Modified SEPIC Converter Performance for Grid-connected PV Systems under Various Conditions

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Abstract

Step-up converter is widely used to increase DC voltage level on PV systems either off-grid or grid connected. One of the step-up converters often used in PV systems is SEPIC converter. To improve its performance, many SEPIC converters have been modified. However, performance on various conditions has not been further investigated. In this study, the modified SEPIC converter was investigated under various change conditions for grid-connected PV applications. This converter was modelled and simulated using PSIM software. The modified SEPIC converter received input from PV array 15 kWp, and its output was connected to the three-phase inverter with grid and load. The irradiance level and ambient temperature were varied to test its performance and compared to Boost converter and SEPIC converter. For all tests, the performance of modified SEPIC converter was better than other step-up converters because it was able to rectify the quality of output voltage and more efficient.

Keywords: SEPIC, converter, PV systems, PSIM.

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1. Introduction

Smart grid systems refer to the use of controls technology and digital information to increase the security, reliability and efficiency of the electric grid in the world [1]. The smart grid system is possibly integrated from various renewable energy sources [2] such as wind turbine [3, 4, 5], fuel cell [6, 7], and photovoltaic [8, 9, 10]. One of the various renewable energy sources that have great potential to be utilized is photovoltaic [11].

The distribution of power from PV systems is possible standalone or grid-connected. For grid applications, PV systems passed through the three-phase inverter and this condition demands high DC voltage [12]. However, characteristics of photovoltaic generate low voltage and do not meet this requirement. The step-up converter is required to overcome this problem by converting low DC voltage from photovoltaic to high DC voltage [13]. Mostly, the preferred topology of the step-up converter is able to generate high step-up voltage, high efficiency, and low ripple of the output/input voltage and current to avoid power losses on the systems [14].

Many researchers have developed and investigated the performance of the step-up converter for PV systems. Boost converter [15–18] is able to generate high step-up voltage with high duty cycle. Unfortunately, that condition may cause voltage stress on the switching device and decrease the efficiency of the Boost converter. The high step-up voltage can also be obtained from two Boost converters that are arranged in series with a single switch, it is called Quadratic Boost Converter [19, 20]. However, switching device receives high current stress. On the other hand, conduction losses also increase, and the efficiency of this converter decreases [21].

Improving performance of step-up converter using Coupled Inductor is also presented by [22, 23]. High voltage gain is achieved by determining coil of the Coupled Inductor. However, during high step-up operation, current ripple increases and causes leakage inductance so that the efficiency decreases. The Coupled Inductor converter has also combined with voltage doubler circuit, which has been developed by [24, 25]. Voltage stress of the switching device has been reduced, but inductor receives magnetizing current which is double than the switching frequency. Furthermore, in [26] the topology using switched capacitors cell has also been presented to achieve a high voltage with static gain. The technique of voltage multiplier cell used in the step-up converter is able to reduce the switching voltage stress and increase the
high voltage gain, but it may increase the cost of converter. Many step-up converters have also been combined to increase efficiency and to obtain high voltage gain such as Boost converter combined with Cuk converter in [27, 28], and Boost converter with SEPIC converter in [29, 30]. However, the switching device on this converter received switching voltage stress equal to the average sum of the output and input voltage [31].

The modified SEPIC converter is developed by combining conventional SEPIC converter with Boost converter and diode-capacitor circuit, and it has been presented by [32] to overcome the above drawbacks. This converter for PV systems is capable of generating high voltage gain, low switching voltage stress, and low conduction losses. However, various conditions such as irradiation changes or ambient temperature which affect the performance of grid-connected PV systems have not been further investigated on this converter. In this study, the performance of modified SEPIC converter presented by [32] will be investigated under various conditions. This converter is investigated on grid-connected PV system simulation using PSIM software for 15 kWp power rating by varying irradiance level and ambient temperature. Furthermore, the result of its performance is compared to Boost converter and SEPIC converter.

2. Overview of Step-up Converters

Step-up converter has been popular in the last few years, especially for high voltage conversion on grid-connected PV systems. The voltage from PV array has to be stepped-up before transferred to the inverter on the grid-connected system. Many step-up converters have been modified to improve its performance. In [32], the conventional SEPIC converter has been modified by combining the Boost converter and diode-capacitor circuit as shown in Figure 1. This converter comprises the main switching device (S), three capacitors (C_1, C_2, and C_3), three diodes (D_1, D_2, and D_3), two inductors (L_1 and L_2), an output diode (D_0), and an output capacitor (C_0). The presence of the diode-capacitor circuit is able to reduce switching voltage stress on switching device (S). The output voltage from Boost converter is used to charges (C_2). Furthermore, the voltage from capacitor 2 (V_C2) is applied to the (L_2) during the conduction period of the switching device (S). This condition increases more voltage gain that is obtained when compared to the conventional step-up converters.

In this study, the performance of modified SEPIC [32] will be investigated and compared to conventional step-up converters. Boost converter is often used for the basic of the conventional step-up converter [33]. Boost converter circuit comprises an inductor, a diode, an output capacitor and the main switching device as shown in Figure 2 [34, 35].

Moreover, Single-Ended Primary Inductor Converter or called SEPIC converter is also often used to step-up DC voltage level. This converter consists of some components such as presented in Figure 3 [35-37]. The energy in SEPIC converter is transferred through capacitor (C_1) and inductor (L_1). Therefore, the switching voltage stress on SEPIC converter is higher than the Boost converter. Each component parameter on step-up converters is calculated by formulas respectively. The formulas of each step-up converter are shown in Table 1.
Table 1. Step-up Converters Formulas

| Parameters       | Boost Converter [35] | SEPIC Converter [35] | Modified SEPIC Converter [32] |
|------------------|----------------------|-----------------------|-----------------------------|
| Duty Cycle       | \(D = 1 - \frac{V_{in}}{V_{out}}\) | \(D = \frac{V_{out} + V_{in}}{V_{out}}\) | \(D = \frac{2V_{out} - 3V_{in}}{2V_{out} + V_{in}}\) |
| Inductance       | \(L_1 = \frac{V_{out} D}{\Delta L / f_s}\) | \(L_2 = \frac{V_{out} D}{\Delta L / f_s}\) | \(L_2 = \frac{V_{in} D}{\Delta L / f_s}\) |
| Capacitors       | \(C_1 = \frac{D}{R(\Delta V_{out} / V_{out})}\) | \(C_1 = \frac{D}{R(\Delta V_{out} / V_{out})}\) | \(C_1 = \frac{I_{out}}{\Delta V_{out} f_s}\) |

3. Grid-Connected PV Systems

The whole grid-connected PV systems comprise PV array, Step-up Converter with MPPT and PWM Generator, Three-Phase Inverter with Controller, Load, and Grid as shown in Figure 4 [38]. PV Array produces electricity from solar energy [39], and its performance is affected by various conditions such as irradiance level and ambient temperature [40]. For generating maximum power, MPPT is applied to grid-connected PV systems [41–43]. The MPPT inputs are current and voltage from PV array. The MPPT produces duty cycle as the input of PWM generator. PWM generator generates PWM signal for controlling switching device on the Step-up Converter. The Step-up Converter is used to increase DC voltage from PV array [44] so that input voltage of the inverter on grid-connected PV systems is fulfilled. This study focuses on investigating the performance of the step-up converter on grid-connected PV systems using modified SEPIC converter and further compared to Boost converter and SEPIC converter.
4. Modelling and Simulation Systems

4.1. PV Array Modelling

The maximum capacity of PV array generates 15 kWp power that consists of 60 PV modules. PV module uses type JAP6 60-250 3BB with maximum power 250 Wp is arranged in 10 series and 6 parallel as shown in Figure 5.

Modelled and simulated PV modules uses PSIM physical model of PV module by entering basic parameters from a datasheet that is shown in Table 2. The results of simulated PV module are presented respectively in Figures 6, 7, and 8.

| Parameters                      | Label   | Value         |
|---------------------------------|---------|---------------|
| Short Circuit Current           | \( I_{SC} \) | 8.92 A       |
| Open Circuit Voltage            | \( V_{DC} \) | 37.66 V      |
| Current at Pmax                 | \( I_{mpp} \) | 8.35 A       |
| Voltage at Pmax                 | \( V_{mpp} \) | 29.94 V      |
| Maximum Power                   | \( P_{mpp} \) | 250 W        |
| \( V_{OC} \) coef. of temperature | \( K_V \) | -0.33%/°C    |
| \( I_{SC} \) coef. of temperature | \( K_I \) | 0.058%/°C    |
| Cell in series per module       | \( N \) | 60           |

![Figure 5. The arrangement of PV modules](image)

![Figure 6. P-V Curve of PV module JAP6 60-250 3BB under various irradiance](image)

(a) Simulated PV module (b) Datasheet PV module
Figure 7. I-V Curve of PV module JAP6 60-250 3BB under various irradiance
(a) Simulated PV module (b) Datasheet PV module

Figure 8. I-V Curve of PV module JAP6 60-250 3BB under various ambient temperature
(a) Simulated PV module (b) Datasheet PV module

4.2. Modelling of Modified SEPIC Converter
Each parameter either the modified SEPIC converter or the other step-up converters is calculated based on formulas in Table 1 and its result are shown in Table 3.

| Parameters                  | Boost Converter | SEPIC Converter | Modified SEPIC Converter |
|-----------------------------|-----------------|-----------------|--------------------------|
| Input Voltage ($V_{in}$)    | 299.4 V         | 299.4 V         | 299.4 V                  |
| Output Voltage ($V_{out}$)  | 750 V           | 750 V           | 750 V                    |
| Switching Frequency ($f_s$) | 24 kHz          | 24 kHz          | 24 kHz                   |
| Duty Cycle ($D$)            | 0.6             | 0.715           | 0.334                    |
| Inductor 1 ($L_1$)          | 75 μH           | 223 μH          | 417 μH                   |
| Inductor 2 ($L_2$)          | -               | 223 μH          | 1.46 mH                  |
| Capacitor 1 ($C_1$)         | -               | 5.68 μF         | 6.2 μF                   |
| Capacitor 2 ($C_2$)         | -               | -               | 6.2 μF                   |
| Capacitor 3 ($C_3$)         | -               | -               | 6.2 μF                   |
| Output Capacitor ($C_0$)    | 66.67 μF        | 5.68 μF         | 37.1 μF                  |
In this study, the types of the components used in modified SEPIC converter, the Boost converter, and SEPIC converter are listed in Table 4. The types are determined based on parameters in Table 3 and matched with datasheet of each component.

| Components | Boost Converter | SEPIC Converter | Modified SEPIC Converter |
|------------|----------------|----------------|--------------------------|
| Power MOSFET (S) | APT60N60BCSG | APT60N60BCSG | APT60N60BCSG |
| Diodes (D) | DUR6060W | DUR6060W | DUR6060W |
| Inductor 1 \( (L_1) \) | HCS-850M-280A | HCS-301M-1000A | HCS-601M-500A |
| Inductor 2 \( (L_2) \) | - | HCS-301M-1000A | T6040S-R6123-X263 |
| Capacitor 1 \( (C_1) \) | - | - | - |
| Capacitor 2 \( (C_2) \) | - | - | - |
| Capacitor 3 \( (C_3) \) | - | - | - |
| Output Capacitor \( (C_0) \) | C4DEIPQ5680A8TK | B32754C3605K000 | C4AEHBW5400A3LJ |

The modified SEPIC converter on grid-connected PV systems is modelled and simulated using PSIM software to evaluate its performance and compared to the other step-up converters. The modified SEPIC converter receives input from PV array through input capacitor \( (C_{in}) \), while switching device is controlled by MPPT through PWM generator. The output from modified SEPIC converter is connected to three-phase inverter which is on the subcircuit afterwards. Figure 9 shows modelling circuit of modified SEPIC converter on PSIM software.

![Figure 9. Modelling circuit of modified SEPIC converter](image)

4.3. Modelling of Grid-Connected PV Systems

The whole modelling systems using PSIM software in this study are presented in Figure 10. The modified SEPIC converter is on subcircuit PV Source with PV array, an input capacitor, MPPT and PWM generator. The simulation parameters are listed in Table 5.

| Table 5. PSIM Simulation Parameters |
|-------------------------------------|
| PSIM Simulation Parameters           |
| Time Step                           | 2 µS |
| Total Time                          | 2.2 S |
| Print Time                          | 0.6 S |
| Print Step                          | 1   |
| Systems Parameters                  |
| Frequency Grid System               | 50 Hz |
| Voltage Grid System                 | 380 V |
| DC Link Voltage                     | 750 |

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5. Results and Analysis

The various conditions were applied to PV array. It was done to investigate the performance of modified SEPIC converter and compared to conventional step-up converters afterwards. The first test was by changing irradiance level on PV array. It was necessary to validate the performance of modified SEPIC converter due to PV array affected by the dynamic conditions such as irradiance level when generates electricity. Figure 11 shows the irradiance profile that was applied to PV array with a fixed ambient temperature of 25º C. The irradiance level was initially 800 W/m². At 1.2 s until 1.6 s, the irradiance level operated at 1000 W/m². However, it was decreased at 1.6 s became 600 W/m² and operate until 2.2 s.

The result from the first test presented in Figure 12 to investigate the output voltage of step-up converters respectively. It can be seen that irradiance change affected the performance of step-up converters. When Irradiance level increased, occurred disturbed on the output voltage so that diverge from 750 V. Boost converter and SEPIC converter were experienced voltage oscillations, while modified SEPIC converter capable was otherwise. The same condition also occurred at 1.6 s, more precisely when irradiance on PV array dropped. It can be observed, modified SEPIC converter was more capable of reducing voltage oscillations than other step-up converters. The results of this test validate the performance of modified SEPIC converter was suitable for grid-connected PV applications. The modified SEPIC converter was able to maintain high voltage gain although PV array received dynamic irradiance.
The performance of modified SEPIC converter was validated again by changing ambient temperature with constant irradiance. This investigation was to illustrate performance in dynamic behaviour although the real temperature in the world does not change fast. Figure 13 shows ambient temperature profile at irradiance level 1000 W/m$^2$. The ambient temperature was initially operated at 35º C and dropped becoming 20º C at 1 s. It condition changes again gradually to 45º C at 1.6 s and operates until 2.2 s.

The output voltage waveforms of step-up converters were given in Figure 14. From the result can be seen that the change of ambient temperature affected the stability of output voltage. Although at the steady-state condition, Boost converter and SEPIC converter still produced voltage oscillations. Its condition was different from modified SEPIC converter that was capable of reducing voltage oscillations in the steady-state condition. The same condition also occurs when the ambient temperature increased. At 1 s, the output voltage of conventional step-up converters experiences voltage oscillations, while the modified SEPIC converter able to the otherwise. The presence of voltage oscillations also occurs at the time ambient temperature increased up to caused Boost converter was experiencing overshoot. From this test, it can be observed that performance of modified SEPIC converter capable of reducing voltage oscillations than other step-up converters. Therefore, the quality of output voltage was increased and more suitable for the three-phase inverter input.

In order to confirm the performance of modified SEPIC converter, varying irradiance and ambient temperature was also applied to calculate the efficiency. Figure 15 shows the efficiency result obtained from this converter and compared to Boost converter and SEPIC converter. From the figures, it can be seen that modified SEPIC converter produced higher efficiency than other step-up converters both under varying irradiance and ambient temperature.

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**Figure 13. Changes of ambient temperature level for the PV array input**

**Figure 14. Comparison the output voltage of step-up converters under changes ambient temperature**

**Figure 15. Efficiency of step-up converters**

(a) under varying irradiance (b) under varying ambient temperature
Partial shading condition was also applied to PV array. Basically, its phenom was unavoidable and significantly capable of decreasing the efficiency and also disturbing the stability of PV systems. The pattern of partial shading in this test is presented in Figure 16. Initially, the PV array received irradiance 1000 W/m² and generated 15 kW power. However, the partial condition occurred at 0.8 s because 10 of 60 PV modules did not generate maximum power. Its condition caused the PV array power to drop becoming approximately 12 kW and lasted until 2.2 s.

![Figure 16. Test pattern of partial shading condition](image)

Partial shading condition was used to investigate output power from step-up converters under the transient condition. Figure 17 shows the characteristic of each step-up converter when partial shading occurred. The output power from Boost converter and SEPIC converter more dropped than modified SEPIC converter, and its effect on efficiency obtained. From this test, the modified SEPI converter was increasingly proved to have performed better than the other step-up converters under various conditions.

The power flow from PV systems under transient condition was also investigated as shown in Figure 18 to verify that the systems worked on grid-connected. In this test, PV systems generated 15 kW power. The initial load was 5 kW so that PV systems through the three-phase inverter supplied the remaining power to the grid 10 kW. When at 1 s until 1.6 s, there was an increase of load becoming 19.4 kW. Its condition caused PV systems insufficient to meet the load capacity. Therefore, the grid also supplied power 4.4 kW to suffice the load. Furthermore, the load dropped to 10 kW at 1.6 s. Its condition causes PV systems were capable of sufficing again the load capacity and distributing the remaining power to the grid. Based on this test, grid-connected PV systems using modified SEPIC converter work properly.

![Figure 18. Power flow grid-connected PV systems using modified SEPIC converter](image)
6. Conclusion

In this study, the modified SEPIC converter is implemented to the grid-connected PV system simulation using PSIM software for 15 kWp power rating. The modified SEPIC converter is developed by combining conventional SEPIC converter, Boost converter and diode-capacitor circuit. The conventional step-up converters are also implemented in this systems and compared to the performance of modified SEPIC converter which is tested under various conditions both irradiance and ambient temperature changes. For all tests, the modified SEPIC converter is more efficient and has high stability for maintaining static gain by rectifying the quality of output voltage.

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References

[1] Abdallah L, El-Shennawy T. Reducing Carbon Dioxide Emissions from Electricity Sector using Smart Electric Grid Applications. J Eng. 2013; 2013: 1–8.
[2] Hossain MS, Madloul NA, Rahim NA, Selvaraj J, Pandey AK, Khan AF. Role of Smart Grid in Renewable Energy: An Overview. Renew Sustain Energy Rev. 2016; 60: 1168–84.
[3] Kadali KS, Rajaji L. Evaluation of Energy in Wind Turbine System using Probability Distribution. Indonesian Journal Electrical Engineering Computer Science. 2018; 9(2): 294–298.
[4] Blaabjerg F. Future on Power Electronics for Wind Turbine Systems. IEEE J Emerg Sel Top Power Electron. 2013; 1(3): 139–152
[5] Fathabadi H. Novel Maximum Electrical and Mechanical Power Tracking Controllers for Wind Energy Conversion Systems. IEEE J Emerg Sel Top Power Electron. 2017; 5(4): 1739–1745.
[6] Chen F, Huangfu Y, Zhuo S, Xu L, Zhao D. Analysis and Control of a High Voltage Ratio and Low Stress DC-DC Converter for Fuel Cell Applications. 2017 IEEE International Conference on Industrial Technology (ICIT). Toronto. 2017: 42–47.
[7] Yang Y, Luo X, Dai C, Chen W, Li Q. Dynamic Modeling and Dynamic Responses of Grid-Connected Fuel Cell. Int J Hydrogen Energy. 2014; 39(26): 14296–14305.
[8] Li S, Haskew TA, Li D, Hu F. Integrating Photovoltaic and Power Converter Characteristics for Energy Extraction Study of Solar PV Systems. Renew Energy. 2011; 36(12): 3238–3245.
[9] Subiyanto, Mohamed A, Hannan M a. Intelligent Photovoltaic Maximum Power Point Tracking Controller for Energy Enhancement in Renewable Energy System. J Renew Energy. 2013; 2013: 1–9.
[10] Razzak MA, Bhuivian WT, Natasha NI, Islam AKMM. Design of a Grid-Connected Photovoltaic Inverter with Maximum Power Point Tracking using Perturb and Observe Technique. Int J Power Electron Drive Syst. 2016; 7(4): 1212–1220.
[11] Blaschke T, Biberacher M, Gadocha S, Schardinger I. ‘Energy Landscapes’: Meeting Energy Demands Andhuman Aspirations. Biomass and Bioenergy. 2013; 55: 3–16.
[12] Isen E, Bakan AF. 10 kW Grid-Connected Three-Phase Inverter System: Control Simulation and Experimental Results. 2012 3rd IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG). Denmark. 2012: 836–840.
[13] Prabaharan N, Palanisamy K. Analysis and Integration of Multilevel Inverter Configuration with Boost Converters in A Photovoltaic System. Energy Convers Manag. 2016; 128: 327–342.
[14] Alonge F, Pucci M, Rabbeni R, Vitale G. Dynamic Modelling of A Quadratic DC/DC Single Switch Boost Converter. Electr Power Syst Res. 2017; 152: 130–139.
[15] Sitbon M, Schacham S, Suntio T, Kuperman A. Improved Adaptive Input Voltage Control of A Solar Array Interfacing Current Mode Controlled Boost Power Stage. Energy Convers Manag. 2015; 98: 369–375.
[16] Abuorrahah A, Al-Hindawi MM, Al-Turki Y, Mandel K, Giaouris D, Banerjee S, et al. Stability of A Boost Converter Fed From Photovoltaic Source. Sol Energy. 2013; 98(PCM): 458–471.
[17] Du Y, Lu DDC. Battery-Integrated Boost Converter Utilizing Distributed MPPT Configuration for Photovoltaic Systems. Sol Energy. 2011; 85(9): 1992–2002.
[18] Marrekchi A, Kammoun S, Sallem S, Kammoun MBA. A Practical Technique for Connecting PV Generator to Single-Phase Grid. Sol. Energy. 2015; 118: 145–154.

[19] Maksimovic D, Cuk S. Switching Converters with Wide DC Conversion Range. IEEE Trans Power Electron. 1991; 6(1): 151–157.

[20] Diaz-Saldaña JA, Leyva-Ramos, J, Ortiz-Lopez MG. Switching Regulator using A Quadratic Boost Converter for Wide DC Conversion Ratios. IET Power Electron. 2009; 2(5): 605–613.

[21] Al-Saffar MA, Ismail EH. A High Voltage Ratio and Low Stress DC-DC Converter with Reduced Input Current Ripple for Fuel Cell Source. Renew Energy. 2015; 82: 35–43.

[22] Freitas AAA, Antunes FLM, Daher S, Sá Júnior EM, Tofoli FL. High-Voltage Gain DC–DC Boost Converter with Coupled Inductors for Photovoltaic Systems. IET Power Electron. 2015; 8(10): 1885–92.

[23] Wai RJ, Lin CY, Duan RY, Chang YR. High-Efficiency DC-DC Converter with High Voltage Gain and Reduced Switch Stress. IEEE Trans Ind Electron. 2007; 54(1): 354–364.

[24] Zhao Y, Li W, He X. Single-Phase Improved Active Clamp Coupled-Inductor-Based Converter with Extended Voltage Doubler Cell. IEEE Trans Power Electron. 2012; 27(6): 2869–2878.

[25] Yang L, Liang T, Lee H, Chen J. Novel High Step-up DC – DC Converter with Coupled Inductor and Voltage Doubler Circuits. IEEE Trans Ind Electron. 2011; 58(9): 4196–4206.

[26] Girál R, Martinez-Saladero L, Leyva R, Maixe J. Sliding-Mode Control of Interleaved Boost Converters. IEEE Trans Circuits Syst. 2000; 47(9): 1330–1339.

[27] Fernández-Pires V, Fito D, Baptista FRB, Fernando Silva J. A Photovoltaic Generator System with A DC/DC Converter Based On An Integrated Boost-Cuk Topology. Sol. Energy. 2016; 136: 1–9.

[28] Pires VF, Fito D, Silva JF. A Single Switch Hybrid DC/DC Converter with Extended Static Gain for Photovoltaic Applications. Electr Power Syst Res. 2017; 146: 228–235.

[29] Gules R, Dos Santos WM, Dos Reis FA, Romaneli EFR, Badin AA. A Modified SEPIC Converter with High Static Gain for Renewable Applications. IEEE Trans Power Electron. 2014; 29(11): 5860–5871.

[30] De Melo PF, Gules R, Romanelli EFR, Annunziato RC. A Modified SEPIC Converter for High Power-Factor Rectifier and Universal Input Voltage Applications. IEEE Trans Power Electron. 2010; 25(2): 310–321.

[31] Saravanan S, Ramesh Babu N. Analysis and Implementation of High Step-up DC-DC Converter for PV Based Grid Application. Appl Energy. 2017; 190: 64–72.

[32] Saravanan S, Babu NR. Design and Development of Single Switch High Step-up DC-DC Converter. IEEE J Emerg Sel Top Power Electron. 2017; 6(2): 855-863.

[33] Saravanan S, Babu NR. A Modified High Step-Up Non-Isolated DC-DC Converter for PV Application. J Appl Res Technol. 2017; 15(3): 242–249.

[34] Hauke B. Basic Calculation of a Boost Converter’s Power Stage. Texas Instruments, Appl Rep Novemb. 2009; (November 2009); 1–9.

[35] Daniel WH. Power Electronics. Indiana: McGraw-Hil. 2011: 144-150.

[36] Fajín J. Designing DC / DC Converters Based on SEPIC Topology. Analog Appl J. 2008; 18–23.

[37] Kircioglu O, Unlü M, Çamur S. Modeling and Analysis of DC–DC SEPIC Converter with Coupled Inductors. 2016 International Symposium on Industrial Electronics, INDEL 2016 - Proceedings. Bosnia Herzegovina. 2016: 1-5.

[38] Saad NH, El-Sattar AA, Mansour AEAM. Improved Particle Swarm Optimization for Photovoltaic System Connected to The Grid With Low Voltage Ride Through Capability. Renew Energy. 2016; 85: 181–94.

[39] Phannil N, Jettanasen C. Ngaopitakkul A. Power Quality Analysis of Grid Connected Solar Power Inverter. 2017 IEEE 3rd Int Futur Energy Electron Conf ECCE Asia (IFEEC 2017 - ECCE Asia). Taiwan. 2017: 1508–1513.

[40] Islam MN, Rahman MZ, Mominuzzaman SM. The Effect of Irradiation on Different Parameters of Monocrystalline Photovoltaic Solar Cell. 3rd International Conference on the Developments in Renewable Energy Technology (ICDRET). Bangladesh. 2014: 1-6.

[41] Bin Jusoh A, Ibrahim Mohammed OJE, Sutikno T. Variable Step Size Perturb and Observe MPPT for PV Solar Applications. TELKOMNIKA (Telecommunication Comput Electron Control). 2015; 13(1): 1–12.

[42] Killi M, Samanta S. Modified Perturb and Observe MPPT Algorithm for Drift Avoidance in Photovoltaic Systems. IEEE Trans Ind Electron. 2015; 62(9): 5549–5559.

[43] Belkaid A, Colak I, Isik O. Photovoltaic Maximum Power Point Tracking under Fast Varying of Solar Radiation. Appl Energy. 2016; 179: 523–530.

[44] Sreedhar M, Panigrahi CK, Dasgupta A, Pati J. A New Advanced Topology for Photo Voltaic Applications. Int J Appl Power Eng. 2015; 4(1): 23–29.