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Analysis of Novel DC-DC Boost Converter topology using Transfer Function Approach

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***Abstract* – Bidirectional DC - DC converters play an important role in applications where conversion of DC – DC is involved. These applications include hybrid electric vehicles, switching mode power supplies, battery charges and uninterruptible power supplies. Many converter topologies are proposed and are available. All these converters utilize energy storage devices for transfer of energy between source and load. The proposed concept makes use of same principles for transfer of energy, but the converter performance is analyzed with the help of transfer function approach. For this purpose a bi-directional DC – DC converter available in reference [] is considered, for which mathematical model is formulated. The model thus formulated is simulated with the help of MATLAB / Simulink and Simpowersystems Blockset.**

***Keywords* – Bi- directional DC – DC Converters, Stored Energy, Energy Factor, Converter Time Constant, Damping Time Constant.**

I. INTRODUCTION

Bi – directional DC – DC Converters are useful in applications where power transfer takes place in either direction i.e power transfer between two DC – DC sources. These converters are widely used in hybrid electric vehicles, photovoltaic hybrid power Systems, Fuel- cell hybrid power systems, uninterruptible power systems and battery charges. Many bi – directional DC – DC Converter topologies are proposed in literature out of the available models, bi - directional DC – DC flyback converters are found to be simple in structure and easy in control. It is observed that the switches used in the switches used in these converters subjected to high voltage stress due to leakage energy released by transformer during energy transfer phase. For minimization of voltage stress of converter switches due this leakage energy release by transformer literature suggests energy regeneration techniques. These techniques suggest that the leakage inductor energy is recycled by clamping the voltage stress on the converter switches. In some of the literature isolated bi – directional DC – DC converters are proposed, these converter technologies includes half – bridge, full – bridge types. These technologies make use of adjustable turns transformers as a result of that these converters provide high step – up and step – down voltage gains. For non – isolated applications non – isolated bi-directional DC – DC Converters are suggested. These converters include topologies like buck / boost, multilevel level converters, Three – level Converters, Sepic / Zeta, Switched capacitor and coupled inductors. Three Level and Multi Level converters suffer with low step – up and step – down voltage gains. Sepic / Zeta converters uses two stages for power conversion, this results in more losses as a result conversion efficiency decreases. Multi level type converters make use of magnetic less converter concept, and require more number of switches for energy conversion. This makes this topology with complicated structure and control circuit. If more step – up and step – down voltage gains are required the number switches are to be increased. This makes the control more complicated. The switched capacitor and coupled inductor converters can provide higher step – up and step – down voltage gains. And the voltages appearing across switches used in these topologies can be made minimum.

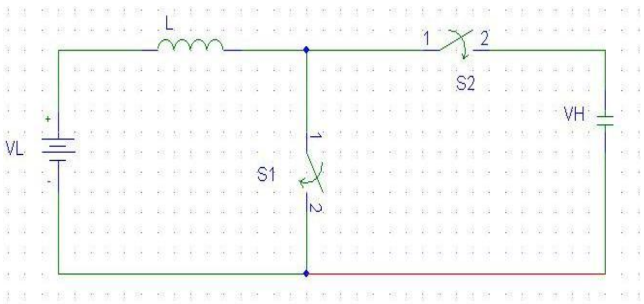

Figure 1: Circuit Diagram of Conventional Bi – directional DC – DC Converter.

Figure 1 Show conventional DC – DC converter with two switches S1 and S2. A modification is made to the above circuit such that the inductor is replaced with a coupled inductor and one more switch is added. New configuration is shown in figure 2. The preceding sections will discuss the modeling issues involved, results obtained.

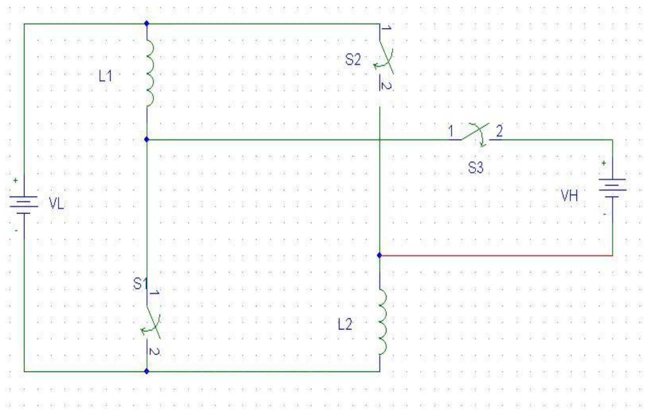

Figure 2: Proposed DC – DC Converter model diagram working as boost converter.

II. DC – DC CONVERTERS

The proposed converter is analysed with the help of transfer function approach. And physical mode l is verified with MATALB – Simpowersystems Blockset.

The transfer function for any DC – DC Converter operating in step – down mode is

$$G(S) = \frac{M}{1 + s\tau + s^2\tau\tau_d}$$

M is the Voltage Transfer Gain, τ is the time constant of the converter, this value is independent of switching frequency. τ_d is damping time constant.

Time response of the system is dependent on damping time constant, converter time constant and time constant ratio.

For Very small values of damping time constant, order of the overall transfer function will be 1. So the system response will have a exponentially rising.

For Small values damping time constant, Where $\tau \ll \tau_d/4$, the system will have real poles on the left half of s-plane, the system response would be better compared to previous case.

For higher values of damping time constant where $\tau_d \gg \tau$, the second order system will have complex conjugate poles and the response would be under damped.

Proposed topology uses MOSFET Switches, coupled inductor and a capacitor. The output power supplied by the converter is varied from 50 watts to 200watts and its performance is estimated using MATLAB/SIMULINK and Simpowersystems Blockset.

It is assumed that the coefficient of coupling of the coupled inductor as 0.5. This value can be adjusted by using a variable gap inductor. The windings of coupled inductors are connected in such a way that they are connected in parallel during charging period and are connected in series during their discharge. When they are connected in parallel with the source the voltage appearing across them is equal to source Voltage. During the period of discharge they made to be connected in series as a result

$$V_{L1} + V_{L2} = V_L - V_H.$$

This results in reduced voltage stress over the converter switches during off period of the Converter. Under this condition the total inductance in the circuit is given by

$$L_{eq} = L_1 + L_2 + 2M$$

The energy in inductor is given by $W_L = \frac{1}{2} L_{eq} I_L^2$

The energy stored by capacitor is

$$W_c = \frac{1}{2} C V_H^2$$

Total energy stored $W = W_L + W_C$

Capacitor to Inductor stored Energy ratio (CIR) $= \frac{W_C}{W_L}$

The output power delivered by the converter varies depending upon the pumping energy and stored energy, as a result CIR varies.

III. ANLYSIS OF BOOST CONVERTER

Model proposed in [1] is considered for analysis, it id found that a prototype is constructed with $L_1 = L_2 = 15.5\text{x}10^{-6}$H, M = $1\text{x}10^{-6}$H, C = 330 X 10^{-6}F, V_1 = 14V, I_1 = 10A, P_0 = 200W, T = 20µSec, for which Energy Factor is found to be 104.53mJ, CIR = 176.4 considering the system as loss less τ = 23.55µSec, and τ_d = 4154.22µSec.

It is observed that $\tau_d \gg \tau$, the system response is under damped. And the damped oscillations will die out in a period of $4\tau_d$.

An attempt is made to reduce the damped oscillations that produced during the transient response by varying the factor like CIR, P_0 and Energy factor, by doing so the magnitudes of τ and τd are varied.

Proposed converter circuit is simulated using MATLAB / SIMULINK, Simpowersystems Blockset for different values of CIF, the response characteristic is observed for connected loads varied from 50watts – 200watts. Converter parameters load Voltage, Load Current, Efficiency, Current through inductors, Voltage across switches and current through the switches are tabulated shown in figures 4 – 9 for k = 0.6, P_0 = 200watts, CIR = 0.25.

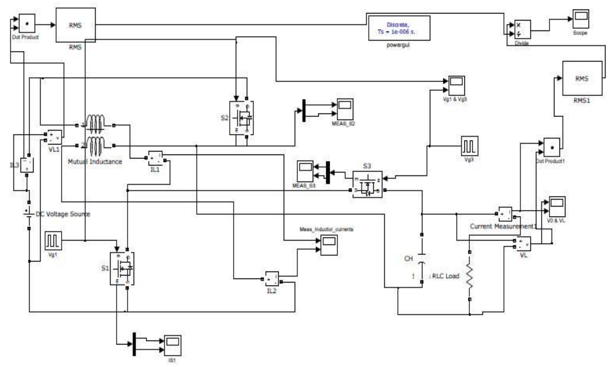

Figure 3: Simulink Model diagram for the proposed model.

IV. RESULTS

L_1 and L_2 are found to be 0.1082H and transfer function of the system $\frac{4}{0.001714\, S^2+0.08279\, S+1}$, efficiency of the system is 93.3%. Load Voltage is equal to 54.7Volts.

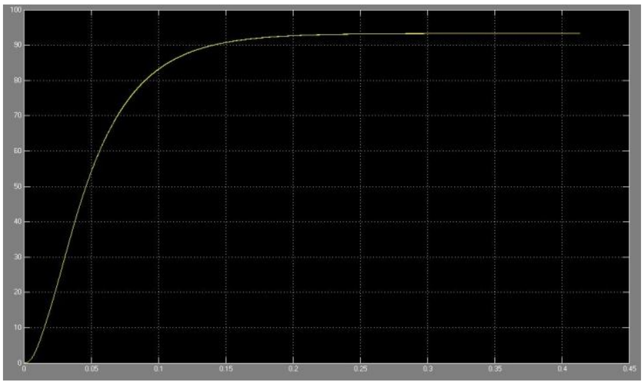

Figure 4: Efficiency characteristic of proposed converter with time for k = 0.6, P0 = 200watts.

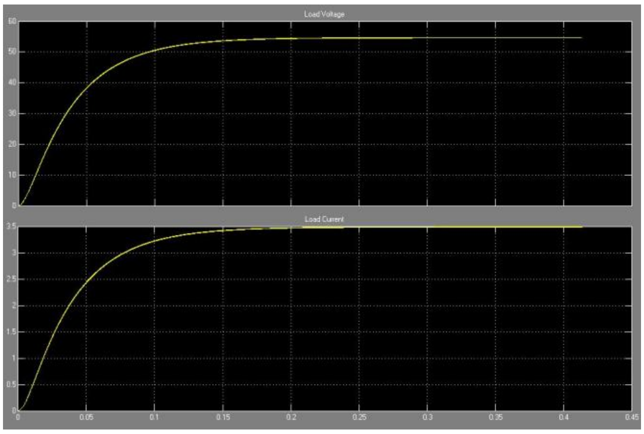

Figure 5: Load Voltage and Load Current characteristic of proposed converter with time for k = 0.6, P0 = 200watts.

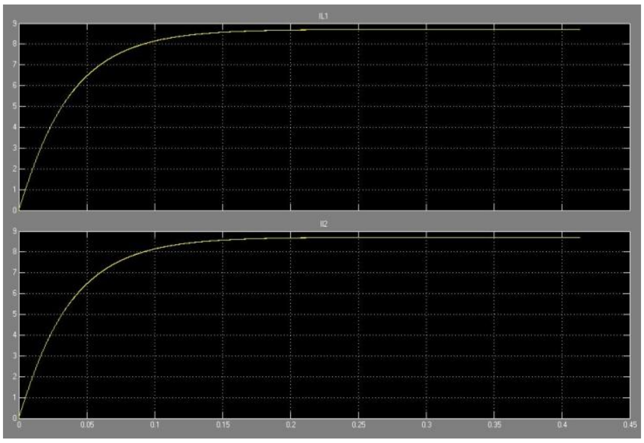

Figure 6: Current through L1 and L2 for the proposed converter with time for k = 0.6, P0 = 200watts.

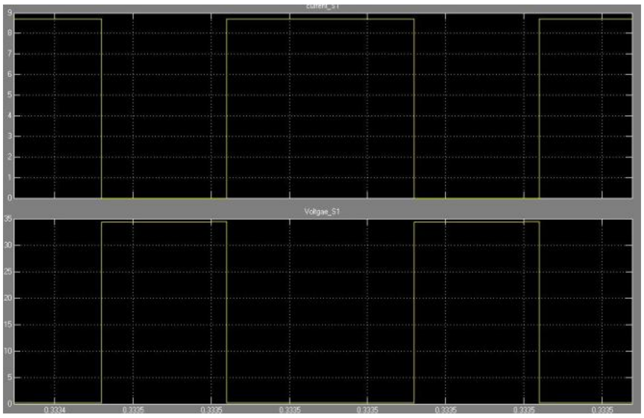

Figure 7: Current through S_1 and Voltage across S_1 for proposed converter with time for k = 0.6, P0 = 200watts.

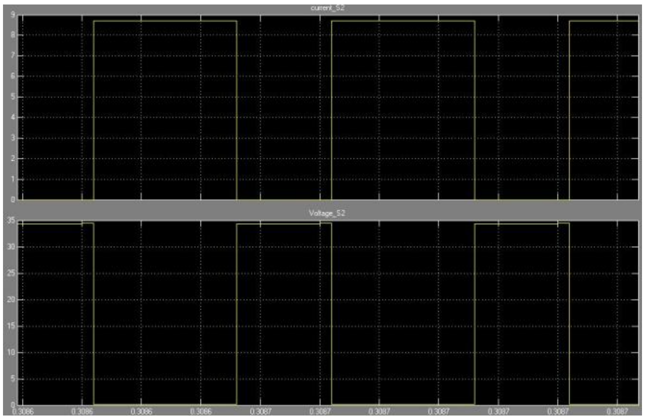

Figure 8: Current through S_2 and Voltage across S_2 for proposed converter with time for k = 0.6, P0 = 200watts.

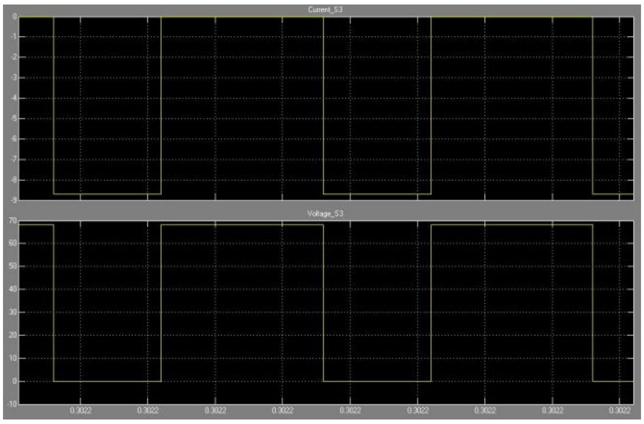

Figure 9: Current through S_3 and Voltage across S_3 for proposed converter with time for k = 0.6, P0 = 200watts.

The proposed converter is simulated for three cases i.e under damped, critically damped cases for duty ratios k = 0.4, 0.5 and 0.6 for output powers 50Watts, 100Watts, 150Watts and 200Watts. Characteristics and transfer functions are tabulated in Table – 1 to table 12.

Table 1: Magnitudes of different parameters for k = 0.6 and C = 330µF

CIF = 0.25, V_1 = 14V					
P_0 in Watts	Lin Henry	V_0 in Volts	I_0 in Amps	%η	Transfer Function
50	1.7306	55.66	0.888	94.95	$\frac{4}{0.02742\,S^2+0.3312\,S+1}$
100	0.4327	55.34	1.766	94.45	$\frac{4}{6.8e-3\,S^2+0.1656\,S+1}$
150	0.1923	55.02	2.63	93.84	$\frac{4}{3.04e-3S^2+0.1104S+1}$
200	0.1082	54.7	3.48	93.28	$\frac{4}{1.71e-3S^2+0.0828S+1}$

Table 2: Magnitudes of different parameters for k = 0.5 and C = 330µF

CIF = 0.25, V_1 = 14V					
P_0 in Watts	Lin Henry	V_0 in Volts	I_0 in Amps	%η	Transfer Function
50	0.5477	41.73	1.18	94.21	$\frac{3}{4.88e-3S^2+0.1397S+1}$
100	0.1369	41.48	2.35	93.61	$\frac{3}{1.22e-3\,S^2+0.0698S+1}$
150	0.0609	41.23	3.50	93.00	$\frac{3}{0.54e-3S^2+0.0466S+1}$
200	0.0342	40.97	4.64	92.40	$\frac{3}{0.31e-3S^2+0.035S+1}$

Table 3: Magnitudes of different parameters for k = 0.4 and C = 330µF

CIF = 0.25, V_1 = 14V					
P_0 in Watts	Lin Henry	V_0 in Volts	I_0 in Amps	%η	Transfer Function
50	0.2004	32.45	1.52	93.69	$\frac{2.333}{1.08e-3S^2+0.0675S+1}$
100	0.0501	32.24	3.02	93.05	$\frac{2.333}{0.27e-3\,S^2+0.03287S+1}$
150	0.0223	32.05	4.50	92.39	$\frac{2.333}{0.12e-3S^2+0.02191S+1}$
200	0.0125	31.82	5.97	91.75	$\frac{2.333}{6.752e-5S^2+0.0164S+1}$

Table 4: Magnitudes of different parameters for k = 0.6 and C = 330µF

CIF = 25, V_1 = 14V					
P_0 in Watts	Lin Henry	V_0 in Volts	I_0 in Amps	%η	Transfer Function
50	0.0173	55.66	0.888	94.97	$\frac{4}{0.27e-3S^2+0.0033S+1}$
100	0.0043	55.34	1.766	94.45	$\frac{4}{6.8e-5S^2+0.0017\,S+1}$
150	0.0019	55.02	2.63	93.84	$\frac{4}{3.04e-5S^2+0.0011S+1}$
200	0.0011	54.7	3.48	93.28	$\frac{4}{1.71e-5S^2+0.0008S+1}$

Table 5: Magnitudes of different parameters for k = 0.5 and C = 330µF

CIF = 25, V_1 = 14V					
P_0 in Watts	Lin Henry	V_0 in Volts	I_0 in Amps	%η	Transfer Function
50	0.0055	41.73	1.18	94.21	$\frac{3}{4.88e-5S^2+0.1397S+1}$
100	0.0014	41.48	2.35	93.61	$\frac{3}{1.22e-5S^2+0.0698S+1}$
150	0.0007	41.23	3.50	93.00	$\frac{3}{0.54e-5S^2+0.0466S+1}$
200	0.0003	40.97	4.64	92.40	$\frac{3}{0.31e-5S^2+0.035S+1}$

Table 6: Magnitudes of different parameters for k = 0.4 and C = 330µF

CIF = 25, V_1 = 14V					
P_0 in Watts	Lin Henry	V_0 in Volts	I_0 in Amps	%η	Transfer Function
50	0.002	32.45	1.52	93.69	$\frac{2.333}{1.08e-5S^2+0.0675S+1}$
100	0.0005	32.24	3.02	93.05	$\frac{2.333}{0.27e-5S^2+0.03287S+1}$
150	0.0002	32.05	4.50	92.39	$\frac{2.333}{0.12e-5S^2+0.02191S+1}$
200	0.0001	31.82	5.97	91.75	$\frac{2.333}{6.752e-7S^2+0.0164S+1}$

V. CONCLUSION

It has been observed that Converter designed with variation of Capacitor to Inductor Ratio and Energy factor the settling time of the system is varying, efficiency of the system remains constant and varies in between 91% to 95%. Efficiency of the system is decreasing with increase in load. The ripple content in the output voltage is low.

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