Indian Journal of Science and Technology, Vol 8(15), 61428, July 2015
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Performance Analysis of Transformer-Less Two Phase Interleaved High Gain DC Converter using MPPT Algorithm

M. Kavitha* **and V. Sivachidambaranathan**

Department of Electrical Electronics Engineering, Sathyabama University, Chennai - 600119, Tamil Nadu, India; kaveem@gmail.com, sivachidambaram_eee@yahoo.com

Abstract

Objectives: The performance of parallel input and series output configured interleaved high gain DC converter using MPPT algorithm is analyzed. **Methods**: The output power of PV varies due to change in temperature and irradiation levels. This reduces the conversion efficiency. Hence, Perturb and Observe (P&O) algorithm is used to achieve maximum power from PV panel with suitable duty ratio and also improves efficiency. The simulations are carried out using MATLAB/SIMULINK to validate the operation and effectiveness of the converter using MPPT algorithm**. Results**: The transformer-less two phase interleaved converter not only produces high output voltage but also reduces voltage stress of active switches. The simulation results for the converter using P&O algorithm is presented in this paper. The various parameters such as output current, output voltage and output power of the transformer-less two phase interleaved DC converter were compared with and without MPPT. **Conclusion and Application**: The converter with MPPT produces an output of 248.2 W which is 1.1 times that of converter without MPPT. Thus, the two phase's interleaved DC converter with MPPT shows better performance and can be used for standalone applications.

Keywords: High Step-Up Voltage Gain Converter, MPPT Algorithm, Photovoltaic, Transformerless

1. Introduction

The photovoltaic is the most promising renewable energy source due to its merits such as infinite power, pollution free and available in abundance. However, the output of photovoltaic is low and has to be boosted. High step up DC-DC converter plays a major role in renewable energy applications that includes photovoltaic system, fuel cell, grid system, electric vehicle applications, etc. Due to build in low voltage characteristics of photovoltaic, high step up DC-DC converter is used. The conventional boost converter with high duty ratio causes switching and conduction losses. Hence the conventional boost converter is not preferred. By using transformer with large turns ratio, high step up conversion can be achieved by isolated converters. But due to large turn's ratio, the leakage inductance is high, voltage and current spikes increases. An isolated converter requires large filter as the input current is pulsed[2–5]. Coupled inductor can achieve high step up conversion ratio, but has high voltage stress, reverse-recovery problem and decreases the conversion efficiency[6,7]. To solve the problems of coupled inductor various methods are used.

High voltage conversion ratio is achieved using switched capacitor[8–11]. But needs large number of switches and leads to complex control strategies[12]. The design rules are proposed for high efficient switched capacitor converters by C. Chun-Kit, T. Siew-Chong, et al.[13] The switching losses and EMI are reduced by using soft switching technique for switched converter topologies[14–16]. A family of interleaved DC-DC converter with winding cross coupled inductor and voltage multiplier cells is proposed in[17–19]. Interleaved converter

* Author for correspondence

with voltage doubler characteristics and converter with MPPT technique is proposed in[20,21]. The transformer-less two phase interleaved DC-DC converter with high voltage gain without large duty cycle and reduced voltage stress is proposed by Ching-Tsai Pan, Chen-Feng, Chuang, Chia-Chi Chu[1].

In this paper, input parallel output series configured interleaved DC-DC converter is proposed for photovoltaic system using MPPT algorithm. The output power of photovoltaic cell varies with respect to temperature and irradiation and reduces the conversion efficiency. Thus continuous tracking of maximum power point is necessary to maximize output power of photovoltaic. To make efficient, MPPT algorithm is used to extract maximum output power from photovoltaic panel. An overview of MPPT algorithm has been proposed by Mohamed A. Eltawil, Zhengming Zhao[22]. The modified perturb and observe algorithm for photovoltaic system is proposed in[23]. These methods are based on various factors such as complicacy, cost, hardware implementation and faster convergence. Though several MPPT methods are proposed, perturb and observe has more advantages due to its simplicity and operation under dynamic and static condition. Thus, in this paper transformer-less interleaved boost converter using Perturbs and Observes (P&O) to extract maximum output power with proper duty cycle is proposed. In this paper, Section II describes the operating principle of proposed input parallel output series configured interleaved DC-DC converter. In Section III, PV modeling and MPPT algorithm are discussed. The simulation of transformer-less interleaved converter with and without MPPT are discussed in Section IV. The conclusion is summarized in Section V.

2. Transformerless Interleaved Converter

The proposed interleaved converter consists of two inductors L_1 and L_2 with active switched S_1 and S_2 across the output of photovoltaic panel as shown in Figure 1. The diodes and blocking capacitors are used to store part of the energy of inductor and this stored energy is begin transferred to the output capacitors C_1 and C_2 to achieve high voltage gain. The proposed converter produces uniform current sharing through the inductor which eliminates the usage of additional circuitry and also complicated control methods.

In order to avoid the pulsating output period, the duty cycle of the proposed converter is made greater than 0.5 and also operated in continuous conduction mode. If the converter operates with duty cycle less than 0.5, then the voltage gain cannot be improved as it is not possible for the inductor (L_1,L_2) to transfer energy to blocking capacitors (C_{b1},C_{b2}), output capacitors (C_1,C_2) and load. In addition, with duty cycle less than 0.5, the uniform current sharing cannot be achieved.

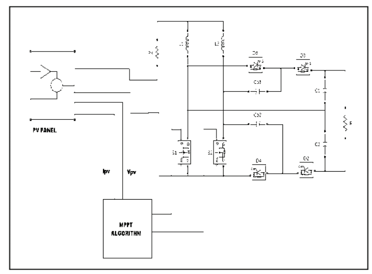

Figure 1. Transformerless interleaved DC converter.

The proposed model consists of PV panel, MPPT Perturb and Observe algorithm and transformer-less interleaved converter. The P&O algorithm used to extract maximum power from the PV panel and decides proper duty ratio for the converter. The converter has four modes of operation.

2.1 Mode 1

The switches S_1 and S_2 are turned ON and diodes D_1, D_2, D_3, D_4 are turned off. In this mode, energy is stored in inductor L_1 and L_2 due to increasing current i_{L1} and i_{L2}. The diodes D_1 and D_4 voltages are clamped to blocking capacitor C_{b1} and C_{b2} voltages.

Voltage across diode D_2, $V_{d2} = V_{c2} - V_{b2}$. (1)

Voltage across diode D_3, $V_{d3} = V_{c1} - V_{b1}$. (2)

2.2 Mode 2

The active switches S_1 is turned ON and S_2 is turned off. Stored energy of blocking capacitor C_{b1} and part of energy stored in inductor L_2 is delivered to output capacitor C_1 and load. At the same time, part of energy stored in inductor is delivered to C_{b2}. In this mode,

$$V_{c3} = V_{b1} - V_{b2}. \quad (3)$$

Hence inductor current i_{L1} increases and i_{L2} decreases.

2.3 Mode 3
The mode 3 is similar to mode 1 operation.

2.4 Mode 4
The active switches S_2 is turned ON and S_1 is turned off. The stored energy of blocking capacitor C_{b2} and part of energy stored in inductor L_1 is delivered to output capacitor C_2 and load. At the same time, the part of energy stored in L_1 is delivered to C_{b1}. Therefore

$$V_{c2} = V_{b1} + V_{b2}. \quad (4)$$

In this mode, current i_{L2} increases and i_{L1} decreases.

2.4.1 Analysis of Parameters

The various parameters[1] to analyze the proposed transformer-less interleaved converter are as follows.

2.4.1.1 Voltage Gain

Voltage gain of the interleaved boost converter is defined as the ratio of output voltage to input voltage. The voltage across output capacitor is given by

$$V_{c1} = V_{b1} + V_{b2} = 2\frac{V_i}{1-D} \quad (5)$$

$$V_{c2} = V_{b1} + V_{b2} = 2\frac{V_i}{1-D} \quad (6)$$

From (5) and (6), the output voltage is given by

$$V_o = V_{c1} + V_{c2} = 4\frac{V_i}{1-D} \quad (7)$$

Therefore, the voltage gain= $\frac{V_o}{V_i} = \frac{4}{1-D}$ (8)

2.4.1.2 Voltage Stresses on Active Switches

By neglecting the voltage ripples of capacitors, the voltage stress on active switches S_1 and S_2 are given by

$$V_{s1} = V_{s2} = \frac{V_i}{1-D} \quad (9)$$

By substituting (7) in (9), the voltage stress on active switches is given by

$$V_{s1} = V_{s2} = \frac{V_o}{4} = 0.25V_o \quad (10)$$

From (10), the voltage stress of active switches is 0.25 times that of output voltage. Thus, one can choose low voltage rating power devices to reduce conduction and switching losses. The voltage stress diodes D_1, D_2, D_3 and D_4 are given by

$$V_{D1} = V_{D2} = V_{D3} = \frac{V_o}{2} \quad (11)$$

$$V_{D4} = \frac{V_o}{4} \quad (12)$$

2.4.1.3 Uniform Current Sharing

The current through the inductor are uniform and given by

$$I_{L1} = I_{L2} = \left(\frac{2}{1-D} + \frac{DC_{b1}}{(1-D)C_1}\right)I_o \quad (13)$$

Where C_1=C_2 and C_{b1}=C_{b2}.

3. PV Modeling and MPPT Algorithm

3.1 Modeling of PV
Figure 2 shows the mathematical model of photovoltaic cell. It is represented as current source I_{pv} connected parallel with the diode D and resistance R_{sh}. The diode D represents the PN junction of the solar photovoltaic cell, I_{pv} represents the generated current of photovoltaic, R_{sh} is the shunt resistance whose value is high to eliminate leakage current between growund and solar cell and R_{se} is the series resistance which includes the resistance of the metal links.

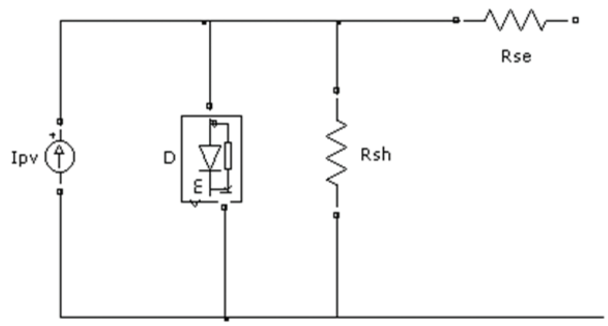

Figure 2. Photovoltaic Model.

The output current of the solar photovoltaic cell is given by

$$I = I_{pv} - I_d - I_{sh} \tag{14}$$

where I_{pv} is the generated current of photovoltaic cell.

I_d is the diode current.

I_{sh} is the current through shunt resistance.

$$I = I_{pv} - I_s(\exp\frac{q(V + R_s I)}{NkT} - 1) - \frac{(V + R_s I)}{R_{sh}} \tag{15}$$

where I_s is the reverse saturation current of diode.

q is electron charge, $1.6\text{x}10^{-9}$C.

V is the voltage across diode.

T is the photovoltaic cell temperature, K.

3.2 MPPT Algorithm

Perturb and Observe (P&O) is the simplest algorithm out of all the other MPPT methods. The method of perturbation is used in the algorithm to find the maximum point and it's an iterative method. By adjusting the operating voltage of photovoltaic, the output power is either increased or decreased.

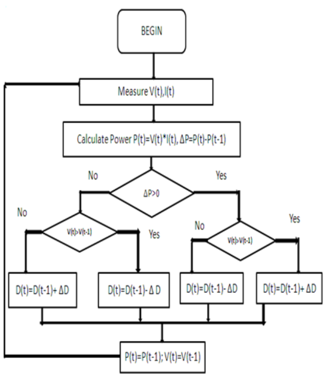

Figure 3. Flowchart of perturb and obeserve algorithm.

Figure 3 shows the flowchart of perturb and observe algorithm. In this algorithm, the voltage and current of the PV panel are measured. The duty cycle of the converter is initialized. Let P(t) be the power of the instant and P(t-1) be the power of (t-1)th instant. The change in power ΔP is calculated. If the change in power ΔP is positive and the difference between voltages at tth and (t-1)th instant is positive, then the duty cycle is increased and if the voltage comparison is negative then duty cycle is decreased. If the change in power ΔP is negative and the voltage comparison is positive then the duty cycle is increased otherwise decreased. The duty cycle varies based on the output power of the PV panel.

4. Simulation Circuit and Results

The simulation results of transformer-less interleaved converter without and with MPPT are explained.

4.1 Simulation Results of Tranformerless Interleaved converter without MPPT

Figure 4 shows the simulation diagram of the transformer-less interleaved converter without MPPT. The PV panel supplies voltage to the converter. The simulation diagram of PV panel consists of current source, diode and resistance. The output of PV panel is 27V and current varies with irradiance. Figure 5 shows the output voltage and current of PV panel without MPPT.

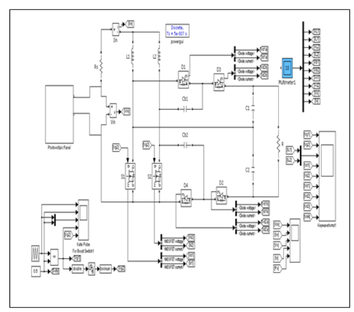

Figure 4. Simulation circuit of transformerless interleaved converter without MPPT.

The output of PV panel is given to converter. The simulation circuit of converter consists of MOSFET switches (S_1,S_2), diodes (D_1,D_2,D_3,D_4), blocking capacitor (C_{b1},C_{b2}) and output capacitors (C_1 and C_2). The duty ratio of both switches S_1 and S_2 are equal to 0.5 and the switching frequency is given as 40 kHz. Figure 6 shows the gate pulse of switches S_1 and S_2 and the waveform of the inductor current. The inductor current ripples (ΔI_{L1} and ΔI_{L2}) are found to be 1.1A. Figure 7 shows the waveform of voltage stress of the active switches without MPPT. The voltage stress of switch is 55V and it is found to be one fourth of the output voltage.

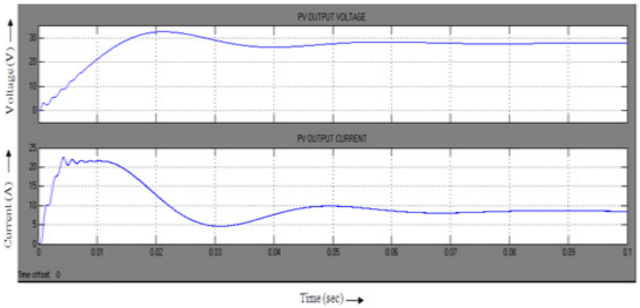

Figure 5. Waveforms of PV panel output voltage and current without MPPT.

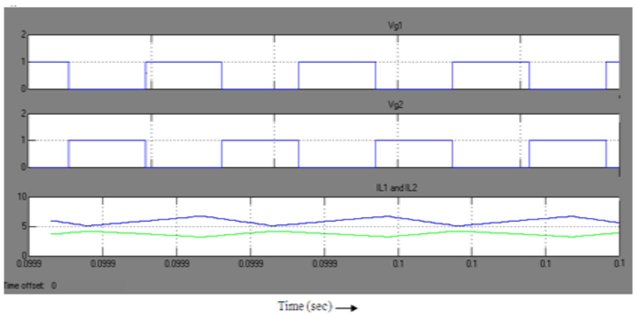

Figure 6. Gate pulse of switches and input current of inductor without.

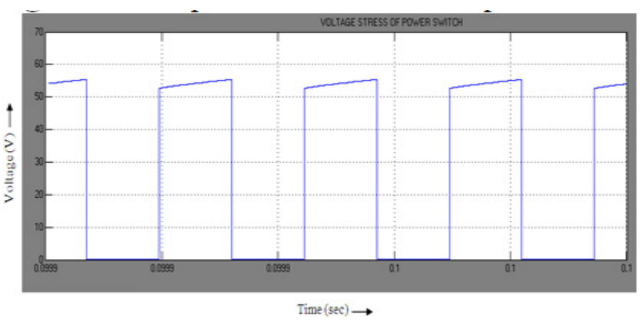

Figure 7. Voltage stress waveform of switch without MPPT.

Figure 8 shows the diode D_1, D_2, D_3 and D_4 voltage stress waveform. The voltage stress of diodes D_1, D_2 and D_3 is 100V and voltage stress of diode D_4 is 55V. Figure 9 shows the waveform of blocking capacitor voltage stress. The voltage stress of blocking capacitor is 54.5V, which is found to be one fourth of output voltage of the converter. Figure 10 shows the waveform of output capacitor voltage stress. The voltage stress V_{c1} and V_{c2} of the output capacitor is 106V and found to be half of the output voltage of the converter.

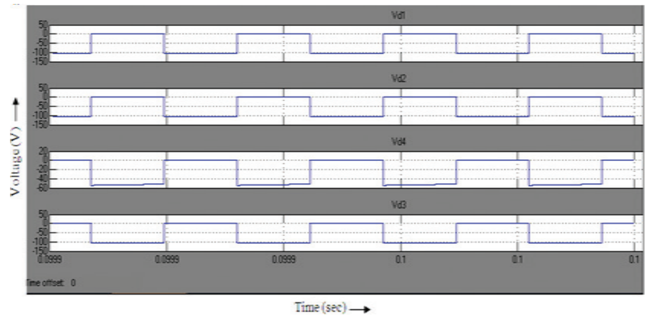

Figure 8. Diode voltage stress waveform without MPPT.

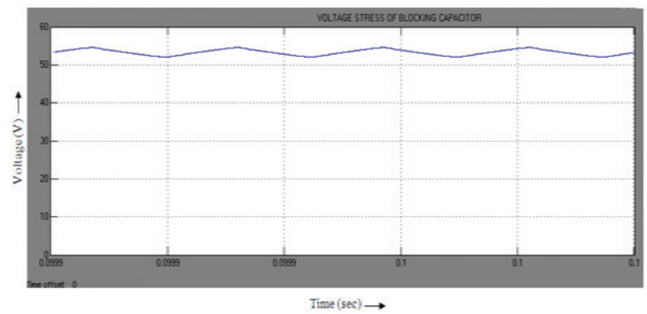

Figure 9. Blocking capacitor voltage stress waveform without MPPT.

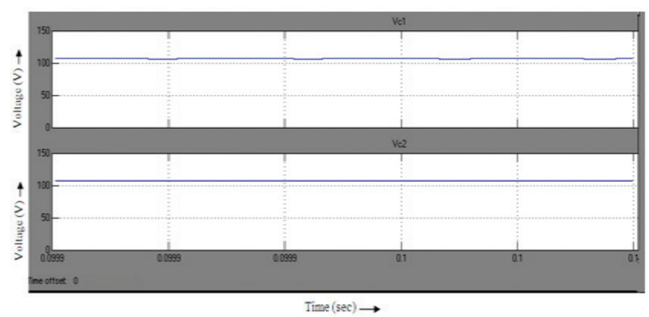

Figure 10. Output capacitor voltage stress waveform without MPPT.

The input voltage 27V is step up to 213V using converter with the voltage gain of 8 and duty ratio 0.5. The output current and power of converter supplied to the load is 1.065A and 226.6W respectively. Figure 11 shows the waveform of output current, voltage and power of supplied to the load.

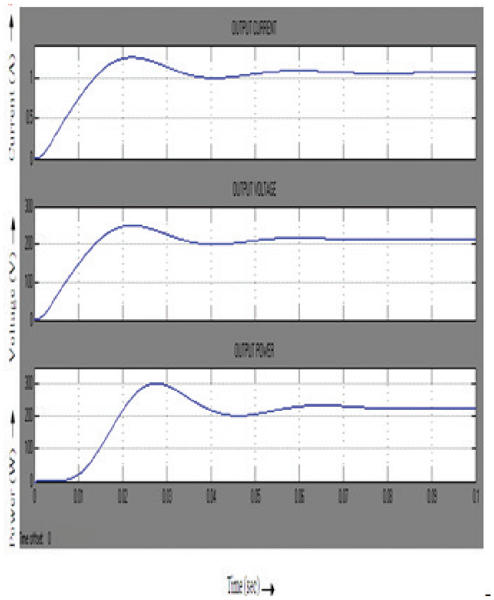

Figure 11. Waveform of output current, voltage and power of transformerless interleaved converter without MPPT algorithm.

4.2 Simulation Results of Tranformer-Less Interleaved Converter with MPPT

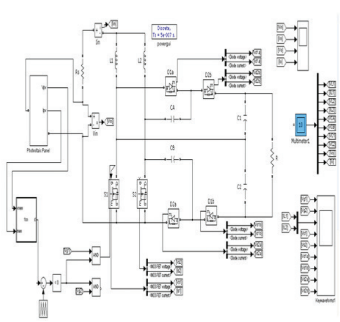

Figure 12. Simulation circuit of transformerless interleaved converter with MPPT algorithm.

The simulation circuit of transformer-less interleaved converter with MPPT is shown in Figure 12. The perturb and observe algorithm is coded in embedded MATLAB function. The input voltage and current of PV panel is given to MPPT algorithm. The range of duty cycle is assigned between 0.5 and 0.85. Based on the change in power and voltage, the duty cycle is varied and PWM signals are given to active switches S_1 and S_2 of the converter.

Figure 13 shows the output voltage and current of PV panel. The output voltage of PV panel is 28V. The gate pulse of switches and input current of inductor is shown in Figure 14. The input inductor current I_{L1} varies between 4.25A and 4.75A and I_{L2} between 4.25A and 3.75A. Therefore, input current ripples of inductor are 0.5A. The waveform of voltage stress of the active switches with MPPT is shown in Figure 15. The voltage stress of switch is 45V and it is found to be one fourth of the output voltage.

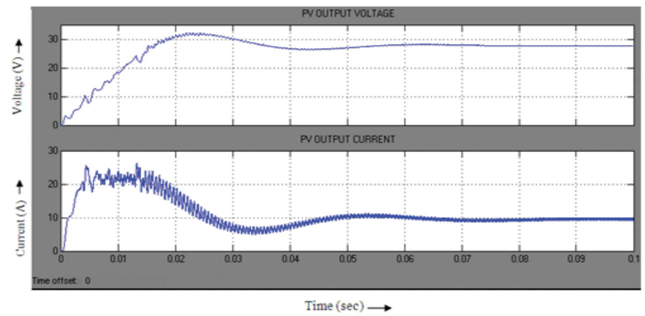

Figure 13. Waveforms of PV panel output voltage and current with MPPT.

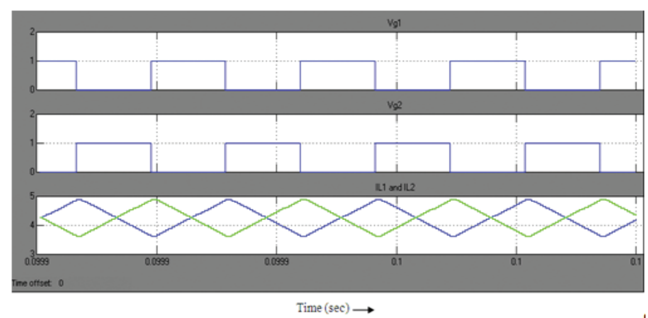

Figure 14. Gate pulse to switches and input current of inductor with MPPT.

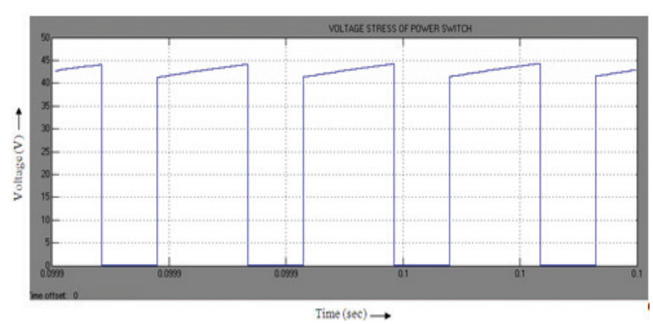

Figure 15. Voltage stress waveform of switch with MPPT.

Figure 16 shows the diode D_1, D_2, D_3 and D_4 voltage stress waveform with MPPT. The voltage stress of diodes D_1, D_2 and D_3 is 100V and voltage stress of diode D_4 is 40V. Figure 17 shows the waveform of blocking capacitor voltage stress. The voltage stress of blocking capacitor is 43V. Figure 18 shows the waveform of output capacitor voltage stress with MPPT. The voltage stress of the output capacitor is 111.52V and found to be half of the output voltage of the converter.

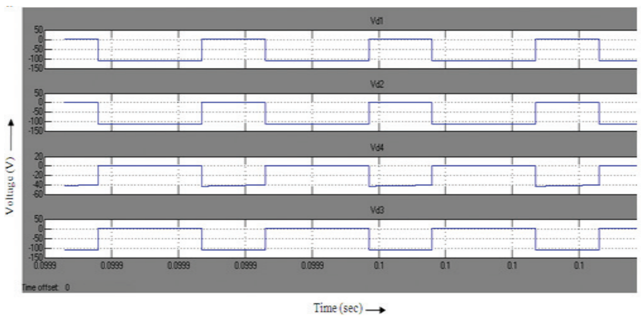

Figure 16. Diode voltage stress waveform with MPPT.

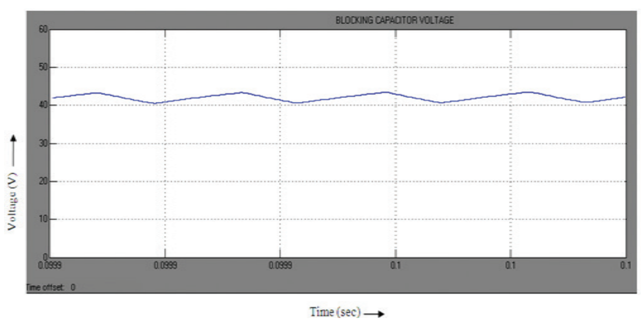

Figure 17. Blocking capacitor voltage stress waveform with MPPT.

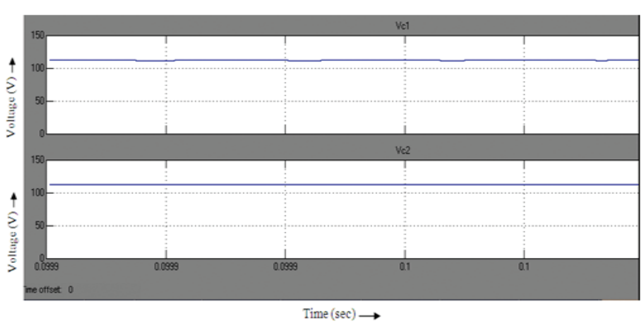

Figure 18. Output capacitor voltage stress waveform with MPPT.

Figure 19 shows the waveform of output current, voltage and power of transformer-less interleaved converter with MPPT. The input voltage 28V is step up to a voltage of 223V using converter with MPPT. The output current and power of converter to the load is 1.11A and 248.2W respectively. The comparison of transformer-less interleaved converter with and without MPPT is tabulated in Table 1. The parameters such as voltage stress of active switches, inductor current ripples, output power, output voltage and output current are compared. The transformer-less interleaved converter with MPPT extracts maximum power of 248.2W. Thus, the output power of converter is 21.6W greater than that of converter without MPPT.

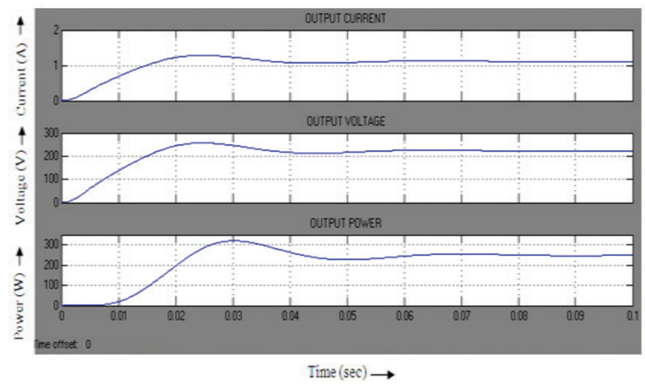

Figure 19. Waveform of output current, voltage and power of transformerless interleaved converter with MPPT.

Table 1. Comparision of Transformer-Less Interleaved Converter with and without MPPT

Parameters	With MPPT	Without MPPT
Input current ripples of inductor (Amp)	0.5	1.1
Voltage stress of active switches (Volt)	45	55
Output voltage of converter(Volt)	223	213
Output current of converter(Amp)	1.11	1.065
Output power of converter(Watt)	248.2	226.6

5. Conclusion

In this paper, the input parallel output series configured transformer-less interleaved converter with and without MPPT algorithm are compared. The various parameter such as input current ripples of inductor, voltage stress of active switches, converter output current, voltage and power are analyzed. The blocking capacitor voltage and output capacitor voltage of interleaved converter with and without MPPT is found to be one fourth and one half of output voltage respectively. However, perturb and observe MPPT algorithm provides proper duty ratio to the active switches of converter to achieve a power output of 248.2W which is 1.1 times that of converter output power without MPPT. Thus, comparing the simulation results of converter with and without MPPT, we conclude that with MPPT the converter inductor input current ripples is reduced to 0.6A, the voltage stress of active switches is reduced to 10V. The converter with MPPT also increases the output current to 0.045A, the output voltage to 10V and output power to 21.6W. Thus, the proposed converter with MPPT shows better performance.

6. References

1. Pan C-T, Chuang C-F, Chu C-C. A novel transformer-less adaptable voltage quadrupler DC converter with low switch voltage stress. IEEE Trans Power Electron. 2014 Sep; 29(9):4787–96.
2. Hyungjoon K, Changwoo Y, Sewan C. An improved current-fed ZVS isolated boost converter for fuel cell applications. IEEE Trans Power Electron. 2010; 25(9):2357–64.
3. Park K-B, Kim C-E, Moon G-W, Youn M-J. PWM resonant single-switch isolated converter. IEEE Trans Power Electron. 2009; 24(8):1876–86.
4. Sivachidambaranathan V, Dash SS. Closed loop controlled LLC half bridge isolated series resonant converter. International Journal of Information and Electronics Engineering. 2011 Nov; 1(3).
5. Jang Y, Jovanovic M. M. New two-inductor boost converter with auxiliary transformer. IEEE Trans Power Electron. 2004 Jan; 19(1):169–75.
6. Dwari S, Parsa L. A novel high efficiency high power interleaved coupled-inductor Boost DC-DC converter for hybrid and fuel cell electric vehicle. Vehicle Power and Propulsion Conf; 2007. p. 399–404.
7. Wai R-J, Duan R-Y. High step-up converter with coupled-inductor. IEEE Trans Power Electron. 2005; 20(5):1025–35.
8. Prudente M, Pfitscher LL, Emmendoerfer G, Romaneli EF, Gules R. Voltage multiplier cells applied to non-isolated DC-DC Converters.IEEE Trans Power Electron. 2008 Mar; 23(2):871–87.
9. Zhang F, Du L, Peng FZ, Qian Z. A new design method for high power high-efficiency switched-capacitor DC-DC converters. IEEE Trans Power Electron. 2008 Mar; 23(2):832–40.
10. Ismail EH, Al-Saffar MA, Sabzali AJ, Fardoun AA. A family of single-switch PWM converters with high step-up conversion ratio. IEEE Trans Circuits Syst. 2008 May; 55(4):1159–71.
11. Axelrod B, Berkovich Y, Ioinovici A. Switched-capacitor/switched-inductor structures for getting transformerless hybrid DC-DC PWM converters. IEEE Trans Circuits Syst. 2008 Mar; 55(2):687–96.
12. Li W, Xiang X, Li C, Li W, He X. Interleaved high Step-Up ZVT converter with built-in transformer voltage doubler cell for distributed PV generation system. IEEE Trans Ind Electron. 2013 Jan; 28(1):300–13.
13. Chun-Kit C, Siew-Chong T, Tse CK, Ioinovici A. On energy efficiency of switched-capacitor converters. IEEE Trans Power Electron. 2013 Feb; 28(2):862–76.
14. Ke Z, Scott MJ, Jin W. Switched-Capacitor-Cell-Based voltage multipliers and DC-AC inverters. IEEE Trans Ind Appl 2012 Sep/Oct; 48(5):1598–609.
15. Lei Y, Pilawa-Podgurski RCN. Analysis of Switched-capacitor DC-DCConverters in Soft-charging Operation. Proceedings of IEEE 14thWorkshop Control Model. Power Electron; 2013. 1–7.
16. Barreto LHSC, Praca PP, Oliveira DS, Silva RNAL. High-Voltage gain boost converter based on three-state commutation cell for battery charging using PV panels in a single conversion stage. IEEE Trans Power Electron. 2014 Jan; 29(1):150–8.
17. Li W, He X. A family of interleaved DC/DC Converters deduced from a basic cell with winding-cross-coupled inductors (WCCIs) for high step-up or step-down conversions. IEEE Trans Power Electron. 2008 Jul; 22(4):1499–507.
18. Li W, He X. ZVT interleaved boost converters for high-efficiency, high-step-up DC/DC conversion. IET-Elect Power Appl. 2007 Mar; 1(2):284–90.
19. Li W, Zhao Y, Wu J, He X. Interleaved high step-up converter with winding-cross-coupled inductors and voltage multiplier cells. IEEE Trans Power Electron. 2012 Jan; 27(1):133–43.
20. Jang T, Jovanovic MM. Interleaved boost converter with intrinsic voltage-doubler characteristic for universal-line PFC front end. IEEE Trans on Power Electron. 2007 July; 22(4):1394–401.
21. Ramesh Babu A, Raghavendiran TA. Performance enhancement of high voltage gain two phase interleaved boost converter using MPPT algorithm. Journal of Theoretical and Applied Information Technology. 2014 Oct; 68(2).
22. Eltawil MA, Zhao Z. MPPT techniques for photovoltaic application. Renewable and Sustainable Energy Reviews. 2013; 25:793–813.
23. Rezvani A, Izadbakhsh M, Gandomkar M, Vafaei S. Investigation of ANN-GA and modified perturb and observe mppt techniques for photovoltaic system in the grid connected mode. Indian Journal of Science and Technology. 2015 Jan; 8(1):87–95.