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MPPT oscillations minimization in PV system by controlling non-linear dynamics in SEPIC DC-DC converter

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Article Info

ABSTRACT

Solar PV power generation has achieved rapid growth in developing countries which has many merits such as absence of noise, longer life, no pollution, less time for installation, and ease of grid interface. A maximum power point tracking circuit (MPPT) consists of DC-DC power electronics converters that are used to improve the energy attainment from solar PV array. This paper presents a detailed analysis to control of chaos, a non-linear dynamic in SEPIC DC-DC converter interfaced solar PV system, to minimize the oscillations near to MPP. In SEPIC DC-DC converter, the input inductor current is continuous and capable of sweeping the whole I-V curve of a PV module from open circuit voltage (V_{oc}) to short circuit current (I_{sc}) operating points. To trace the true maximum power point and to nullify the oscillations near to MPP, the yield output voltage needs to ensure period-1 operation.

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1.   INTRODUCTION

Solar power is a Green energy sources that employs DC-DC converter to harvest maximum power. The efficiency of the energy conversion process is declined due to climate variable temperature, partial shading, and atmospheric irradiation change and load conditions. The PV current changes with irradiation greatly and the atmospheric temperature affects PV voltage [1-4]. The MPP is detected by Adaptive perturb and observer MPPT algorithm which is embedded in Microcontroller, generate gate pulse which is applied to the DC-DC converter switches [5-8].

The various types of DC-DC converters [9-12] such as buck, boost, buck boost, Cuk and SEPIC are implemented in PV system by considering suitability factors such as cost, efficiency, maximum power flow, ease of drive system, Positive output voltage, system stability and concluded that SEPIC converter is commonly used in PV system to track maximum power from PV panel. Higher order converter such as SEPIC and Cuk are widely used for MPPT charge controller because of their excellent steady state performance, isolation, over current limit protection [13-21]. Quamruzzaman [17] has argued that the PV current with less ripple and improved dynamic response can be achieved by SEPIC converter also proved that high input current ripple content of the converter reduces the average value of current which may leads to wrong true MPP tracking.

Non-linear dynamics in power electronics circuits was put forward in [22-24] undergo sub-harmonics, quasi-periodic oscillations, and chaotic mode of operation. The chaos is experienced in DC-DC converters and its control methods are conducted in power electronics circuits. This abnormal operation would affect converter tracking efficiency since the period -1 operation need to be ensured for MPP tracking in order to minimize oscillations near to MPP. Several studies [25-27] have suggested many control methods that are mitigated to

supress chaos. Also, The PID controller and sliding mode controllers are also experimented to nullify the effect of chaos in DC-DC converters.

       This paper explores that SEPIC DC-DC converter interfaced solar PV system may enter into chaotic-aperiodic mode during maximum power tracking process. The analysis and suppression of chaos in a voltage mode-controlled SEPIC converter-based solar PV system has been mitigated and the use of adaptive sliding control method is experimented to nullify the chaos effect and that control has been examined to minimize the oscillations near to MPP.

2. SEPIC CONVERTER BASED SOLAR PV SYSTEM
2.1. System description

       Figure 1 and Figure 2 show the block diagram and hardware setup of sliding mode controlled SEPIC DC-DC converter interfaced solar PV system. The power circuit has an inductors L_1, L_2, capacitors C_1, C_2, a Power switch S, a load resistance, a solar PV module (L1235-37Wp) shown in Figure 3.

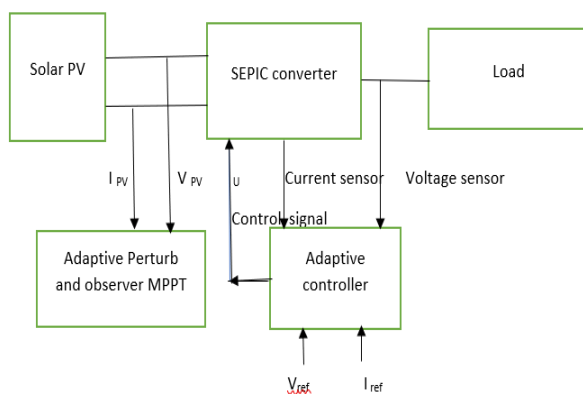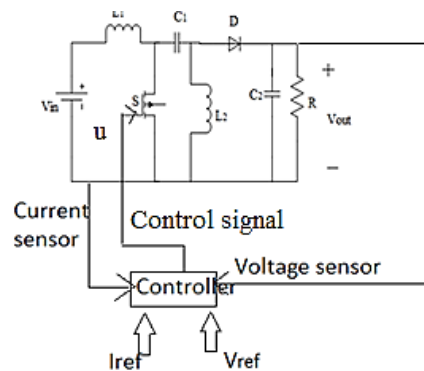Figure 1. Block diagram   Figure 2. Experimental setup

Figure 3. SEPIC DC-DC converter

2.2. Design of SEPIC converter

       The SEPIC DC-DC converter has advantages such as non-pulsating nature of load current and positive load voltage and has high efficiency than Buck-Boost converter. The positive output voltage is obtained based on the following two modes of operation in one switching period. 1) MOSFET is ON and the diode is not operated. The input inductor, L_1, is charged from the PV input voltage. The output inductor L_2 finds energy from the first capacitor, and the output capacitor C_2 is left to provide the load current. The fact is that both L_1 and L_2 are disconnected from the load when the switch S, is turned on. In mode 2), The MOSFET is turned off and diode is operated, the input inductor L_1 charges the capacitor C_1 and also provides current to the load. The second inductor is also connected to the load during this time. The steady state output voltage equation is given by

$$\frac{V_O}{V_{IN}} = \frac{D}{(1-D)} \tag{1}$$

Also, the steady state current equation is

$$\frac{I_{IN}}{I_0} = \frac{D}{(1-D)} \tag{2}$$

The (3) shows the designed value of inductors

$$L_1 = L_2 = L = \frac{V_{IN(MIN)} * D_{MAX}}{\Delta I_L * f_S} \tag{3}$$

The voltage specifications of capacitor C_1 is selected as high as input voltage. The ripple voltage of C_1 is given by

$$\Delta V_{c1} = \frac{I_{(OUT)} * D_{MAX}}{C_1 * f_S} \tag{4}$$

The SEPIC DC-DC converter is designed with inductors $L_1 = L_2 = 500\mu H$, Capacitors $C_1 = C_2 = 220\mu F$, switching frequency=25 KHz, MOSFET-IRF510, and diode-MUR450 are selected for hardware implementation.

2.3. L1235-37Wp Solar PV module

The solar PV output power depends on insolation, atmospheric temperature and type of load characteristic. From the equivalent circuit shown in Figure 4(a), the current and voltage equations are given by (5) and (6) respectively.

$$I_{sc} = I_D + I_{pv} + (V_D / R_p) \tag{5}$$

$$V_{pv} = V_D - (I_{pv} * R_s) \tag{6}$$

Where diode current is, $I_D = I_o + (e^{(V_D / V_T)} - 1)$, I_{sc} is the short circuit current, $V_t = N_s KT / q$ is the thermal voltage with N_s cells connected in a series (K is the Boltzmann constant, q is the electron charge and T is the temperature of the PV cells). Using the equations 5 and 6, solar PV is modelled and simulated in MATLAB, has V-I charecteristics which is shown in Figure 4(b), The V-I characteristics depend on the conductance of the load. If the conductance value is high, The PV cell behaves like a constant current source region. If conductance value is low, the PV cell acts as a constant volatge source. The parameters of L1235-37W solar PV module which is used for experimental validation are open circuit voltage $(V_{oc})=21$, Voltage at MPP $(V_m)=16.4$, Short circuit current $(I_{sc})=2.5$ A, Current at MPP $(I_m)=2.25A$, Rated power=37Wp.
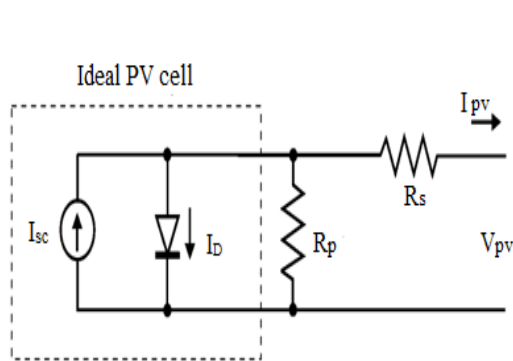

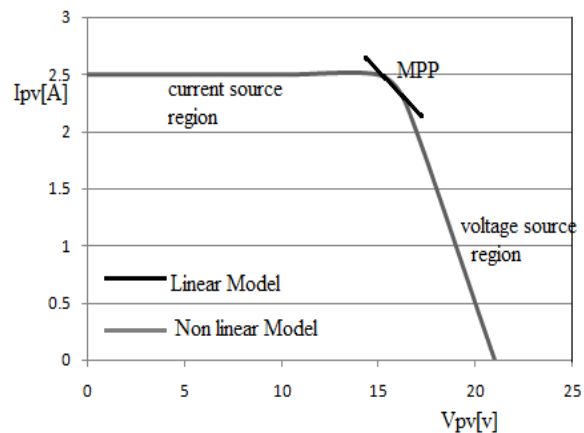Figure 4. (a) Equivalent circuit of solar PV   Figure 4. (b) Non-linear V-I characteristics of L1235-37Wp solar module

3.   RESULTS AND ANALYSIS

The SEPIC DC-DC converter interfaced solar PV system is simulated in MATLAB/Simulink shown in Figure 5, which comprises PV electric circuit subsystem (MATLAB model), SEPIC DC-DC converter and a resistive load.
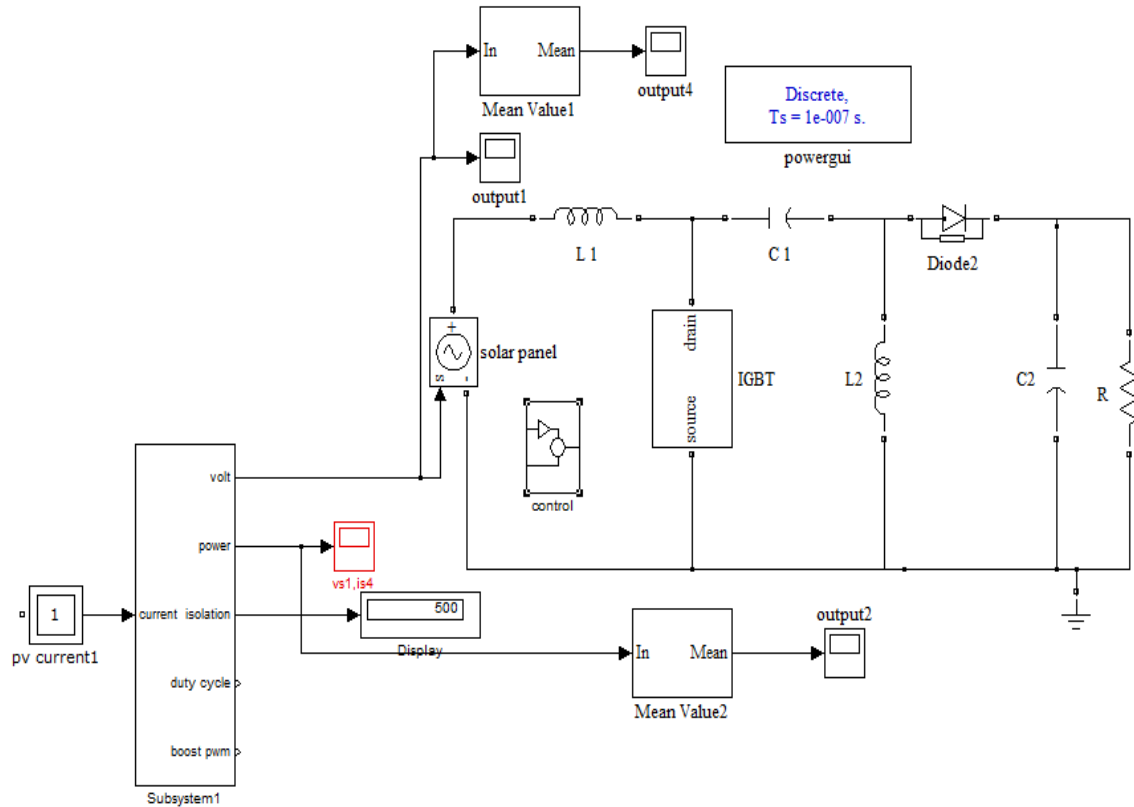

Figure 5. SEPIC converter based adaptive perturb and observer MPPT

The atmospheric constant temperature is considered at 25°C and the irradiation level is set as 1000W/m^2 and after 0.01sec, the irradiation (G) is suddenly changed to 500W/m^2 in computer simulation to test the effectiveness of the adaptive Perturb and Observer algorithm and it was implemented in ATMEGA16 microcontroller. The step size of MPPT algorithm is adjusted which in turn to vary the duty cycle of the switch in order to harvest maximum power which are shown in Figure 6 and Figure 7. The output power is extracted from solar PV module at irradiation of 1000 W/m^2 and 500W/m^2 are 36.74W and 17W respectively.
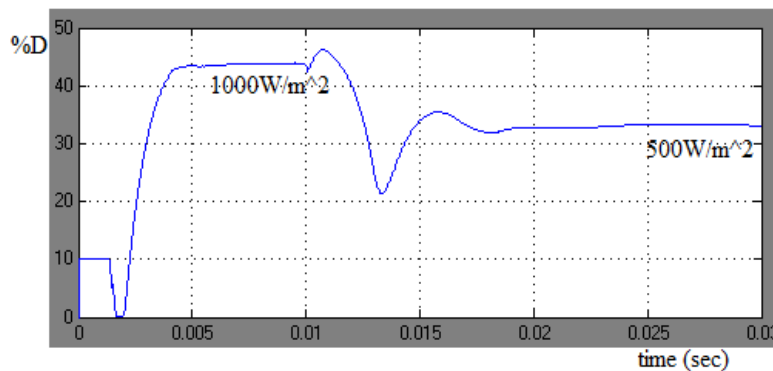

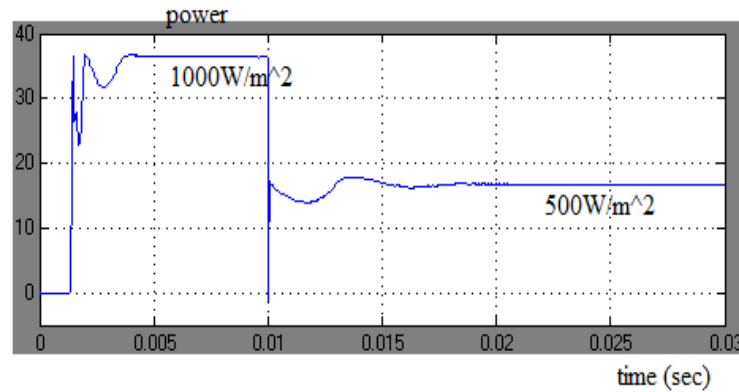Figure 6. Change in duty cycle for various irradiation level

Figure 7. Extracted power for various irradiation level

3.1. Bifurcation analysis of adaptive controlled SEPIC converter based MPPT

Under maximum power point tracked condition, to minimize oscillations near to MPP the non-linear dynamic behavior of SEPIC DC-DC converter system is mitigated by adjusting reference voltage V_{ref}. The input voltage of the PV fed SEPIC converter is 16.4 V. The ripples of the tracked voltage are examined and found that the fundamental period 1-waveform is repeated with V_{ref} =5.68V. At this condition, SEPIC DC-DC converter system has stable periodic operating behavior. The input voltage ripple of the period-1 operation under this condition is given in Figure 8.

When the reference voltage (V_{ref}) is adjusted and set as 5.2V and the ripples of input is examined. Now, SEPIC DC-DC converter undergo an unstable periodic behaviour. The 1-periodic orbit loses its stable operation, via flip bifurcation it experienced a 2-periodic waveform. The voltage ripple of the period-2 operation is shown in Figure 9.
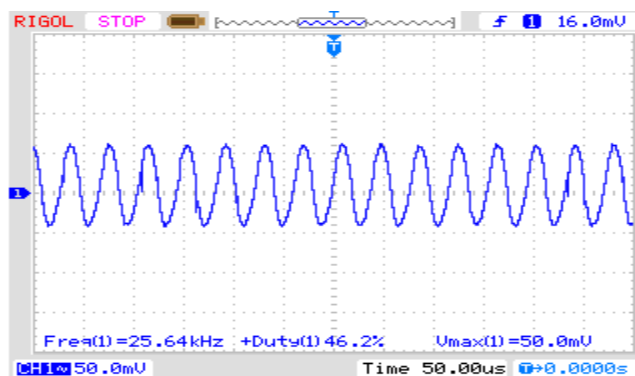

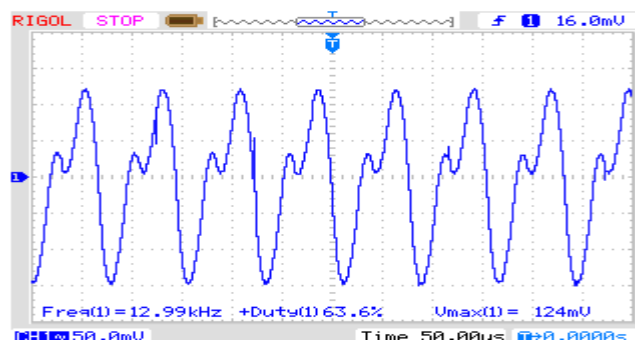Figure 8. Tracked voltage ripples-period-1 waveform when V_{ref} =5.62V

Figure 9. Tracked voltage ripples-period-2 waveform when V_{ref}=5.2V

Further, if V_{ref} is varied, the converter operation changed from a stable period-1 operation to an unstable operation. The input voltage ripples of SEPIC converter-has unstable aperiodic behavior. Chaotic waveform is observed for the $V_{ref=}$4.6V as shown in Figure 10. The state change from periodic to aperiodic when Vref is adjusted, be the main cause to near to MPP. The sliding mode controller is designed for SEPIC DC-DC converter by sensing output voltage and input inductor current. The V_{ref} is varied from 4.00V to 5.6 V and Iref is set as 0-2 A and it is proved from Figure 11 that the SEPIC DC-DC converter is operated in period-1 stable region for parameter variation

The chaotic free tracked input voltage from solar PV string is shown in Figure 12. The oscillations are nullified near to MPP by eliminating aperiodic-chaos in solar PV system. The Figure 13 shows the experimental harvested non oscilating power of 36.5w from solar PV under standard test conditions.

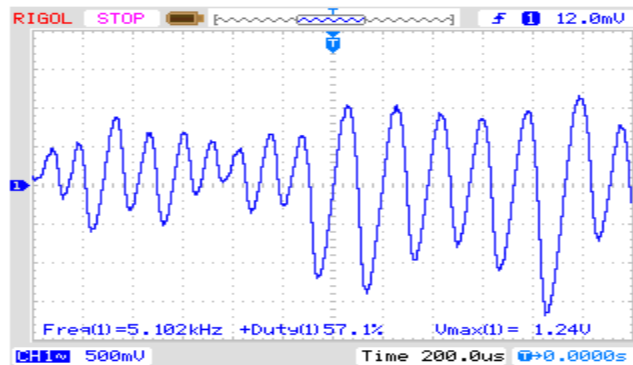

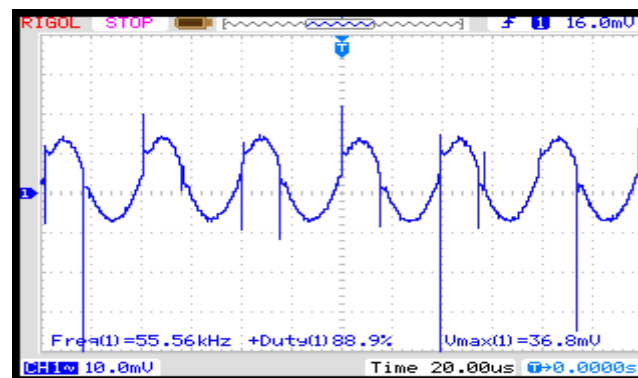Figure 10. Tracked voltage ripples – aperiodic waveform when V_{ref} =4.6V

Figure 11. Tracked voltage ripples-period-1 waveform for 3V< V_{ref} < 5.76V
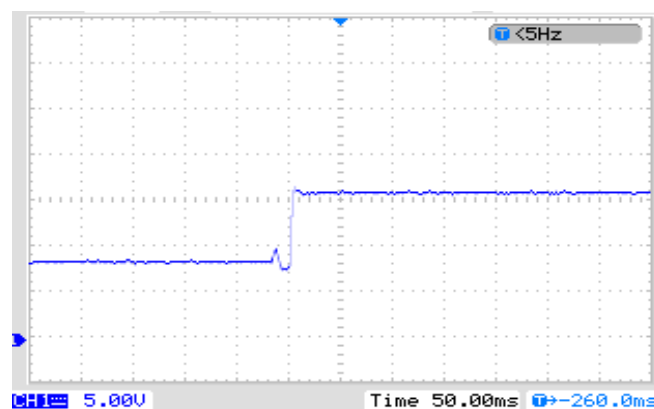

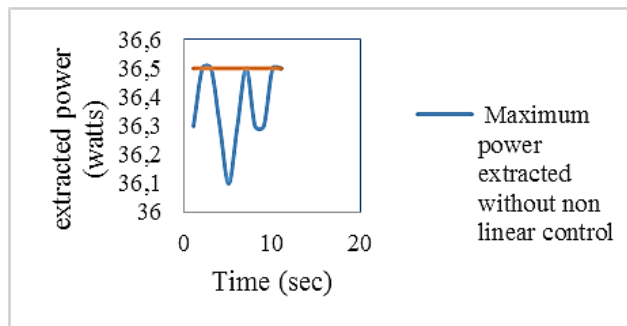Figure 12. Tracked Input voltage waveform of the converter

Figure 13. Experimental harvested power from solar PV

4.   CONCLUSION

The adaptive Perturb and Observer algorithm is implemented and harvested maximum power from solar PV using SEPIC DC-DC converter. To nullify the oscillations near to MPP, aperiodic chaotic behavior of DC-DC converter is exempted experimentally. The sliding mode controller is designed to ensure period 1-operation of the input voltage of SEPIC DC-DC converter.

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