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Analysis Of Coupled Inductor Type Power DC-DC Boostconverter With Synchronized PWM Control

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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 using a coupled inductor as one of the commutating element, performance of the converter is analyzed with the help synchronized pulse width modulation control scheme. For this purpose a bi-directional DC – DC converter available in reference [1] is considered, for which state-space model is formulated. The model thus formulated is simulated with the help of MATLAB / Simulink and SimpowersystemsBlockset for different values of conversion ratios and when supplying load power varying from 50W to 200W for different values of Capacitor to Inductor Factor.**

***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.

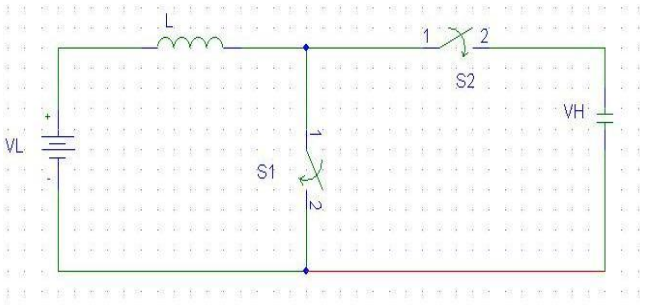

Figure 1: Circuit Diagram of Conventional Bi – directional DC – DC Converter.

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.

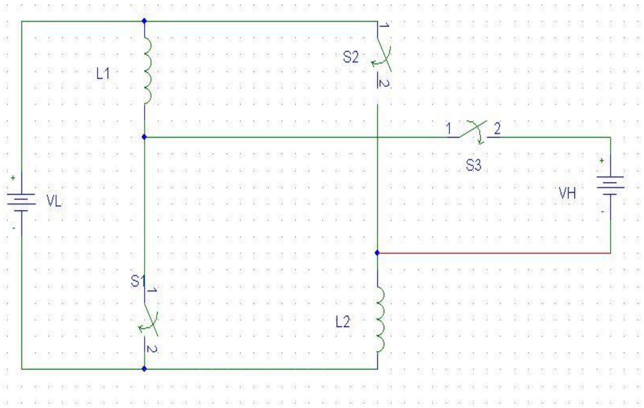

Figure 2: Proposed DC – DC Converter model diagram working as boost converter.

II. DC – DC CONVERTERS

Coupled inductor type DC-DC converter circuits make use of coupled inductors for energy transfer during conduction period. In most of the configurations these inductors are charged by connecting in parallel during charging mode and discharged by connecting in series.

Good literature is available for such applications, it has been prove that this kind of converters offer wide range of conversion ratios.

Consider the bi-directional DC-DC converter topology given in [1] for analysis purposes. During mode 1 operation of the converter Inductors and capacitor are allowed to charge and discharge that means inductors will get charged and capacitor gets discharged.

Amount energy stored by the inductor is

$$W = \int p(t).dt \qquad \ldots\ldots(2)$$

During mode 1 of operation current flowing through the inductor is given by

$$\frac{di_{L1}(t)}{dt} = \frac{di_{L2}(t)}{dt} = \frac{V_s}{(1+k)L}$$

$$i_{L1} = \int_0^{t_1} \frac{V_s}{(1+k)L} dt$$

$$i_{L1} = \frac{V_s}{(1+k)L} t_1 \qquad \ldots\ldots(3)$$

Where

Instantaneous power is $p(t)$

Applied voltage is V_s

Inductance of the coils $L_1 = L_2 = L$

Coefficient of coupling is k

Energy stored by inductor is W

Instantaneous power is given by $p(t) = v_{L1} i_{L1}$

Substitute values of v_{L1} and i_{L1} in equation (2)

$$W = \int v_{L1} i_{L1}.dt$$

But from equation (3) substitute value of i_{L1}

$$W = \int v_{L1} \frac{V_s}{(1+k)L} t_1.dt$$

Energy stored by inductor by the end of mode1 is

$$W = \int_0^{t_1} V_s \frac{V_s}{(1+k)L} t_1.dt$$

$$= \frac{V_s^2 t_1^2}{2(1+k)L}$$

Total energy stored by the inductors is

$$W_L = \frac{V_s^2 t_1^2}{(1+k)L_1} \text{ J} \qquad \ldots\ldots(4)$$

During Mode 2 load connected to the source as a result the inductors are connected in series and will get discharged, the energy thus stored by these inductors will be transferred to the capacitor, there by the capacitor starts charging.

During this mode

$$i_{L1} = i_{L2} = i_L \text{ And}$$

$$v_{L1} + v_{L2} = V_s - V_c$$

$$\frac{di_L}{dt} 2(1+M)L = V_s - V_c$$

$$\frac{di_L}{dt} = \frac{V_s}{2(1+M)L} - \frac{V_c}{2(1+M)L}$$

Voltage across capacitor is given by

$$v_c = \frac{1}{C} \int i_L dt$$

$$\frac{dv_c}{dt} = \frac{1}{C} i_L$$

Take $v_c = x_1$ and $i_L = x_2$

$$\dot{x}_1 = \frac{1}{C} x_2$$

$$\dot{x}_2 = -\frac{1}{2(1+M)L} x_1 + \frac{1}{2(1+M)L} v_s$$

State variable model of the system is given by

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & \frac{1}{C} \\ -\frac{1}{2(1+M)L} & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{2(1+M)L} \end{bmatrix} v_s \qquad \ldots\ldots(5)$$

Take v_c as control variable.

Then

$$y = x_1$$

Where y is the output variable

From equation (4) it is clear that amount of energy stored by an inductor is controlled by controlling the charging and discharging periods of the converter. The magnitude of output voltage is controlled by proper selection of ON and OFF periods of converter circuit. There by the equations (1) and (5) are equally applicable to buck, boost and buck-boost configurations.

III. ANLYSIS OF BOOST CONVERTER

Model proposed in [1] is considered for analysis, Model is simulated by taking $L_1 = L_2 = 15.5\text{x}10^{-6}$H, $M = 1\text{x}10^{-6}$H, $C = 330 \text{ X } 10^{-6}$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 $\tau_d >> \tau$, 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, SimpowersystemsBlockset 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.

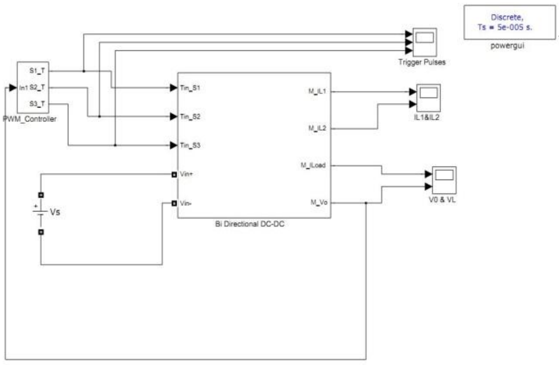

Figure 3: Simulink Model diagram for the proposed model.

IV. RESULTS

L_1 and L_2 are found to be 0.1082H and efficiency of the system is 93.3%. Load Voltage is equal to 54.7Volts.

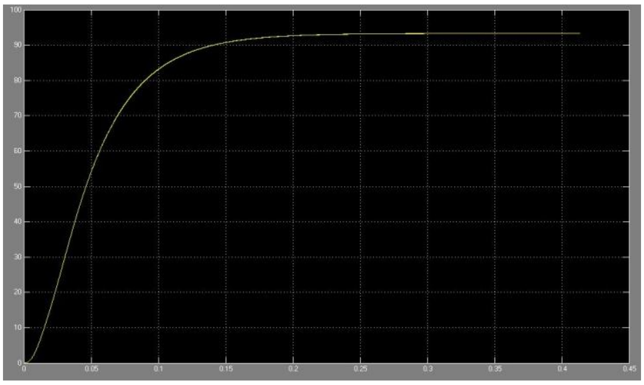

Figure 4: Efficiency characteristic of proposed converter with time for k = 0.6, P0 = 200watts.

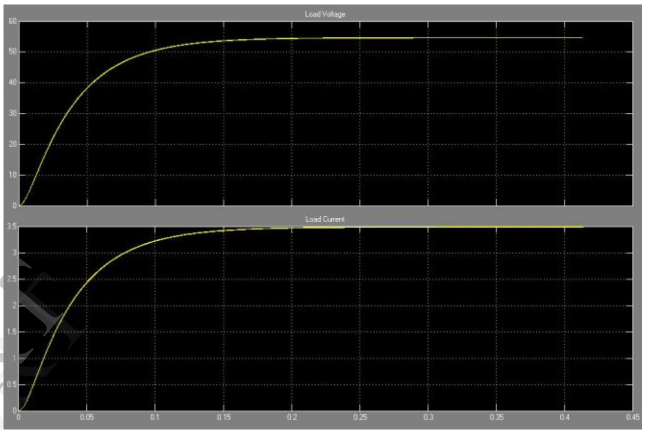

Figure 5: Load Voltage and Load Current characteristic of proposed converter with time for k = 0.6, P0 = 200watts.

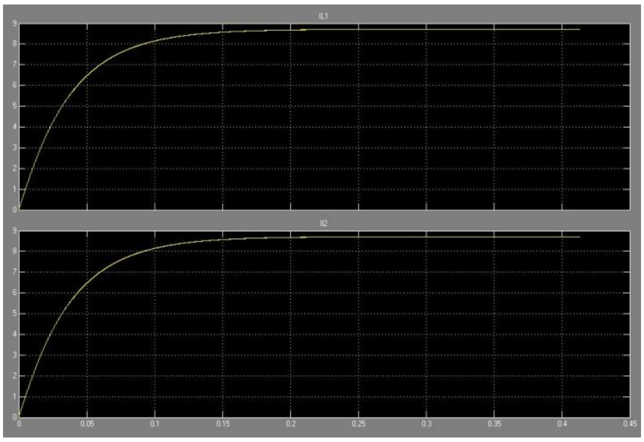

Figure 6: Current through L1 and L2 for the proposed converter with time for k = 0.6, P0 = 200watts.

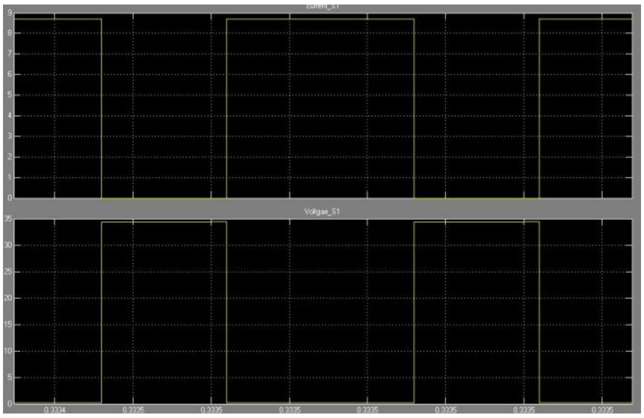

Figure 7: Current through S_1 and Voltage across S_1 for proposed converterwith time for k = 0.6, P0 = 200watts.

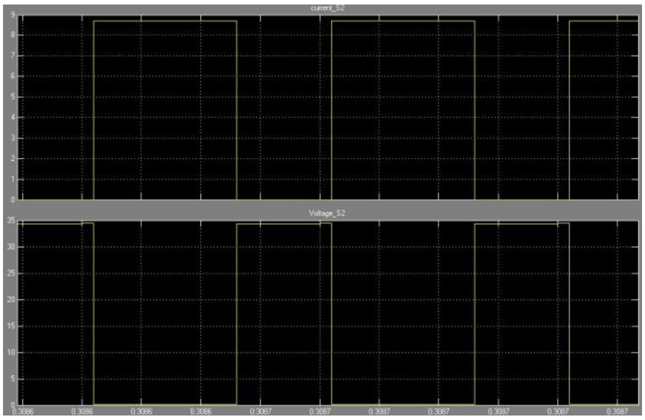

Figure 8: Current through S_2 and Voltage across S_2 for proposed converterwith time for k = 0.6, P0 = 200watts.

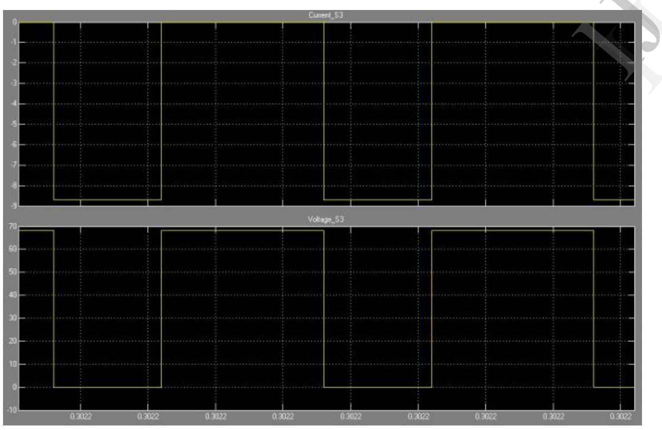

Figure 9: Current through S_3 and Voltage across S_3 for proposed converterwith time for k = 0.6, P0 = 200watts.

The proposed converter is simulated for three cases k = 0.4, 0.5 and 0.6 for output powers 50Watts, 100Watts, 150Watts and 200Watts. Characteristics and circuit parameters are tabulated in Table – 1 to table 6.

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
50	1.7306	55.66	0.888	94.95
100	0.4327	55.34	1.766	94.45
150	0.1923	55.02	2.63	93.84
200	0.1082	54.7	3.48	93.28

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
50	0.5477	41.73	1.18	94.21
100	0.1369	41.48	2.35	93.61
150	0.0609	41.23	3.50	93.00
200	0.0342	40.97	4.64	92.40

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
50	0.2004	32.45	1.52	93.69
100	0.0501	32.24	3.02	93.05
150	0.0223	32.05	4.50	92.39
200	0.0125	31.82	5.97	91.75

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
50	0.0173	55.66	0.888	94.97
100	0.0043	55.34	1.766	94.45
150	0.0019	55.02	2.63	93.84
200	0.0011	54.7	3.48	93.28

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
50	0.0055	41.73	1.18	94.21
100	0.0014	41.48	2.35	93.61
150	0.0007	41.23	3.50	93.00
200	0.0003	40.97	4.64	92.40

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
50	0.002	32.45	1.52	93.69
100	0.0005	32.24	3.02	93.05
150	0.0002	32.05	4.50	92.39
200	0.0001	31.82	5.97	91.75

V. CONCLUSION

It has been observed that DC-DC Boost Converter designed using synchronised PWM control 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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