IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 08, Issue 8 (August. 2018), ||V (VI) || PP 62-69

Exploration of Chaos and Bifurcations in a Solar PV MPPT SEPIC Converter System

M. Subashini, M. Ramaswamy
(Department of Electrical Engineering, Annamalai University, Annamalai Nagar-608 002, Tamil Nadu, India)
Corresponding Author: M. Subashini

Abstract: The solar PV appears to be a vital source of renewable energy well suited for distributed energy production, utility and dispatch. The philosophy of the maximum point power tracking (MPPT) becomes crucial in an effort to exploit the full capability of the source of energy. The attempt owes to explore the choice of SEPIC dc-dc converter as a maximum power point (MPP) tracker for the solar PV system. The paper develops methods to extradite the performance of a solar PV SEPIC converter system under a changing irradiation condition with a view to facilitate the design of the converter and enable the choice of an appropriate control system strategy. The change of irradiation in the solar PV system reflects to bring in a variable current source fed to the converter, which in turn introduces a rich variety of nonlinear dynamics. The effort owes to study the nature of dynamics from the chosen SEPIC converter for various irradiation conditions applied to the solar PV system. The investigative results expose the behaviour of the system through discrete time domain waveforms, phase portraits and bifurcation diagrams to evolve measures for improving the efficacy of the system.

Keywords: *Solar PV, P and O, MPPT, SEPIC, Chaos, Bifurcation*

Date of Submission: 26-08-2018 Date of acceptance: 07-09-2018

I. INTRODUCTION

The energy- allied CO_2 emissions from the use of liquid fuels, natural gas, and coal significantly increase devastation of greenery and degradation of air, land and water that bring in ecological scarcities. The vibrant economic growth in developing countries set the fire for modern power system design and uninterrupted energy supplies in various industrial sectors [1]. The green economy concepts and policies engage keys to reduce environmental impact on economic sectors and potential climate change mitigation. The economic progress and environmental sustainability strike the need of harmonious prototype with careful examination to afford sustainable growth initiations across the globe [2].

The enormous availability of solar energy increases the PV market with a sharp peak worldwide and the affordability of the solar PV resources hand over the sustainable economic growth of the country to societal levels [3]. The feasibility of solar PV makes it to contribute a significant share in the global energy portfolio [4]. However the intermittent nature of the solar PV increases the cost of installation and necessitates storage devices to be incorporated to enhance the reliability of the PV system [5].

The solar PV source being nonlinear and variable in nature needs a dc-dc converter to comply with most of the practical loads and perform maximum power point tracking since the PV maximum power owes its dependence to the irradiation from the sun, temperature conditions and the nature of the load [6], [7].

A rich variety of nonlinear dynamics has been reported from dc-dc converters [8] and the phenomenon of chaos has been practically significant to realize a well-designed converter configuration [9]. The theory of chaos in dc-dc converter and its related stability analysis has been explained to be important in the debugging of converter design and control [10].

The inability of averaged models to predict the chaos, bifurcations and fast scale instabilities in the operation of dc-dc converter system has been presented and the need for different modelling methods that include sampled data modelling, iterated nonlinear mapping and higher state resolution approaches brought out[11]-[13], [14].

The nonlinear analysis of buck, boost, buck boost, Cuk, SEPIC and Luo converters operating under voltage or current mode control has been reported [15]-[20]. The analyses have been based on different methods to explore bifurcations and study the route to chaos in the dc-dc converters. A host of configurations in the form of cascaded, paralleled, interleaved, high gain and multilevel dc-dc converters have been examined in the perspective of gaining insights into their nonlinear dynamics and chaotic behaviour [21]-[26].

A study on different types of bifurcations, mechanism of bifurcations and transitions to chaos in various topologies of dc-dc converter has been presented in [27]. The investigations have been related to the course of their operation as a switching regulator and or switch mode power supplies. The dynamics of dc-dc converters in their course of power factor correction applications has been studied in [28] – [29]. The dc-dc converters applied for MPPT has been examined in [30] and [31] in which a pre-set input voltage or input current corresponding to a MPP at a particular irradiation and temperature condition has been as the reference.

The dc-dc converters assuage to be a nonlinear dynamical system that may be subjected to various nonlinearities and the study of the nonlinear dynamics gathers strength. It invites interest to explore a variety of qualitative change in the behaviour of the system since the dc-dc converters used for tracking applications experience different perspectives of control. Besides when the dc-dc converters used for MPPT with an intermittent, nonlinear solar PV input, it augurs stimulating to design and implement an efficient, reliable and low-priced PV system.

II. MATHEMATICAL MODEL OF THE SYSTEM

The solar PV panel is modeled using a single diode equivalent circuit that can be a user friendly tool to simulate and analyze the solar PV characteristics and also to evaluate the performance of the complete MPPT system. The panel output current I_{pv} can be represented as in (1)

$$I_{pv} = N_p I_{ph} - N_p I_d - I_{sh} \tag{1}$$

where N_p represents the number of cells in parallel (N_p=1 as the study involves only one module), I_{ph} the photon generated current, I_d the diode current or dark current and I_{sh} the current through the shunt resistance of the panel. The photon generated current I_{ph} can be calculated using (2)

$$I_{ph} = I_{rr}[I_{sc} + K_i(T_{op} - T_{ref})] \tag{2}$$

where I_{rr} indicates the irradiation in per unit i.e. (actual irradiation/nominal irradiation), nominal irradiation at Standard Test Condition (STC) of 1000W/m^2, I_{sc}, the short circuit current of the PV panel, K_i the temperature coefficient of short circuit current, T_{op} the operating temperature in Kelvin and T_{ref} the nominal temperature in Kelvin. The diode current I_d relates as expressed in (3), where I_s refers to the cell saturation dark current at a 25 °C and 1 kW/m^2, V_{pv} the panel output voltage, N_s the number of cell in series, N the ideality factor and V_t the thermal voltage of the diode given by (4)

$$I_d = I_S\left[\exp\left(\frac{V_{pv} + I_{pv}R_s}{N_s V_t N}\right) - 1\right] \tag{3}$$

$$V_t = \frac{KT_{op}}{q} \tag{4}$$

where K (= 1.38 × 10^{-23} J/K) stands for the Boltzmann constant and q (= 1.6 × 10^{-19} C) the electron charge. The cell saturation dark current varies with temperature as described using (5).

$$I_S = I_{rs}\frac{T_{op}}{T_{ref}}\left[\exp\left(\frac{qE_g}{NK}\left(\frac{1}{T_{ref}} - \frac{1}{T_{op}}\right)\right)\right] \tag{5}$$

where E_g relates the band-gap energy of the semiconductor used in the panel and I_{rs} the cell reverse saturation current at a reference temperature and a solar radiation which can be approximately obtained from (6)

$$I_{rs} = \frac{Isc}{\left[\exp\left(\frac{qV_{oc}}{KN_s T_{op} N}\right) - 1\right]} \tag{6}$$

where V_{OC} expresses the PV open-circuit voltage at the reference temperature. The shunt current I_{sh} can be expressed as in (7)

$$I_{sh} = \frac{\frac{N_p}{N_s} V_{pv} + I_{pv} R_s}{R_p} \qquad (7)$$

III. SYSTEM DESRIPTION

The effort owes to use a SEPIC as a MPPT for a solar PV system with the P and O algorithm on account of its simplicity and ease of adaption. This study endeavors to analyze the nonlinear dynamics of solar PV system and predict the system behavior to changing environmental conditions and establish the margins of stability. The exercise attempts to measure the performance parameters of the solar PV MPPT system to stereotype the system for standard test conditions.

The solar PV system includes a 250W polycrystalline solar panel with 60 solar cells and a SEPIC dc-dc converter constitutes to be the MPP tracker for providing the maximum power to the load over a range of environmental and load conditions. The P and O algorithm tracks the maximum power and provides the corresponding duty signals to the switch in SEPIC converter shown in Fig.1.

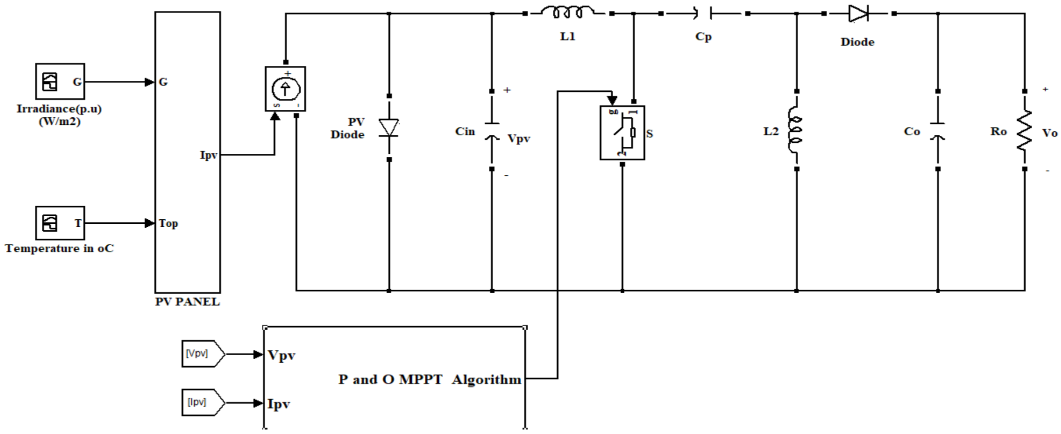

Fig.1. Schematic diagram of solar PV fed SEPIC converter under P and O MPPT control

The Table I includes the specifications of the solar panel under study with the ideality factor N, the series resistance R_s and the shunt resistance R_{sh} for a polycrystalline silicon of 15.6 ×15.6 cm^2 chosen as 1.18, 0.3Ω and 2200Ω respectively

TABLE. I PARAMETERS OF THE SOLAR PANEL UNDER STC CONDITIONS

Module Type	SRP-250-6PB
Rated Maximum power (Pmax)	250W
Current at Pmax (Imp)	8.35A
Voltage at Pmax (Vmp)	29.9V
Short-Circuit Current (Isc)	8.92A
Open-Circuit Voltage (Voc)	37.1V
Voc Temperature Coefficient	-0.32 %/°C
Isc Temperature Coefficient	+0.04 %/°C

STC: lrradiance 1000 W/m^2; Module Temperature 25°C; AM=1.5;
Power measurement tolerance: +/-3%

The choice of the SEPIC parameters follow the values of T_s=50µs, input inductor, L_1=0.5 mH, coupling inductor, L_2=0.5 mH, input filter capacitor C_{in}=47µF, coupling capacitor C_p=47µF and the output capacitor C_o=100µF to supply a nominal load resistance of 33Ω. The filter capacitor connected between the panel and the converter form a fifth order system with the inductor currents and the capacitor voltages as the state variables.

IV. SIMULATION RESULTS AND DISCUSSION

The procedure simulates the system described in Fig.1 using the SEPIC fed from the solar PV modeled through (1) to (7) in MATLAB platform and it operates using MPPT by P and O algorithm control. The design of the system echoes to operate in continuous conduction mode and the map of the system obtained by the stacking method. The solution of the state variables during on time serves as the initial conditions for solving the state variables during off time and vice versa.

The system uses a filter capacitor in between the panel and the converter and reflects the frequency derived by the combination of the filter capacitor and inductor in the circuit operation and also forms an additional driving force along with the switching frequency. However as the system topologies change in accordance with the switching frequency the system states and their bifurcations fall in synchronism with the switching frequency.

The system apart from the switching frequency of 20 kHz finds another driving frequency of approximately 1000Hz formed by the input inductor and the input filter capacitor. The inductor currents when observed for a few cycles of switching frequency exhibit a period-1 operation. However the inductor currents demonstrate the LC circuit frequency oscillation when observed for a longer duration.

It allows the simulation of the solar PV system owing to its continuous operation for extreme test points of irradiations i.e. at 1000W/m^2 and at 200W/m^2. The Fig. 2 shows the input inductor current at 1000W/m^2 in continuous (a) and discrete time (b) domain and the input inductor current at 200W/m^2 in continuous (a) and discrete time (b) domain in Fig. 3. It can be observed that the periodicity of the input inductor current changes from one to four for change in irradiation from 1000W/m^2 to 200W/ m^2 correspondingly.

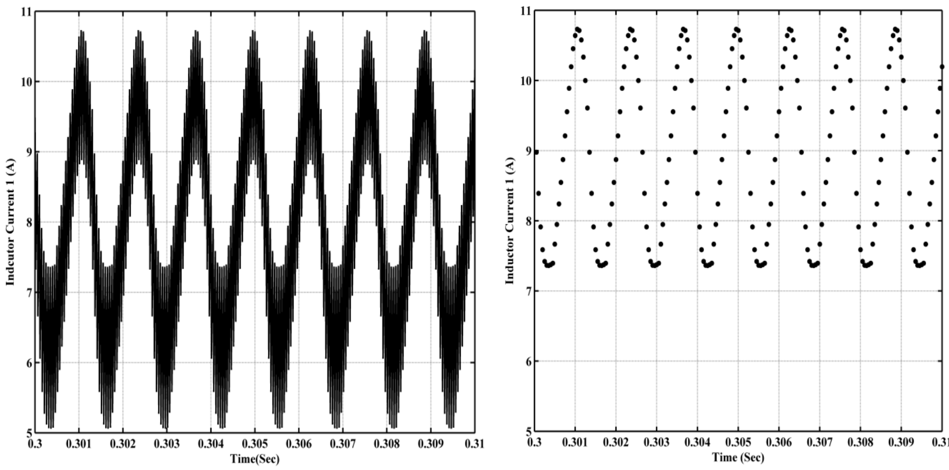

Fig. 2. Input inductor current in continuous and discrete time domain at 1000W/m^2

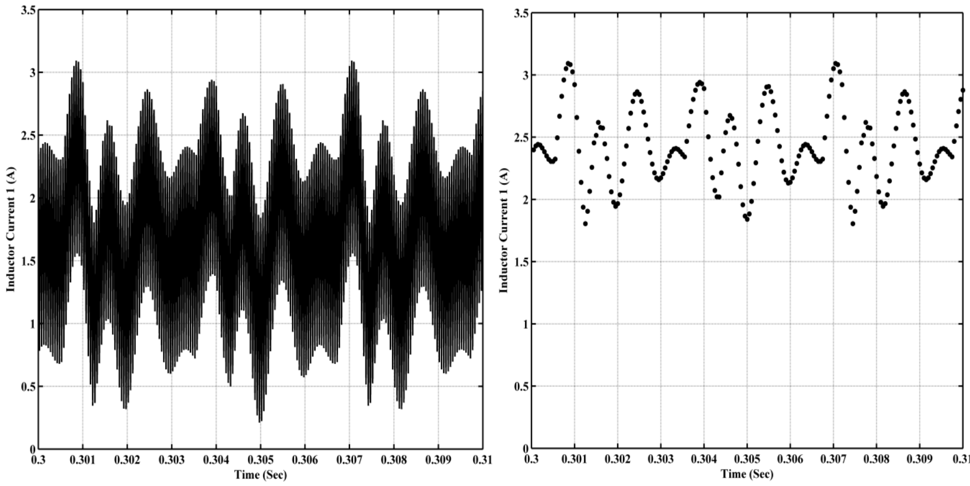

Fig. 3. Input inductor current in continuous and discrete time domain at 200W/m^2

The Fig. 4 displays the coupling inductor current at 1000W/m^2 in continuous (a) and discrete time (b) domain and the coupling inductor current at 200W/m^2 in continuous (a) and discrete time (b) domain in Fig. 5. It follows that the periodicity of the coupling inductor current changes from one to two for change in irradiation from 1000W/m^2 to 200W/ m^2.

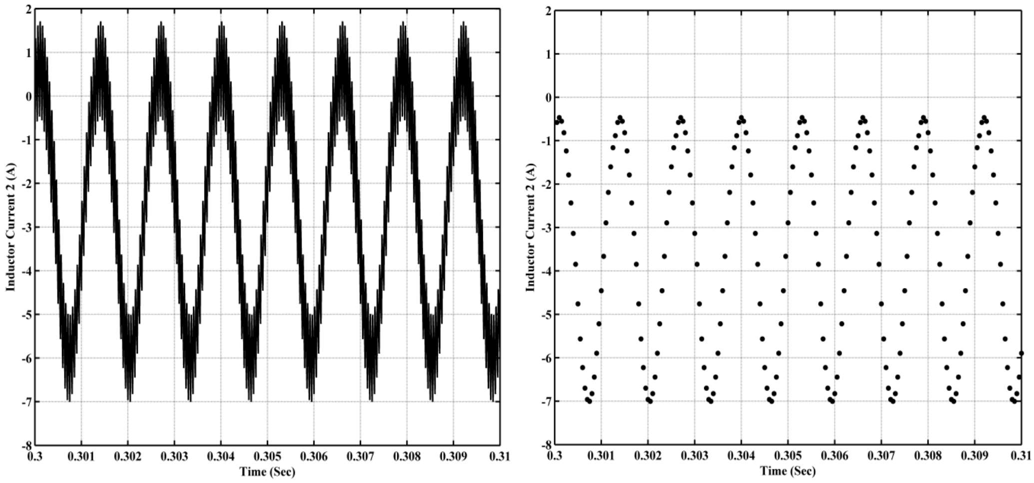

Fig. 4. Coupling inductor current in continuous and discrete time domain at 1000W/m^2

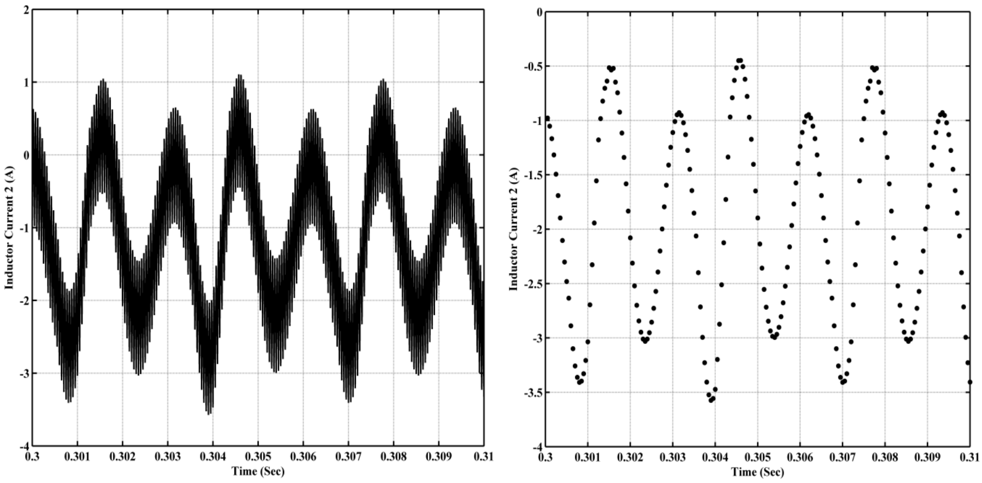

Fig. 5. Coupling inductor current in continuous and discrete time domain at 200W/m^2

The LC circuit frequency oscillations acts as an additional driving force on the circuit and so the discrete state space forms a closed loop instead of a fixed point. The Fig.6 and Fig.7 depict the discrete phase portrait of the state variables for 1000W/m^2 and 200W/m^2 respectively which clearly demonstrates that the system undergoes sub-harmonic oscillations and exhibit aperiodic state of solutions.

The change in the dynamical behavior of the system can be studied by the bifurcation diagram of the state variables of the system. It engages to investigate the dynamics of the inductor currents with irradiation as the bifurcation parameter. The Fig.8 and Fig.9 respectively extract the bifurcation diagram of the input inductor current and the coupling inductor current and the transition in dynamics of the system though not explicitly visible in the bifurcation diagram because of the LC circuit oscillations imposed on the switching frequency component of the state variable.

However careful examination of the state variable for a small variation ranges of bifurcation parameter as shown in the subplots of Fig. 8 and Fig. 9 give a clear picture of the nature of state variable at the corresponding irradiation condition. The system gradually loses its periodicity, enters into quasi periodic state and eventually becomes chaotic.

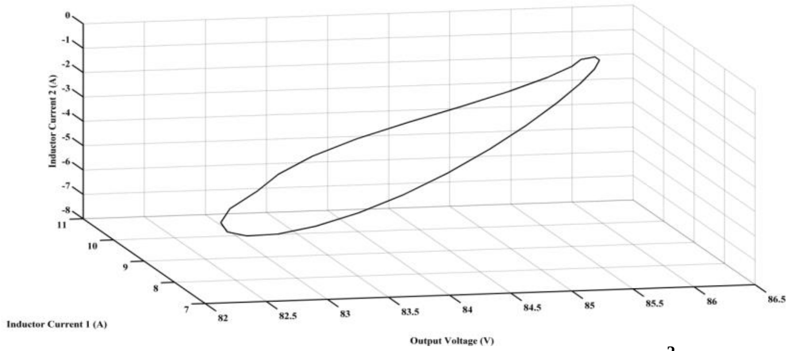

Fig.6. Phase portrait of the system at 1000W/m^2

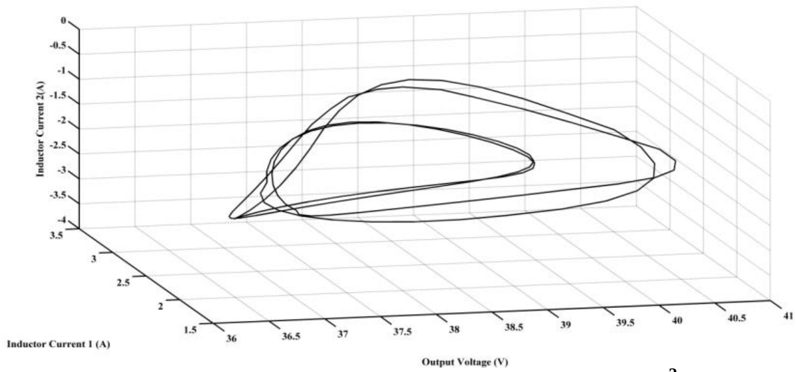

Fig.7. Phase portrait of the system at 200W/m^2

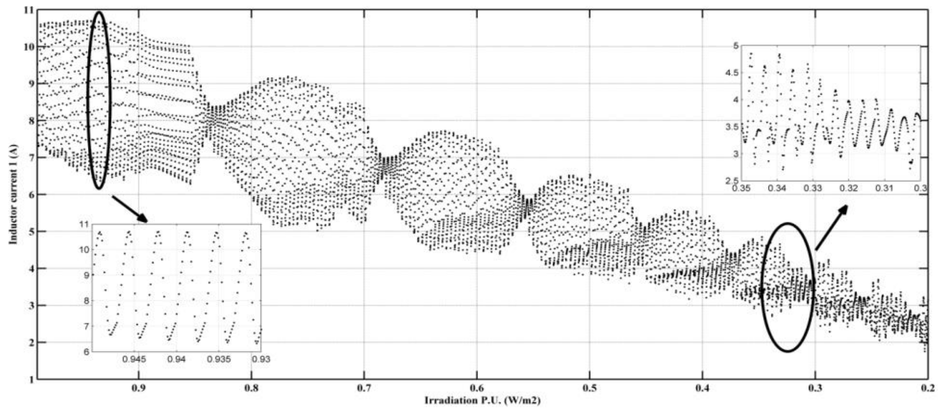

Fig.8. Bifurcation diagram of input inductor current.

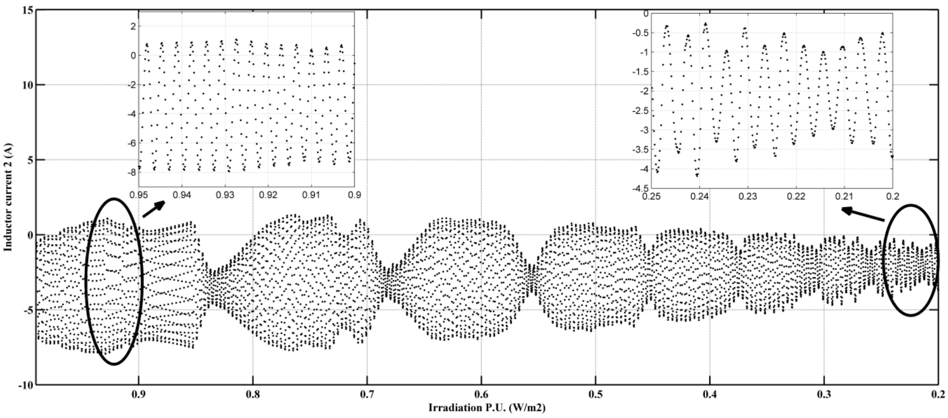

Fig. 9. Bifurcation diagram of coupling inductor current.

The exercise measures the performance of a converter as a MPP tracker in terms of the efficiency for a given irradiation condition, oscillations around the maximum power point, ripple in the output voltage and the ratio of output power to input PV power. The chaotic behaviour of the converter degrades the efficiency of the converter and also the performance of the converter as a MPP tracker as observed from Table.II.

TABLE. II MPP TRACKING PERFORMANCE OF THE SOLAR FED SEPIC CONVERTER

S. No.	Irradiation (w/m^2)	Tracking efficiency (%)	% of Oscillations around MPP to Max. Power	Peak-Peak Output Voltage Ripple (V)	Conversion Efficiency (%)
1	1000	94.4	11.6	5	96.46
2	800	92	26.5	6.9	95.95
3	600	90	21	6.5	96.29
4	400	93.5	16.2	6	95.72
5	200	86.5	14.6	5.5	95.74

The system presents a higher tracking and conversion efficiency when operated at $1000W/m^2$ and the sub-harmonics in the system for lower value of irradiation reflects in the reduced performance of the system such as increased oscillations around the MPP and higher output voltage ripple.

V. CONCLUSION

The solar PV system with SEPIC DC-DC converter has been simulated using the solar PV modeled using single diode equivalent circuit and mapping of solution of state variables of the converter. The behaviour of the PV system has been studied for variation of the irradiation under P and O MPPT control and the system exhibits periodic operation for the peak values of irradiation. The system has been embellished through quasi periodicity, bifurcation to demonstrate chaos and non-periodicity with the decrease in radiation. The aperiodic behaviour of the circuit has been projected to deteriorate the tracking performance of the SEPIC and offer directives to improve the performance of the solar energy system.

ACKNOWLEDMENTS

The authors thank the authorities of Annamalai University for providing the necessary facilities to accomplish this piece of work.

REFERENCES

[1]. J. Lefèvre, W. Wills and J. Hourcade, Combining low-carbon economic development and oil exploration in Brazil? An energy–economy assessment, *Climate Policy*, 2018, 1-10.

[2]. R. Turvey, Green economy and development in small urban municipalities: towards sustainable community development, *GeoJournal*, *80(5)*, 2014, 607-618.

[3]. C. Crago and E. Koegler, Drivers of growth in commercial-scale solar PV capacity, *Energy Policy, 120,* 2018, 481-491.

[4]. A. Shukla, K. Sudhakar, P. Baredar and R. Mamat, Solar PV and BIPV system: Barrier, challenges and policy recommendation in India, *Renewable and Sustainable Energy Reviews, 82(3)*, 2018, 3314-3322.

[5]. B. Sivaneasan, N. Kandasamy, M. Lim and K. Goh, A new demand response algorithm for solar PV intermittency management, *Applied Energy, 218*, 2018, 36-45.

[6]. M. Kamran, M. Mudassar, M. Fazal, M. Asghar, M. Bilal and R. Asghar, Implementation of improved Perturb & Observe MPPT technique with confined search space for standalone photovoltaic system, *Journal of King Saud University - Engineering Sciences*, *in press* 2018.

[7]. A. Haque and Zaheeruddin, A fast and reliable perturb and observe maximum power point tracker for solar PV system, *International Journal of System Assurance Engineering and Management*, *8(2)*, 2016, 773-787.

[8]. S. Banerjee and G. Verghese, *Nonlinear phenomena in power electronic* (New York: IEEE Press, 2001).

[9]. X. Zhou, J. Li and Y. M, Chaos Phenomena in DC-DC Converter and Chaos Control, *Procedia Engineering, 29,* 2012, 470-473.

[10]. Yumei Zhang, Hong Qin, Yanhua Qu and Jianhua Wu, Chaos phenomenon in the DC-DC switching converters, *Proc. 10th IEEE World Congress on Intelligent Control and Automation*, Beijing, China, 2012, 2039-2043.

[11]. C. Fang and E. Abed, Sampled-data modelling and analysis of the power stage of PWM DC-DC converters, *International Journal of Electronics*, *88(3)*, 2001, 347-369.

[12]. D. Hamill, J. Deane and D. Jefferies, Modeling of chaotic DC-DC converters by iterated nonlinear mappings, *IEEE Transactions on Power Electronics*, *7(1)*, 1992, 25-36.

[13]. S. Tabatabaei, M. Jahed-Motlagh and M. Yazdi, Investigation of Chaotic Behaviour in a DC–DC Converter Using the v-Resolution Approach, *IFAC Proceedings Volumes, 45(12)*, 2012, 121-125.

[14]. P. Siewniak and B. Grzesik, A brief review of models of DC–DC power electronic converters for analysis of their stability, *International Journal of Electronics, 101(10)*, 2013, 1405-1426.

[15]. A. Harb, S. Harb and I. Batarseh, Chaos and bifurcation of voltage-mode-controlled buck DC-DC converter with multi control parameter, *International Journal of Modelling and Simulation, 30(4)*, 2010, 472-478.

[16]. A. El Aroudi and R. Leyva, Quasi-periodic route to chaos in a PWM voltage-controlled DC-DC boost converter, *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, 48(8)*, 2001, 967-978.

[17]. K. Cheng, M. Liu and J. Wu, Chaos study and parameter-space analysis of the DC–DC buck–boost converter, *IEE Proceedings - Electric Power Applications, 150(2)*, 2003, 126-138.

[18]. P. Deivasundari, S. Ashita and G. Uma, Chaotic dynamics of a zero average dynamics controlled DC–DC Ćuk converter, *IET Power Electronics, 7(2)*, 2014, 289-298.

[19]. S. Wang, Y. Zhou, H. Iu and J. Chen, Dynamical behaviour and stability analysis in SEPIC converter based on sliding-mode control, *Australian Journal of Electrical and Electronics Engineering, 4(1)*, 2008, 47-54.

[20]. A. Kavitha and G. Uma, "Experimental Verification of Hopf Bifurcation in DC--DC Luo Converter", *IEEE Transactions on Power Electronics, 23(6)*, 2008, 2878-2883.

[21]. H. Zhang, X. Yang, X. Ma and F. Zheng, Theoretical and experimental investigation of bidirectional Hopf bifurcations in cascade DC–DC buck converters, *Mathematics and Computers in Simulation, 82(4), 2011*, 540-557.

[22]. W. Li-li, Study of Intermittency in Parallel-Connection Buck Converters, *Procedia Engineering, 24*, 2011, 658-662.

[23]. A. Natsheh, J. Kettleborough and J. Nazzal, Analysis, simulation and experimental study of chaotic behaviour in parallel-connected DC–DC boost converters, *Chaos, Solitons & Fractals, 39(5)*, 2009, 2465-2476.

[24]. P. Deivasundari, K. Murali, G. Uma and C. Vincent, Non-linear intermittent instabilities and their control in an interleaved DC/DC converter, *IET Power Electronics, 7(5), 2014,* 1235-1245.

[25]. A. Alzahrani, P. Shamsi, M. Ferdowsi and C. Dagli, Chaotic Behavior in High-Gain Interleaved Dc-dc Converters, *Procedia Computer Science, 114*, 2017, 408-416.

[26]. Z. Zhusubaliyev and E. Mosekilde, Multistability and hidden attractors in a multilevel DC/DC converter, *Mathematics and Computers in Simulation, 109*, 2015, 32-45.

[27]. M. Subashini and M. Ramaswamy, Bifurcation and Chaos in Converter Interfaces in Solar PV Systems-A Review, *Journal of Engineering Science and Technology Review, 10(5)* 2017, 90-97.

[28]. M. Orabi and T. Ninomiya, Nonlinear dynamics of power-factor-correction converter, *IEEE Transactions on Industrial Electronics, 50(6)*, 2003, 1116-1125.

[29]. M. Ye and S. Li, Simulation Study of PFC Boost Converter Based on Predicted Average Current Control, *Advanced Materials Research, 462*, 2012, 738-742.

[30]. 30. M. Vaigundamoorthi and R. Ramesh, Experimental Investigation of Chaos in Input Regulated Solar PV Powered Cuk Converter, *International Journal of Computer Applications, 43(10)*, 2012, 11-16.

[31]. A. Abusorrah, M. Al-Hindawi, Y. Al-Turki, K. Mandal, D. Giaouris, S. Banerjee, S. Voutetakis and S. Papadopoulou, Stability of a boost converter fed from photovoltaic source, *Solar Energy, 98*, 2013, 458-471.

IOSR Journal of Engineering (IOSRJEN) is UGC approved Journal with Sl. No. 3240, Journal no. 48995.

M. Subashini "Exploration of Chaos and Bifurcations in a Solar PV MPPT SEPIC Converter System." IOSR Journal of Engineering (IOSRJEN), vol. 08, no. 8, 2018, pp. 62-69.