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Interleaved Converter Integrated With A Voltage Multiplier Module For High Step – Up DC-DC Conversion

[1]Likhita Minu Jose and [2]Dr. V. Sivachidambaranathan

[1]PG student M.E/Power Electronics, Sathyabama University, India.
[2]Professor and head / EEE SathyabamaUniversity, India.

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ABSTRACT

An interleaved boot converter with a voltage multiplier module is proposed for a PV system. This converter is an excellent candidate for renewable energy applications. The voltage multiplier module consists of switched capacitors and coupled inductors which makes the converter capable of obtaining high step up gain without operating at extreme duty ratio. The passive clamp performance of the converter allows the leakage energy to be recycled to the output terminals. The operation of the converter is such that it reduces the input current ripple and hence the lifetime of the renewable energy source is increased. Also the voltage stress on the power electronic switches is low. So low voltage rated MOSFETs can be incorporated for reducing cost. The efficiency of the PV system can be improved by implementing Maximum Power Point Tracking (MPPT) techniques. The performance of the converter is analyzed using hill climbing and incremental conductance MPPT techniques.

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INTRODUCTION

Conventional energy sources are fast depleting and they contribute to environmental contamination. So, renewable energy sources are increasingly employed now a days as they are clean sources of energy and are available in abundance[1]-[4]. Photovoltaic systems are expected to play an active role in future energy production. Fig.1 shows a typical renewable energy system. It consists of a renewable energy source like PV system, wind power generation or fuel cell, a step up converter and inverter which is added for ac applications. Renewable energy systems convert energy from the renewable energy sources into electricity. The output voltage generated by the renewable energy systems is very low. Hence they essentially require a high step up converter in order to boost the voltage to a higher level.

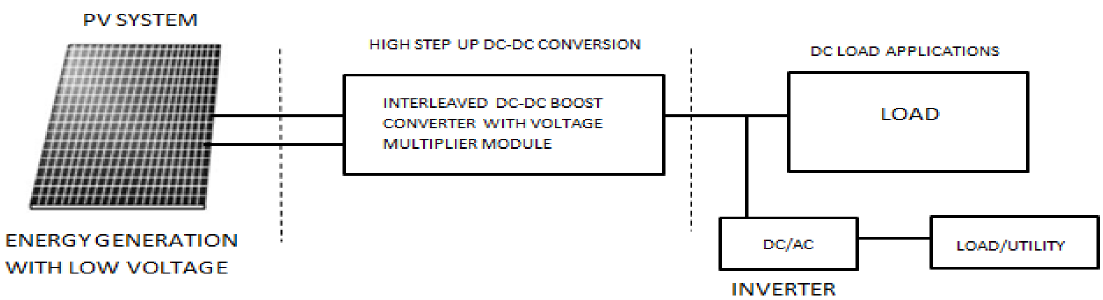

Fig. 1: Typical renewable energy system

The commonly used conventional boost converters and fly back converters cannot achieve a high step up conversion with high efficiency. This is mainly due to the resistance of elements and leakage inductance. Also the voltage stress on the switches is high. The high step up singleswitch converters are not suitable to operate at heavy loads because of large input current ripple, which increases the input current ripple. So many novel

Corresponding Author: Likhita Minu Jose, PG student M.E/Power Electronics, Sathyabama University, India.
E-mail: likhitamj007@gamil.com

converters weredeveloped that can eliminate the limitations of the conventional converters [5]-[7]. For high power applications and power factor correction, the conventional interleaved converter is an excellent candidate [8].But the voltage stress on the semiconductor switches are equal to the output voltage and the voltage gain is limited. So, a suitable approach is to modify the conventional boost converter for high power and high step up applications.

Integrating switched capacitors into an interleaved boost converter makes the voltage gain reduplicate. But if coupled inductors are not used the voltage gain becomes low[9]. And if only switched capacitors are used without employing coupled inductors, the voltage gain becomes ordinary[10]. Thus the synchronous employment of coupled inductors and switched capacitors is a suitable approach. With this approach, high step-up gain, high efficiency and low voltage stress can be achieved even for high power applications [11]-[12].

Maximum Power Point Tracking:

Maximum power point tracking maximizes the power transferred from the PV array to an electrical system. The main function of MPPT technique is to adjust the panel output voltage to avalue at which the panel supplies maximum energy to the load [13]. The power feedback type MPPT algorithm uses the voltage and current of PV module as the feedback parameters. When the condition $dp/_{dv} = 0$ is accomplished, the maximum power point is reached. The MPPT algorithms have to achieve this condition in order to find the maximum power point. Several MPPT techniques have been developed so far [14]. Some of the most commonly used methods include the constant voltage approach, perturb and observe approach, incremental conductance approach and hill climbing approach. In this paper the performance of the interleaved converter is analyzed for a photovoltaic system by implementing the Incremental conductance and hill climbing MPPT techniques.

The theory of incremental conductance method is to determine the variation in direction of the terminal voltage for PV modules by measuring and comparing the incremental conductance and instantaneous conductance. When the operating point of the PV array is exactly on the maximum power point, the slope of power curve is zero i.e.$dp/_{dv} = 0$.The advantage of hill climbing method is its simplicity. The operating theory of hill climbing method is similar to that of P&O method. In both these methods P(n) is compared with P(n-1).The P&O method uses $\frac{dP}{dV}$, whereas the hill climbing method uses the condition $\frac{dP}{dD}$to judge whether the maximum power point is found or not. The hill climbing method uses the duty cycle D of the switching mode power interface devices as judging parameter when the task of maximum power point tracking is to be implemented. When the condition $\frac{dP}{dD} = 0$ is accomplished, the maximum power point is reached.

Principle of Operation:

Fig.2 shows the high step up interleaved converter composed of voltage multiplier module. The voltage multiplier module is inserted in between the conventional interleaved boost converter .It is composed of two switched capacitors and two coupled inductors. The converter can be considered to have a modified boost-fly back-forward interleaved structure. When the switches turn OFF by turn, the phase whose switch is in OFF condition performs as a flyback converter and the other phase whose switch is in ON state performs as a forward converter.

The primary windings of the coupled inductor have Np turns and the secondary windings have Ns turns. The primary windings are employed to decrease the input current ripple. The secondary windings are connected in series to extend the voltage gain. Both the coupled inductors have the same turns ratio. "." and "*" represents the coupling reference of the coupled inductors.

Fig.3. shows the equivalent circuit of the high step up interleaved converter. S_1 and S_2 represent the power switches [MOSFET]. The switched capacitors are represented by Cc1 and Cc2. The output capacitors are represented by C_1, C_2 and C_3.Db_1, Db_2 represents the output diodes for boost operation and Df_1, Df_2 represents the output diodes for output diodes for flyback- forward operation. The magnetizing inductors are represented by Lm_1 and Lm_2 and the leakage inductors are represented by Lk_1 and Lk_2. The series leakage inductor in the secondary side is represented by L_s. n is defined as the turns ratio $Ns/_{Np}$.

The converter operates in continuous conduction mode (CCM) during circuit analysis. The converter has eight modes of operation which are depicted in Fig.4.

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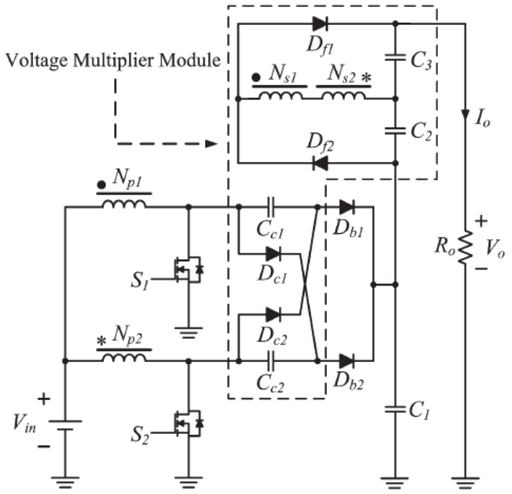


Fig. 2: High Step-up interleaved converter with voltage multiplier module

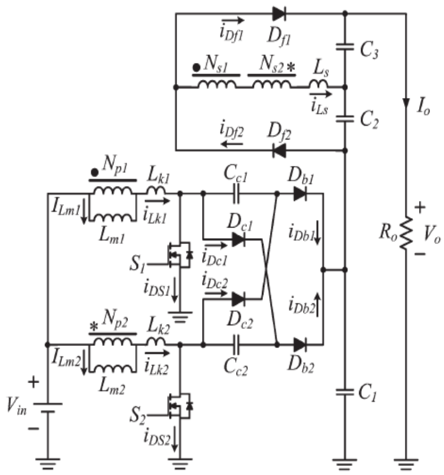
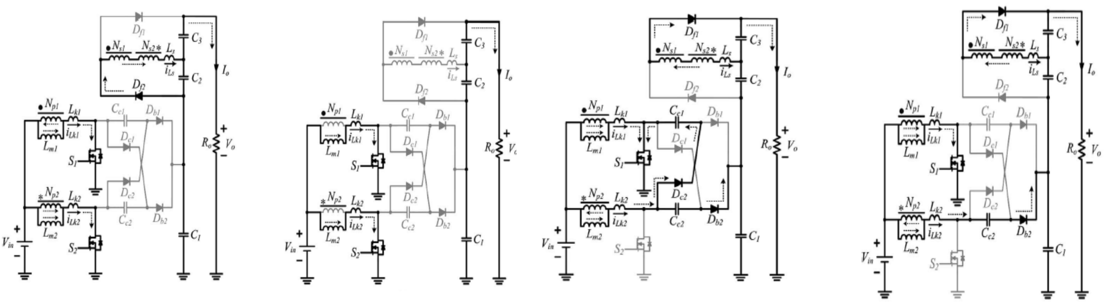


Fig. 3: Equivalent circuit

MODE 1[t_0,t_2]: At t=t0, S2 remains in ON state and S1 begins to turn on. The diodes .Dc_1, Dc_2, Db_1, Db_2 and Df_1 are reverse biased as shown in Fig.4(a). L_s quickly release the stored energy to output terminal via Df_2, and current through L_s decreases to zero. Thus Lm_1 still transfers the energy to the secondary side of the coupled inductors. The current through Lk_1 increases linearly and Lk_2 decreases linearly.

MODE II[t_1,t_2]: At t=t_1, both switches S_1 and S_2 remain in ON state, and all diodes are reverse biased as shown in Fig.4(b). The current through Lk_1 and Lk_2 are increased linearly due to charging by V_{in}.

MODE 111[t_2,t_3]: At t=t_2, S_2 remains in ON state and S_2 begins to turn off. The diodes Dc_1, Db_1 and Df_2 are reverse biased as shown in Fig.4(c). The input voltage source Lm_2, Lk_2 and Cc_2 release energy to output terminal. Thus, Vc_1 obtains a double output voltage of boost converter.



(a) (b) (c) (d)

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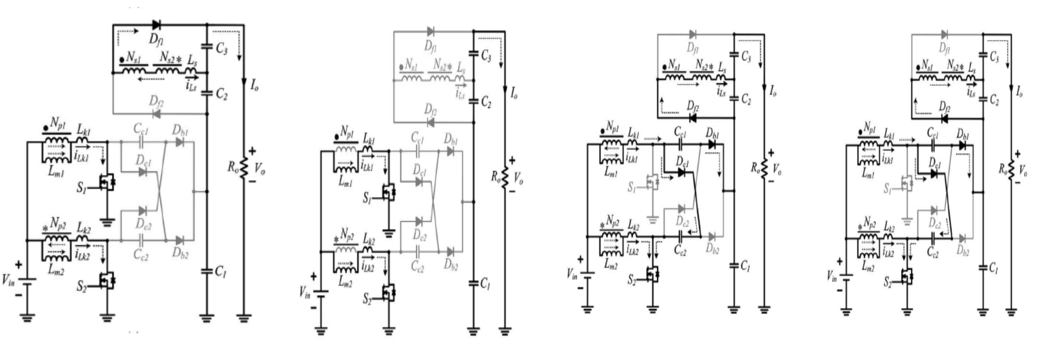

(e) (f) (g) (h)

Fig. 4: Operating modes of the converter. (a) Mode1[t_o,t_1], (b) Mode I[t_1,t2], (c) Mode III[t_2,t3], (d) Mode 1V[t_3,t_4], (e)Mode V[t_4,t_5], (f)Mode VI[t_5,t_6],(g) Mode VII[t_6,t_7], (h)ModeV111[t_7,t_8]

*MODE IV[t_3,t_4]:*At t=t_3, the current iDc_2 has naturally decreased to zero due to magnetizing current distribution , and hence , diode reverse recovery losses are alleviated and conduction losses are decreased. Both power switches and all diodes remain in previous state except the clamp diode Dc_2as shown in Fig. 4(d).

*MODE V[t_4,t_5]:*At t=t_4, S_1 remains in ON state and S_2 begins to turn on. The diodes Dc_1, Dc_2, Db_1, Db_2 and Df_2 are reverse biased as shown in Fig.4(e) and Ls quickly release the storedenergy to output terminal via Df_1 and the magnetizing inductor Lm_2 still transfers the energy to secondary side of coupled inductor. The current through Lk_2 increases linearly and Lk_1 decreases linearly.

MODE VI[t_5,t_6]: At t=t_5, both of the power switches S_1 and S_2 remains in ON state, and all diodes are reverse biased as shown in Fig.4(f). Both current through Lk_1 and Lk_2 are increased linearly due to charging by V_{in}.

MODE VII[t_6,t_7]: At t=t_6, S_2 remains in ON state and S_1 begins to turn off. The diodes Dc_2, Db_2 and Df_1 are reverse biased as shown in Fig.4.(g). The energy stored in Lm_1 transfers to the secondary side of coupled inductor. The input voltage source, Lm_1, Lk_1 and Cc_1 release the energy to output terminal and Vc_1 obtains double output voltage of boost converter.

MODE VIII[t_7,t_8]: At t=t_7, the current iDc_1 has naturally decreased to zero due to magnetizing current distribution and hence, diode reverse recovery losses are alleviated and conduction losses are decreased. Both power switches and all diodes remain in previous state except the clamp diode Dc_1as shown in Fig.4. (h).

Steady State Analysis:

The assumptions made during the operation of the converter in CCM are as follows:

(i). Because of the infinitely large capacitance, the voltage on all the capacitors are considered to be constant.

(ii). All the components are assume to be ideal.

(iii). The leakage inductors $L_s$and Lk_1 and Lk_2 are neglected.

Voltage gain

Voltage across C_c, the clamp capacitor can be regarded as the output voltage of the boost converter. Thus,

$$VCc = \frac{1}{1-D}Vin \quad (1)$$

When one of the switch turns off, VC_1 can obtain double the output voltage of the boost converter given by,

$$Vc1 = \frac{1}{1-D}Vin + VCc$$

$$Vc1 = \frac{2}{1-D}Vin \quad (2)$$

Due to energy transformation from the primary side, the output filter capacitors C_2 and C_3 are charged. When S_2 is in ON state and S_1 is in OFF state, Vc_2 is equal to the induced output voltage of Ns_1 and induced voltage of Ns_2, and when S_1 is in ON state and S_2 is in OFF state, Vc_3 is equal to induced voltage of Ns_1 plus induced voltage of Ns_2. Thus, voltages Vc_2 and Vc_3 can be derived from

$$Vc2 = Vc3 = n.Vin(1 + \frac{D}{1-D}) \quad (3)$$

The output voltage can be obtained as

$$Vo = Vc1 + Vc2 + Vc3 = \frac{2n+2}{1-D}Vin \quad (4)$$

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Thus the voltage gain of the converter is

$$\frac{Vo}{Vin} = \frac{2n+2}{1-D} \quad (5)$$

Equation (7) shows that the converter has high step up voltage gain without an extreme duty cycle.

Simulation Circuit And Results:

Fig.5 shows the Simulink circuit diagram of the high step-up interleaved converter with R-L load. It consists of a dc voltage source, two coupled inductors, switched capacitors, flyback diodes ad output capacitors. The inputvoltage is 40V and the output voltage is 370V as shown in Fig.6. Fig.7.and fig.8.Indicates the voltage across the MOSFETS is much lower than the output voltage.

Fig. 9. shows the Simulink block diagram of the converter with implementation of MPPT techniques.Closed loop operation is also implemented with the help of a PID controller. Fig.10 shows the efficiency by the implementation of incremental conductance method. Fig.11 shows the input voltage output voltage and efficiency by the implementation of hill climbing method. It is seen that the efficiency of the converter is 91.3% with incremental conductance method and 87% with hill climbing method.

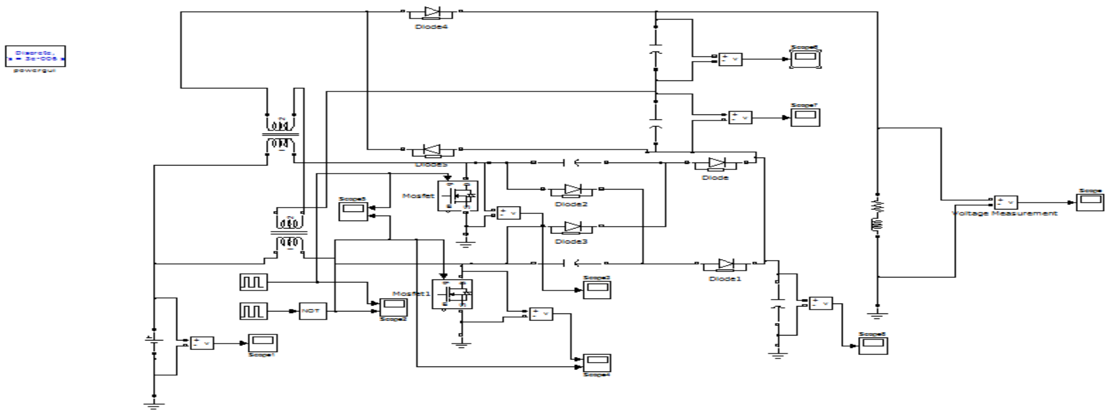

Fig. 5: Simulink block diagram for high step-up interleaved converter with R-L load

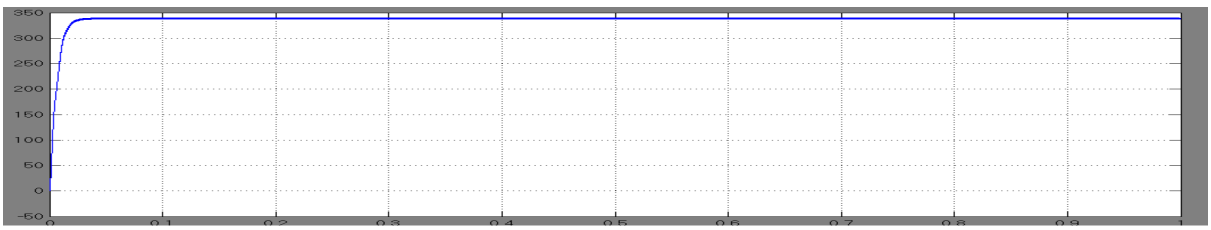

Fig. 6: Output voltage

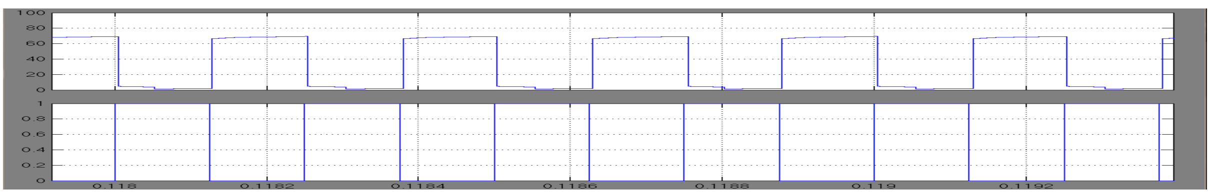

Fig. 7: Gain to source voltage and gate to source voltage of MOSFET 1

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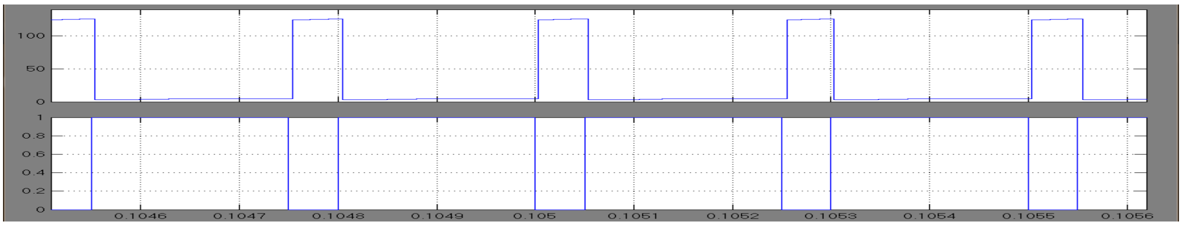

Fig. 8: Gain to source voltage and gate to source voltage of MOSFET 2

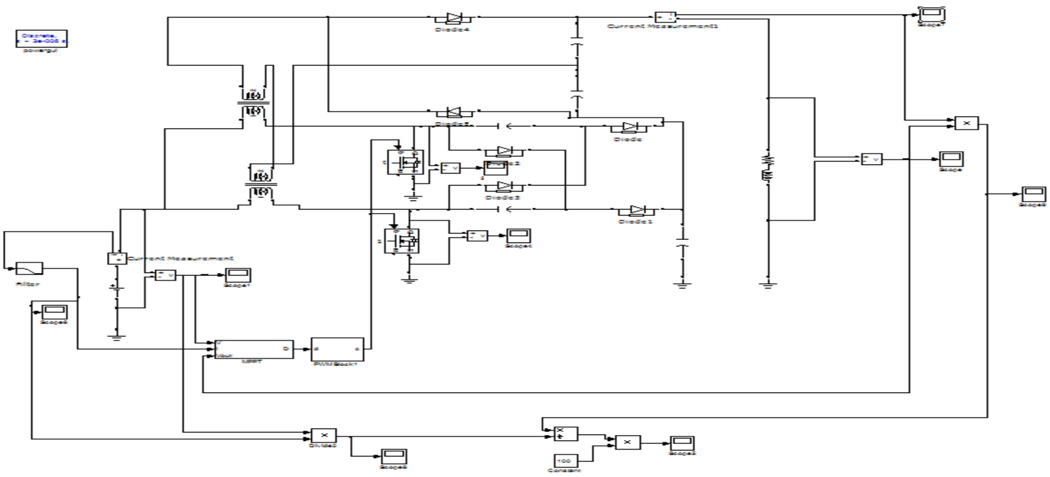

Fig. 9: Simulink block diagram for closed loop operation with implementation of MPPT techniques

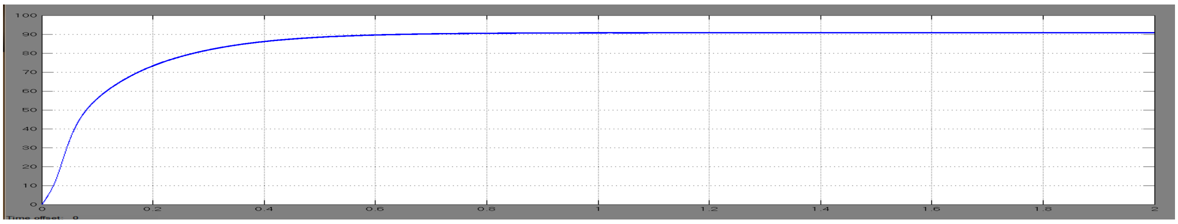

Fig. 10: Efficiency with incremental conductance technique

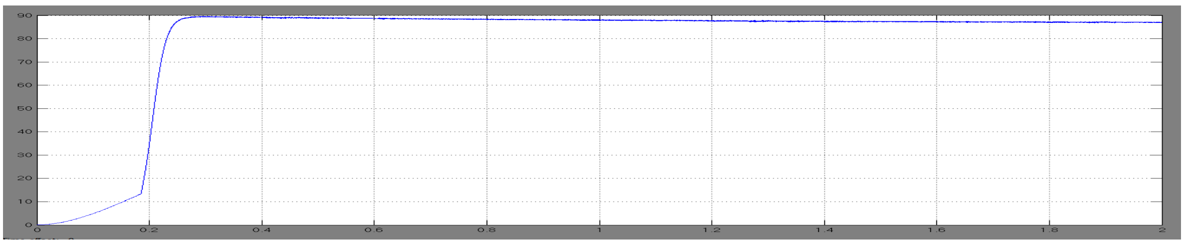

Fig. 11: Efficiency with hill climbing method

Conclusion:

This paper has proposed a high step up high efficiency interleaved converter with voltage multiplier module for photovoltaic system. This converter can be an excellent candidate for boosting up the low output of voltages PV modules to higher voltages. The proposed converter has been simulated. The voltage stress on the switches is much lower than the output voltage. A comparative study of the converter with the implementation of incremental conductance and hill climbing MPPT methods has been done. From the results it is seen that the converter gives a higher efficiency with the incremental conductance method. Thus the interleaved converter has been successfully implemented for high step –up conversion through the voltage multiplier module.

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