IJCTA, 9(31), 2016, pp. 129-138 ISSN: 0974-5572

Investigation of Enhanced DC-DC Converter for Renewable Energy Applications

Vinoth Kumar P.*, Suresh A. and Rashmi M.R.*****

ABSTRACT

The renewable resources are boundless but they require suitable converters for effectual power transfer. The effortlessly available energy resources are solar and wind energy and they must be utilized properly by boosting the voltage since at low irradiance and low wind speed the voltage gain obtained by the boost converters are low. This work proposes an enhanced DC-DC interleaved boost converter (IBC) for renewable energy system. The comparison of conventional IBC and IBC with voltage multiplier when connected with the solar and wind system is analyzed. The traditional IBC when connected with the renewable sources does not yield the maximum output voltage due to the switching losses and complex control techniques and the same time the proposed converter must not be in complex in control and size. Hence the traditional IBC modified with the additional capacitor and diode improves voltage gain with the reduced voltage stress and multiplying output voltage. When connected with the solar and wind energy systems the input is unstable, so higher stability output voltage of the converter is achieved with the closed loop control for different load conditions. The proposed system is simulated for solar and wind energy systems using MATLAB/Simulink. The voltage gain obtained was 87.5 % higher than the conventional IBC and the evaluation of open loop and closed loop for IBC with voltage multiplier was performed. The interleaved boost converter with the voltage multiplier gives high output voltage which can be used for standalone applications within the agriculture water pumping, high intensity discharge lamps, residential electrification and electric vehicles.

Keywords: Interleaved boost converter (IBC), voltage multiplier, voltage gain, higher stability, voltage stress

1. INTRODUCTION

The electrical energy available in renewable energy is not suitable for direct use in many applications. The extracting maximum power from the solar system depends on the proper utilization of DC to DC converter and power transfer from the critical input AC to DC converter in wind applications where power rating exceeding in kilowatts can be efficiently done with DC- DC Boost converter.

The EMI is caused because of voltage step up on DC to DC power converters due to improper switching and high current ripple. There are multiple techniques such as soft switching techniques and advanced PWM techniques are employed for improving the efficiency. The alternative to the bidirectional DC–DC converter in high power applications with the soft switching technique reducing the current stress at transformer and switches are achieved in [1] [2]. EMI mitigation in portable charger that produced by the DC-DC converter was proposed in [3] [4]. Though the ZCS- PWM interleaved forward converter with interleaved operation increase the output power and decrease the output ripple proposed in [5], certain assumptions have to be made and harder in analysis.

* Research Scholar, Dept. of Electrical & Electronics Engineering, St. Peter's University, Chennai, *Email: vinothkumarktp@gmail.com*

** Professor, Dept. of Electrical & Electronics Engineering, S.A. Engineering College, Chennai, *Email: asuresz@gmail.com*

*** Associate Professor, Dept. of Electrical & Electronics Engineering, Amrita Vishwa Vidyapeetham, Amrita School of Engineering, Bangalore, *Email: mr_rashmi@blr.amrita.edu*

Interleaved boost converter appropriate for renewable energy application that achieves sensible performance in terms of efficiency and reduced voltage ripple are discussed in [6]. The limitation of the isolated DC-DC converter and various parameters of non-isolated DC-DC converter are analyzed to select the suitable converter for renewable energy application are discussed in [7]. The effective energy conversion is firmed by the reduction in voltage, current stress and duty cycle that provides the high voltage gain [8].

Interleaved boost converter is accomplished to decrease output current ripple without any variation on PWM proposed by [9]. The reduction of complex PWM control techniques and filter size makes the interleaved boost converter more reasonable even though the additional components of inductor and capacitor increase the budget of the system as discussed by [10] [11]. Interleaved boost converter is coupled with the inductor due to the current ripple but the EMI is caused due to the leakage inductance of the coupled inductor that operate the diode with the high current stress was said by [12]. In the solar application to improve the power transfer at the time of low irradiance step up in voltage is provided by the conventional boost converter with the limited gain due to their components in the circuit and conduction losses are discussed in [13]. The two phase interleaved boost power factor corrector which is controlled by the average current mode control method is investigated by [14] proposing that interleaving extends the maximum practical power level of the control of 300W to 800W.

The efficiency of the interleaved boost converters is decided by the voltage gain and attainment of voltage gain with the voltage doubler circuit and soft switching was explicated by [15]. In the high voltage applications energy supplied by the solar and wind can be efficiently utilized by boosting the output voltage with the reduction in transformers ratio and peak current flowing across the switches with the capacitor and diode combined circuit named as voltage multiplier as said by [15] [16]. The voltage multiplier circuit that operate with the conventional boost converter in accumulation with the added boost circuit to obtain the high step up gain for solar system is proposed by [18] [19]. Although the extreme duty cycle is reduced and turns ratio of the inductor and voltage lift capacitor will increase the cost and size of the converter as discussed by [18][20].

The evaluation and assessment of some non- isolated interleaved boost converter in terms of reduced duty cycle and voltage stress on switches are analyzed by [21]. The aim of this proposed work is to compare the conventional IBC and IBC with voltage multiplier circuit with the working parameters when connected with the solar and wind system.

2. INTERLEAVED BOOST CONVERTERS

2.1. Without Voltage Multiplier

The circuit operation of conventional non-isolated interleaved boost converter is shown in Figure 1 use equal inductance L_1 and L_2 and the duty cycle of the switches S_1 and S_2 are considered to be equal [21].

Stage 1: Initially when S_1 is closed the current flowing charges the inductor L_1 while L_2 discharges.

Stage 2: When both S_1 and S_2 are opened the current in both the inductors get discharged through the load.

Stage 3: Next when S_2 closed the current flowing charges the inductor L_2 while L_1 discharges.

Stage 4: Similar to stage 2 when the both S_1 and S_2 opened the current in inductor discharges through load.

2.2. With Voltage Multiplier

In the proposed topology the interleaved boost converter is added with the additional capacitor and diode that acts as a voltage multiplier proposed in [22] and the interleaved boost converter with voltage multiplier

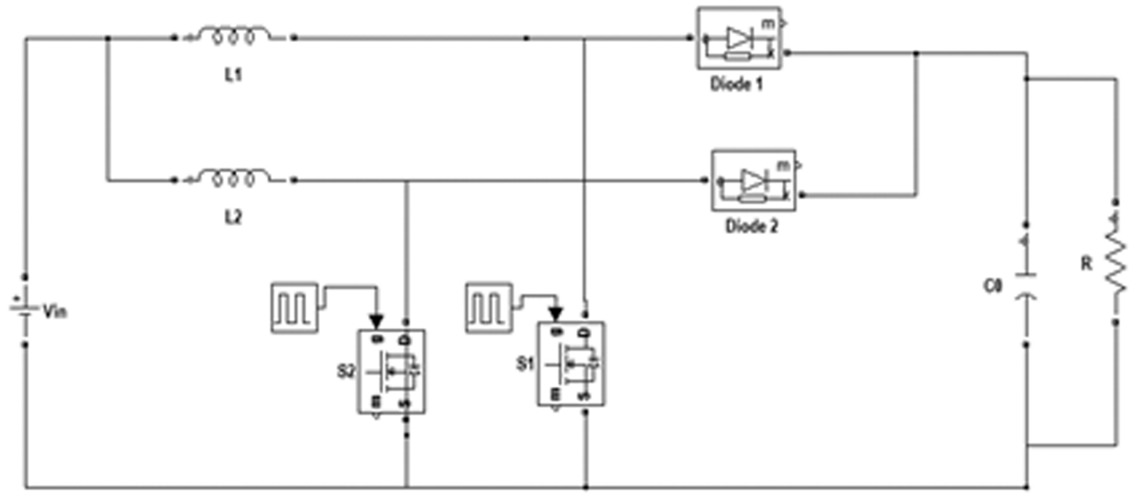

Figure 1: Circuit of conventional interleaved boost converter

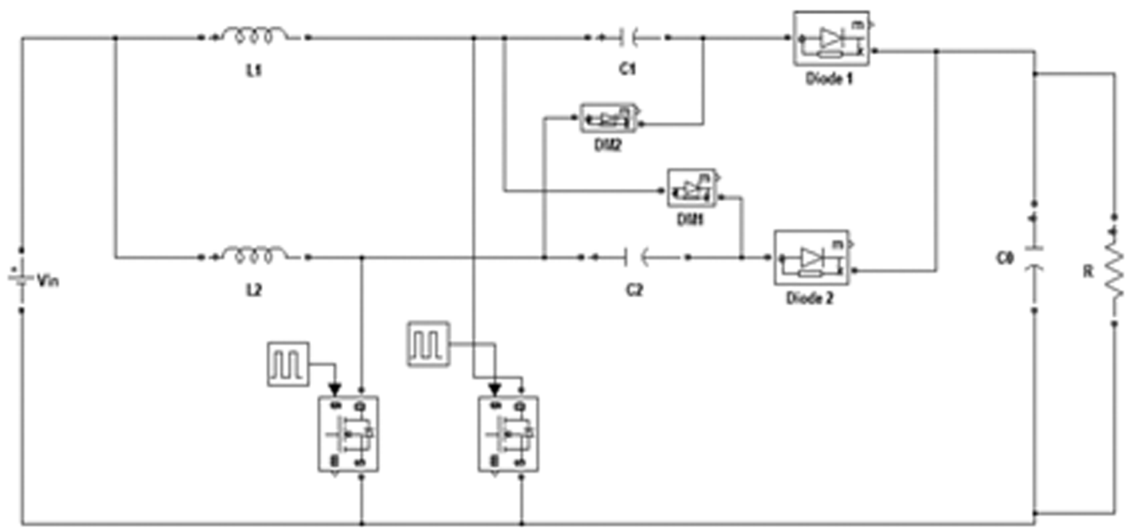

Figure 2: Circuit of Interleaved boost conveter with voltage multiplier

for fuel power system is already explained in [16] [19] [22] . In this paper it is explained for wind and solar system which is shown in Figure 2 [24].

Stage 1: When S_1 and S_2 are in OFF condition, the inductor L_1 and C_2 transferring output to capacitor Co through D_2

Stage 2: When the switch S_1 is turned ON, L_1 begins to save the energy from zero. At the time V_0 greater than $Vc_1 + Vc_2$, D_2 is switched OFF and D_{M1} starts to conduct and the current L_1 is transferred to C_1.

Stage 3: At this stage the inductor current L_2 becomes zero, L_1 is charges until S_1 is OFF. All the diodes are in OFF state and current in L_1comes to peak value.

Stage 4: S_1 and S_2 are turned OFF and the energy transferred C_O from L_1, C_1 through D_1. At the end, current in L_1 decreases.

Stage 5: S_2 is turned ON and L_2 stores energy, current in L_1 reduces to Zero.

Stage 6: All diodes are turned OFF and L_2 is in charging .When the next switching period comes the stages begin from the first.

The selection of duty cycle and design of inductor and capacitor values are obtained from the following equations [25].

2.3. Design of Proposed Interleaved Converter

2.3.1. Duty cycle

$$\frac{Vout}{Vin} = 1/(1-D) \tag{1}$$

$$D = (Vout - Vin)/Vout \tag{2}$$

$$Iout = \frac{Output\ Power}{Output\ voltage} \tag{3}$$

Relation between input and output current

$$Iin = \frac{Iout}{(1-D)} \tag{4}$$

$$2IL = \frac{Iout}{(1-D)} \tag{5}$$

Inductor

$$Vout * \frac{1}{R} > TsVoutD(1-D)^2 / 2L \tag{6}$$

$$L\min > RTsD(1-D)^2\, 2L \tag{7}$$

$$R_L = \frac{Vout}{Iout} \tag{8}$$

$$Ts = 1/Fs \tag{9}$$

$$L = VdDTs/\Delta IL \tag{10}$$

Capacitor

$$C = Iout * D * \left(\frac{TS}{2}\right) / \Delta V \tag{11}$$

With 5-10% voltage ripple of the voltage difference between input and output on the capacitor and current ripple of the conventional IBC, the value of C1and C2 are calculated as by [1]. The closed loop control of interleaved boost converter is achieved with the PI controller is shown in Figure 3 [17].

The Simulation of Solar and Wind power plant is shown in Figure 4 and Figure 5.

3. SYSTEM EVALUATION

The solar panel designed such that 100 w/m^2 yields 73.2 volts which is given as the input to the interleaved boost converter is shown in Figure 6[25]. The output voltage required is 400 Volt hence duty cycle is 0.8 and the inductor value is L1 = L2 = 1075 µH. The output capacitor is 217 µH and the Load resistance is 75.47 Ω. Capacitor C_1 and C_2 are 10% of ripple voltage.

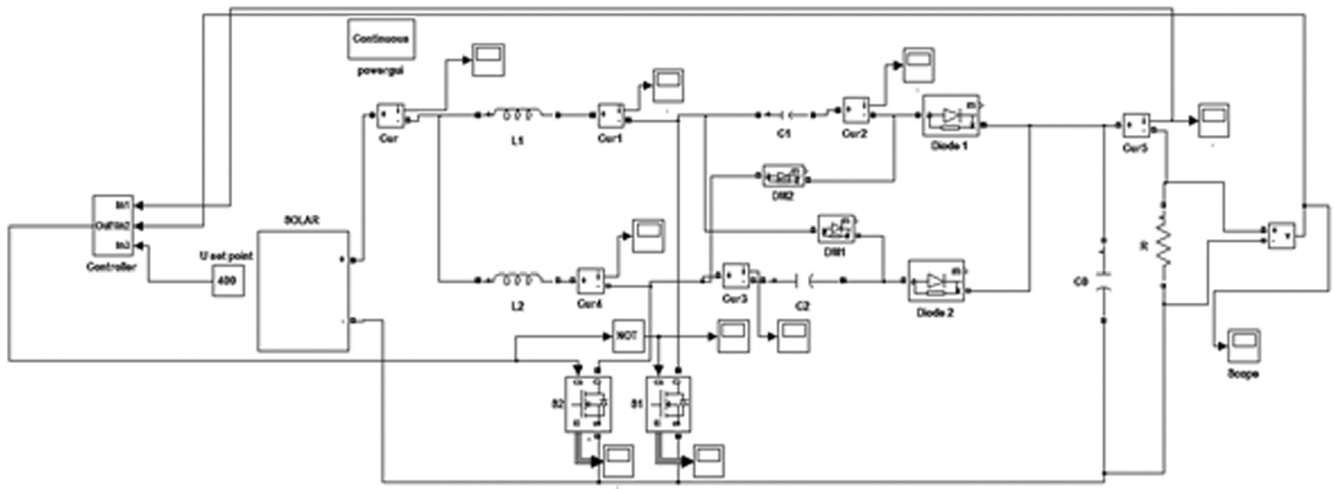

Figure 3: Closed loop control circuit for voltage multiplier circuit

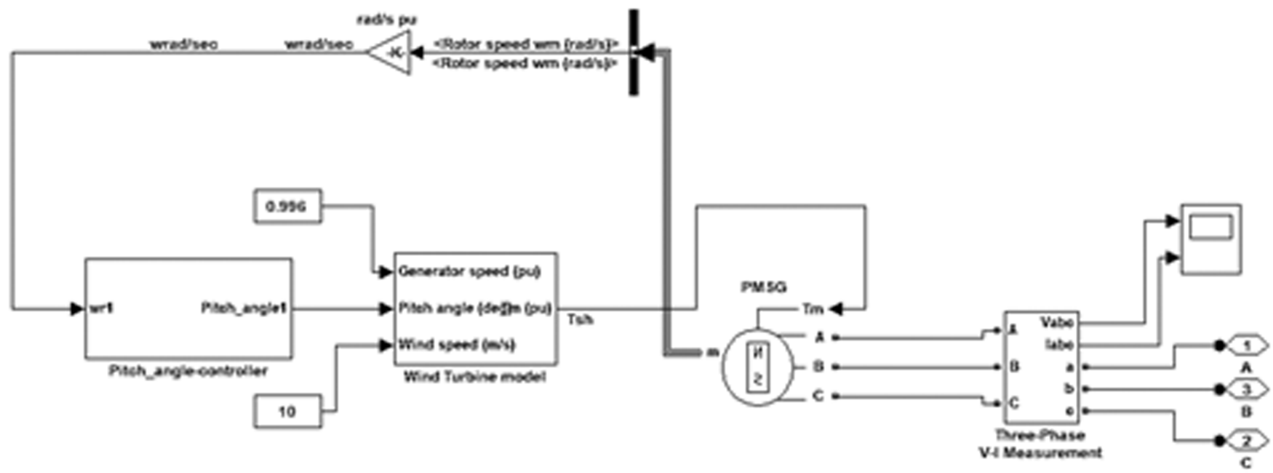

Figure 4: Simulation circuit for Wind power plant

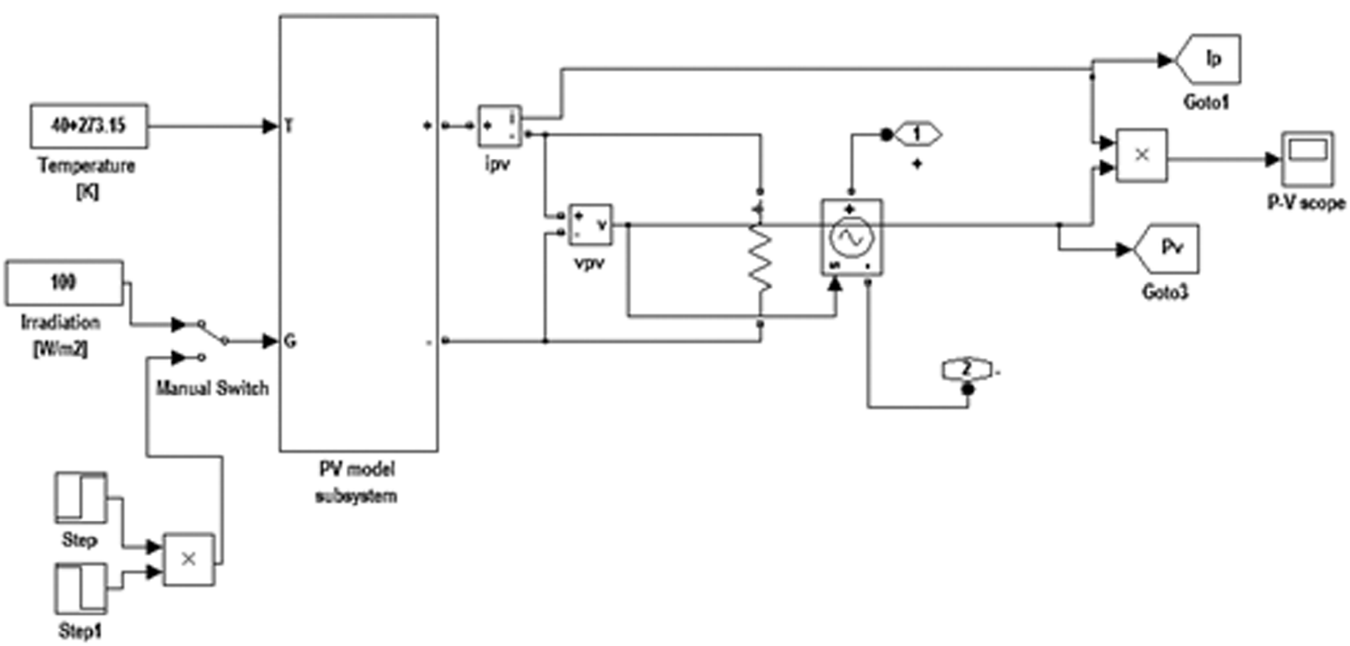

Figure 5: Simulation of Solar power plant

With the same input volatge of 73.2 V from the solar panel gives 750 V with the voltage multiplier circuit connected to the conventional interleaved boost converter is shown in Figure 7.

The current of the inductors L1 and L2 which are 5.5 A when connected to the voltage multiplier circuit is shown in Figure 8[10].

The interleaved boost converter without voltage multiplier circuit when the input voltage is 73.8V supplied from the wind palnt with the wind speed of 10m/s produces output voltage of 420V

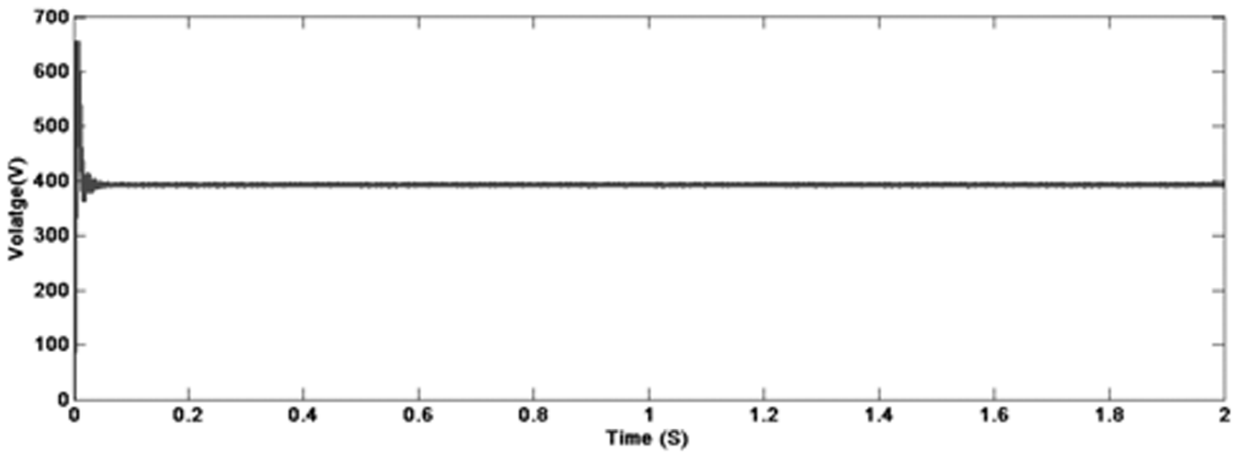

Figure 6: Output voltage of interleaved boost conveter without voltage multiplier

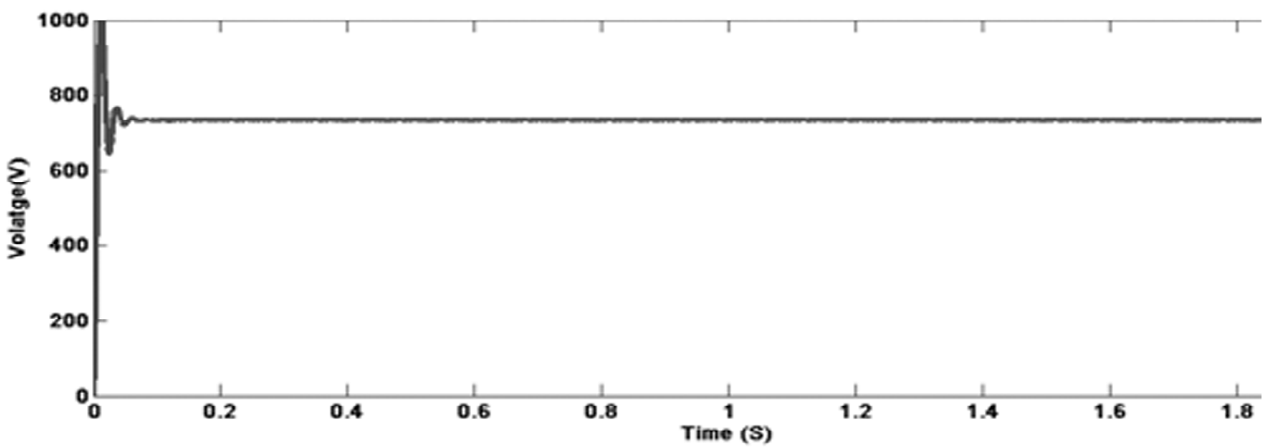

Figure 7: Output voltage of interleaved boost conveter with voltage multiplier.

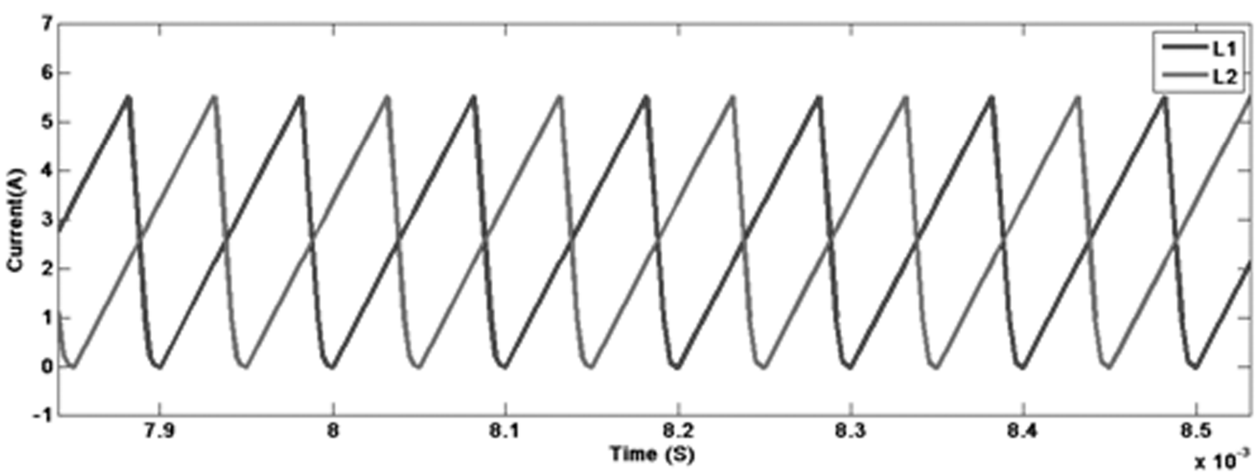

Figure 8: Inductor current of interleaved boost conveter with voltage multiplier.

is shown in Figure 9. The current of the inductors L1 and L2 which ranges between 13A and 14A when interleaved boost converter connected to the wind plant with voltage multiplier circuit is shown in Figure 10 [1].

The closed loop control is achieved to get the stability at load conditions with the PI controller connected with renewable energy sources is proposed in [25], similarly closed loop voltage control is achieved in this work.

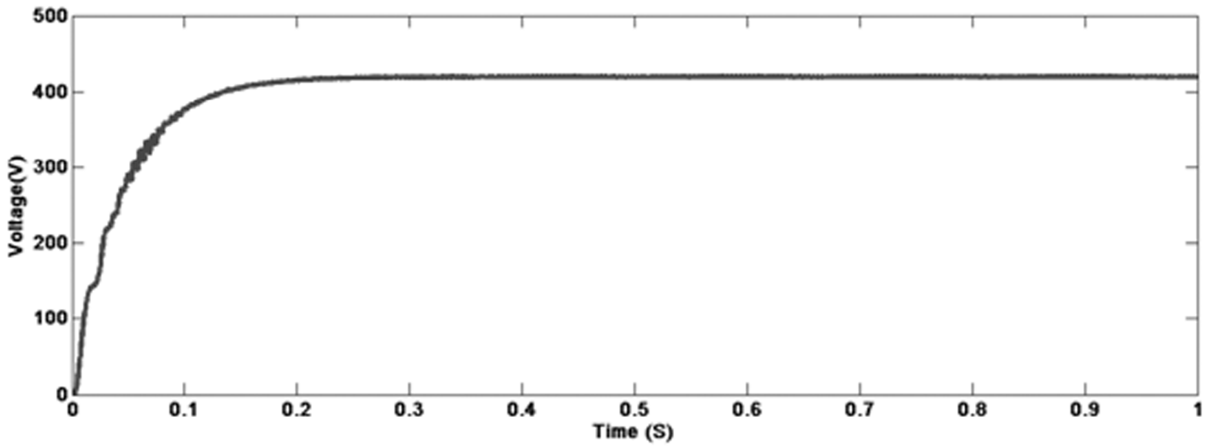

Figure 9: Output voltage of interleaved boost conveter without voltage multiplier connected to wind plant.

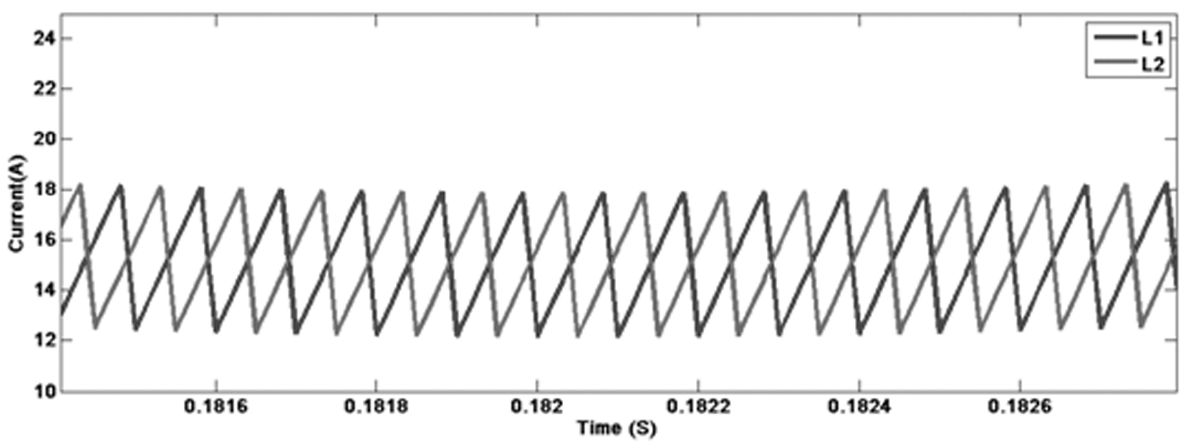

Figure 10: Inductor current of interleaved boost converter connected to wind plant.

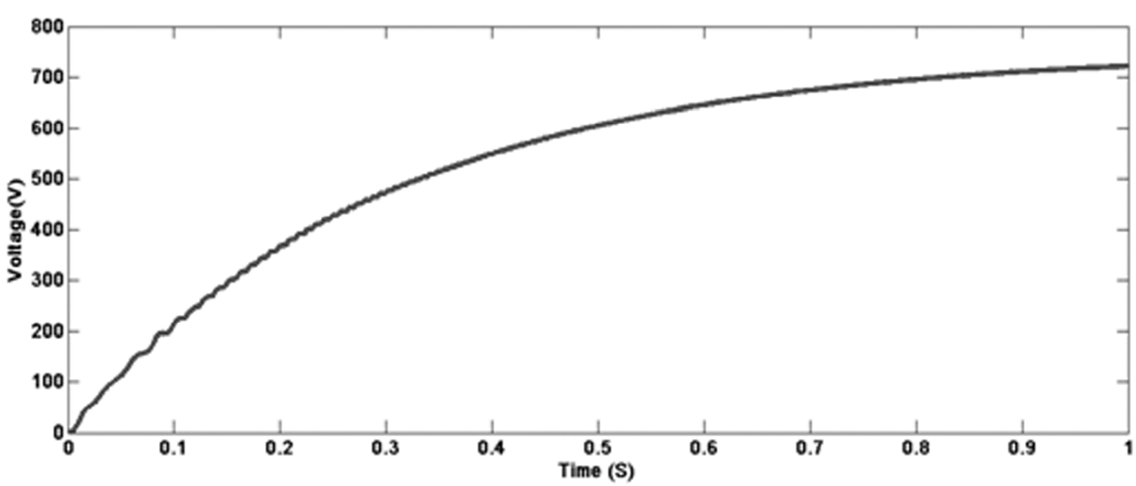

Figure 11: Output voltage of interleaved boost conveter with voltage multiplier connected to wind plant

The output voltage of interleaved boost conveter with voltage multiplier connected to wind plant simulated in Figure 11and output voltage of proposed converter with the closed loop is shown in Figure 12 [25].

The output voltage of interleaved boost converter without the closed loop at different load conditions is shown in Figure 12**.** The output voltage of interleaved boost converter with the closed loop at different load conditions is shown in Figure 13 indicates that the constant voltage is maintained when there is change is load voltage. In the Table 1 comparison of conventional interleaved boost converter without and with voltage multiplier are tabulated [13].

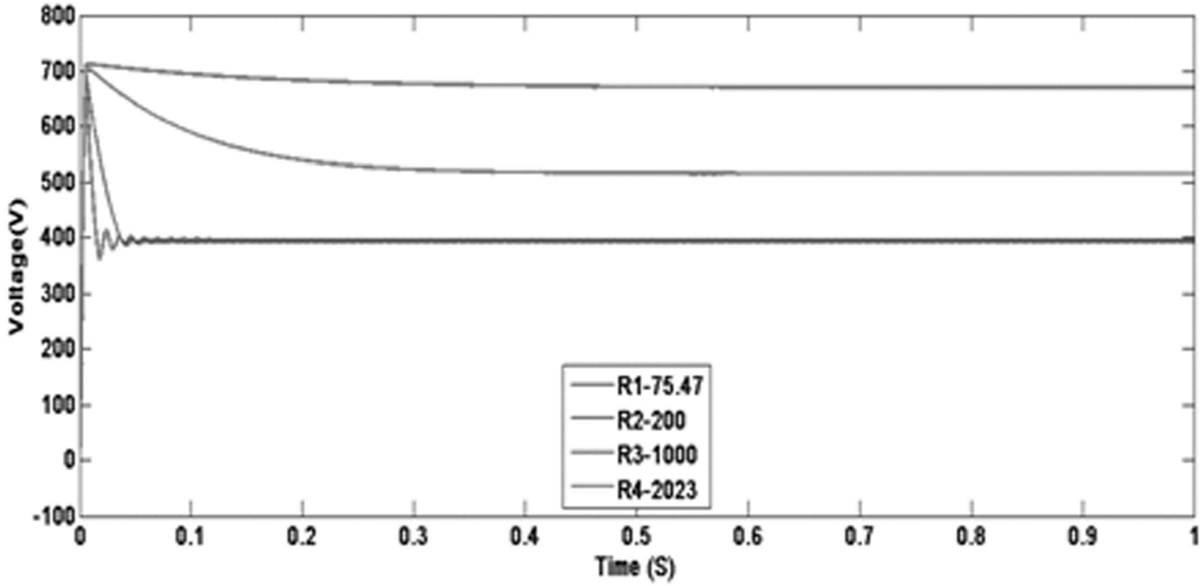

Figure 12: Output voltage at open loop for different load conditions

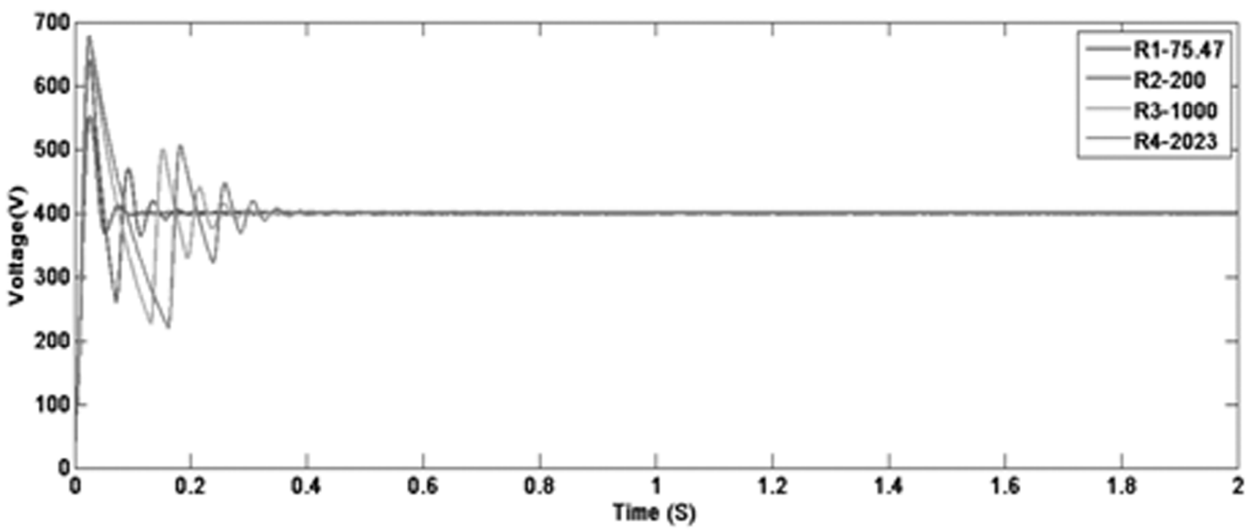

Figure 13: Output voltage at closed loop for different load conditions

Table 1
Comparison of voltage obtained in with and without voltage multiplier.

Input voltage	*Energy Source*	*Conventional interleaved boost converter*	*Interleaved boost converter with the voltage multiplier*
73.2 V	Solar	400	750
73.8 V	Wind	420	730

4. CONCLUSIONS

The improved interleaved boost converter is proposed for solar and wind energy system. From the simulation results shown in Figure. 7 it is observed that the high output voltage is obtained by using voltage multiplier circuit. The constant output voltage with the closed loop system is achieved even though the load is nonlinear shown in Figure 14.It can be concluded that from Table.1 that the voltage gain obtained is 87.5 % higher than the conventional converter.

REFERENCES

[1] F. Z. Peng, Hui Li, Gui-Jia Su and J. S. Lawler, "A new ZVS bidirectional DC-DC converter for fuel cell and battery application,"*IEEE Transactions on Power Electronics*, vol. 19, no. 1, pp. 54-65, Jan. 2004.

[2] S. Inoue and H. Akagi, "A Bidirectional DC–DC Converter for Energy Storage System with Galvanic Isolation,"*IEEE Transactions on Power Electronics*, vol. 22, no. 6, pp. 2299-2306, Nov. 2007.

[3] T. S. Kim and S. W. Kim, "A method for reducing EMI noise in portable charging applications," *3rd IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG)*, Aalborg, 2012, pp. 200 -206.

[4] C. M. Wang, C. M. Lu, C. H. Lin and J. C. Li, "A ZVS-PWM interleaved boost DC/DC converter," *TENCON 2013 - 2013 IEEE Region 10 Conference (31194)*, Xi'an, 2013, pp. 1-4.

[5] C. M. Wang, C. M. Lu, J. C. Li, C. H. Lin and C. Y. Ho, "A ZCS-PWM interleaved forward converter,"*Future Energy Electronics Conference (IFEEC), 2013 1st International,* Tainan, 2013, pp. 344-348.

[6] F. S. Alargt, A. S. Ashur, M. A. Shrud and A. H. Kharaz, "Simplified Ó-Ä modulation controller for interleaved boost DC-DC converter suitable for renewable energy applications,"*2015 4th International Conference on Systems and Control (ICSC),* Sousse, 2015, pp. 230-236.

[7] S.Sivakumar, M.JagabarSathik, P.S.Manoj, G. Sundararajan,"An assessment on performance of DC–DC converters for renewable energy applications,"Renewable and Sustainable Energy Reviews,Vol.58, pp.1475–1485,2016.

[8] K.Anoop, V.Rajini "Investigation on voltage multiplier cells for high step up conversion, ARPN Journal of Engineering and Applied Science,vol.10,no.1,pp.924-932.

[9] F. Khoucha, A. Benrabah, O. Herizi, A. Kheloui and M. E. H. Benbouzid, "An improved MPPT interleaved boost converter for solar electric vehicle application," *Power Engineering, Energy and Electrical Drives (POWERENG), 2013 Fourth International Conference on,* Istanbul, 2013, pp. 1076-1081.

[10] S. A Rahavi, T .Kanagapriya, R. Seyezhai."Design and analysis of Interleaved Boost Converter for renewable energy source," *International Conference onComputing, Electronics and Electrical Technologies,* pp.447-451.2012.

[11] Erickson, R.W., &Maksimovic, D. (2001) Fundamentals of Power Electronics. Kluwer Academic, Beilin.

[12] N. Subramanian, P. Prasanth, R. Srinivasan, R. R. Subesh and R. Seyezhai, "A comparative study of conventional, coupled inductor and RCN based interleaved boost converter for photo-voltaic applications," *Sustainable Energy and Intelligent Systems (SEISCON 2013), IET Chennai Fourth International Conference on*, Chennai, 2013, pp. 71-77.

[13] W. Li and X. He, "Review of Nonisolated High-Step-Up DC/DC Converters in Photovoltaic Grid-Connected Applications," in *IEEE Transactions on Industrial Electronics*, vol. 58, no. 4, pp. 1239-1250, April 2011.

[14] P.Vinoth Kumar, A.Suresh,M.R. Rashmi ,(2015) "Optimum design of single stage interleaved DC-DC converter with the reduced inductor volume."Australian journal of basic applied sciences, vol.9.no.1,pp.258-264,2015.

[15] X. Hu and C. Gong, "A High Gain Input-Parallel Output-Series DC/DC Converter With Dual Coupled Inductors,"*IEEE Transactions on Power Electronics,* vol. 30, no. 3, pp. 1306-1317, March 2015.

[16] L. Zhang, G. Shen, Min Chen, A. Ioinovici and D. Xu, "Two-phase interleaved boost converter with voltage multiplier under APS control method for fuel cell power system," *Power Electronics and Motion Control Conference (IPEMC), 2012 7th International,* Harbin, 2012, pp. 963-967.

[17] R.Seyezhai, "Investigation of Closed Loop Control for Interleaved Boost Converter with Ripple Cancellation Network for Photovoltaic Applications," International Journal of Information Technology and Computer Science. Pp.66-72, 2015

[18] W. Li and X. He, "High step-up soft switching interleaved boost converters with cross-winding-coupled inductors and reduced auxiliary switch number,"*IET Power Electronics,* vol. 2, no. 2, pp. 125-133, March 2009.

[19] L. Zhang, D. Xu, G. Shen, M. Chen, A. Ioinovici and X. Wu, "A High Step-Up DC to DC Converter Under Alternating Phase Shift Control for Fuel Cell Power System,"*IEEE Transactions on Power Electronics,* vol. 30, no. 3, pp. 1694-1703, March 2015.

[20] N. Zhang, D. Sutanto, K. M.Muttaqi, B. Zhang and D. Qiu, "High-voltage-gain quadratic boost converter with voltage multiplier,"*IET Power Electronics*, vol. 8, no. 12, pp. 2511-2519, 2015.

[21] F. L. Tofoli, D. d. C. Pereira, W. Josias de Paula and D. d. S. Oliveira Júnior, "Survey on non-isolated high-voltage step-up dc–dc topologies based on the boost converter," in *IET Power Electronics*, vol. 8, no. 10, pp. 2044-2057, 10 2015.

[22] M. R. Yazdani and S. Fattahi, "An interleaved high step-up switched-capacitor converter,"*Power Electronics, Drive Systems and Technologies Conference (PEDSTC), 2014 5th*, Tehran, 2014, pp. 154-159.

[23] L. Zhang, D. Xu, G. Shen, M. Chen, A. Ioinovici and X. Wu, "A High Step-Up DC to DC Converter Under Alternating Phase Shift Control for Fuel Cell Power System," *IEEE Transactions on Power Electronics,* vol. 30, no. 3, pp. 1694-1703, March 2015.

[24] Sheng-Yu Tseng, Hung-Yuan Wang , "A Photovoltaic Power System Using a High Step-up Converter for DC Load Applications,"Vol.6.pp. 1068-1100, 2013.

[25] ChinnarajKamalakannan, L. Padma Suresh, SubhransuSekhar Dash, BijayaKetanPanigrahi,(2014).Power Electronics and Renewable Energy Systems: Proceedings of ICPERES 2014.

[26] T N.Ajit,"Two Stage Interleaved Boost Converter Designand Simulation in CCM and DCM," International Journal of Engineering Research & Technology,vol.3,no.7,2014.