temperature and irradiance. The positive effect on I_{ph} causes increase in irradiance [21] and is obtained using equation (3) and (4). Series and shunt resistances variation affect the peak power point generated by the array. These parameters are varied, to obtain an exact PV model.

$$I_{ph} = \frac{G}{G_{stc}}\left(I_{sc} + K_i\left(T - T_{stc}\right)\right) \quad (3)$$

$$I_s = \frac{I_{sc} + K_i\left(T - T_{stc}\right)}{e^{\left(V_{oc} + \frac{K_v(T-T_{stc})}{AV_t}\right)} - 1} \quad (4)$$

Where the irradiance G at standard test condition (STC) (1000 W/m^2) is G_{stc}, I_{sc} coefficient of temperature is α, temperature at STC (25^{0}C) is T_{stc}, and V_{oc} temperature coefficient is β.

2.2 MPPT methods

MPPT converter was developed with different types of MPPT algorithms [22]. Since, the simulation is performed under normal irradiance, classical MPPT techniques are enough to attain peak power operation. In this paper, the modified InC and P&O methods are chosen as the MPPT methods for the MPPT converter. These methods are used for the estimation of the duty cycle. The perturbation step depends on ΔP_{pv} and ΔV_p. The perturbation of 0.07% is selected for simulation purpose.

2.2.1. Modified perturb and observe (P&O) method

The flowchart of the algorithm is shown in Fig.3.

The automatic tuning parameter 'M' is estimated using equation (5).

M = abs (ΔP) (5)

Where ΔP is change in power at each perturbation

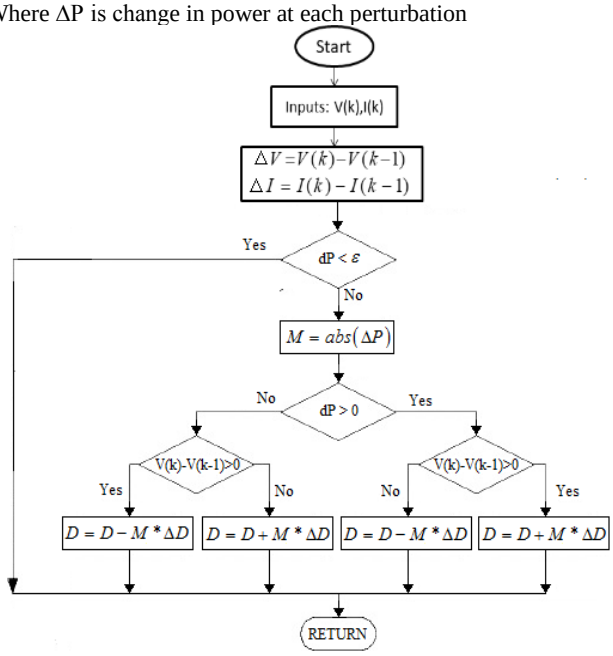


Fig. 3: Flowchartof Modified P&O Algorithm.

2.2.2. Modified INC algorithm

The change of output power "P" for the change of voltage of the array equal to "0" at the MPP is the basic principle used in this algorithm [23]. The relationship for zero slope is calculated using equation (6), (7) and (8).

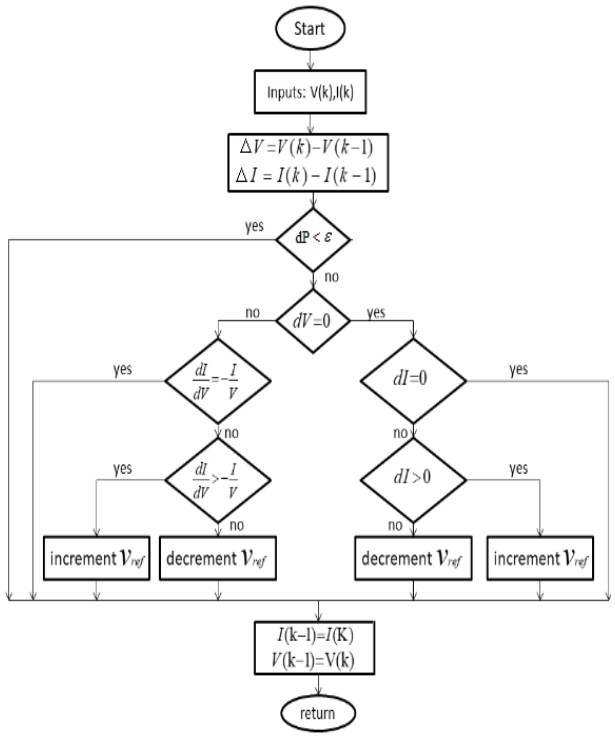


Fig. 4: Flowchartof Modified INC Algorithm.

$$\frac{dP}{dV}=\frac{d(VI)}{dV}=I\frac{dV}{dV}+V\frac{dI}{dV} \tag{6}$$

$$\frac{dP}{dV}=I+V.\frac{dI}{dV} \tag{7}$$

When MPP can be attained, the slope $\frac{dP}{dV}=0$

$$\frac{dI}{dV}=-\frac{I}{V} \tag{8}$$

i.e, Change in conductance = conductance at that instant.

The MPP can be obtained by satisfying the equation (8). The flowchart of the algorithm is shown in Fig.4

2.3. DC-DC boost converter for MPPT

The MPP resistance, R_{mp}, is the overall resistance from the input side, as shown in Fig. 5. Depending on the MPPT method used, V_{mp} and I_{mp} can be oscillated. The MPP resistance, R_{mp}, depends on the MPP voltage and the MPP current, as given in (9).

$$R_{mp}=\frac{V_{mp}}{I_{mp}} \tag{9}$$

The MPPT boost converter is capable to identify the MPP at any G and T.

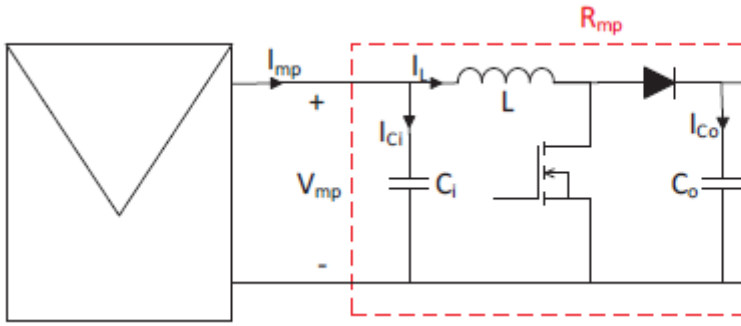


Fig. 5: The Electric Circuit of the Boost Converter.

Output resistance, inductance [24], input capacitor, output capacitor and duty cycle of boost converter at fixed switching frequency are estimated using (10) to (16).

$$R_0=\frac{R_{mp}}{(1-D)^2} \tag{10}$$

$$D=1-\sqrt{\frac{R_{mp}}{R_0}} \tag{11}$$

$$V_o=V_{mp}\sqrt{\frac{R_o}{R_{mp}}} \tag{12}$$

$$V_{o\max}=\frac{V_{mpG}}{(1-D_{\max})} \tag{13}$$

$$L=\frac{V_sD}{\Delta i_L f} \tag{14}$$

Where V_s is the voltage of PV array, Δi_L means the ripple the inductor, current, and f denotes the switching frequency.

$$C_i=\frac{D}{8L\gamma_{V_{mp}}f^2} \tag{15}$$

$$C_o=\frac{D(1-D)^2}{R_{mp}\gamma_{V_o}f} \tag{16}$$

3. Simulation results

Using commercial MPPT algorithms PV module is simulated and evaluated using Matlab/Simulink tool. The Simulink model is depicted in Fig.6

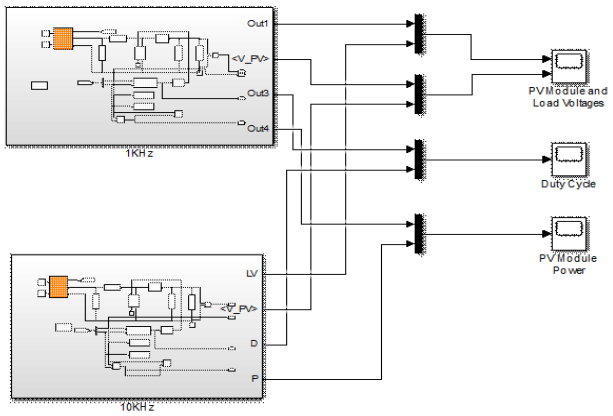


Fig. 6: SimulinkDiagram of MPPT Controlled PV System.

3.1. Model description

The user defined PV system simulated model can provide I_{mpp} of 3.55A, V_{mpp} of 17.04V and a P_{mpp} of 60.53W at STC. DC-DC converter elements are inductor (13 mH), input and DC bus capacitors (1000µF) and switching element operating at frequencies of 1KHz and 10KHz. Load fed to the PV module is 30Ω. Each algorithm gives duty cycle based on climatic changes. Further controller output is fed to PWM which controls the operation of boost converter.

3.2. Simulation results

Simulation results of the overall system are analyzed at two switching frequencies using two classical algorithms.
Case1: PV system is simulated under STC using modified P&O algorithm at two switching frequencies. The PV Characteristics and Duty cycle of modified P&O algorithm with fixed irradiance at 1KHz and 10KHz can be seen in Fig.7 and Fig.8 respectively.

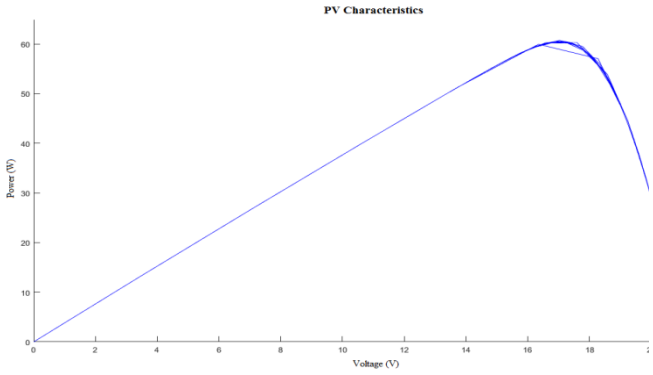


Fig. 7: PVCharacteristics for Modified P&O Algorithm.

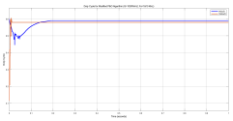


Fig. 8: DutyCycle Output of MPPT Controller.

The PV module power, input and output voltages of PV system for modified P&O algorithm are shown in Fig.9 and Fig.10 respectively.

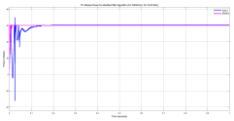


Fig. 9: PVModule Power at MPP.

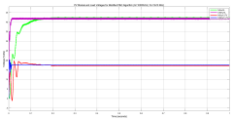


Fig. 10: Boost Converter Voltages at Input and Output.

The observations of various performance indices for modified P&O algorithm at two switching frequencies from the simulated graphs are tabulated in table 1.

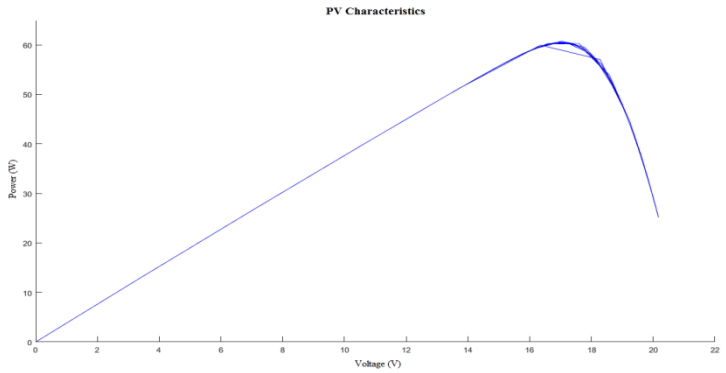


Fig. 11:PV Characteristics for Modified INC Algorithm.

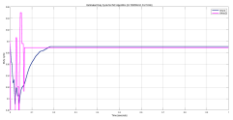


Fig. 12: Duty Cycle Output of MPPT Controller.

Case2: PV system is simulated under STC using modified InC algorithm at two switching frequencies. The PV characteristics and Duty cycle of modified Inc algorithm with fixed irradiance at 1 KHz and 10 KHz are shown in Fig.11 and Fig.12 respectively.

The PV module power, input and output voltages of PV system for modified InC algorithm are shown in Fig.13 and fig.14 respectively.

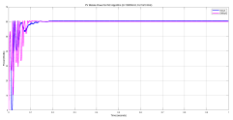


Fig. 13: PVModule Power at MPP.

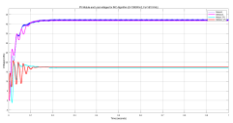


Fig. 14: BoostConverter Voltages at Input and Output.

The observations of various performance indices for modified InC algorithm at two switching frequencies from the simulated graphs are tabulated in table 2.

3.3. Observations

The switching frequency does play an important job in the overall performance of PV system. Due to the change in the switching frequency, various parameters such as settling time, peak over shoot, steady state response, MPPT voltage, MPPT current, maximum power and output voltage values are affected. These time domain specifications are useful to determine the performance of the solar photovoltaic system.

Table.1: Modified P&O Algorithm

Performance Indices	Modified P&O Algorithm	
	Fs = 1KHz	Fs=10KHz
Settling time (sec)	0.23	0.02
Power Peak Overshoot (%)	0.06	0.13
Steady state error (Watts)	0.04	0.43
Ripple in output voltage (%)	1.97	1.94
V_{MPP} (V)	17.13	17.44
I_{MPP} (A)	3.53	3.45
P_{out} (W)	60.49	60.10
V_{out} (V)	42.02	41.74

From the table 1, the values of different parameters clearly state the difference in performance of solar PV system due to change in the switching frequencies. The major changes that can be noticed while increasing the switching frequency of a solar PV system are

- The settling time decreases thereby achieving fast response.
- The peak overshoot value increases which means that tracking point does go slightly far from the MPP.
- The steady state error increases by a considerable value.
- Ripples in the output voltage decreases.
- V_{MPP} Increases by a small value.
- I_{MPP} (A), P_{out} (W) and V_{out} (V) decrease by a small value.

From the table 2, the values of different parameters clearly state the difference in performance of solar PV system due to change in the switching frequencies. The major changes that can be noticed while increasing the switching frequency of a solar PV system are

Table 2: Modified INC Algorithm

Performance Indices	Modified InC Algorithm	
	Fs = 1KHz	Fs=10KHz
Settling time (sec)	0.22	0.17
Power Peak Overshoot (%)	0.06	0.003
Steady state error (Watts)	0.04	0.002
Ripple in output voltage (%)	1.97	0.16
V_{MPP} (V)	17.13	17.45
I_{MPP} (A)	3.53	3.45
P_{out} (W)	60.50	60.11
V_{out} (V)	42.02	41.74

- The settling time decreases thereby achieving fast response.
- The peak overshoot value decreases which means that tracking point doesn't go far from the MPP.
- The steady state error decreases by a considerable value thereby achieving better accuracy
- Ripples in the output voltage decreases.
- V_{MPP} Increases by a small value.
- I_{MPP} (A), P_{out} (W) and V_{out} (V) decrease by a small value.
- For given specifications, solar PV systems with InC algorithm have better performance indices when compared with modified P&O algorithm, they are
- Less settling time at 1 KHz, that is faster response.
- Less peak overshoot, so the tracking point stays near to MPP.
- Less steady state error.
- Less error in P_{out} and V_{out}.

4. Conclusion

In this paper, modified classical MPPT algorithms are discussed and the simulations are performed for these algorithms at different switching frequencies with the topology of boost DC-DC converter. The performance indices of the overall PV system are analyzed at two switching frequencies based on the simulation results. The modified P&O scheme is easy to simulate but results in more power loss and oscillations with increased peak overshoot at switching frequency of 10KHz when compared to 1KHz. Modi-

fied InC controller shows better performance indices at 10KHz switching frequency in terms of accuracy, voltage ripples and tracking point towards MPP due to less peak overshoot. The modified Inc MPPT technique can work efficiently with increased switching frequency while used in real time applications than the modified P&O algorithms.

Future work of this paper includes identifying the optimum converter topology and switching frequency for the realistic and sophisticated thermodynamic model of PV system with modified InC algorithm to achieve optimum performance.

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Not applicable

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