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Relative analysis and Fuzzy Feedback Implementation of High Gain DC to DC Converter

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Abstract: This study presents design and relative analysis of a modified high boost ratio configuration to achieve higher boost ratio and improved efficiency over similar component count boost converters . The circuit Energizes in parallel similar to interleaved boost converter and de-energizes in series, thus improving overall boost ratio. A comparative study of the proposed circuit with variants of boost converters considering non ideal parameters is carried out. DC transformer model is designed for determining the boost ratios and simulated to validate it. The comparative simulation results show a net improvement of the boost factor for the new proposed topology. Regulated feedback is achieved using fuzzy controller.

Key words: Boost ratio, DC transformer model, perturbation, fuzzy control, relative analysis, proposed topology

INTRODUCTION

DC-DC converters finds wide application in devices which make use of batteries. Battery power systems make use of cells in series to get higher voltage. But the space constraint makes it limited to low voltage applications. Boost converter, a variant of DC-DC converter amplifies the input voltage based on its connection circuitry. Boost converter being efficient can reduce overall number of cells and make a system compact. An enhanced boost factor circuit finds many applications in the automotive, telecoms, IT industry as well as in power generating units such as fuel cells, solar arrays and wind mills. Many topologies like cascaded, interleaved and tapped inductor boost have been proposed to get a higher boost ratio than the basic boost circuit. This study provides a modified configuration which gives an higher boost factor, improve d efficiency over others with an easier switch control.

Ideal analysis and practical implementation show huge deviation in the results. This is due to omission of non ideal parameters during analysis. Importance of considering non ideal parameters in DC converter analysis have been shown by Aziz1 and Ali (2016), Bukar *et al*. (2015) and Garg *et al*. (2016) for Boost and Buck-Boost topologies. Interleaved Boost topology, a improvement on output voltage. An enhanced boost ratio topology having similar component count as the latter is discussed by Kamtip and Bhumkittipich (2011) which energises similar to interleaved thus reducing switch stress and de-energises in series. This results in improved boost ratio. Hu *et al*. (2015), discusses an open loop variant of boost which has similar design as Rensburg *et al*. (2008) with a simpler control. This topology is cost efficient, retains all the advantage of the previous converters and is found to be more efficient. DC transformer averaging approach is followed to determine the boost ratio and for closed loop regulation fuzzy controller approach (Anand *et al*., 2014) is followed.

MATERIALS AND METHODS

Proposed topology: The proposed schematic is shown in Fig. 1. The inductors L1 and L2 in the circuit are assumed to have same values, the diodes D1 to D4 are the same type and switches are assumed to be similar.

"On" state equivalent diagram: Assuming all components as ideal when switch S1 and S2 are in "ON" state, energy transfer takes place from DC supply into the inductors. Capacitor supports the load. Let i_{L1} be the current through inductor L1 and i_{L2} be current through L2, i_o is the load current (Fig. 2).

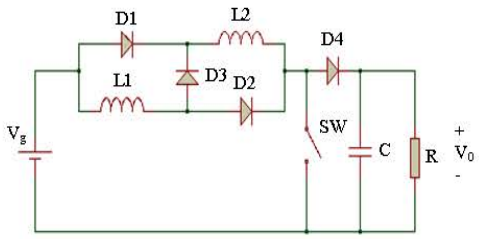

Fig. 1: Open loop schematic of modified topology

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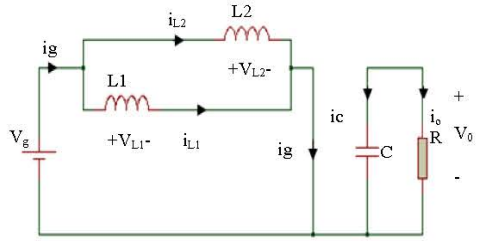

Fig. 2: Equivalent schematic for S1, S2 = ON

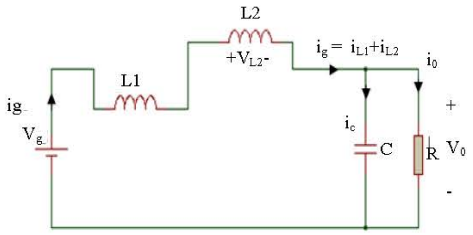

Fig. 3: Equivalent schematic for S1, S2 = OFF

"Off" state equivalent diagram: During "OFF" state , the two inductors along with voltage source come in series and supply the load (Fig. 3). Hence, an higher gain is achieved.

Boost factor: From the above schematics inductor voltage during charging and discharging is obtained. During the charging interval (S1, S2 = ON), the voltage across each inductor is V_g and the currents are written as:

$$i_{L1}(t) = i_{L2}(t) = \frac{V_g - V_0 * D'T_s}{L} \quad (1)$$

When the switches are OFF at t = DT, the voltage across inductors is V_g-V_o and the current $i_L(t)$ is:

$$i_{L1}(t) = i_{L2}(t) = \frac{V_g - V_0 * DT_s}{2L} \quad (2)$$

Under steady state the Eq. 2 results to:

$$\frac{V_0}{V_g} = \frac{(1+D)}{D'} \quad (3)$$

Here, V_0/V_g is the boost ratio of the proposed schematics under ideal conditions. Waveforms for inductor currents and voltage, capacitor current, diode currents and switch voltage are plotted in Fig. 4 and 5.

Inductance for a desired ripple is obtained by rearranging Eq. 1:

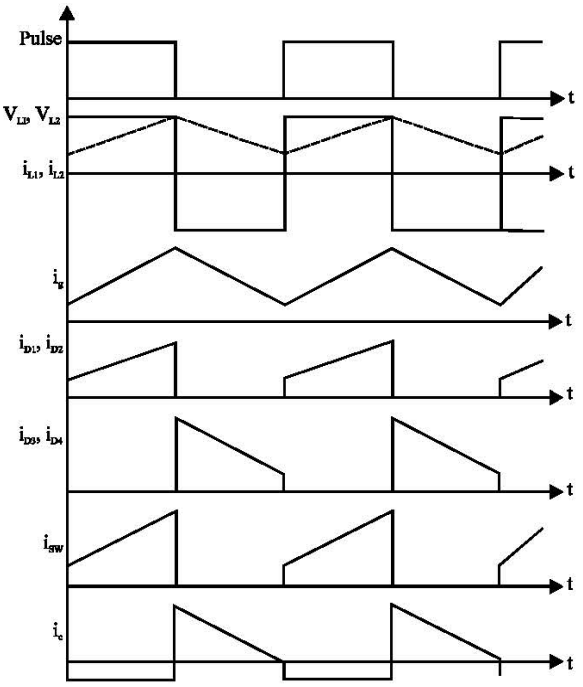

Fig. 4: Converter waveforms

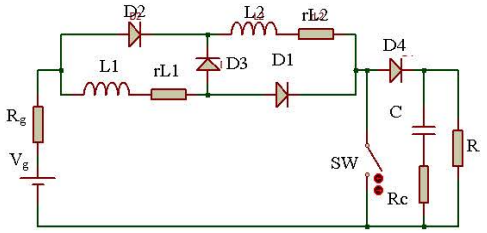

Fig. 5: Modified boost converter schematic

$$L = \frac{V_{g,max} * D_{min}}{\Delta i_{L,min} * f_s} \quad (4)$$

Capacitance for a desired ripple is calculated as:

$$\Delta q = C * \Delta v$$
$$\frac{V_0}{R} * D^{T_s} = C * \Delta v \quad (5)$$
$$C = \frac{V_{g,max} * D_{min}}{\Delta i_{L,min} * f_s}$$

Boost ratio comparision: A boost ratio comparison of the modified converter with simple boost, interleaved boost and enhanced boost taking in consideration all the non ideal parameter is done. The equivalent boost ratio is obtained by forming a DC transformer model for each

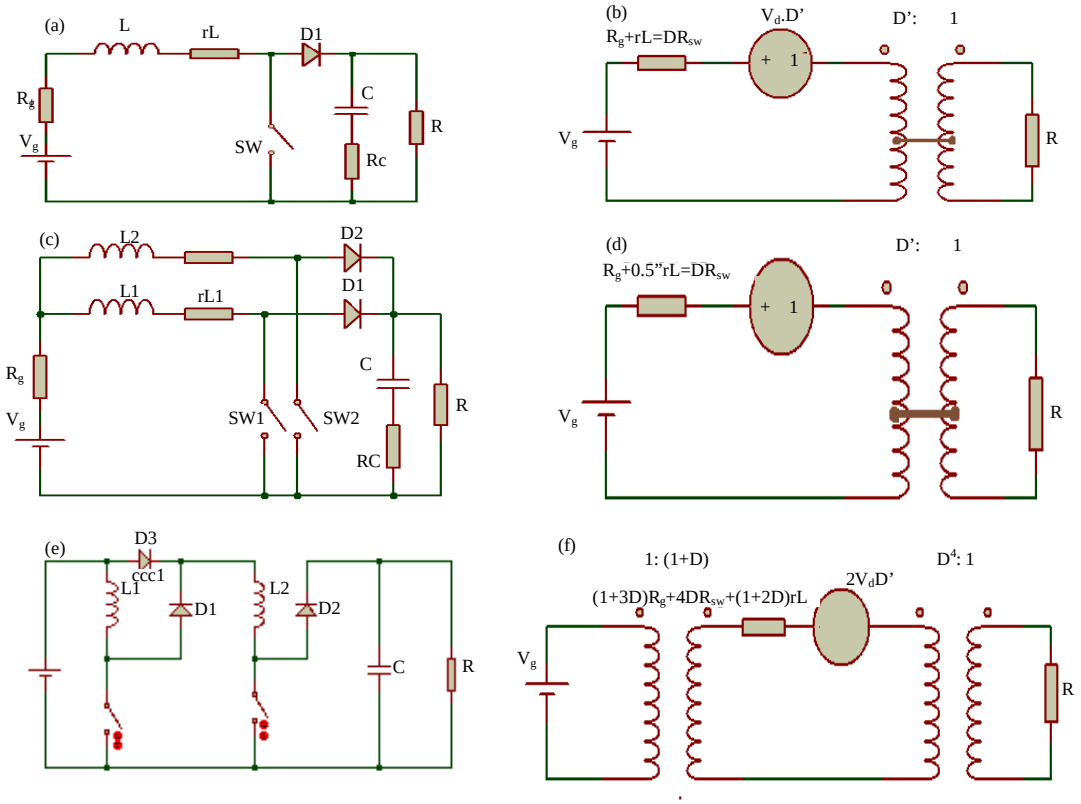

Fig. 6: a) Boost Converter (BC); b) DC transformer model (BC); c) Interleaved Boost Converter (IBC); d) DC transformer model (IBC); e) Enhanced Boost Converter (EBC) and f) DC transformer model (EBC)

configuration including ESR of coil of inductor, ON state resistance of switch, forward voltage drop of diode and source resistance. DC transformer model is obtained by writing equations of $i_L(t)$, $i_g(t)$ and $V_c(t)$ for switch "ON" and "OFF" states. Averaging all the above three quantities gives us the required expression for DC transformer model.

Modified boost converter: During Switch ON (Fig. 5):

$$L\frac{di_L(t)}{dt} = V_g - i_g(t)r_g - i_L(t)r_L - V_d - i_g(t)r_{sw}$$

$$C\frac{dv_c(t)}{dt} = -\frac{V_0(t)}{R}$$

$$i_g = 2i_L$$

During switch off:

$$L\frac{di_L(t)}{dt} = 0.5V_g - 0.5i_g(t)r_g(t)(r_{L1}+r_{L2}) - V_d - 0.5V_0$$

$$C\frac{dv_C(t)}{dt} = i_L(t) - \frac{V_0(t)}{R}$$

$$i_g = i_L$$

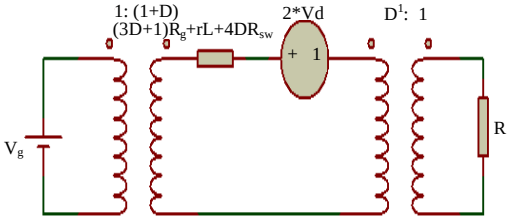

Fig. 7: DC transformer model of modified boost converter

Referring all the elements (Fig. 6) primary of transformer to secondary side gives boost factor as:

$$V_0 = \left(\frac{V_g(1+D) - 2V_dD}{D'}\right)\frac{D'^2R}{D'^2R + 4DR_{sw} + 2R_g + (4-3D)r_L} \quad (6)$$

The above averaging method is repeated for Boost, Interleaved and Enhanced topology. The circuit and their DC transformer model are shown in Fig. 7.

RESULTS AND DISCUSSION

The above study is simulated for $V_g = 10$ V, $V_o = 60$ V, $\Delta v_0/V_0 = 2\%$, $\Delta i_L = 20\% I_L$, R = 100 Ω, $f_s = 50$ KHz using MATLAB/Simulink. Circuit component values are calculated as per the analysis and practical equivalent of these components are considered (Table 1) for simulation. Analysis similar to modified boost converter is repeated to simple, interleaved and enhanced boost converters.

A plot of output voltage for duty cycle variation is plotted in Fig. 8. This plot shows the difference in output voltage on considering non ideal parameters. Inductor, Source and load side diode waveforms are plotted in Fig. 9. Line to output transfer function for other topologies are calculated similar to Eq. 8 and tabulated in Table 2 along with boost ratios and voltage ripple.

It can be observed that output of boost and interleaved, enhanced and modified are nearly equal. The same is realized in the output voltage vs duty ratio plot of all converters (Fig. 10). For higher boost ratio, duty ratio above 0.6 is best suited (Fig. 11).

Modified boost converter is found to give an higher output voltage compared to interleaved with same number of component count and is found more efficient over enhanced converter (Fig. 12) .Interleaved converter due to its 180° out of phase switching resulting in the reduced output ripple has nearly equal efficiency of that of the modified.

Efficiency of the proposed model: Large duty ratio usually results in the overall reduction of efficiency of the converter. But the proposed topology needs to operate at higher duty ratio to get larger boost factor:

$$\text{Efficiency} = \frac{R\times D'^2}{R\times D'^2+Rs+DR_{sw}+0.5Dr_L+R\left(\frac{V_d}{V_0}\right)DD'+\frac{R^2R_cD'^2}{(R+R_c)^2}+2r_LD'+2R\left(\frac{V_d}{V_0}\right)D'^2+RRD'^2C_{sw}f_s+(T_{on}+T_{off})}$$

Efficiency of all converters are similarly calculated and tabulated in Table 1. It can be concluded that efficiency improvement is possible by selecting the component with reduced non ideal values.

Fuzzy logic controller: The complex small signal transformer modeling to determine the transfer function can be avoided by a fuzzy logic approach (Fig. 13). Here, voltage regulation is done using mamdani implication. Error and changes in error are the two inputs to the fuzzy controller while duty being the output (Table 3 and Fig. 14-17). Fuzzy membership function with a universe of

Table 1: Circuit components

Componen	Values
Capacitor	15 µF, 100 V, 3.5 Ω (ESR)
Inductor	682 µF, 0.035 Ω (Coil)
Diode	by 299, ($V_{f(max)}$ = 1.1 V)
Mosfet	IRF 540 (R_{on} = 0.2 Ω, C_{sw} = 38 nC, T_{on} = 15ns, T_{off} = (40 nsec)
Source	30 V DC supply (R_s = 0.7 Ω)

Table 2:Comparitive analysis of similar topologies

Converter	Line to output Transfer Function	Theoretical (V_0/V_g)	Simulated (V_0/V_g)	$\Delta v_0/V_0$ (%)	η(%)
Boost	$(V_g/D'-V_d)$ D'^2R/D^2R+ D $R_{sw}+R_g+r_L$	3.0400	3.116	3	91.23
Interleaved	$(V_g/D'-V_d)$ D'^2R/D^2R+ D $R_{sw}+R_g+0.5r_L$	3.0416	3.115	1.3	87.23
Enhanced	$(V_g(1+D)-V_d(2-D)/D')$ D'^2 R/D'^2R+2D R_{sw} $+2Rg+(4-3D)r_L$	4.4540	4.44	2	84.22
Modified	$(V_g(1+D)-2V_dD/D')$ D'^2 R/D'^2 R+ 4D $R_{sw}+$ $2R_g+(4-3D)r_L$	4.5903	4.546	2	85.76

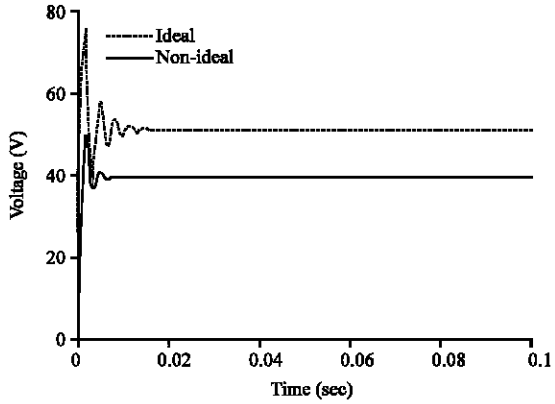

Fig. 8: Output voltage waveform for ideal and non ideal case

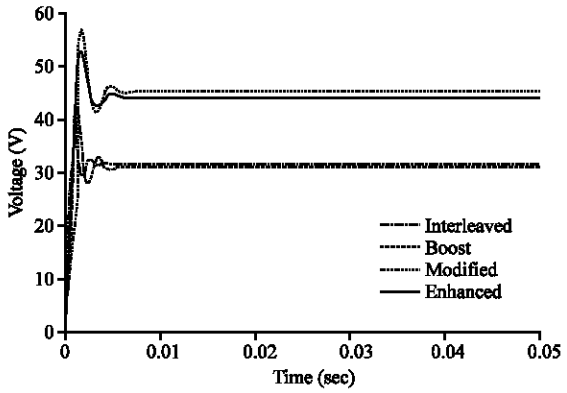

Fig. 9: Plot of diode, inductor and Source currents

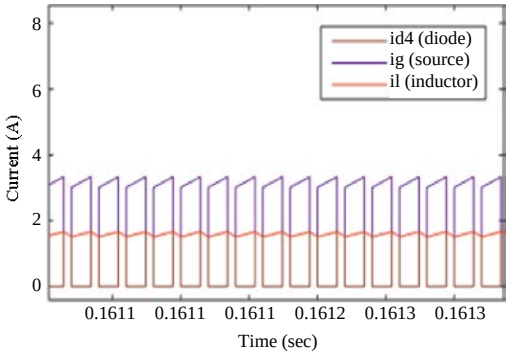

Fig. 10: Output voltage plot of all the converters

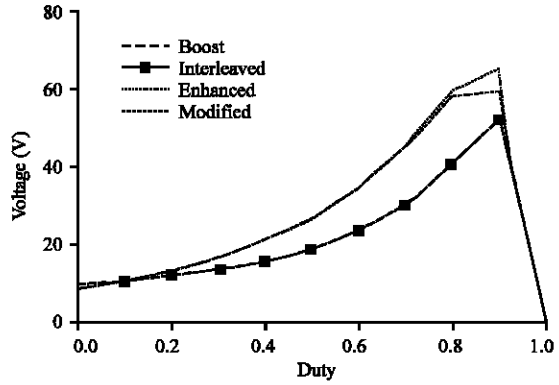

Fig. 11: Plot of output voltage variation with duty

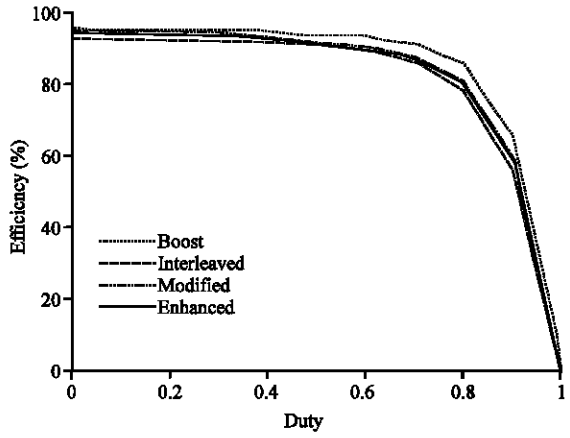

Fig. 12: Plot of efficiency variation with duty

Table 3: Rule base for fuzzy controller

Δe(k)/e(k)	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NM	NM	NM	NS	ZO	PS
NS	NB	NM	NS	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PS	PM	PB
PM	NS	ZO	PS	PM	PM	PM	PB
PB	ZO	PS	PS	PB	PB	PB	PB

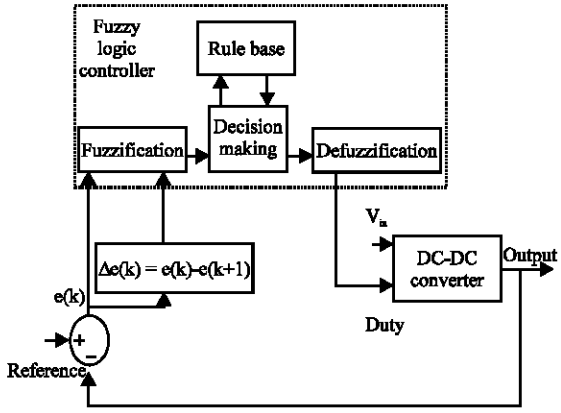

Fig. 13: Block diagram of Fuzzy Logic Controller (FLC)

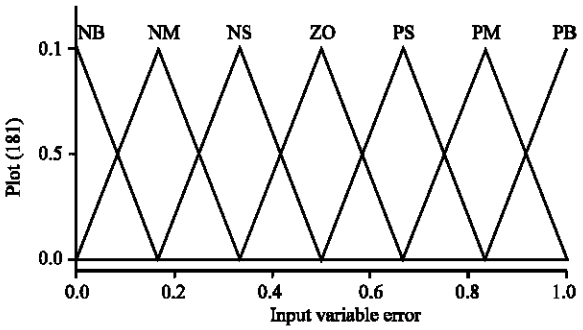

Fig. 14: Error membership function plot

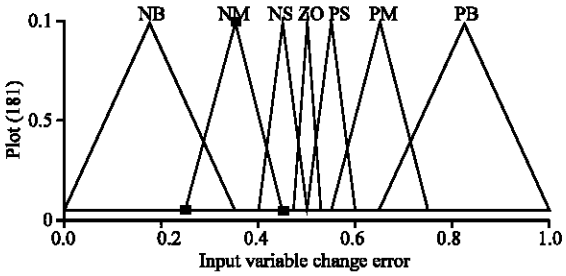

Fig. 15: Change in error membership function plot

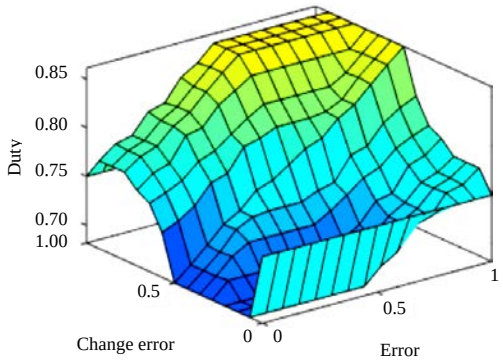

Fig. 16: Rule base surface

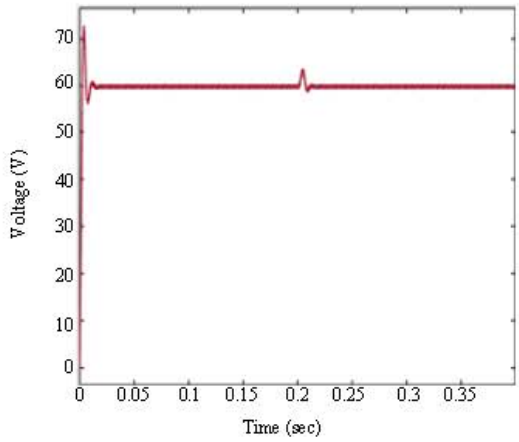

Fig. 17: Output voltage plot with source perturbation ($V_g = 9.6V$) at t = 0.2 sec

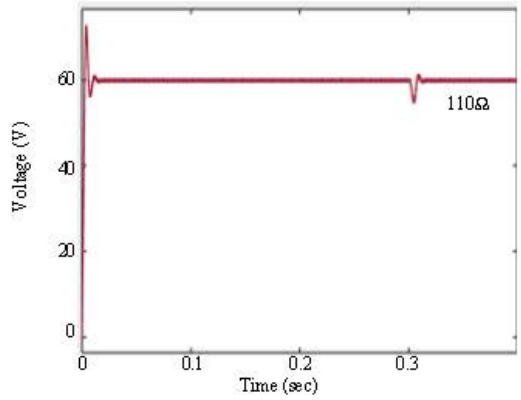

Fig. 18: Output voltage plot with load perturbation ($R = 110\ \Omega$) at t = 0.3 sec

discourse of seven is taken for the inputs (Fig. 14 and 15) A rule base (Table 3) is formed. Surface for rule base is shown (Fig. 16).

The system with fuzzy controller is tested for stability by source perturbing (Fig. 17) and load perturbing (Fig. 18).

CONCLUSION

This study presents a comparative study of three boost topologies. The proposed modified topology gives an enhanced boost ratio/improved efficiency over existing converters. The modified boost topology is modeled with non ideal parameters to achieve near practical results. Graphical comparison is done using mathematical equations. Boost factor is theoretically determined by DC transformer model and validated through simulations. Comparison with similar component count boost topologies helps understand application suitability of the converter. The simulation results shows an improved boost factor and efficiency with easier control over other boost topologies. Closed loop fuzzy implementation gives a regulated output. The design requirement has been achieved at a lower duty with added advantage of easier control and higher boost.

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