The Comparison of PI Control Method and One Cycle Control Method for SEPIC Converter

Enes Bektaş[1], Ahmet Karaarslan[2]

[1]Çankırı Karatekin University, Engineering Faculty, Department of Electrical and Electronics Engineering, Çankırı (enesbektas@karatekin.edu.tr)
[2]Ankara Yıldırım Beyazıt University, Faculty of Engineering and Natural Sciences, Department of Energy System Engineering, Ankara (akaraarslan@gmail.com)

Abstract

DC-DC converters, reducing or decreasing the input voltage at the output, are commonly used in many power electronics application. Generally, all types of converter are derived from Buck or Boost converter topology. Similarly, Single-Ended Primary-Inductor Converter (SEPIC) is composed from buck converter topology, but may reduce or decrease the input voltage. In this paper, SEPIC converter is analyzed and two control methods, PI and One Cycle Control (OCC), have been applied to set the output voltage at desired voltage level with 500 W output power and 20 kHz switching frequency. In order to get better result with OCC, the generalized control structure has been changed and different types of OCC method are presented. The simulation results have been obtained by using Simulink/MATLAB and compared with each other. The results include the dynamic response of the suggested control methods with variation of reference, power at output and input voltages. And, the proposed OCC method has better results from the point of load and reference variation. For input voltage variation PI control method is superior.

1. Introduction

Nowadays, widespread requirement of modern power electronic equipment and systems leads to common usage of DC-DC converters that are designed to be used in various power electronic applications. High frequency switching converters are significant power electronic devices commonly used in power electronic applications [1].

SEPIC topology consists of an active power switch, a diode and four energy storage components (two inductors and two capacitors). Because of four energy storage elements suggested topology is nonlinear system modelling of which is time-consuming issue [2]. Some applications that need both buck and boost operation can simply use the SEPIC, Cuk, Flyback, Buck-Boost topology. In buck converter operation, discontinuous input current and input current ripple may occur. This ripple can lead to harmonics that can be reduced only with a filter including large capacitor. This may also result in low efficiency and necessity of bulky heatsink because of overheating in power switch. SEPIC converter has low distorted input current and is superior solution for input current pulsating [3]. Unlike buck-boost and Cuk converters SEPIC is a non-inverting converter. In other words, suggested topology has not inversed polarization. In addition, the power switch in hardware of SEPIC converter is referenced to ground. Thus, it is easy to drive the switch [2].

SEPIC converter is used in battery-charger systems because of having both buck and boost mode operation. In addition, suggested topology is useful for LED drivers and used in PFC applications [2, 3].

Recently, researches about modeling and controlling of the SEPIC converter have been performed. In [3], Bridgeless SEPIC converter is a suggestion for THD problem. One-cycle control method studied in [4] for a single-phase UPS inverter. OCC method is practical and provides quality output voltage for UPS inverter. Steady state and stability analyzes of SEPIC converter is studied in [5]. And, researchers have indicated that the diode voltage is unstable and not suitable for feedback of OCC method. The work including hybrid control methods for SEPIC converters is proposed in [6]. SEPIC has been controlled by so called Fuzzy PI method [7]. Researchers in [2, 8] have used State-Space Averaging (SSA) method, operating in continuous conduction mode, to model SEPIC converter and get transfer function of the system. Another research have studied on performance of PID and Fuzzy Logic Controllers for SEPIC converter [9]. And in [10], researchers have compared hysteresis and OCC control methods. They have concluded that OCC have better results than hysteresis control method for SEPIC topology.

In this paper, Single-Ended Primary-Inductor Converter (SEPIC) has been analyzed including 500 W output power, 20 kHz switching frequency, 12V to 3V buck mode operation. In addition to this, PI control and One Cycle Control (OCC) methods have been applied to SEPIC converter topology to obtain the controlled output voltages with suggested working operation. In order to increase the efficiency of OCC, different types of OCC methods have been improved. The simulations have been carried out by using Simulink/MATLAB.

This paper is organized as follows; in Section 2, the structure of SEPIC is analyzed and equations for demanded working operation is given. Control methods, PI and OCC, have been investigated. In addition, improved OCC methods have been given in Section 3. The next Section includes simulation results for suggested control methods. After all, conclusion is represented in Section 5.

2. The analysis of SEPIC Topology

In Fig.1 the structure of SEPIC topology has been given. As shown in the Figure, the structure of SEPIC has two capacitors and inductors. The circuit structure is derived from buck converter by adding C_1 and L_2 components. The L_1 and L_2 parameters are chosen with equal value of inductance.

When the switch is on, L_1 is charged with the input voltage. C_1 is discharged by the L_2 and L_2 stores energy. Load current is supplied by the output capacitor C_2, in that, C_2 is discharged though the load.

When the switch is off, C_1 is recharged by the energy stored in L_1 that also supplies the load current during this period. And, L_2 is connected to load via D_1. C_2 is recharged tough second inductor. To summarize, in off state capacitors and in on state inductors is charged. The load current is supplied by output capacitor and input inductor in on and off state respectively [11, 12, 13].

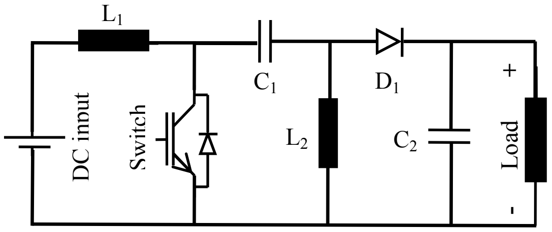

Fig. 1. SEPIC topology

For all converter topologies the correlation between input and output voltage is specified according to duty cycle (D). For SEPIC topology, the duty cycle can be calculated as follows and the output voltage is defined as in Equation 2:

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

$$V_{out} = \frac{D}{1-D} V_{in} \quad (2)$$

In addition, the average value of input and output current can be calculated considering the power equality between input and output for the ideal components. The average value of output current I_{out} is obtained by considering output voltage and output power. Current equation is given in following:

$$I_{in} = \frac{D}{1-D} I_{out} \quad (3)$$

In order to obtain value of inductors, Equation 4 is taken into consideration. The most important parameter needed for designing SEPIC is inductor ripple current ΔI_L. And in this paper, the ripple current is 30% that is suitable for design because of defined rule of thumb, between the 20% and 40%. Values of L_1 and L_2 is equal to each other. However, in practice, coupled inductor L_1 and L_2 do not have the same inductance and the ripple current. And C_1, C_2 have been calculated by Equation 5 and 6 [13].

$$L_1 = L_2 \geq \frac{1}{2} * \frac{V_{in} D}{\Delta I_L f_{sw}} \quad (4)$$

$$C_1 = \frac{I_{out} D}{\Delta C_p f_{sw}} \quad (5)$$

$$C_2 = \frac{I_{out} D}{\Delta C_{out} f_{sw}} \quad (6)$$

In Table 1, the calculated value of components have been given for desired working operation. For next Sections, these values have been adapted to the simulations. And, Fig. 2 shows the current of inductors, current of capacitors, voltage drop of each component for the desired working operation with the calculated value given in Fig. 2.

Table 1. Calculated parameters for 12 to 3 V_{out}

Name of variable	Value of components	Name of variables	Calculated component value
Input voltage	12 V	Load	0.018 ohm
Output voltage	3 V	Duty cycle	22.58%
Output power	500 W	L_1 and L_2	5.4 uH
ΔI_L	30%	C1	37.6 mF
ΔV_{C1}, ΔV_{C2}	400 mV, 100mV	C_2	4.7 mF

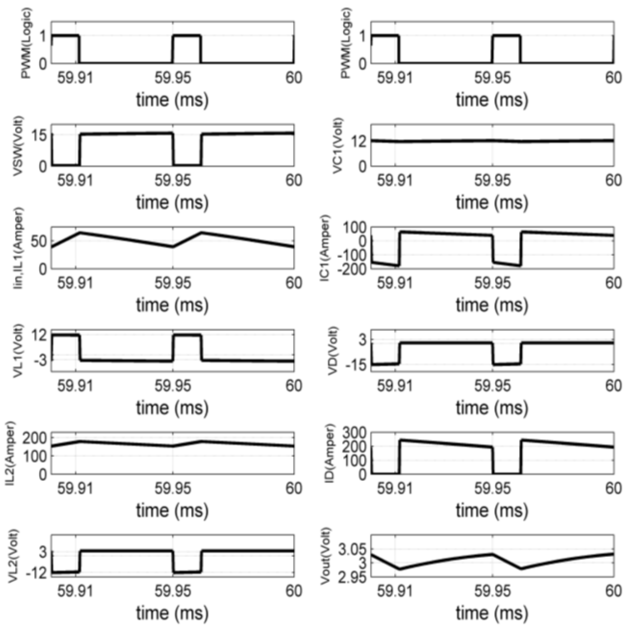

Fig. 2. Output voltages, current of inductors, current of capacitors of SEPIC converter with 12 to 3 V_{out}

3. Control Methods

There have been several closed loop control methods such as sliding mode control, PI control, hysteresis control, one cycle control that can be applied to switch mode power supplies to set the output voltage in desired voltage levels by minimizing the settling time and overshoots of the output voltage. In this work PI and OCC control methods have been compared and analyzed for start-up transient, line variations, load variations and reference variations.

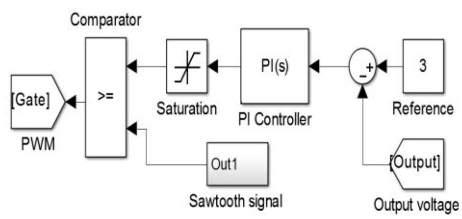

Fig. 3. Simulink control block of PI control method

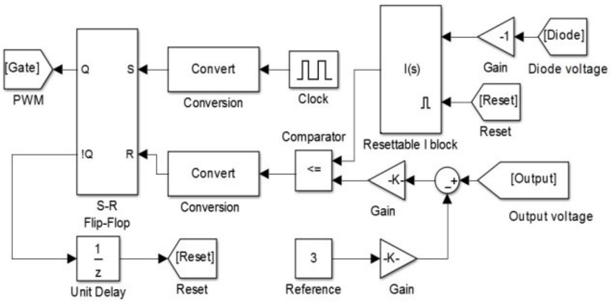

Fig. 4. Simulink control block of improved OCC method

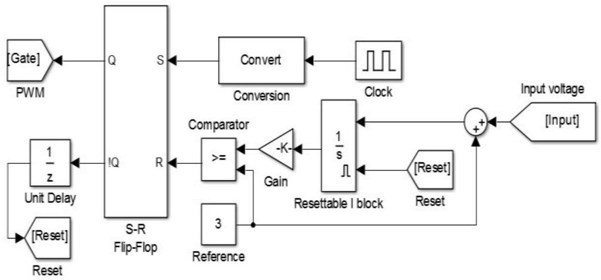

Fig. 5. Simulink control block of proposed OCC method

In Fig. 3., PI control block has been given. First stage of control block is comparison of output voltage and reference voltage and producing of error signal. The PI controller seeks to minimize the error which is difference between measured output voltage and reference voltage [14].

In Fig. 4 and Fig. 5, different OCC methods have been given. In Fig. 4, the improved OCC method taking feedback from the diode voltage have different K (Gain) factors and these Gain factors must be adjust carefully. As, the stability of system's control is specified according to Gain factor. In order to implement OCC method to SEPIC converter, OCC method must be modified because of voltage perturbation of the diode voltage. In [5], efficiency of general OCC method have been analyzed and have indicated that general OCC method taking feedback from diode voltage is not useful for SEPIC topology. For this reason, the other OCC methods have been analyzed. Improved OCC method in [15] and OCC method taking feedback from input voltage in [16] have been changed and adapted to SEPIC converter topology.

4. Simulation Results

In this study, PI and OCC control methods have been applied to SEPIC topology. Simulation results have been given to assess to effectiveness of PI and OCC methods. The switching frequency is 20 kHz, input voltage is 12 V, power at output is 500 W and desired voltage at the output is 3V. The parameters needed for 12 V to 3 V working operation have been calculated with Eq. 1-6 and have been given in Table 1.

In Fig. 6, output voltage of uncontrolled SEPIC is shown. As seen in the suggested Figure, the output voltage is fluctuating from 3.025 V – 2.975V. Maximum overshot is around 4.1 V, in that with 36.6% of output voltage ad minimum overshoot is 2.7 V. In addition, the settling time is 60 ms for uncontrolled SEPIC converter.

Fig. 7 shows the response of output voltage with different PI parameters, K_i and K_p, given in Table 2. As seen in Fig. 7. The

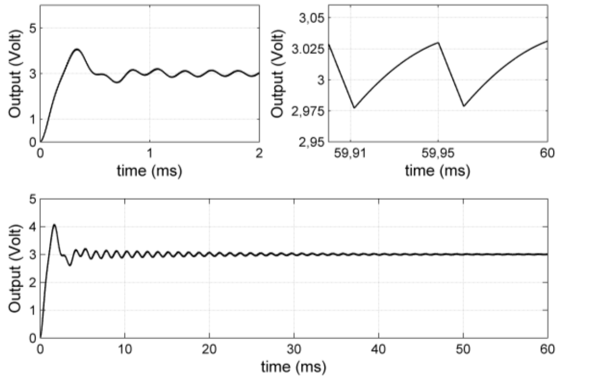

Fig. 6. Output voltage of uncontrolled SEPIC converter for 12 to 3 V_{out}

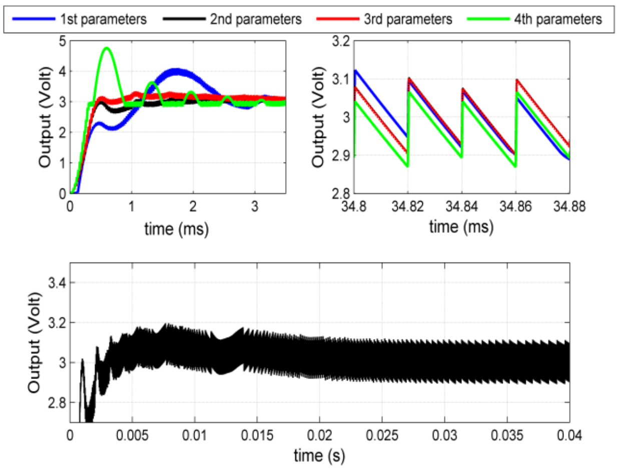

Fig. 7. Step responses of PI controlled SEPIC converter for 12 V to 3 V operation including different K_p and K_i parameters

Table 2. Results for different K_p and K_i parameters

Number of parameters	Max overshoot [V]	Settling time [second]	Steady state variation [V]
1(K_i=0.0001, K_p=20)	4.1	0.035	0.2
2(K_i=0.1, K_p=20)	3.2	0.03	0.2
3(K_i=0.1, K_p=50)	3.34	0.015	0.2
4(K_i=5, K_p=100)	4.75	0.014	0.2

results of first and fourth parameters are not practicable because of overshoots. When compared the results of second and third parameters it can be concluded that damping of second parameter is lower and more practicable.

After specifying of PI parameters, results of improved and proposed OCC methods the structure of which is given with Fig. 8-9 have been compared to determine more suitable OCC control type for SEPIC topology. As seen in Fig. 8., the fluctuating after settling of output voltage is equal and about 0.2 V. The settling time is 7 ms and 11 ms for improved and proposed method respectively. However, maximum overshoots are 5V and 3.8 V.

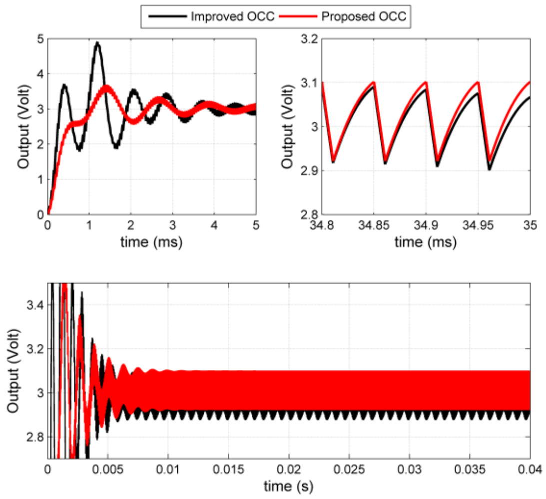

Fig. 8. Output voltages of proposed OCC and improved OCC controlled SEPIC converter with 12 to 3 V_{out}

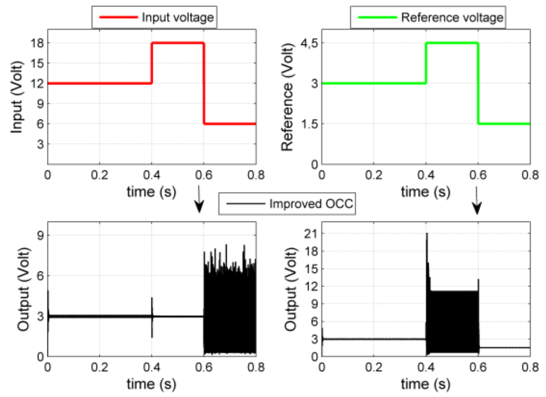

Fig. 9. Unbalanced dynamic responses of improved OCC controlled SEPIC converter 12 to 3 V_{out}

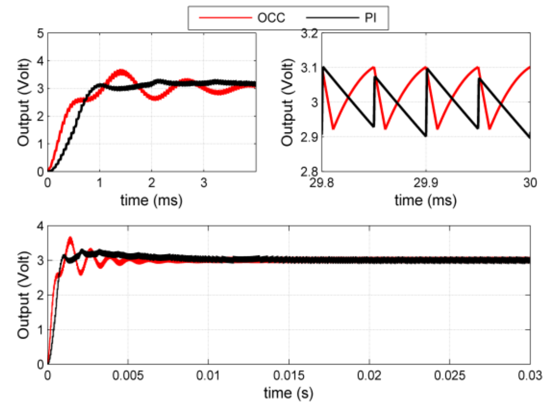

Fig. 10. Output voltages of PI and OCC controlled SEPIC converter for 12 to 3 V_{out}

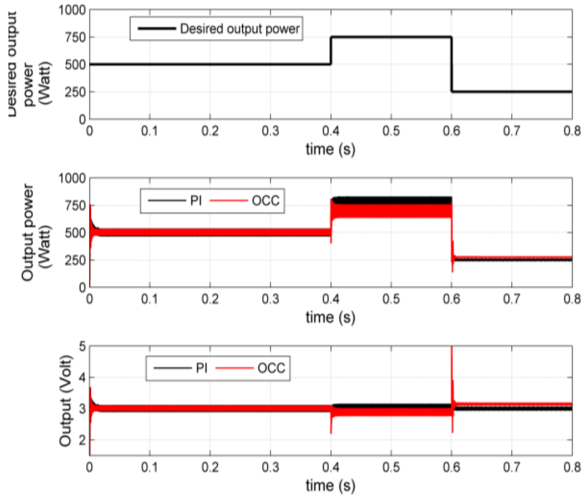

Fig. 11. Dynamic response of PI and OCC controlled SEPIC converter 12 to 3 V_{out} for load variation

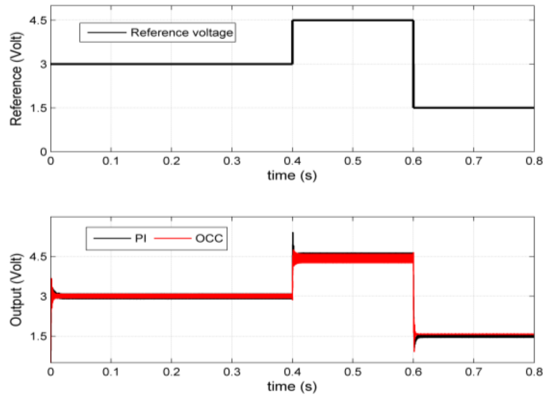

Fig. 12. Dynamic response of PI and OCC controlled SEPIC converter 12 to 3 V_{out} for reference variation

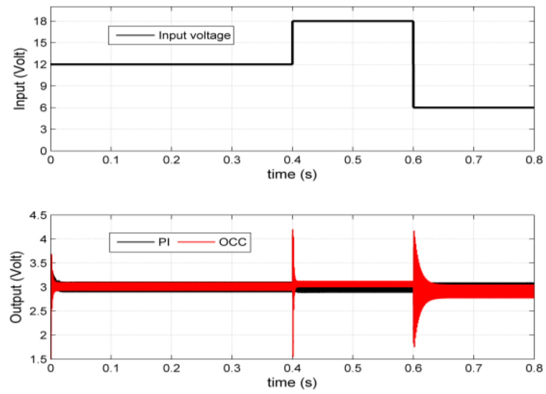

Fig. 13. Dynamic response of PI and OCC controlled SEPIC converter 12 to 3 V_{out} for input voltage variation

In addition, with Fig. 9, the dynamic response of reference variation and line variation with 50% have been given. As seen, the dynamic response of improved OCC method is unbalanced when the input voltage decreases and reference voltage increases. For this reason, it is concluded that proposed OCC method is more practicable.

Fig. 10 both depicts and compares the output voltage of PI and proposed OCC controlled SEPIC converter. The peak value of OCC controlled output voltage is 3.8 V that is more than output voltage of PI control, 3.2 V. However, settling time is lower than PI control method. In Fig. 11-13, dynamic responses of suggested control methods have been given. The working operations for Fig.11 is desired working operations suggested before between 0 and 0.4 second, between 0.4 and 0.6 seconds desired output power have been increased to 750 W by decreasing load from 0.018 ohm to 0.012 ohm. Between 0.6 second and 0.8 second, the SEPIC converter is loaded with 250 W. It can be concluded that, with lower power the fluctuation of output voltage decreases, in all working operation with load variation, the perturbation in both the output power of OCC controlled voltage and output voltage is lower than PI control method. In load variation, proposed OCC method gives better results than PI control method.

In Fig. 12, the output voltage of proposed OCC method has lower perturbation than PI method for reference variation. Especially at 0.4 and 0.6 seconds, also critical point for reference variation, PI control has excessive overshoot at 0.4 seconds and has excessive undershoot. Proposed OCC method gives better performance and undistorted output voltage. However, results of line variation is better for PI control method. As seen in Fig. 13., in critical points, where inputs increases to 18 V and decreases 6 V after 0.4 seconds, the output voltage of proposed OCC method has excessive overshoots and undershoots problem.

5. Conclusion

In this paper, Single-Ended Primary-Inductor Converter (SEPIC) has been analyzed for different working structure including 500 W output power, buck mode operation. Additionally, PI control and One Cycle Control (OCC) methods have been applied to SEPIC converter topology. Different types of OCC methods have been analyzed to increase the dynamic response of the control method. Analyzes have apparently proved that the generalized OCC method can't be applied to suggested converter topology because of the perturbation of diode voltage. Improved OCC method has practicable results for suggested working operation. However, dynamic response for the variation of reference and input voltage is very low. For this reason, other OCC method using input voltage as feedback, have been applied to SEPIC topology. When compared general OCC method taking the feedback from the diode's voltage, the improved OCC and proposed OCC method taking the feedback from the input voltage gives better results. The simulation results have been obtained by using Simulink/MATLAB and compared with each other. Proposed OCC method have lower settling time. However the overshoot is little more than PI's. For variation of load and reference proposed OCC method is outstanding. PI control method has given better results in terms of disturbance of input voltage. In following studies, different converter topologies are aimed to perform with PI and OCC control methods and compare with SEPIC converter results.

6. References

[1] A. Karaarslan, I. Iskender, "DSP microprocessor based-on power factor correction to improve power quality of converters using predictive control", *International Review of Electrical Engineering*, vol. *6,* no. *2,* pp. *512-521,* April, 2011.

[2] O. Kircioglu, M. Unlu, S. Camur "Modelling and analysis of DC-DC SEPIC converter with coupled inductors", in *International Symposium on Industrial Electronics (INDEL)*, Banja Luka, Bosnia Herzegovina, 2016.

[3] B. V. Sudha, P. N. Champa, "High power factor bridgeless SEPIC converter to improve total harmonic distortion", *IJIRCCE. International Journal of Innovative Research in Computer and Communication Engineering*, vol. *5,* no. *4,* pp. *7768-7774,* April, 2017.

[4] L. Xiangli, Q. Hanhong, "One-cycle controlled single phase UPS inverter", in *International Conf. on Solid State Devices and Materials Science*, Kyoto, Japan, 2012, pp. *1048-1054.*

[5] M. Gurbina, D. Lascu, "Analysis of one cycle controlled SEPIC converters", in *7th IEEE International Symp. on Applied Computational Intelligence and Informatics*, Timişoara, Romania, 2012, pp. *415-420.*

[6] D. Patino, M. Baja, P. Riedinger, H. Cormerais, J. Buisson, "Hybrid control technique for a single ended primary inductor converter (SEPIC)", in *European Control Conf.*, Budapest, Hungary, 2009, pp. *3599-3604.*

[7] V. R. Bhasker, "Accelerated fuzzy PI controlled SEPIC for voltage controlled inverter", *Asian Journal of Information Technology*, vol. *x,* no. *x,* pp. *970-977,* 2016.

[8] V. Eng, U. Pinsopon, C. Bunlaksananusorn, "Modeling of SEPIC converter operating in continuous conduction mode", in *Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology Conf.*, Pattaya, Chonburi, Thailand, 2009.

[9] B. Paranthagan, M. Marimuthu, S. P. Shamili, "Comparative analysis of performance of the SEPIC converter sing PID and Fuzzy Logic controllers for LED lightening application", *IJETCSE, Journal of Emerging Technology in Computer Science & Electronics*, vol. *12,* no. *2,* pp. *34-42,* Abbrev. Jan., 2015.

[10] P. M. Binitha, T. G. S Kumar, "Comparison of PWM and One-Cycle control for switching converters", *IJETAE. International Journal of Emerging Technology and Advanced Engineering*, vol. *3,* no. *4,* pp. *34-42,* Apr., 2013.

[11] T. G. L. K. Reddy, P. Ramamurthyraju, V. R. Kumar, "Analysis of SEPIC for PV-applictions using PI controller and Current Mode controller", *IJSRD. International Journal for Scientific Research Development*, vol. *1,* no. *9,* pp. *1821-1824*, 2013.

[12] R. Ridley, "Analysing the SEPIC converter", *Power Systems Design Europa*, Nov., 2006.

[13] J. Falin, "Designing DC-DC converter based on SEPIC topology", *Texas Instrument-Analog Appl. Journals*, 2008.

[14] A. Karaarslan, "Analysis and comparison of current control methods on bridgeless converter to improve power quality", *Electrical Power and Energy Systems*, vol. *51,* pp. *1-13,* 2013.

[15] K. Subramanian, V. K. S. Kumar, E. M. Saravanan, E. Dinesh, "Implementation of one cycle control technique I DC-DC buck converter", *Indian Journal of Science and Technology*, vol. *8,* no. *2,* pp. *200-206,* Jan, 2015.

[16] K. Anoop, M. Nandakumar, "A novel control technique for voltage regulation and island detection of a DC microgrid connected photo voltaic converter system", in *International Conf. on Power, Instrumentation, Control and Computing (PICC)*, Thissur, India, 2015.