Solar PV System With Modified High Gain SEPIC Converter And Multiple Step Size P&O MPPT Technique

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Abstract

For efficient and economic operation of solar Photo Voltaic (SPV) systems, Maximum Power Point Tracking (MPPT) algorithms and power interfacing units (dc-dc converters) play a vibrant role. High Gain SEPIC (Single-Ended Primary-Inductor Converter) with multi Step Size (MSS) P&O MPPT technique is chosen for the analysis of the solar PV system, which is discussed in this paper. A complete simulation study is performed for various environmental conditions in MATLAB/Simulink and results are presented. Performance analysis of the system are done in terms of tracking speed, amount of ripple content in the input current and output voltage of the dc-dc SEPIC converter.

Keywords: *SPV, MPPT, MSS P&O, High Gain SEPIC converter.*

1 Introduction:

In recent times the electricity generation mainly depends on renewable energy sources (RES). Due to its abundance in availability and pollution free nature, solar energy is superior among all the RES available. The electric power generated by solar energy depends on natural factors like solar irradiation and temperature. To produce electricity efficiently and economically from a SPV system, it should be operated effectively. For the better operation of a PV system, a controller capable of tracking maximum power and a power interface capable to do DC-DC conversion is required. Fig.1 symbolically represents a stand-alone SPV system with the MPPT controller and a power interface to deliver DC power from the converter to the load.

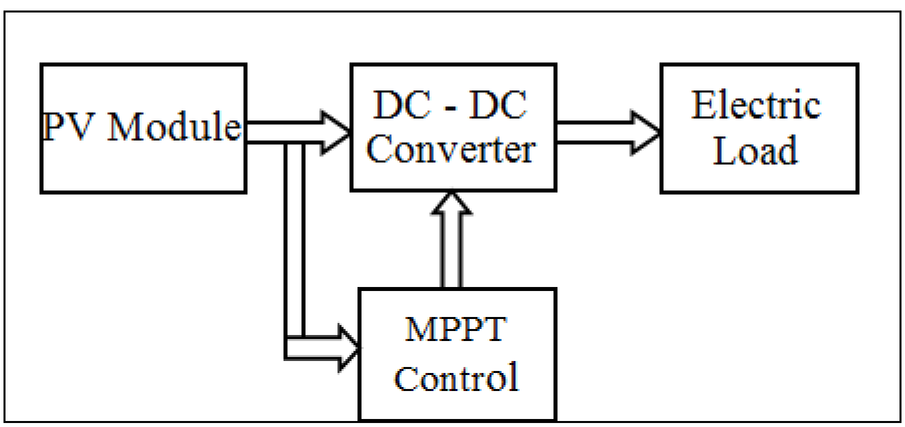

Figure 1. Block schematic of a stand-alone Photo Voltaic system.

Since the output power from a PV module depends on the temperature and irradiation level at its input, PV modules exhibit non-linear characteristics. This nonlinear power characteristics of the PV module for various environmental variations are shown in Fig. 2. The figure shows the dependence of PV module

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output power on temperature and irradiation level. MPPT controllers used in PV systems are capable to control the operation of power interface unit to extract maximum power under any environmental conditions.

The interface device, DC-DC converter transfers maximum power between PV panel and the load. By the action of MPPT controller, converter can be controlled efficiently. Various MPPT algorithms are currently available for the control purpose.

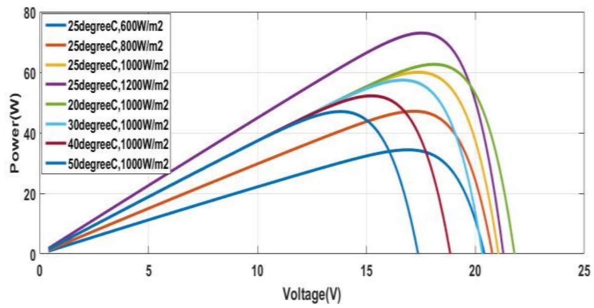

Figure 2. power- voltage characteristics of PV Module

Among the available MPPT control algorithms, Perturb and Observe (P&O) algorithm is common in use [1]. P&O algorithm is the simplest online or model-free method. Some of the other model free MPPT techniques are Incremental Conductance (InC) method [2], Extremum seeking Control (ESC) [3] and Ripple Correlation Control (RCC) method [4].

P&O algorithm keeps on observing the instantaneous current (Ipv) and voltage (Vpv) of the PV module and adjusts the duty cycle value with a given perturbation value until it reaches maximum power point. The demerit of P&O MPPT algorithm is that the duty cycle slowly increases or decreases from its set point in steps for the given perturbation value. It also oscillates around MPP after reaching the steady state. Increasing the perturbation value may help to improve the tracking speed. But, on the other hand tracking will become improper and the oscillation around MPP will be higher. Moreover, the performance of P&O MPPT is not good under rapidly changing weather conditions and less efficient during cloudy days [5].

In addition to the online methods to extract maximum power, various offline methods such as Fuzzy Logic [6] & Artificial Neural Network (ANN) [7] are also in use. These methods can effectively track the MPP under frequently varying environmental variations at the input and they are also fast and accurate. But, the development and implementation of such techniques are complex. Fuzzy Logic requires expert knowledge for development. ANN technique need large amount of hardware data. GA technique also require large amount of data for training. AI techniques may require a high performance processor. The software development and hardware implementation of AI technique based MPPT techniques are complicated compared to the conventional methods.

Though it has many disadvantages, P&O MPPT algorithm is found to be popular amongst the model free algorithm due to the implementation easiness. Hence, multi step size P&O (MSS P&O) MPP tracking method is proposed to limit the disadvantages of P&O MPPT. By the introduction of MSS P&O in the system, the above mentioned problems are almost solved [8].

In this paper, the performance of a SEPIC with multiple step size P&O MPPT for various environmental conditions are presented. Simulation of SPV system with boost converter and SEPIC converter are carried out for various environmental conditions. The results obtained from the simulation are analyzed and compared. The selected MPPT algorithm is discussed in section II. Section III describes the high gain SEPIC converter used in the system. Comparative analysis of the system with the chosen converters with the selected MPPT algorithm is done in section IV and the presented work is concluded in section V.

2 Multi Step Size P&O MPPT:

MPPT methods has a vital role in the extraction of maximum power from the solar panel. In this study, multi step size P&O MPPT is considered. The conventional P&O MPPT control algorithm flow chart is shown below in Fig.3. In P&O, the ratio of dP and dV is calculated and then a small constant perturbation (0.01) value is given to the duty cycle ratio in order to attain the maximum power point. The process is repeated in P&O algorithm until . Based on the flow chart algorithm, P&O changes duty cycle in the same direction if power is positive after perturbation and in the opposite direction if otherwise. P&O algorithm, though the simplest method, has certain drawbacks. Due to the slow tracking nature, this algorithm is not efficient in rapidly changing weather conditions. Also input current and output voltage oscillates at steady state. To overcome the drawbacks of the P&O algorithm, multi step size P&O MPPT algorithm (MSS P&O) is proposed. MSS P&O and conventional P&O are almost similar. This algorithm reduces the oscillation and increases the tracking speed. The MSSP&O control algorithm flow chart is shown in Fig. 4.

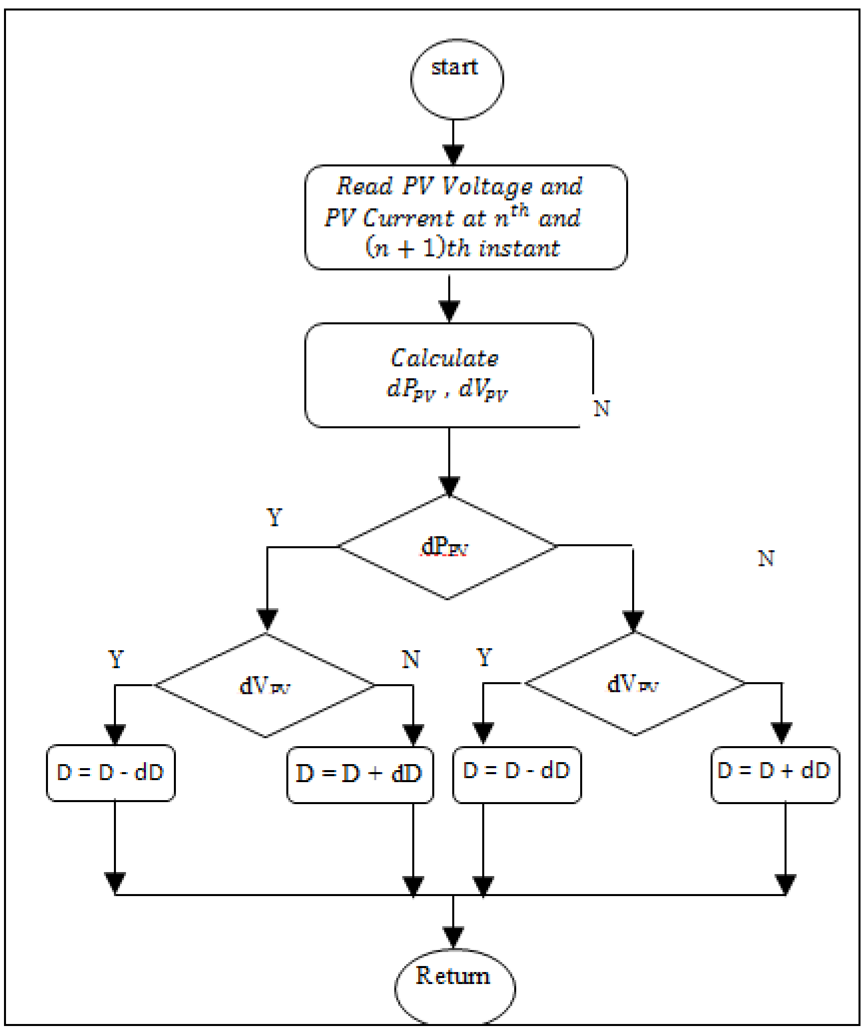

Figure 3. Flow Chart of P & O MPPT Algorithm

For MSS P&O MPPT, two different duty cycle values are provided. For conventional P&O dD/ΔD is set as 0.01. In MSS P&O, dDbig=0.02 and dDsmall=0.005.

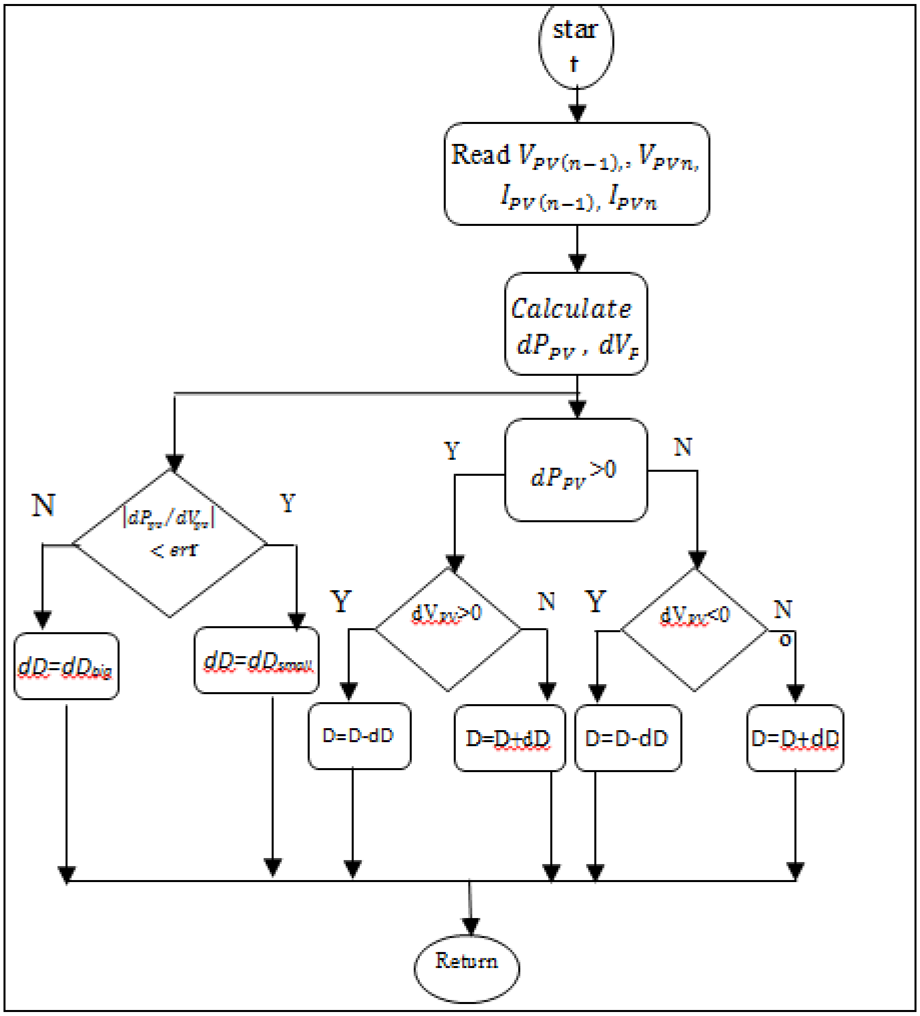

Figure 4. Flow Chart of the Multi Step Size P&O

3 High Gain SEPIC Converter:

DC-DC Boost converter is mostly used in SPV systems. But, the gain of conventional boost converter is low. During the high step up operation, current ripple is higher in the power devices and increases the conduction loss.

The single-ended primary inductor converter (SEPIC) operates based on the principle of both step-up and step down converters. It contains of two inductors for buck or boost operation of the input voltage and gives a non-inverted output. It converts the energy transferred through capacitor CS and inductor L1; for the reason that, the switching voltage is greater than the boost converter. High Gain SEPIC converter has very high static gain when compared to conventional boost converter. The voltage across the switch is nearly equal to the addition of both input and output voltages. The inrush input current for inductor L1 is minimized when equated to the boost converter but it has voltage stress.

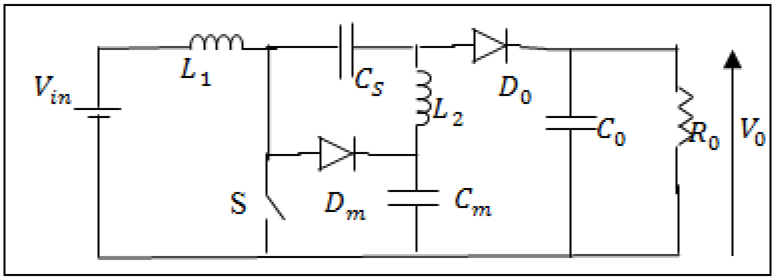

Figure 5. High Gain SEPIC converter

Voltage gain of High Gain SEPIC converter is many times that of SEPIC converter. By varying the duty cycle ratio, the voltage at the output of the converter can be made even nineteen times that of input voltage. The duty cycle ratio of the converter with respect to its input voltage, V_in and output voltage V_o is represented in equation (1).

$$D = \frac{V_O - V_{in}}{V_O + V_{in}} \quad (1)$$

Additional capacitor C_m and additional diodes D_m and D_(o ,)

used in the converter manages stress across the semiconductor power switch. Moreover this converter eliminates one of the two switches used in SEPIC converter.

a) Selection of Inductors L1 and L2

Average inductor voltage in one switching cycle is equal to zero.

Assumptions

1. Current ripple through inductor is 10 % to 30 % of the steady state current.
2. Voltage ripple in capacitor is 1 % to 10 % of voltage across capacitor under steady state.

$$L_1 = L_2 = \frac{V_{in} D}{\Delta I_L f_s} \quad (2)$$

Where f_s is the switching frequency and ΔI_L is the input ripple current. The value of ΔI_L is obtained from the equation, ΔI_L= 30% I_L

b) Selection of Capacitors CM and CS

The capacitors CS and CM has the same voltage ripple.

$$C_M = C_S = \frac{I_O \mathrm{D}}{\Delta V_c f_s} \quad (3)$$

Where,

$$\Delta V_c = 10\%\ of\ V_c$$

$$V_c = V_{in} D/(1 - D)$$

$$C_o = I_o D/\Delta V_o f_s$$

Where ΔV_O is the output voltage ripple which is equal to 10% of V_O.

Table 1. DESIGN VALUES OF HIGH GAIN SEPIC CONVERTER

Power *(P)*	60 W
Output voltage (V_o)	48 V
Input voltage (V_{in})	17 V
Duty cycle ratio (*D*)	0.49
Load Resistance (*R*)	40 Ω
Inductances (L_1 and L_2)	750 μH
Capacitances (C_S and C_M)	50μF
Capacitance (C_o)	25μF

4 Result Analysıs:

A stand-alone Solar PV system with conventional Boost Converter (BC) and High Gain SEPIC Converter (HGSC) with P&O and also with MSS P&O MPPT control algorithm is modeled with MATLAB/Simulink. The chosen 60W PV module has a short circuit current of 3.8A and open circuit voltage of 21.1V under STC. The solar PV system is operated under STC and under fast changing irradiation conditions. The simulation results are analyzed in this section.

Fig.6(a) shows the duty cycle ratio of conventional BC with P&O and MSS P&O MPPT algorithms under STC. The actual duty cycle is 0.69 at MPP for the given conditions and the controller attains the same. But, as seen from the figure, the tracking of MSS P&O is much faster than that of the P&O. Output voltage(V0) and output power of BC with different MPPT under STC are given in figure 6(b) and 6(c) respectively.

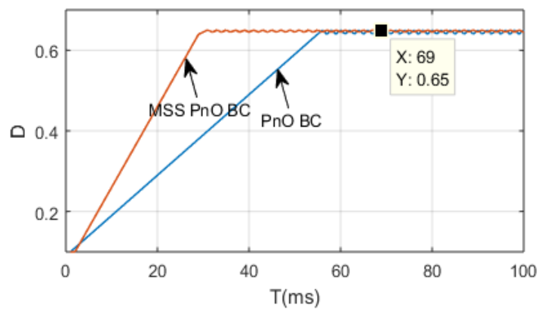

Figure 6. Duty Cycle of BC with P&O and MSS P&O

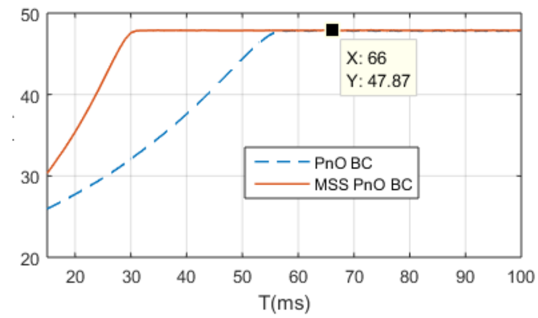

Figure 7. Output voltage of BC with P&O and VSS P&O

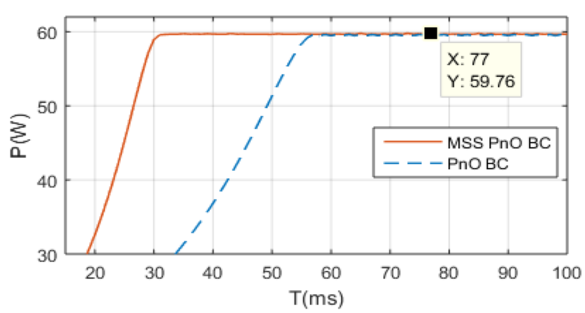

Figure 8. Output Power of BC with P&O and VSS P&O

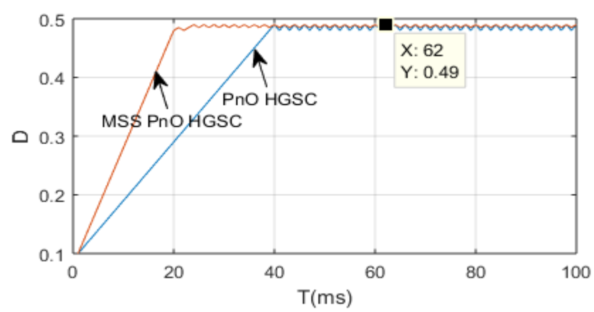

Figure 9. Duty Cycle of HGSC with P&O and MSS P&O at STC

HGSC converter is also simulated for 250C and 1 kW/m2 and the otained reslts are presented below. Fig. 7(a) shows the duty cycle of converter and 7(b) shows oscillation of duty cycle at MPP.

The duty cycle values selected for MSS P&O are dDbig = 0.02 and dDsmall = 0.005. Fig.7(b) shows the enlarged portion of duty cycle of SEPIC with P&O and MSS P&O for a particular case. The step size of P&O is 0.01 whereas the step size of MSS P&O is 0.005. So while examining the plots it is inferred that the oscillation of duty cycle after reaching MPP is less than conventional P&O with MSS P&O.

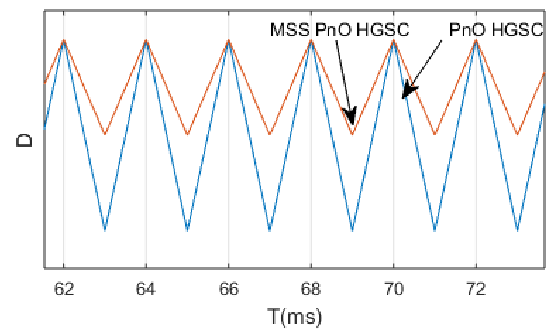

Figure 10. Duty Cycle Oscillation at MPP

Output voltage of HGSC is shown in fig 7(c). HGSC produces same output voltage (48V) from the given input of 17V at lesser duty cycle than that of BC. Fig 7(d) shows the power output of HGSC with P&O and MSS P&O.

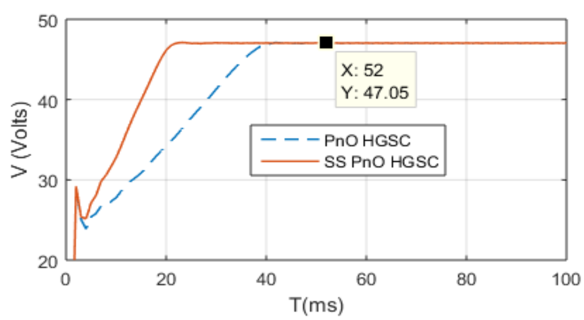

Figure 11. Output voltage of HGSC with P&O and MSS P&O at STC

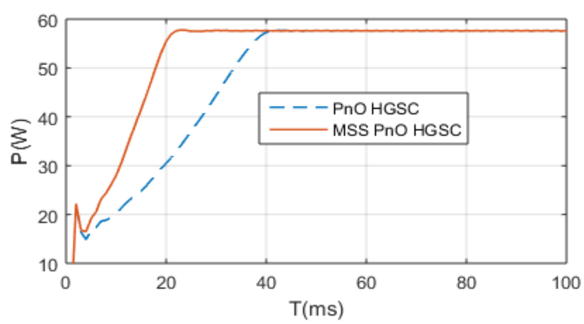

Figure 12. Output Power of HGSC with P&O and VSS P&O at STC

The fast changing irradiation condition applied to the SPV module as input is shown in fig. 8(a). Temperature is maintained as 300C.The tracking of duty cycle by P&O and MSS P&O is given in Fig.8(b) and the response of the control algorithm with respect to rapid changing irradiation is given in fig. 8(c). From the depicted plots it is inferred that the tracking of MSS P&O is faster than P&O and the transition of duty cycle ratio is smooth under fast changing irradiations with less oscillation.

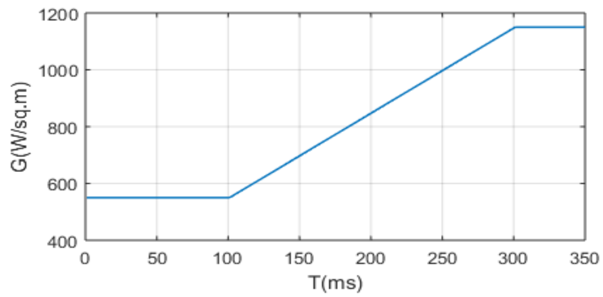

Figure 13. Changing Irradiation

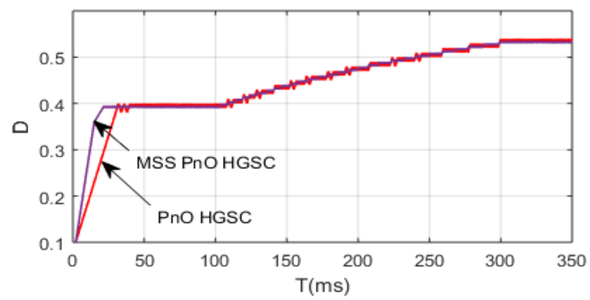

Figure 14. Duty Cycle of HGSC with P&O and MSS P&O under changing irradiation

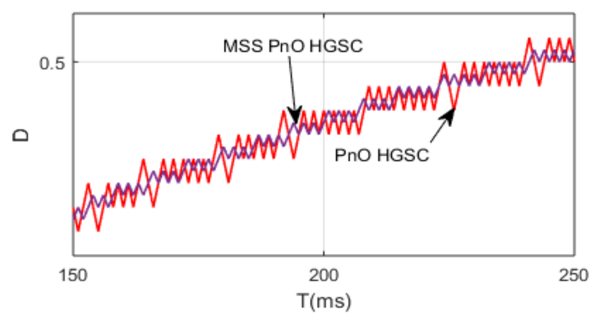

Figure 15. Duty Cycle Oscillation of P&O and MSS P&O under changing irradiation

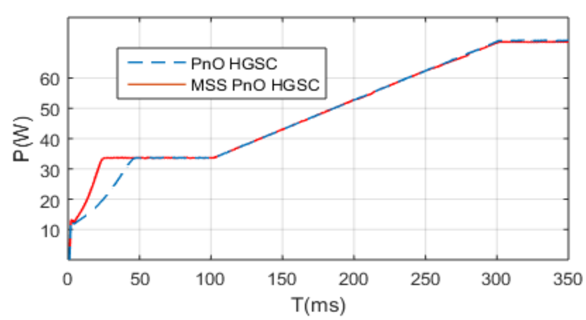

Figure 16. Output Power of HGSC with P&O and MSS P&O under changing irradiation

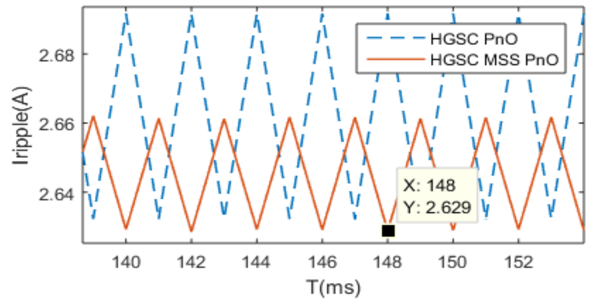

Figure 17. Input current ripple at 750 W/sq.m and 25oC

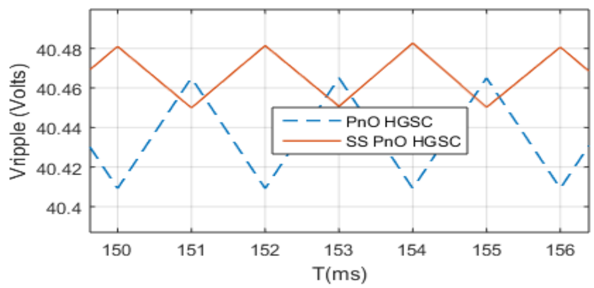

Figure 18. Output voltage ripple at 750 W/sq.m and 25oC

Fig. 9 gives the input current of HGSC with a conventional P & O and MSS P&O, whereas the output voltage of the same converter using the above mentioned two control algorithms is given in Fig.10. MSS P&O MPPT tracked voltage and current plots of high gain SEPIC has less ripples compared to that of P&O MPPT algorithm based system. From the output ripple curve of HGSC with both MPPT's, it is clear that, the main drawback of the conventional P&O ie, ripple, is reduced by using MSS P&O.

Output voltage, input current, power output and the ripple generated by HGSC with P&O and MSS P&O MPPT under different input conditions are presented in table II.

Table 2. COMPARATIVE ANALYSIS

HGSC	P&O		VSS P&O	
Condition (25 °C)	1000 W/m^2	750 W/m^2	1000 W/m^2	7500 W/m^2
Input Current	3.4965	2.662	3.5275	2.6455
Input Current ripple	3.174	2.253	1.389	1.247
Output voltage	47.03	40.44	47.035	40.465
Output voltage ripple	0.0851	0.1483	0.0637	0.0741
Output Power	57.605	42.58	57.62	42.645
Output Power ripple	0.1909	0.2818	0.1388	0.1641

From the presented results it is clear that the ripple in the output of converter can be effectively reduced by the introduction MSS P&O with smaller perturbation step. The overall performance of the system in terms of tracking is also improved by MSS P&O. It is also evident that the reductions in ripple obviously increase the efficiency of the system under all input conditions. In addition to this, the voltage gain can also be boosted by using HGSC. Thus, the proposed combination can be utilized for applications where high voltage gain is required.

5 Conclusıon:

A comparative analysis of conventional P & O MPPT, MSSP & O MPPT with boost converter and HGSC converter are presented and analyzed in this paper. The standalone solar PV system model developed is analyzed for different environmental condition for the chosen control algorithms. Performance of the system is found better with MSSP&O controller for both boost converter and proposed High gain SEPIC converter. Validating the results of Table II, HGSC based system with MSSP&O controller is a good solution where, gain, tracking speed, ripple reduction are the main concerns under different environmental conditions.

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