Soft switching and Efficiency Enhancement of Improved Multiple Input High Step-up Non-Isolated DC-DC Converters for Renewable Energy Applications

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***Abstract*: A Non Isolated Multi Input High Step up DC-DC converter is presented in this paper. This Multi Input DC-DC converter attains high voltage gain and low stress across the switches. This converter can be operated in bi-directional; with simple construction the controlling mechanism and generation of switching signals are easy. Principle of operation and analysis of the converter can be presented in detail. Multi Input High Step up DC-DC converter simulation with the closed loop controllers, PI and FUZZY logic controller are presented for getting stiff voltage regulation under sudden disturbances in load. Low Switching loss improves the converter performance.**

Keywords: multi input dc-dc converter, pi controller, fuzzy logic controller, and voltage gain

1. Introduction:

Renewable energy sources requirement increase because of the echo friendly nature and exhaustion of the fossil fuels. Photovoltaic, fuel cells, wind energy etc all this are renewable energy sources. We need renewable sources because of the requirement of more demand at the same time reduction of Non renewable energy sources. These Photovoltaic modules contain Photovoltaic modules which are connected in parallel or in series. More number of the cells avoids because of divergence and also it causes the reducing of the output voltage [1]. With the isolated converters attain high step up ratios by implanting of transformer, which requires more turns ratio. These more turn ratio causes the leakage inductance during the secondary side of the transformer, voltage spike and current spike problems are arises that will reduce the performance of the converter. Pulsed input current is required for the isolated converter that is weak point for Photovoltaic modules as per the characteristics of the Photovoltaic cell [2]. So input side large filters are necessary. In case of Non isolated converters there is no transformer requirement and simple arrangement but less voltage gain. For improving these voltage gain different method are presented. With the tapped inductor high step up ratios can be obtain but voltage spike appear due to the leakage inductance which causes the high voltage stress lead to Electromagnetic Interference problems. Another method is Switched capacitors improves the voltage gain but it needs more number of the capacitors but switching loss and stress increases [3, 4]. Voltage lifting technique also improves the output voltage but controlling becomes difficult and complex also [5]. In this Multi input converter is discussed. These converters combine the different renewable sources which is available for reliability. This Multi input converters are simple in arrangement and it act as Bidirectional also with slight changes. In previous one N number of Multi input converter is present [1], which is formed with the N number of conventional boost converters. The voltage gain of the converter is low when compared with the converter which is presented in this paper. Low voltage stress on switch in these Improved Multi Input boost converter.

2. Operational Principle

The arrangement of n-input high boost converter is as shown in Fig: 2.a. Multi input Converter combines various sources with various Voltage and current characteristics, to attain the power demand

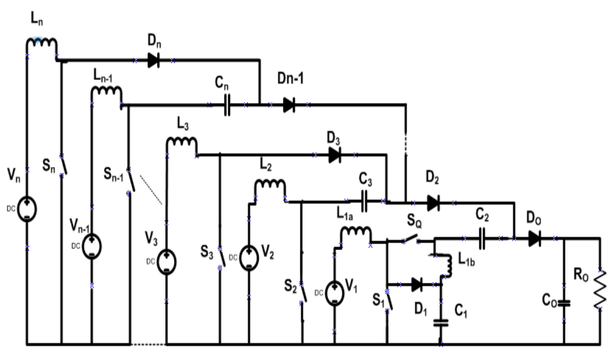


Fig: 2.a: n-input version topology

The V_{in1}, use capacitor, Two Inductors, 2 Switches and one diode, other inputs uses 1 switch, 1 inductor, 1 diode and one capacitor and capacitor is used at output side to filter Vo. This three input version contain uni-directional switches those are MOSFET'S with Anti-parallel diode. Therefore during Vin1unit, the S_1, S_Q operates simultaneously. The three input:

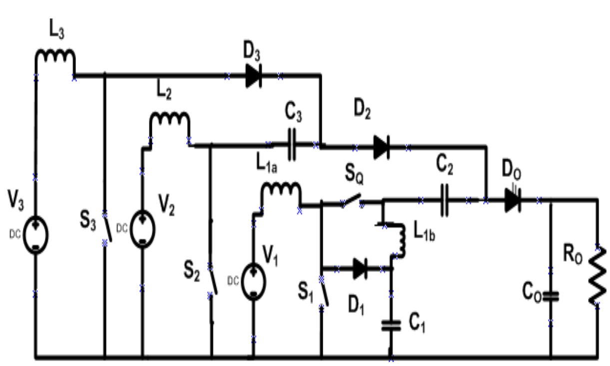


Fig 2.b three input version topology

Figure. 2.b contain four diodes, four inductors, four capacitors and four switches. Bi-directional converter operation can be possible by in 1st unit, the D_o& D_1 are replace as unidirectional switches.

3. Modes of Operation

Here three-inputs is considered for explanation. The switching method of three-input converter is shown in Fig3. The duty cycle of switches are considering as: $D_{S1} = D_Q = d_1$, $D_{S2} = d_2$ and $D_{S3} = d_3$.

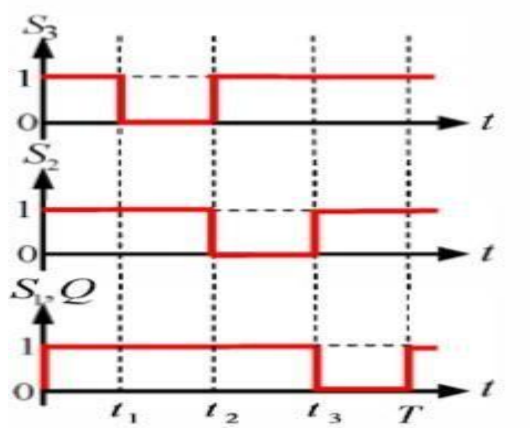


Fig3: switching scheme of three input topology

A. Mode 1-[0-t1]

During this mode (time interval of [0-t_1]), all the switches conduct. So, the energy of input sources is stored in the inductors. The L_{1_a} is charged by V_1 through S_1 and the L_{1_b} is charged by C_1 through S_1 and Q switches. For the other inputs the energy of V_i sources are stored in L_i inductors through S_i switches (i=2,3). The load power is supplied from output capacitor (Co) and none of the diodes conduct as shown in Fig 3.(a). Thus:

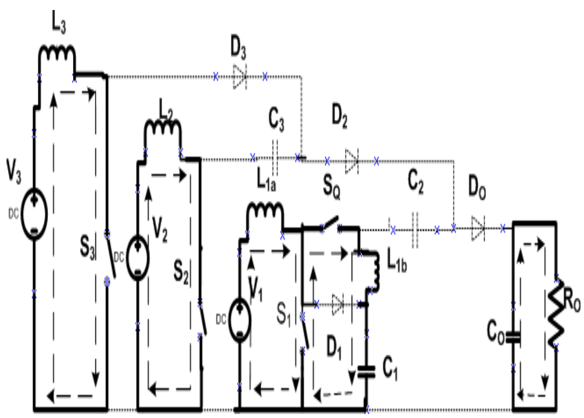


Fig 3(a) .Equivalent circuit of First Mode

Inductor across voltages in mode one

$$\begin{cases} V_{L_{1a}} = V_1 \\ V_{L_{1b}} = V_{c_1} \\ V_{L_2} = V_2 \\ V_{L_3} = V_3 \end{cases} \tag{1}$$

B. Mode 2-[t1-t2]

In this mode, the S_1, S_2, Q and D_3 conducts, but S_3 is off. The first input (V_1) charges the$L1_a$, the C_1 charges the $L1_b$ and the second input (V_2) charges the L_2. During this mode, the energy of third input (V_3) and L_3 is transferred to the C_2 through D_3 and S_2 as shown in Fig 3.(b)

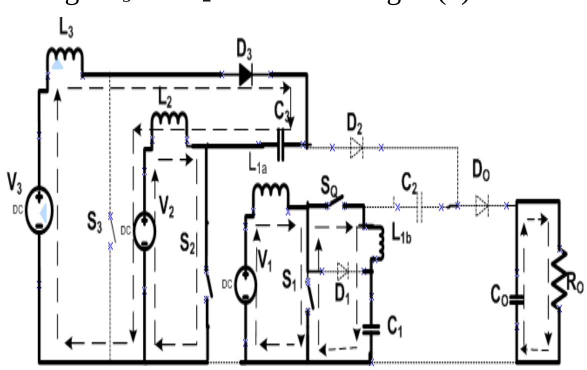


Fig 3(b): Equivalent circuit second mode

Inductor across voltages in mode two

$$\begin{cases} V_{L_{1a}} = V_1 \\ V_{L_{1b}} = V_{c_1} \\ V_{L_2} = V_2 \\ V_{L_3} = V_3 - V_{C_2} \end{cases} \tag{2}$$

C. Mode 3-[t2-t3]

In this mode the V_1 and C_1, charges the L_{la} and L_{lb}, respectively. The V_3 charges the L_3 through S_3. The D_3 goes off and S_3 turns on. So, the energy of V_2, L_2 and C_3 are transferred to C_2 through D_2, Q and S_1 as shown in Fig 3.(c).

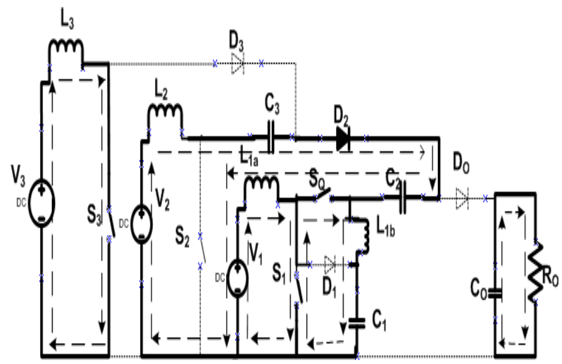


Fig 3.(c) Equivalent circuit third mode

Inductor across voltages in mode three.

$$\begin{cases} V_{L_{1a}} = V_1 \\ V_{L_{1b}} = V_{c_1} \\ V_{L_3} = V_2 + V_{C_3} - V_{C_2} \\ V_{L_3} = V_3 \end{cases} \tag{3}$$

D. Mode 4-[t3-t4]:

In this mode, S_2 and S_3 conduct but S_1 and Q goes off. The V_1 and L_{la} charge the C_1 through D_1. Also, the energy of V_1, L_{la}, L_{lb} and C_2 is delivered to the load through D_1 and D_o. The other sources charge their respective inductor Shown in

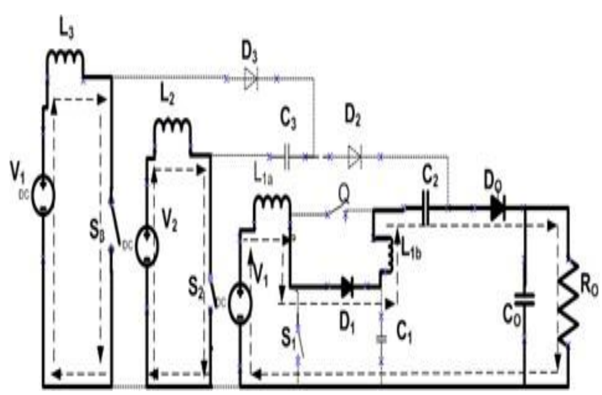


Fig 3.(d). Inductor across voltages in mode four

$$\begin{cases} V_{L_{1a}} = V_1 - V_{C_1} \\ V_{L_{13}} = V_{C_1} + V_{C_2} - V_0 \\ V_{L_2} = V_2 \\ V_{L_3} = V_3 \end{cases} \quad (4)$$

In this continuous conduction mode of analysis is considered. Waveforms of IL1,IL2 ,IL3&IL1a,IL1bhave been shown in fig 4.

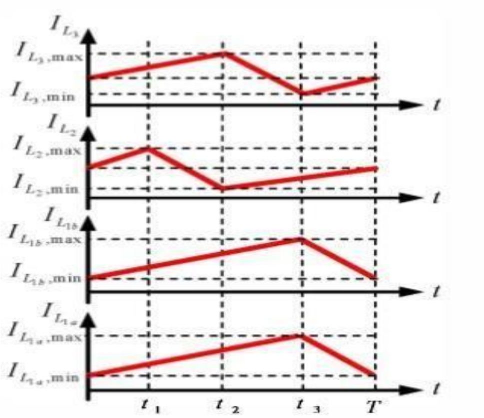


Fig 4: current waveforms of inductors

4 Continuous Conduction Mode Analysis

Voltage gain:

For calculate the gain of converter in Continuous Conduction Mode, according to the VOLT-SEC balance principle voltage across inductors is defined below

$$V_L = 0 \Longrightarrow (d_1)(V_1) + (1 - d_1)(V_1 - V_{C_1}) = 0 \quad (5)$$

$$V_{L_{1b}} = 0 \Longrightarrow (d_1)(V_{C_1}) + (1 - d_1)(V_{C_1} + V_{C_3} - V_0) = 0 \quad (6)$$

$$V_{L_2} = 0 \Longrightarrow (d_1 + d_2 + d_3 - 2)(V_2) + (1 - d_3)(V_3) + (1 - d_2)(V_2 - V_{C_2} + V_{C_3})(1 - d_1)(V_3) = 0 \quad (7)$$

$$V_{L_3} = 0 \Longrightarrow (d_1 + d_2 + d_3 - 2)(V_3) + (1 - d_2)(V_3) + (1 - d_3)(V_3 - V_{C_3}) + (1 - d_1)(V_3) = 0 \quad (8)$$

By simplifying above equations

$$v_{c1} = \frac{v_1}{1 - d_1} \quad (9)$$

$$v_0 = \frac{v_{c_2}}{1 - d_1} + v_{c_2} \quad (10)$$

$$v_{c_2} = \frac{v_2}{1 - d_2} + v_{c_3} \quad (11)$$

$$v_{c_3} = \frac{v_3}{1 - d_3} \quad (12)$$

Replacing equations (9), (11) and (12) in (15), then the relationship in between input and output voltages is shown as

$$v_0 = \frac{v_1}{(1-d_1)^2} + \frac{v_2}{(1-d_2)} + \frac{v_3}{(1-d_3)} \quad (13)$$

I[th] input D (duty cycle) of switch is denoted as d_i . Input and V_0 relations for the n number of sources are expressed as

$$v_0 = \frac{v_1}{(1-d_1)^2} + \sum_{i=2}^{n} \frac{v_i}{(1-d_i)} \quad (14)$$

Consider Vin2,Vin3 ....Vinn=V and d2,d3…dn=d then equation 14 can be expressed as

$$v_0 = \frac{v_1}{(1-d_1)^2} + \left\{\frac{n-1}{1-d}\right\} v \quad (15)$$

For V_1=V and d_1=d then equation (15) can be represented as

$$\frac{v_0}{v_{in}} = \left\{\frac{n(1-d)+d}{(1-d)^2}\right\} \quad (16)$$

5 Design Parameters

Inductance:

The current ripple of inductor L_{1a} under CCM can be expressed by

$$\Delta i_{L_{1a}} = \frac{V_1 d_1}{L_{1a} f_s} \quad (17)$$

Then, the inductance L_1can be determined by

$$L_{1a} = \frac{V_1 d_1}{\Delta i_{L_{1a}} f_s} = \frac{V_1 d_1}{\Delta i_{L\%} i_{L_{1a}} f_s} \quad (18)$$

Where $\Delta i_{L\%}$ is the ripple tolerance of inductor current Similarly, the inductances of L_{1b},L_2,L_3 can defined by

$$L_{1b} = \frac{V_1 d_1}{(1-d_1)\Delta i_{L_{1b}} f_s} = \frac{V_1 d_1}{(1-d_1)\Delta i_{L\%} i_{L_{1b}} f_s} \quad (19)$$

$$L_2 = \frac{V_2 d_2}{\Delta i_{L_2} f_s} = \frac{V_2 d_2}{\Delta i_{L\%} i_{L_2} f_s} \quad (20)$$

$$L_3 = \frac{V_3 d_3}{\Delta i_{L_3} f_s} = \frac{V_3 d_3}{\Delta i_{L\%} i_{L_3} f_s} \quad (21)$$

Maximum inductor currents as follows

$$i_{L_{1a,max}} = \frac{V_o}{R(1-d_1)^2} + \frac{d_1 V}{2 l_{1_a} f} \quad (22)$$

$$i_{L_{1a,max}} = \frac{V_o}{R(1-d_1)} + \frac{d_1 V_1}{2(1-d_1) L_{1_b} f} \quad (23)$$

$$i_{L_{2,max}} = \frac{V_o}{R(1-d_2)} + \frac{d_2 V_2}{2 l_2 f} \quad (24)$$

$$i_{L_{3,max}} = \frac{V_o}{R(1-d_3)} + \frac{d_3 V_3}{2 L_3 f} \quad (25)$$

Capacitance:

The capacitance of C_1, C_2, C_3, and C_0 can be defined by

$$C_1 = \frac{I_0 d_1}{\Delta V_1 f_s} \quad (26)$$

$$C_2 = \frac{I_0 d_2}{\Delta V_2 f_s} \quad (27)$$

$$C_3 = \frac{I_0 d_3}{\Delta V_3 f_s} \quad (28)$$

$$C_0 = \frac{I_0 d_3}{\Delta V_0 f_s} \quad (29)$$

Where $\Delta V_0\%$ is the ripple tolerance of capacitor voltage, the capacitances of c_0 should be large enough to keep the capacitor voltage constant.

Switching Components:

The maximum voltage appear across the switch or diode in its open condition is denoted as voltage stress Stress on switch in STEADY STATE Continuous Conduction mode is

$$v_{s_1} = v_{c_1} \quad (30)$$

$$v_q = v_0 - v_{c_3} \quad (31)$$

$$v_{s_2} = v_{c_2} - v_{c_3} \quad (32)$$

$$v_{s_3} = v_{c_3} \quad (33)$$

I Stress across the switches is represented as:

$$i_{stress-s_1} = \frac{V_0}{R(1-d_1)^2} + \frac{d_1 v}{2 l_{1a} f} \quad (34)$$

$$i_{stress-Q} = \frac{v_0}{R(1-d_1)} + \frac{d_1 v_1}{2(1-d_1)} + \frac{d_1 v_1}{2(1-d_1) l_{1b} f} \quad (35)$$

$$i_{stress-s_2} = \frac{v_0}{R(1-d_2)} + \frac{d_2 v_2}{2 l_2 f} \quad (36)$$

$$i_{stress-s_3} = \frac{v_0}{R(1-d_3)} + \frac{d_3 v_3}{2 l_3 f} \quad (37)$$

in this the V_o/V_{in} of two input improved converter is differentiate with the two input version multi input converter The voltage gain of the each converter is shown as

6. Design of PI Controller

The best method of control the industrial drives is PI controller . Figure 5 represents the block diagram of PI control technique

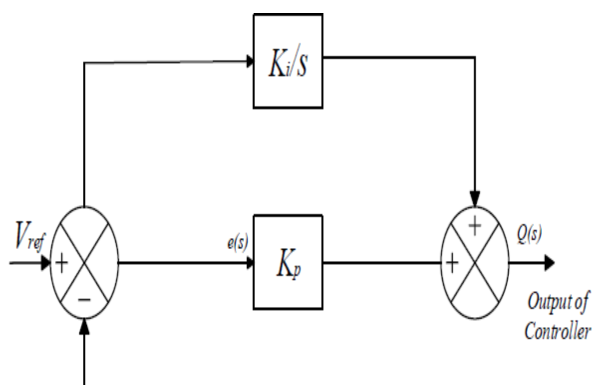


Fig. 5. Block diagram of proposed PI controller for converter

The error signal e(s) fed back to the PI controller and controlled output signal Q(s) is :

$$(S)=[KP+(K_i/s)]\times e(s) \quad (38)$$

7 Design of FL controller

It is very simple in designing the FL controller which is shown in Fig 6.

1 Gaussian shaped
2 Signoidal shaped
3 Trapezoidal shaped
4 Π shaped
5 Triangular shaped

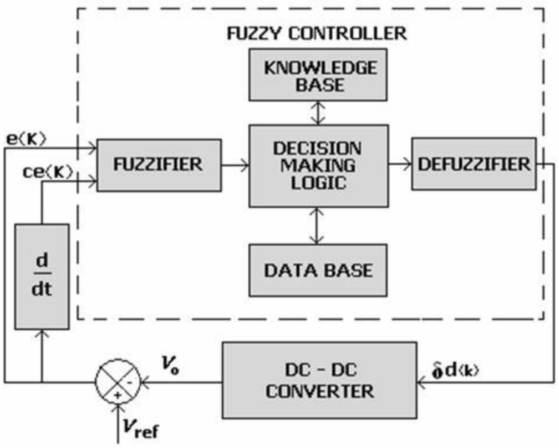


Fig. 6. Block diagram of proposed FL controller for converter

A. Fuzzification

NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big).

Fig 6(a) shows the fuzzy membership function of error input variable with 7 linguistic terms as NB: Negative Big PB: Positive Big

NM: Negative Medium PM: Positive Medium

NS: Negative Small PS: Positive Small

ZE: Zero

Fig 6(b) shows the fuzzy membership function of change in error input variable with 7 linguistic terms as

NB: Negative Big PB: Positive Big

NM: Negative Medium PM: Positive Medium

NS: Negative small PM: Positive small

ZE: Zero

Fig 6(c) shows the fuzzy membership function of control signal output variable with 7 linguistic terms as

NB: Negative Big PB: Positive Big

NM: Negative Medium PM: Positive Medium

NS: Negative Small PS: Positive Small

ZE: Zero

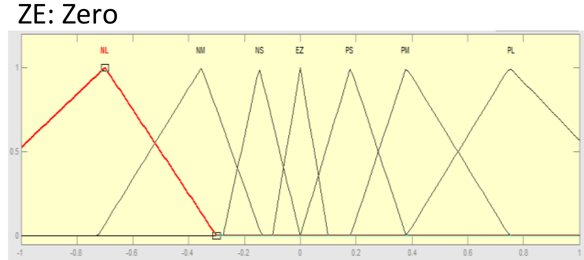


Fig. 7(a). Membership function for single input

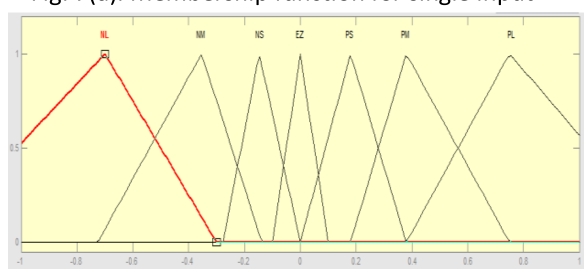


Fig. 7(b). Membership functions for change in error

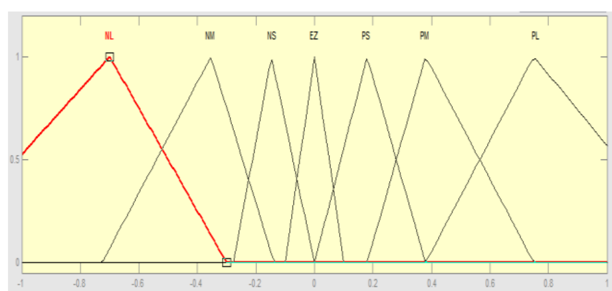


Fig. 7(c). Membership function for control signal

B. Rule Set

The processing is based on a collection of logic rules in the form of IF-THEN statements, where the THEN part

is called the consequent and the IF part is called the antecedent . basically fuzzy control systems have various rules.

In practice, AND is one popular definition, simply uses the minimum weight of all the antecedents, while or uses the maximum value. There is also a NOT operator that subtracts a membership function from 1 to give the complementary function. Table 1 gives the rules set for fuzzy controller.

Table (a) Rule base table for the fuzzy controller

e \ ce	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

8 Comparison Of Improved Topology And Multi- Input Converter

Here V1=V2=V and d1=d2=d then the simplifying equations represented

$$V_{0\ improved\ version} = \frac{V_1}{(1-d_1)^2} + \frac{V_2}{(1-d_2)} \quad (39)$$

$$V_0 = \frac{V_1}{(1-d_1)} + \frac{V_2}{(1-d_2)} \quad (40)$$

Here $V_1=V_2=V$ and $d_1=d_2=d$ then the simplifying equations represented as

$$V_{0\ improved\ version} = \frac{2-d}{(1-d_1)^2} V \quad (41)$$

$$V_0 = \frac{2}{(1-d)} V \quad (42)$$

Fig 7 shows that range of duty cycle [0.5-0.85] , improved converter gain is more than multi input converter. For example d=0.7 then V0/Vin of improved multi input converter and multi- input converter are 14.45 and 6.67 respectively. At any D this multi-input converter contains more voltage gain. Finally gain of improved multi input high boost converter gain is very by changing the duty cycle.

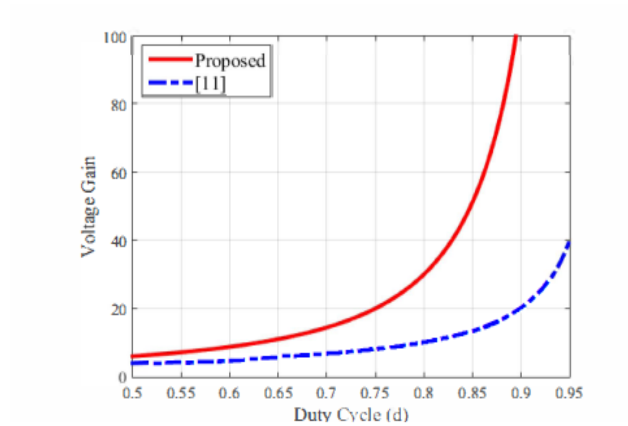


Fig 8: voltage gain of improved and topologies [11] voltage gain for $V_1=V_2=V$ and $d_1=d_2=d$

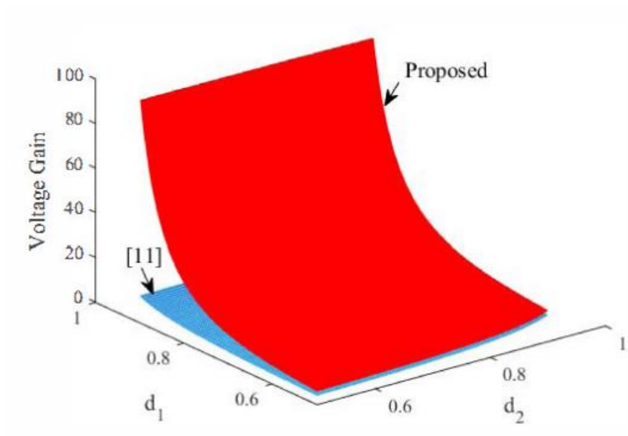


Fig 8.1: Voltage gain of improved structure and [11] topologies for $V_1=V_2=V$

SPECIFICATIOS	VALUE	SPECIFICATIOS	VALUE
D_1	0.7	switching Frequency	30 KHz
D_2	0.7	Load Resistance	390 Ω
D_3	0.7	Capacitor C_3	47 µF
V_{in1}	10 Volts	Output capacitor	220 µF
V_{in2}	10 Volts	Inductor L_{1a}	1.5mH
V_{in3}	10 Volts	Inductor L_{1b}	1mH
Capacitor C_1	88 µF	Inductor L_2	2mH
Capacitor C_2	47 µF	Inductor L_3	2mH

Table1: parameters for Improved Multi-Input High Step-up DC- DC converter

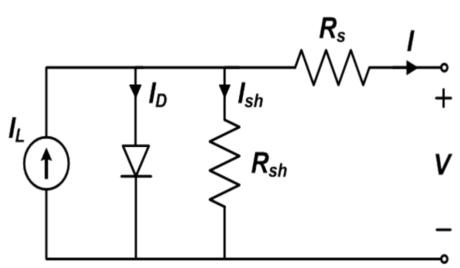
9 MULTI INPUT CONVERTER INPUT SOURCES:

Input sources for this converter are consider as PV panel, battery and dc sources

PV panel:

Solar cell is a P-N semiconductor junction. This cell expose to light then dc current is generated. By sola irradiance current vary linearly. Equivalent circuit for the solar cell is shown below

$$I = I_L - I_0\left(e^{\frac{q(V+IR_S)}{KT}} - 1\right) - \frac{V+IRs}{Rsh} \qquad (43)$$



	SPECIFICATIONS	VALUES
PV	V(oc)	10V
	I(sc)	3.8A
CONVERTER	V(in)	10V
	V(out)	177V
	capacitor	C_1=88µF C_2,C_3=47 C_0=220 µF
	Inductor	L_{1a}=1.5 Mh L_{1b}=1 mH L_2,L_3=2 Mh
	Switching frequency	30Khz

Table 2: parameters for pv panel

Battery modeling:

For battery modeling parameters are V_b (terminal voltage) and State of Charge equation can be is as follows

$$V_b = V_0 + i_b R_b - K\frac{Q}{Q+\int i_b dt} + A.\exp\left(B\int i_b dt\right) \quad (44)$$

$$soc = 100\left(1 + \frac{\int i_b dt}{Q}\right) \qquad (45)$$

R_b=battery internal resistance

V_o=open circuit voltage

I_b=battery charging current

K= polarization voltage

Q= battery capacity

A=exponential voltage

B=exponential capacity

10 SIMULATION RESULTS & ANALYSIS

Simulation of improved multi-input high step-up dc-dc converter with pv panel and battery as input sources for pi controller:

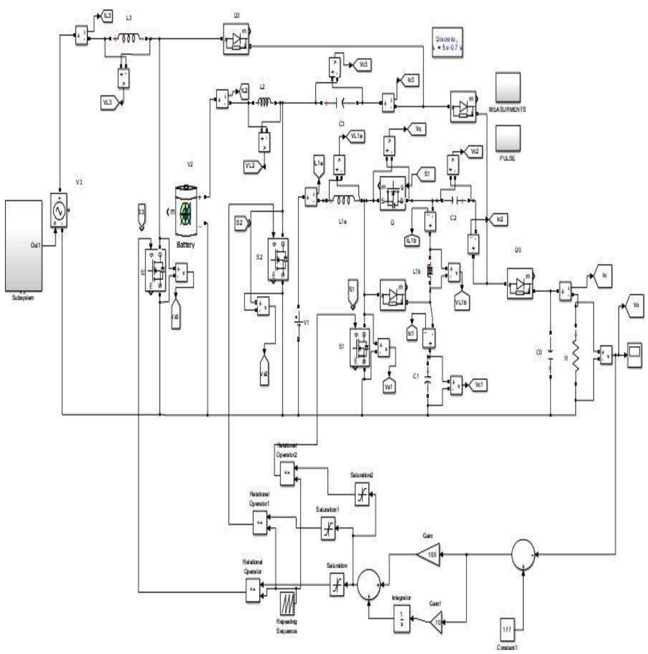


Fig 10: MATLAB/SIMULINK circuit of improved multi-input high-step up converter with PI Controller

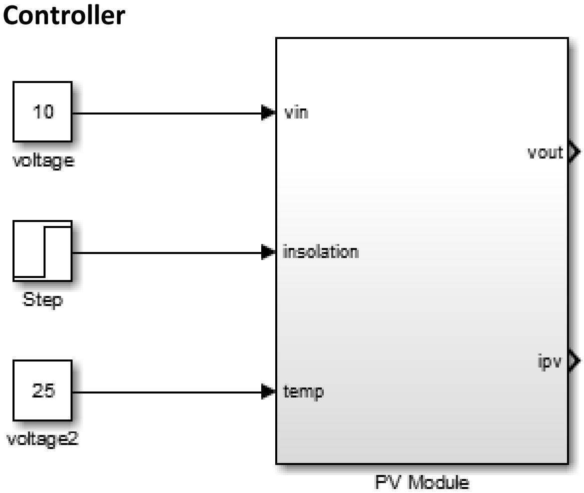


Fig 10.1(a): PV model

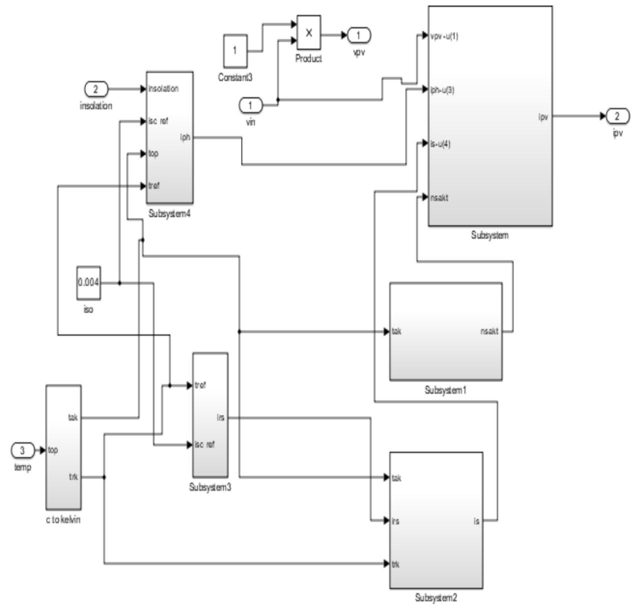


Fig10.1 (b) .subsystem for pv model

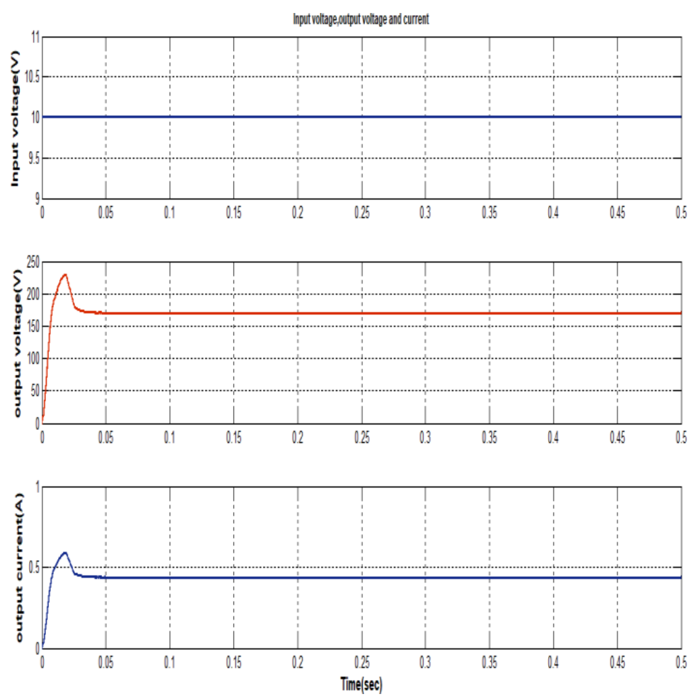


Fig 11 : input voltage, output voltage and current response of converter with pi controller

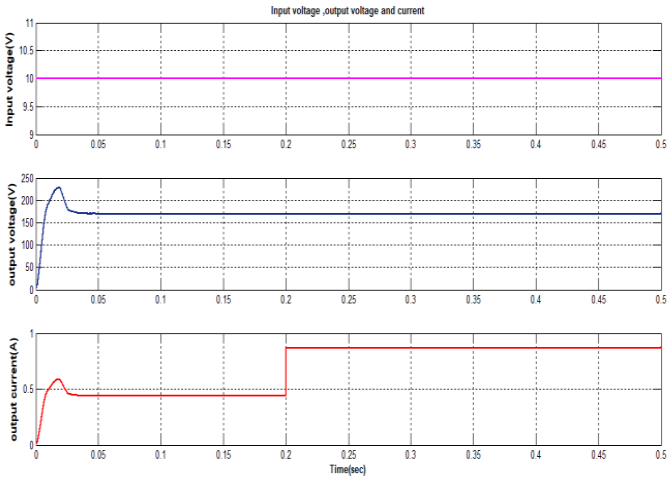


Fig 12: input voltage, output voltage and current response of converter for step chance in oad from 0.455A 0.87A with pi controller

Fig 12: shows the input voltage 10V, output voltage 177V and load current from 0.455A to 0.87A with pi controller.Most of applications require a stiff voltage during sudden load conditions for that voltage controller is require

11 Simulation of improved multi-input high step-up dc-dc converter with PV panel and battery as a input sources for fuzzy controller:

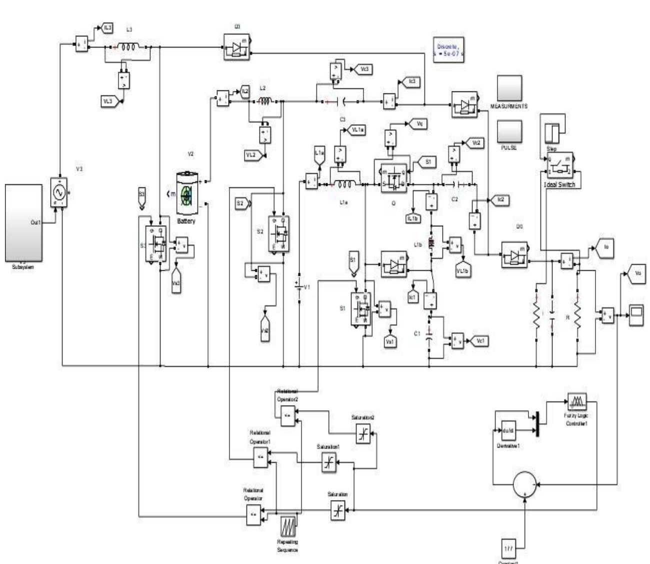


Fig 13: MATLAB/SIMULINK circuit of improved Multi-Input High Step up converter with fuzzy

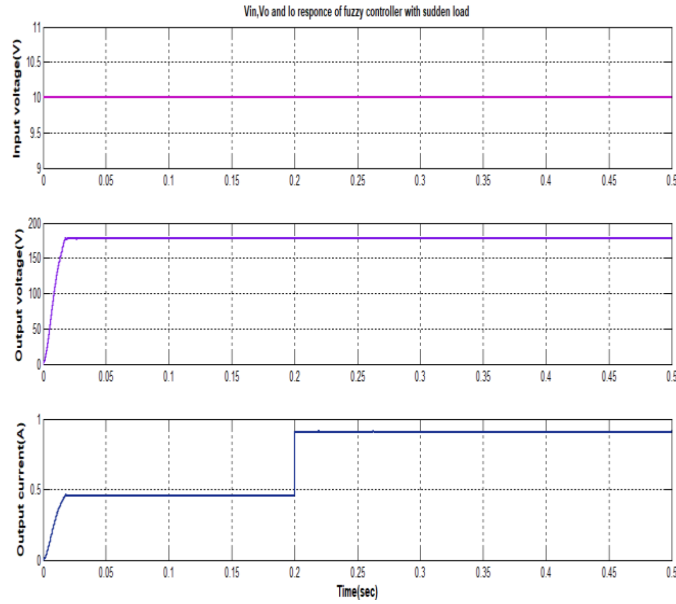


Fig 14: input voltage, output voltage and current response of converter with fuzzy controller

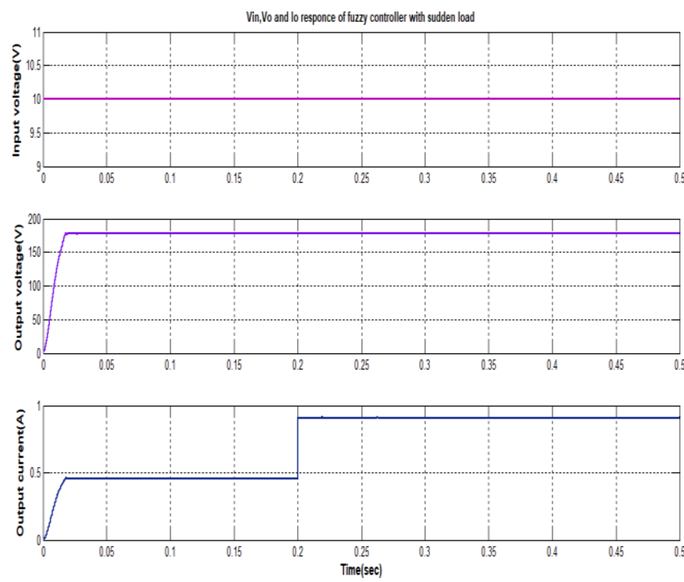


Fig 15: input voltage, output voltage and current response of converter for step chance in load from 0.455A to 0.87A with fuzzy controller

Fig 15: shows the input voltage 10V, output voltage 177V and load current from 0.455A to 0.87A with fuzzy controller. Most of applications require a stiff voltage during sudden load conditions for that voltage controller is require

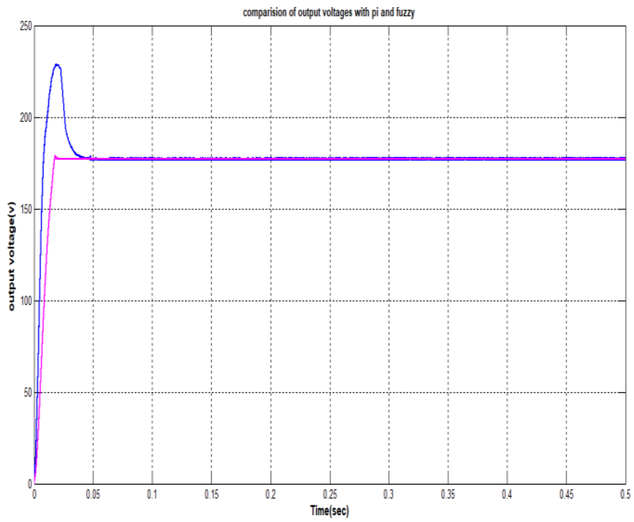


Fig.16 Comparison of output voltage responses of PI and Fuzzy Logic Controlled improved multi input high boost DC-DC Converter

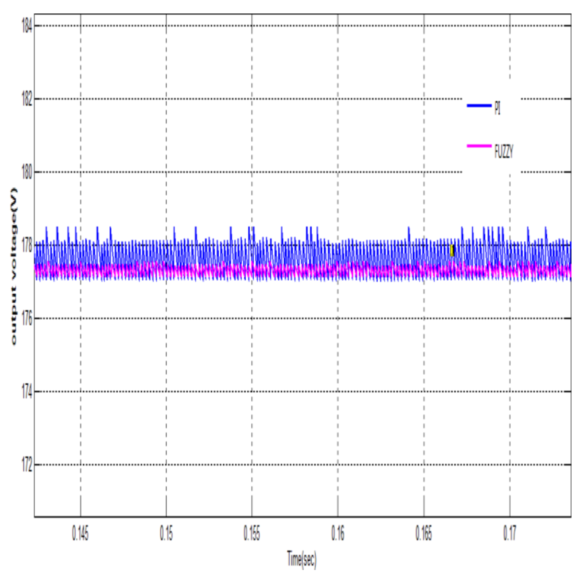


Fig 17: comparison of output voltage ripple of improved topology with pi and fuzzy controllers

Fig 16 shows that comparison of output voltages ripple for the improved multi-input High Step-up boost converter. In this pi and fuzzy controller output voltage ripple be 1.4V and 0.3V

Improve multi input high boost Converter	Rise time (tr) m sec	Peak (time tp) m sec	Settling time (ts) msec	Ripple in V0
PI Control of improved multi input high boost converter	0.0176	0.02	0.035	1.4V
FUZZY Control of improved multi input high boost converter	0.0135	0.017	0.02	0.3V

Table-3: comparison provides a performance of different controllers for a step change in load current from 0.455A to 0.87A at t=0.2 sec for constant input voltages of V_1=10, V_2=10, V_3=10

12. CONCLUSION

A improved multi-input high boost dc-dc converter has been describing in this paper. The proposed converter is compared with the previous multi –input high step-up dc-dc converter thus results shows that proposed topology gives high voltage gain with low voltage stress and simple structure, control mechanism and generation of switch signal be uncomplicated. Stiff voltage regulation is obtained in the power supply unit for a load voltage of 177V in opposition to the disturbances in the load applied at 0.2sec with an increment in current from 0.45A to 0.88 A in closed loop operation using the Proportional-Integral (PI) and FUZZY controllers, Study state analysis, operational principle have been presented. The three input version of multi input high boost converter has been simulated

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