

A High Efficiency DC-DC Converter with FLC for Solar PV

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ABSTRACT— This paper presents a high efficiency converter with input power source from a low voltage, high current DC source solar PV system. Therefore, it is desirable to create a power converter with a topology suited to the attributes. This converter has a coupled inductor with high transformation ratio and a voltage multiplier is adapted to step-up the input voltage with high conversion ratio. In step up mode, the primary and secondary windings of the coupled inductor are operated in parallel for charging and series for discharging to achieve high step up voltage gain. It is also proposed fuzzy logic controller (FLC) for significantly improving the performance of DC-DC converter, FLC improves the efficiency of converter by control the output voltage.

KEYWORDS— Boost converter, coupled inductor, voltage multiplier, FLC.

I. INTRODUCTION

In order to protect the natural environment on the earth, the development of clean energy without pollution has the major representative role in the last decade. By accompanying the permission of Kyoto Protocol, clean energies, such as fuel cell (FC), photovoltaic (PV), wind energy, etc., have been rapidly promote. Batteries or super capacitors are usually taken as storage mechanisms for smoothing output power, start-up transition, and various load conditions .The corresponding installed capacity of clean energies can be further reduced to save the cost of system purchasing and power supply. Solar energy is abundantly available that has made it possible to harvest it and utilize it properly.

Due to the electric characteristics of clean energies, the generated power is critically affected by the climate or has slow transient responses, and the output voltage is easily influenced by load variations.

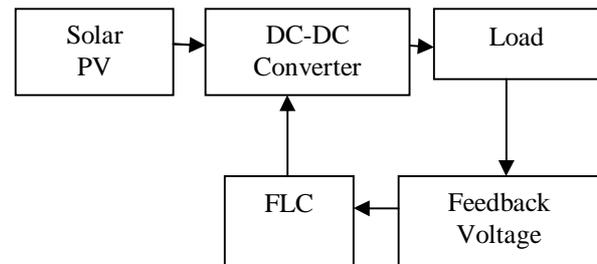


Figure1. General block diagram of proposed system.

Solar energy can be a standalone generating unit or can be a grid connected generating unit depending on the availability of a grid nearby. Thus it can be used to power rural areas where the availability of grids is very low. Another advantage of using solar energy is the portable operation whenever necessary. The proposed dc-dc converter has an input dc voltage from a solar PV systems [19].This circuit is given a closed loop through FLC from output to input by an feedback voltage with comparison of error and respective change in error from the output of the DC-DC converter [17], such that the dc-dc converter act as a boost converter which steps up the voltage from solar PV system .MOSFET switch is used due to its high switching speed and efficiency. FLC have some advantages compared to other classical controller such as simplicity of control, low cost and the possibility to design without knowing the exact mathematical model of the process. Fuzzy logic is flexible. With any given system, it is easy to layer on more functionality without starting again from scratch. Fuzzy logic is conceptually easy to understand and control the output voltage and increase the efficiency.

A converter may be designed to operate in continuous mode at high power there have been various techniques used to create high step-up converters that maintain high efficiency. Converters utilizing repeated

component networks, such as multiplier capacitors or voltage doublers, are described.

This paper presents a high efficiency Boost Converter, which uses the coupling inductor and voltage Multiplier technique .The circuit diagram of proposed converter is shown if fig.2. and the features of this converter are as follows: 1) High Efficiency 2) Duty ratio can be designed to 0.66 by adjusting the turns ratio of the coupled inductor. Thus the proposed converter can be operated under Continuous conduction mode. 3) The energy stored in the leakage inductance of the transformer is recover, thus increasing the efficiency. 4) The voltage is clamped on the switch and enabling the power switch to be selected with a low voltage rating and low conduction resistance. 5) The converter uses low –rating switch and diodes to minimize the cost.

The conventional Boost converters cannot provide such a high dc voltage gain, even for an extreme duty cycle. As a result, the conversion efficiency is degraded and the electromagnetic interference (EMI) problem is severe under this situation [1]. In order to increase the conversion efficiency and voltage gain, many modified boost converter topologies have been investigated in the past decade [4]-[14].

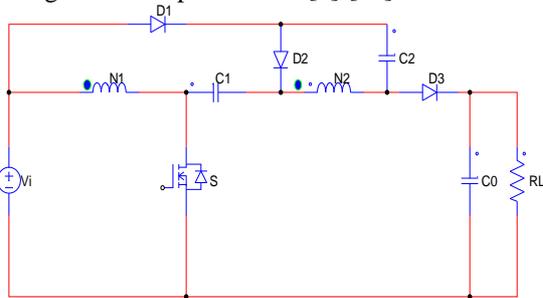


Figure 2.Circuit Diagram for high step-up gain converter.

II. PROPOSED CONVERTER AND OPERATION PRINCIPLE

The Fig 3 shows the circuit configuration of the proposed converter, a boost converter with a voltage multiplier and coupled inductor techniques [18]. The model of coupled inductor includes leakage inductance L_k and a magnetizing inductance L_m and an ideal transformer. This converter consist of a DC input supply V_i , one coupled inductor , three diodes , one power switch and three capacitors. The most basic implementation of this principle, which is seen in[10] a Interleaved version. Which involves the capacitor is being charged by a winding of the coupled inductor when switch S is ON, and then discharging in series with both winding into the respective load such the voltage across the three components combine together to boost up the output voltage and same principle is adopted to utilize the multiple capacitors such that they charge independently at the time of switch S is ON and discharge during OFF state condition. For that the components are arranged so that during ON state, one capacitor along with the both windings discharges to another capacitor and thus boost up the output voltage even higher. During OFF state the

higher voltage capacitor can discharge, in the series with the windings into the respective load, while the other capacitor is recharged.

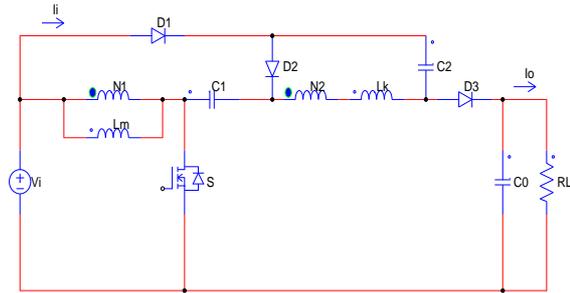


Figure 3.Equivalent circuit For Proposed Converter.

In order to realize this concept, the switch ON and OFF states of converter are treated for various arrangements of components in order to find the combination that result in desirable gain function [22]. During ON state capacitor C_2 is placed in series with both primary and secondary windings of the coupled inductor so that it discharges into and boost the voltage of C_1 , whereas during OFF state, C_1 discharges in series with both windings and into the load, where C_2 get recharged by high voltage secondary winding respectively. Here the circuit operates at four different stages according to the parameters, the main difference among the four stages are duration of conduction of three diodes D_1 , D_2 and D_3 . Stage1 is a continuous conduction mode (CCM), where switch and diode D_1 conduct for a switching cycle followed by the diode D_2 , D_3 conducting for the remainder. Stage 2 is same as Stage 1 except the current in D_1 which reduces to zero before the switch S is turned OFF. Stage 3 begins as Stage 1 action; where D_2 , D_3 both simultaneously reduced to zero before the switch S is turn ON so thus put the converter into discontinuous conduction mode (DCM).In Stage 4 all three diodes D_1 , D_2 and D_3 reduced to zero according to their respective operation interval. Therefore whereas Stage 1 has two main switching modes, Stage 2 and 3 have three modes, Stage 4 has four modes. This paper is focus on the main operating modes of Stage 2.

The switching modes of proposed converter as follows, the coupled inductor are modeled as an ideal transformer with magnetizing inductance and secondary series leakage inductances. The switch S and diode D_1 both have parasitic capacitance placed in parallel with them. Let capacitors C_i , C_0 , C_1 and C_2 are assumed to maintain a constant voltage over the entire switching period. The modes are described as follows,

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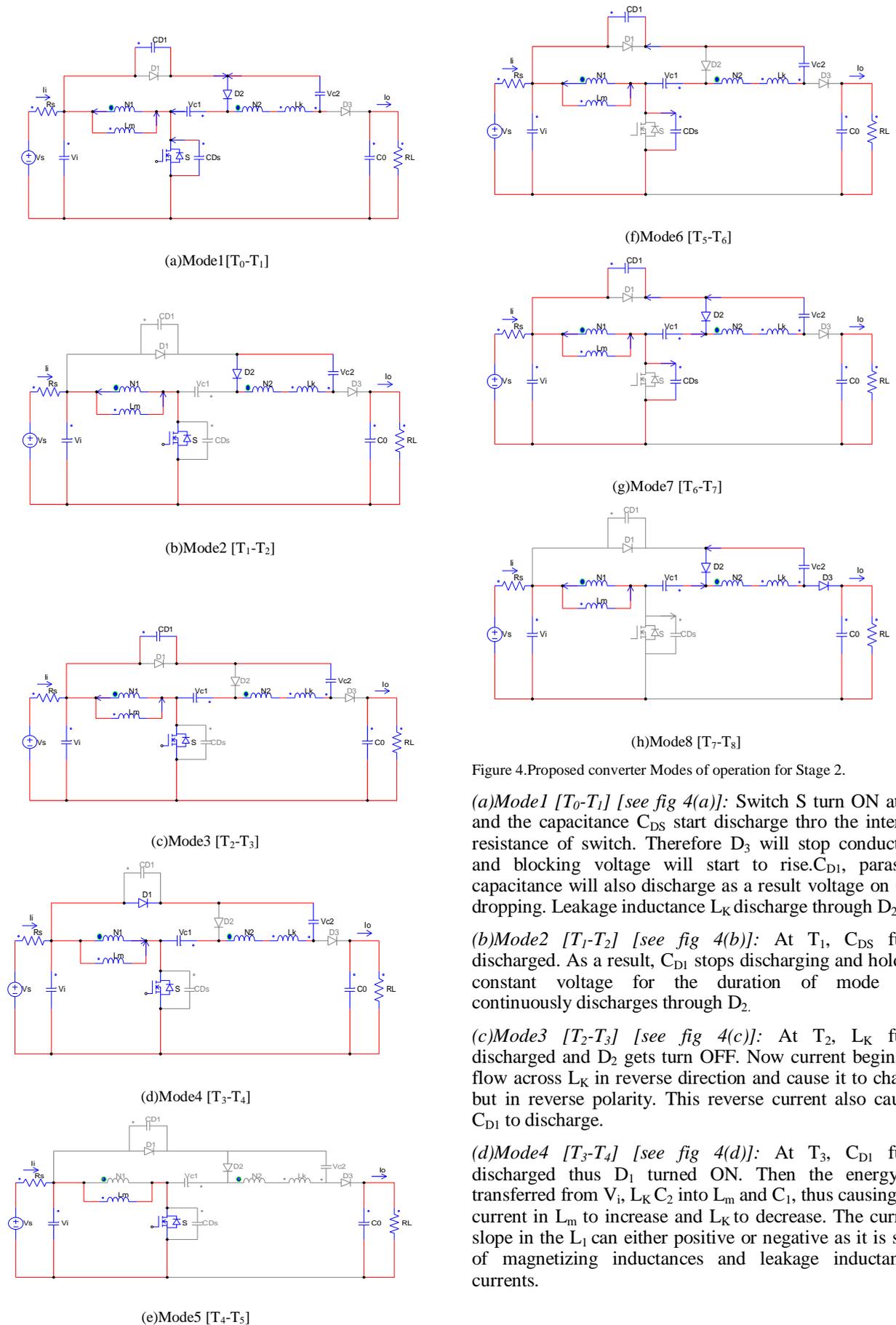


Figure 4. Proposed converter Modes of operation for Stage 2.

(a) Mode1 [T_0-T_1] [see fig 4(a)]: Switch S turn ON at T_0 and the capacitance C_{DS} start discharge throu the internal resistance of switch. Therefore D_3 will stop conducting and blocking voltage will start to rise. C_{D1} , parasitic capacitance will also discharge as a result voltage on C_{DS} dropping. Leakage inductance L_K discharge through D_2 .

(b) Mode2 [T_1-T_2] [see fig 4(b)]: At T_1 , C_{DS} fully discharged. As a result, C_{D1} stops discharging and holds a constant voltage for the duration of mode. L_K continuously discharges through D_2 .

(c) Mode3 [T_2-T_3] [see fig 4(c)]: At T_2 , L_K fully discharged and D_2 gets turn OFF. Now current begins to flow across L_K in reverse direction and cause it to charge but in reverse polarity. This reverse current also causes C_{D1} to discharge.

(d) Mode4 [T_3-T_4] [see fig 4(d)]: At T_3 , C_{D1} fully discharged thus D_1 turned ON. Then the energy is transferred from V_i , L_K C_2 into L_m and C_1 , thus causing the current in L_m to increase and L_K to decrease. The current slope in the L_1 can either positive or negative as it is sum of magnetizing inductances and leakage inductances currents.

(e) Mode 5 [T₄-T₅] [see fig 4(e)]: At T₄, current in leakage inductance L_k has returned to zero and D₁ gets turn OFF. L_m Continuously charges from V_i and thus, its current increases.

(f) Mode 6 [T₅-T₆] [see fig 4(f)]: At T₅, switch S gets turn OFF. C_{DS} begins to charge. Thus in turn causes C_{D1} also charge, as a result D₂ and D₃ begin to reduce. Current draw at C_{D1} causes L_k to charge.

(g) Mode 7 [T₆-T₇] [see fig 4(g)]: At T₆, Voltage across D₂ reduces to zero and begins to conduct. The blocking D₂ continues to decrease.

(h) Mode 8 [T₇-T₈] [see fig 4(h)]: At T₇, Voltage across D₃ reduces to zero and begins to conduct. L_m, L_k, C₁ discharges their energy to C₂ and to the load.

III. CONVERTER ANALYSIS

A). Converter Gain:

The converter gain can be determined by modes 4,5 and 8. Where there energy transfer between the source, energy storage elements and load is shown fig 4(d),4(e) and 4(h). The voltage across L_m can be written in two ways, from mode 4

$$V_1(t) = \frac{V_{C1} - V_{C2} - V_i}{n} \tag{1}$$

$$V_{C1} = (N + 1)V_i + V_{C2}$$

From mode 8,

$$V_1(t) = V_i + V_0 + V_{C1} + V_{C2} \tag{2}$$

Or

$$V_1(t) = \frac{-V_{C2}}{n}$$

Similarly, equation (2) can be written as

$$n(V_i - V_0 + V_{C1}) + (n + 1)V_{C2} = 0 \tag{3}$$

By using voltage second balance principle on L_m of the coupled inductor for these three stages is

$$V_i DT + (V_i - V_0 + V_{C1} + V_{C2})(1 - D)T = 0 \tag{4}$$

By solving equations (1) – (4), the voltage gain is,

$$\frac{V_0}{V_i} = \frac{(n - 1)D + n + 2}{(1 - D)} \tag{5}$$

B). Efficiency analysis

The overall efficiency can be analyzed with the ratio output power and input power of the proposed converter respectively.

$$\eta = \frac{P_o}{P_i} \tag{6}$$

$$\eta = \frac{V_o \times I_o}{V_i \times I_i} \tag{7}$$

$$I_o = \frac{V_o}{R_L}$$

From the equation (6), the efficiency is calculated to be 88.2% respectively.

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C). Designing of coupled inductor:

Here coupled inductor is modeled as an ideal transformer, the magnetizing inductor (L_m) and a leakage inductor (L_k), the turns ratio (n) and the coupling coefficient (k) of ideal transformer is defined

$$K = \frac{L_m}{L_m + L_k}$$

(8)

From equation (1), L₁ is defined

$$L_1 = \frac{RD}{2 \left(\frac{nD - D + n + 2}{1 - D} \right) (D)(2D - 1)}$$

(9)

$$n = \frac{L_1}{L_2}$$

(10)

$$L_2 = \frac{nRD}{2 \left(\frac{nD - D + n + 2}{1 - D} \right) (D)(2D - 1)}$$

(11)

Duty cycle is defined from the equation (5)

$$D = \frac{V_i(n) + 2V_i - V_0}{V_i(1 - n) - V_0}$$

(12)

IV. FUZZY LOGIC CONTROLLER

Fuzzy logic starts with the concept of a fuzzy set. It can contain elements with only a partial degree of membership. A membership function is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. The input space is sometimes referred to as the universe of discourse. The degree an object belongs to a fuzzy set is denoted by a membership value between 0 and 1.

Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. The membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible, and in many cases much more efficient, to use a single spike as the output membership functions rather than a distributed fuzzy set. In the Mamdani Fuzzy inference system, There will be two input membership function, they will be error and change in error. It consists of six membership function. There are as follows: Zero, Negative small, Negative large, Negative medium,

positive small, positive medium, and positive large[17]. Error and Change in error consists of these six membership functions. Output also consists of six membership function. With consideration of the inputs, output could be framed and it is controlled in it.

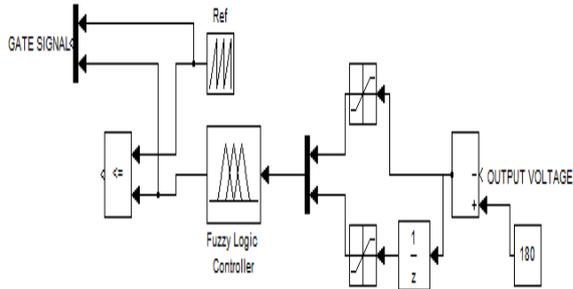


Figure 5. FLC simulink block.

The fuzzy logic controller block is shown in figure (5), which is implemented to stabilize the output by designing the rules in is done with the help of FAM table respectively [3].

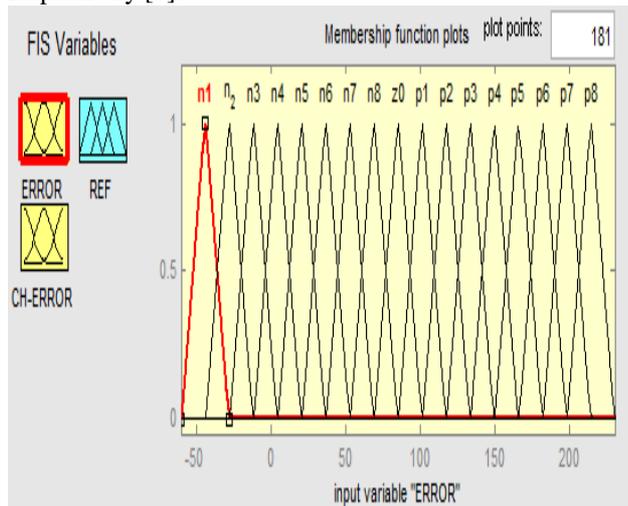


Figure 6. Membership function plots of error.

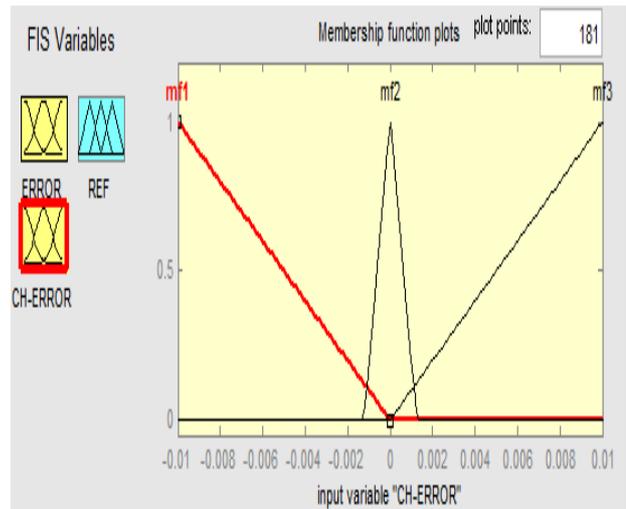


Figure 7. Membership function plots of change error.

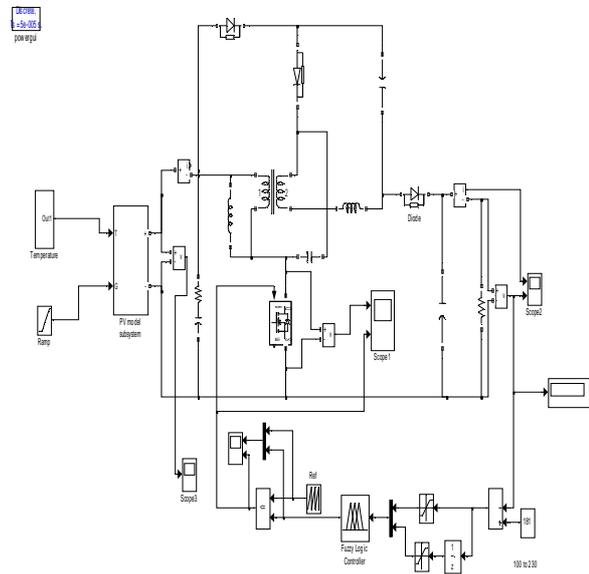


Figure 8. Simulation diagram of proposed converter.

TABLE I
FAM TABLE WITH RULES FOR ERROR AND CHANGE OF ERROR

| de e | MF1 | MF2 | MF3 |
|---------|-----|-----|-----|
| N1 | P2 | P1 | P |
| N2 | P3 | P2 | P3 |
| N3 | P1 | P2 | P1 |
| N4 | P5 | P4 | P2 |
| N5 | P6 | P5 | Pm8 |
| N6 | P7 | P6 | Pm8 |
| N7 | P1 | P7 | Pm8 |
| N8 | P1 | Pm0 | Pm3 |
| Z0 | Pm1 | Pm0 | Pm8 |

| | | | |
|----|-----|-----|-----|
| P1 | Pm2 | P8 | P8 |
| P2 | Pm3 | Pm2 | Pm8 |
| P3 | Pm4 | Pm3 | Pm1 |
| P4 | Pm3 | Pm4 | Pm1 |
| P5 | Pm6 | Pm5 | Pm3 |
| P6 | Pm7 | Pm6 | Pm5 |
| P7 | Pm8 | Pm7 | Pm6 |
| P8 | Pm8 | Pm8 | Pm7 |

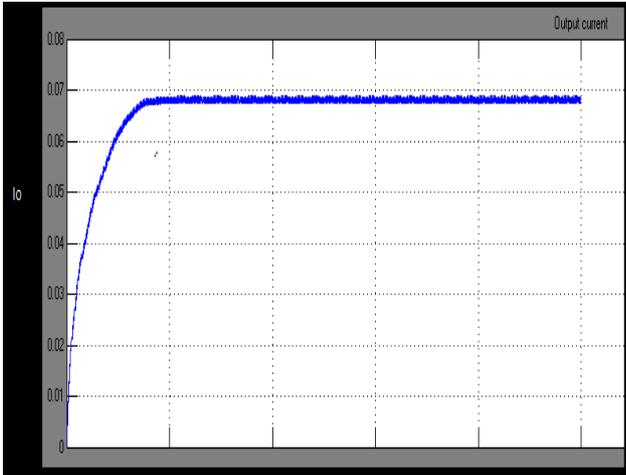


Figure 9. Simulation result for output current.

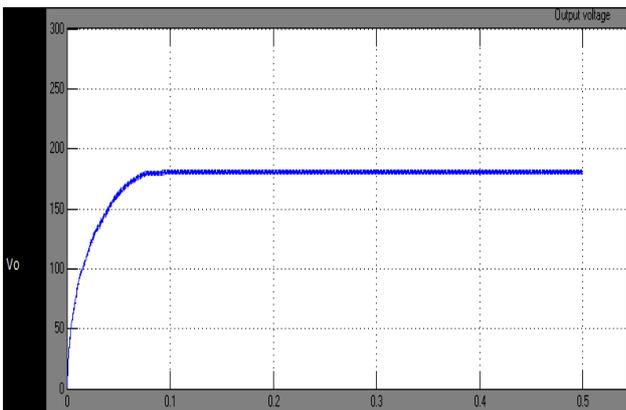


Figure 10. Simulation result for output voltage.

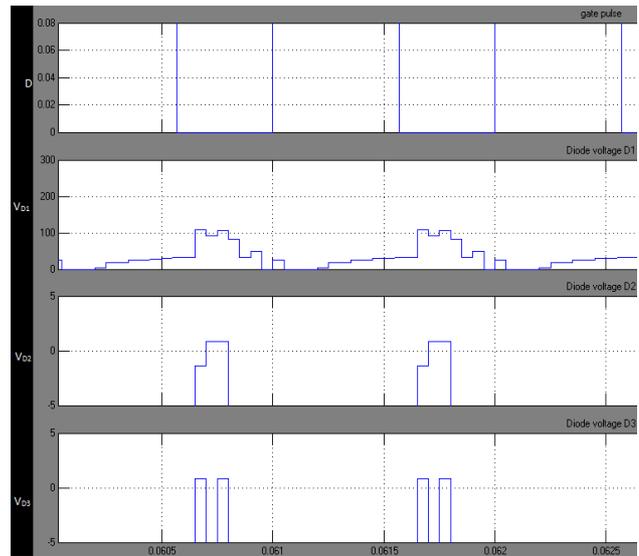


Figure 11. Simulation result of V_{D1} , V_{D2} and V_{D3} .

Thus the proposed converter high efficiency conversion is shown in the figure (10), $V_o=180V$, which is higher than the conventional converter.

TABLE II
PERFORMANCE COMPARISON

| S.NO | CONVERTERS | OUTPUT VOLTAGE | EFFICIENCY (%) |
|------|-----------------------------------|----------------|----------------|
| 1 | PROPOSED CONVERTER WITH OPEN LOOP | 175.5 | 73.7 |
| 2 | PROPOSED CONVERTER WITH FLC | 180.1 | 88.2 |

V. CONCLUSIONS

A boost converter successfully driven by a single switch is achieved a high step-up voltage gain; the voltage gain is up 42 times more than the input and the maximum efficiency is 88.5%. Thus, future power supply controller in addition to providing conventional closed loop control, will be required to perform many intelligent operations. Fuzzy control and expert system based control seem to provide an easy solution to this problem. So, in this paper fuzzy controller for closed loop regulation of dc/dc converter is proposed. In conclusion this paper has presented a novel high step-up converter that utilizes the coupled inductor and voltage multiplier principles for use with a solar PV. Matlab/simulink model is developed and simulation results are presented.

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