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Research Article

COMPARATIVE STUDY OF TWO-INDUCTOR AND TWO-PHASE BOOST CONVERTER FOR HIGH VOLTAGE APPLICATIONS

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ABSTRACT

These boost converter are making use of current splitting in two branches, which uses inductor and switch to boost the voltage level. By current splitting stress are removed from the switching device. Higher voltages with good efficiency are found due to parallel cascading of two boost converter. The advantages of DC-DC boost converters include increased efficiency, reduced sizeand faster transient response of system. The outputs of two phase boost converter are compared with two inductor boost converter. This paper compares the output waveforms of the two-inductor boost converter and two-phase boost converter used for high voltage applications. These are used for boosting the level of DC voltages by dividing the currents in two phases.

INTRODUCTION

DC/DC converters are widely used for interconnections of two or more networks with different voltage levels. There are such different topologies, which varies in complexity of circuits, stress on used components and quality of input and output power [1]. In these types of boost converter are used to boost the low variable dc voltage from the fuel cell / battery and provide the high quality, regulated dc voltage to the output. From last decades isolated topologies with high frequency step-up transformer have been used commonly in the boost converter topologies.

A cleaner energy future depends on the development of alternative energy technologies to meet the world's growing energy needs but that also mitigate carbon dioxide emissions. Some of sustainable energy based power plants, including hydro, geothermal, biofuel-plants, use synchronous generators directly connected to the grid. But some other sources like fuel cells (FC) and photovoltaic (PV) basically produce a dc voltage. Such systems which have a large scope of small scale of implementation produce dc voltage which is much lower for direct implementation. So, an interface between the source and load is a need and the power electronic converter is the interface [2].

A non-isolated two-inductor boost converter consists of a common ground both for the input as well as for output, i.e. absent the electrical isolation. The two inductor boost converter exhibits benefits in high power applications [3], [4]. High input current is split between two inductors, thus reducing I^2R power loss in both copper windings and primary switches. Furthermore, by applying an interleaving control strategy, the input current ripple can be reduced [5].

The main obstacle of the circuit is its limited power regulation range. Inductor L_{p1} must support input voltage when-ever T_{p1} turns on. This is also true for L_{p2} and T_{p2}. Since the minimum duty ratio of each switch is 0.5, the magnetizing currents of the two inductors can't be limited. This leads to a minimum output power level. If the load demands is less than minimum power level, the output voltage increases abnormally because excessive energy has been stored in the inductors [6].

In connection with large input current, it results in a high conduction loss, this limits both efficiency and rated power of the converter topologies [7]. On the other hand the voltage gain curve becomes steeper when duty cycle increases. At one point it's fairly difficult to control the converter, while a very small variation in duty cycle δ results in a large change in the voltage gain k. This small variation in the duty cycle δ may be desired, as a response to change the operating conditions [8]. But it can be undesired, e.g. caused by delays in the driver circuit or

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different switching of the transistor due to the temperature or ageing.

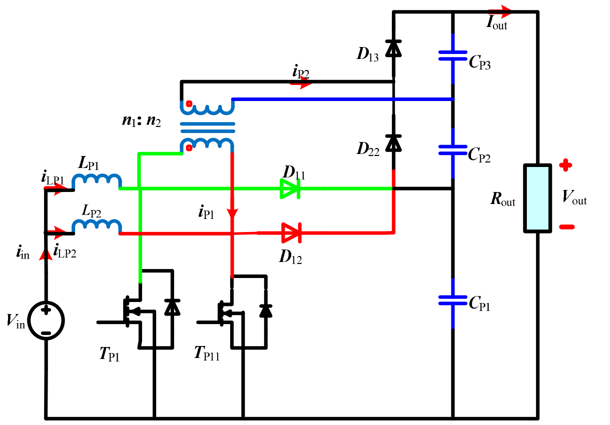

Fig. 1 Two inductor boost converter circuit

Use of several boost converters in parallel expands the output power of the whole system, while the input current is shared between two or more converter modules. The two-phase boost converter operates in the same way like the basic boostconverters [9-10] presented in Fig. 2.Sometimes many devices are not capable to withstand such stresses.

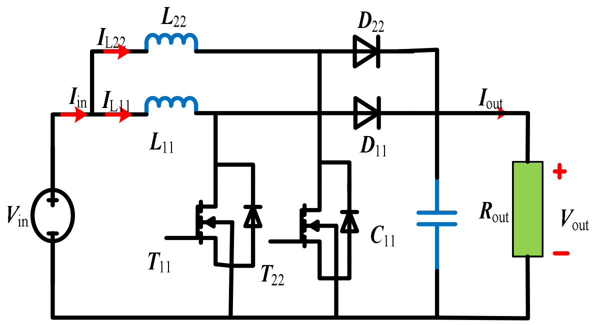

Fig. 2 Two-phaseboost converter circuit

An extensive amount of research has been carried out on these issues. Many different topological modifications have developed from this. Multilevel converters have had a lot of success, especially on DC-AC applications. Nevertheless, a two level version of the boost converter will be very simple efficient and will have a low part count [11- 17]. Gating signals for both transistors have the same duty cycle and phase shifted by 180º (interleaving). One may observe that the input current ripple is smaller than ripples observed in particular inductor current. Main challenges in case of paralleled boost converters are to provide exactly the same duty cycle for all transistors. Even a small mismatch in duty cycles may lead to a significant current sharing unbalance and reduce reliability of the system. Different active and passive current sharing methods are discussed in [18].

WORKING OF BOOST CONVERTER

There are four basic operational stages; stage-1 and 3 are identical. When both transistors are on the input current $i_{in(t)}$ increases and energy is stored in inductors L_{p1} and L_{p2}. The winding n_{11} is essentially shorted and no voltage induces in the winding n_{22}. All diodes are reverse biased, so the load is supplied from output capacitors. At the beginning of stage-2 the transistor T_{p1} is turned-off and the diode D_{11} starts to conduct because of continuous inductor current $i_{Lp1(t)}$. The capacitor voltage $v_{Cp1(t)}$ is being applied to the winding n_{11} and voltage $n{*}v_{Cp1(t)}$ induces in the winding n_{22}. If this voltage is larger than the capacitor voltage $v_{Cp3(t)}$ then the diode D_{13}become forward biased and conducts the current $i_{n2}(t)$ recharging the capacitor C_{p3}. Stage-4 is similar to stage-2 but the transistor T_{p11} is turned-off and T_{p1}remains on. Diodes D_{12} and D_{22}conduct and capacitors C_1 and C_2 are recharged during stage-4.

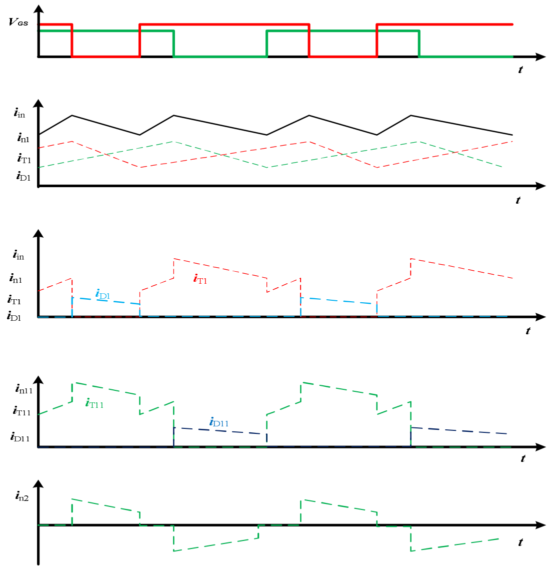

Fig. 3 Waveforms of the two-inductor boost converter

The voltage gain of this converter is given by (2). Voltage stress of transistors and diodes D_{11} and $D_{12}$is given by (3). Diodes D_{22} and D_{13}have to handle reverse voltage given by (4). Assuming that the inductor currents have only a very small ripple and the current $i_{p2(t)}$ is almost rectangular, the transistor rms current is found with (5). The average forward current of diodes D_{22} and D_{13} is equal to the output DC current I_{out}. The average forward current of diodes $D_{11}$and D_{12} equals half of the output DC current, since these diodes are connected in parallel. Required power rating of transistors and diodes is found by (6-10). The required storage inductances L_{p1} and L_{p2} are calculated by (11), while (12) gives the effective output capacitance.

$$n = \frac{n_{22}}{n_{11}} \tag{1}$$

$$k = \frac{1+2.n}{1-\delta} \tag{2}$$

$$V_{Tp1(off)} = V_{Tp11(off)} = V_{D11(R)} = V_{D12(R)} = \frac{1}{1+2.n} . V_{out} \tag{3}$$

$$V_{D22(R)} = V_{D13(R)} = \frac{2.n}{1+2.n} . V_{out} \tag{4}$$

$$I_{Tp1(rms)} \approx \sqrt{(1 \quad \delta).\left(\frac{k.I_{out}}{2} + n.\frac{I_{out}}{1-\delta}\right)^2 + (2\delta \quad 1).\left(\frac{k.I_{out}}{2}\right)^2} \tag{5}$$

$$\text{volt X amp}_{Tp1} = V_{Tp1(off)}.I_{Tp1(rms)}$$

$$\approx \frac{1}{2.n+1}.\sqrt{(1 \quad \delta).\left(\frac{k}{2} + \frac{n}{(1-\delta)}\right)^2 + (2\delta \quad 1).\left(\frac{k}{2}\right)^2} . P_{out} \tag{6}$$

$$\text{volt X amp}_{TT} = 2.\text{volt X amp}_{Tp1} \tag{7}$$

$$\text{volt X amp}_{D11} = \frac{1}{1+2.n} . V_{out}.\frac{I_{out}}{2} = \frac{1}{2.(1+2.n)} . P_{out} \tag{8}$$

$$\text{volt X amp}_{D22} = \frac{2.n}{2.n+1}.V_{out}.I_{out} = \frac{2.n}{2.n+1}.P_{out} \quad (9)$$

$$\text{volt X amp}_{DT} = 2.(\text{volt X amp}_{D11} + \text{volt X amp}_{D22}) = \left(\frac{4.n+1}{2.n+1}\right).P_{out} \quad (10)$$

$$L_{p1} = L_{p2} = \frac{V_{in}.\delta}{2.\ i_{Lp1}.f_s} \quad (11)$$

$$C_{out} = \frac{I_{out}.\delta}{2.\ v_{out}.f_s} \quad (12)$$

In case of paralleled converters the voltage gain $k$does not change and it is given by (13). Also transistors blocking voltage and diode reverse voltage don't change and about to output voltage V_{out}, and the transistor rms current is given by (14). A significant inductor current ripple can't be neglected this time and it has an influence on the transistor power rating according to (15).The term $n$means number of paralleled modules, sharing the input current, required power rating of the diode D_{11} is given by (16). The required inductance L_1 is given by (17).

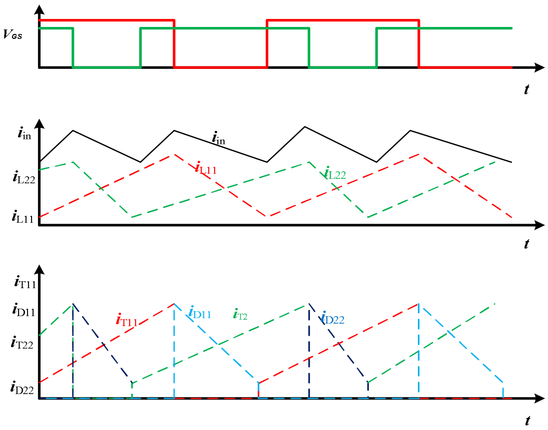

Fig.4 Waveforms of a two-phase boost converter

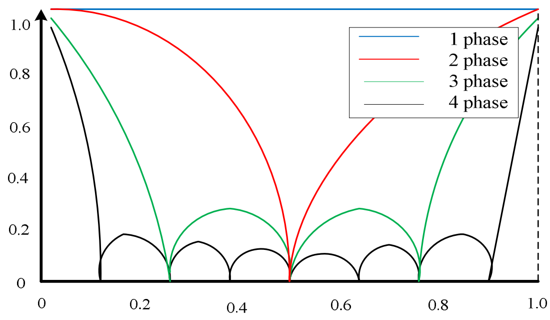

Fig. 5 Reduction of current ripple in a multi-phase converter

$$k = \frac{1}{1-D} \quad (13)$$

$$I_{T11(rms)} = \frac{I_{in}}{n}.\sqrt{1+\frac{1}{3}.\left(\frac{i_{L11}}{I_{L11}}\right)^2}.\sqrt{D} \approx \frac{k}{n}.I_{in}.\sqrt{1+\frac{1}{3}.\left(\frac{i_{L11}}{I_{L11}}\right)^2} \quad (14)$$

$$\text{volt X amp}_{T11} = V_{T11(off)}.I_{T11(rms)} \approx V_{out}.\frac{k}{n}.I_{in}.\sqrt{1+\frac{1}{3}.\left(\frac{i_{L11}}{I_{L11}}\right)^2} = \frac{k}{n}.P_{out}.\sqrt{1+\frac{1}{3}.\left(\frac{i_{L11}}{I_{L11}}\right)^2} \quad (15)$$

$$\text{volt X amp}_{D11} = V_{out}.\frac{I_{out}}{n} \approx \frac{P_{out}}{n} \quad (16)$$

$$L_{11} = \frac{V_{in}.D}{2.\ i_{L1}.f_s} \quad (17)$$

$$C_{11} = \frac{I_{out}.D}{2.\ v_{out}.f_s.n} \quad (18)$$

It is important to note that allowed inductor current ripple may become significantly larger than allowed input current ripple ($\Delta i_{L11} > \Delta i_{in}$), thus required inductance L_{11} can be reduced. The current ripple reduction depends on number of interleaved phases and duty cycle. However one should be aware that increased inductor current ripple may lead to increased ac copper losses in the inductor winding and increased conduction losses in the transistor.

SIMULATION RESULTS

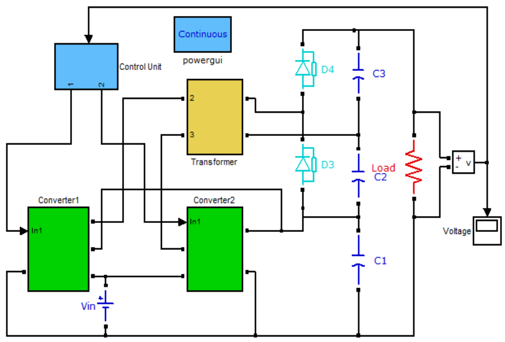

Fig. 6 Simulink diagram of two-inductor boost converter

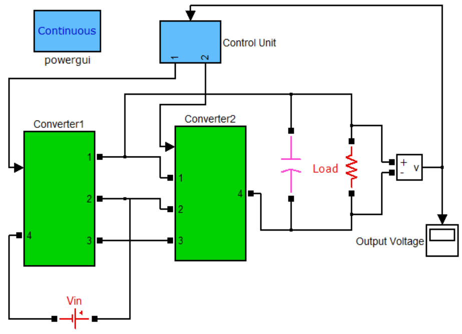

Fig. 7 Simulink diagram of two-phase boost converter

The performance of the boost converter is verified via computer simulation. The simulation is conducted using MATLAB/SIMULINK software package.

Analysis of the converters

By making use of MATLAB/SIMULINK software package the analysis of both converters are performed and results are observed.

Two inductor boost converter waveforms

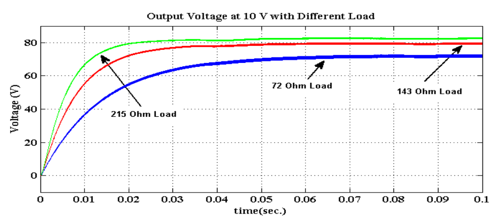

Fig. 8 Output voltage for different load at 10 V

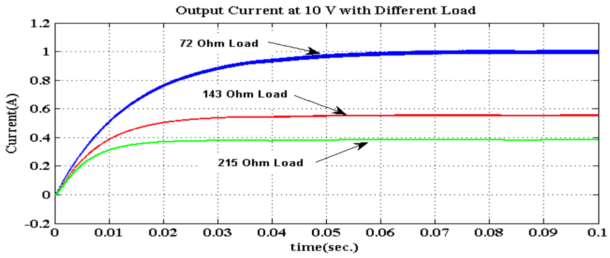

Fig. 9 Output current for different load at 10 V

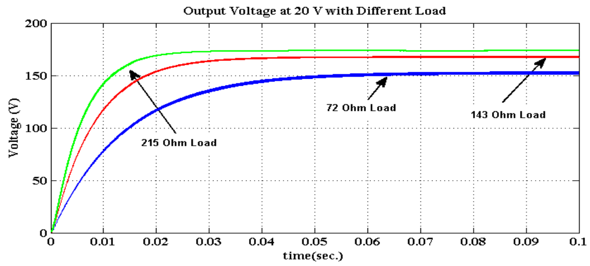

Fig. 10 Output voltage for different load at 20 V

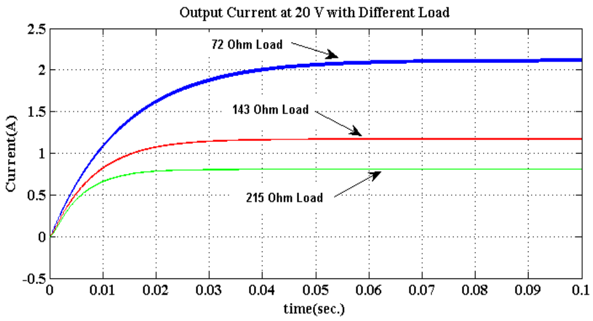

Fig.11 Output current for different load at 20 V

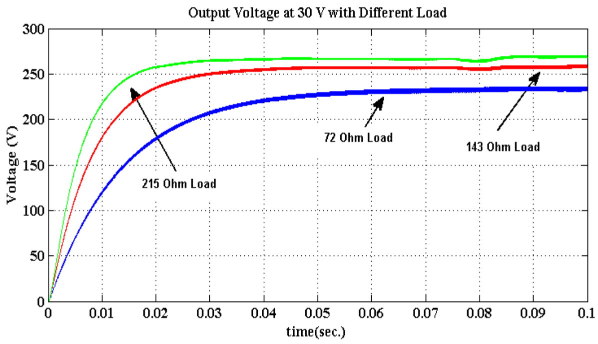

Fig.12 Output voltage for different load at 30 V

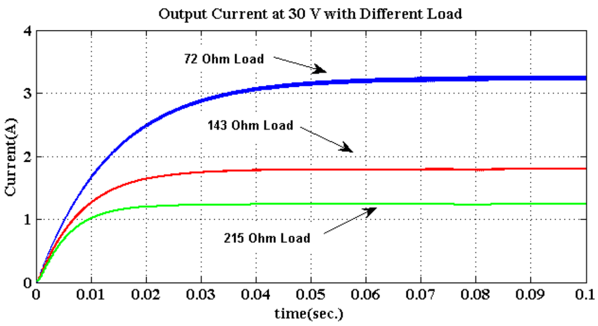

Fig.13 Output current for different load at 30 V

Two-Phase boost Converter waveforms

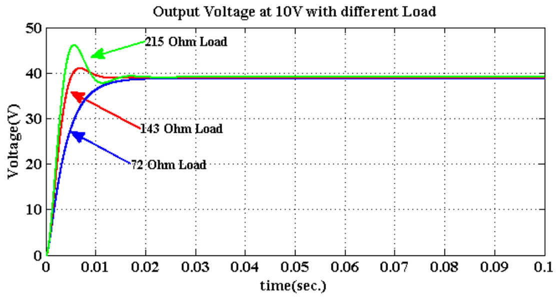

Fig. 14 Output voltage for different load at 10V

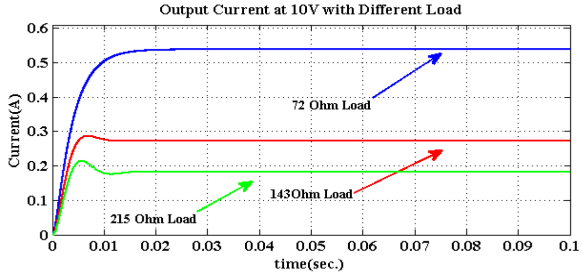

Fig. 15 Output current for different load at 10V

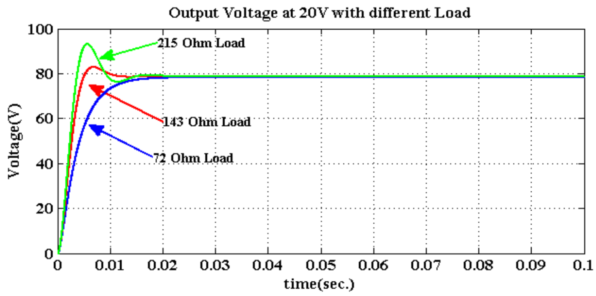

Fig. 16 Output voltage for different load at 20V

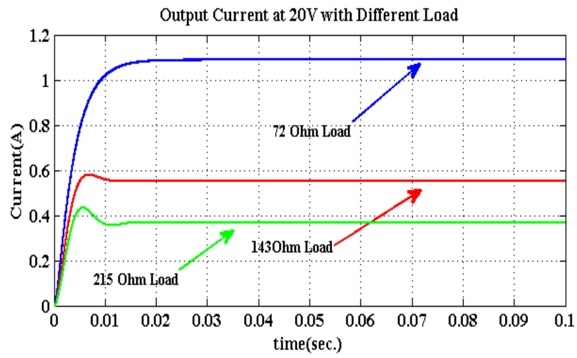

Fig. 17 Output current for different load at 20V

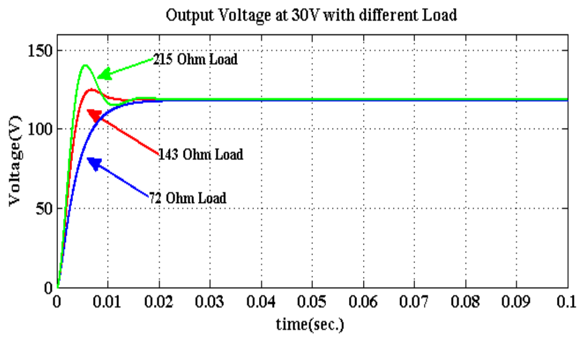

Fig. 18 Output voltage for different load at 30V

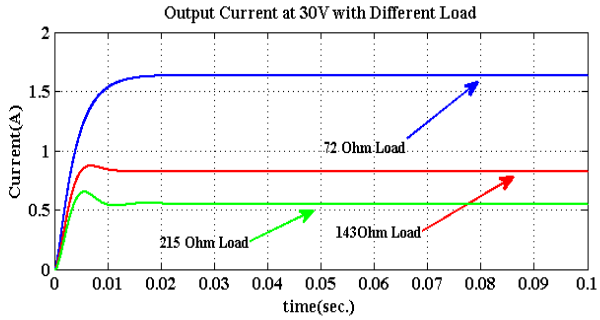

Fig. 19 Output current for different load at 30V

The performance of the two-inductor and two-phase boost converter system with resistive load in tabular form is shown in Table-1. Where three input voltages (10V, 20V and 30V) and three resistive loads (72Ω, 143Ω and 215Ω) are used for analysis of the converters. Performances of the converters are made according to the output voltage, current and efficiency and study takes place.

Table-1 Comparison chart of the converters

S. N.	V_{in} (V)	Load (Ω)	Output Current (A)		Output Voltage (V)		Efficiency	
			Two Inductor	Two Phase	Two Inductor	Two Phase	Two Inductor	Two Phase
1	10	72	0.991	0.541	71.31	38.95	71.34	92.54
2	10	143	0.551	0.273	78.79	39.07	72.40	88.17
3	10	215	0.381	0.182	81.91	39.10	70.49	84.05
4	20	72	2.109	1.093	151.8	78.70	76.58	93.54
5	20	143	1.166	0.552	166.8	78.93	77.64	89.16
6	20	215	0.804	0.368	172.9	79.01	75.52	85.03
7	30	72	3.229	1.645	232.5	118.4	78.12	93.47
8	30	143	1.777	0.831	254.1	118.8	77.79	89.49
9	30	215	1.247	0.553	268.1	118.9	77.01	85.35

The comparison of the converters is shown in form of the graph below, which includes waveforms of voltage, current and efficiency of the systems. By this the comparisons of the converters takes place and analysis is done by these waveforms.

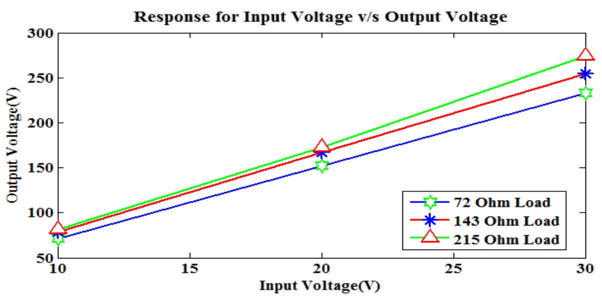

Fig. 20 Response of two-inductorat different load

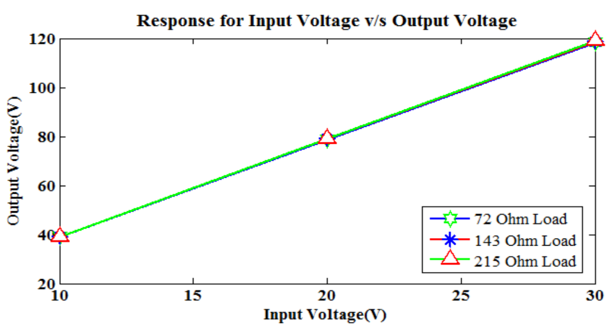

Fig. 21 Response of two-phaseat different load

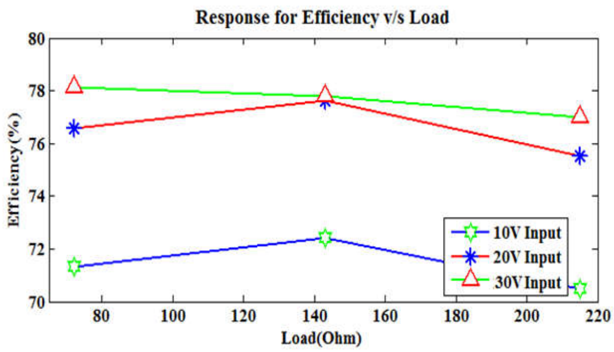

Fig. 22 Efficiency response of two-inductorboost converter

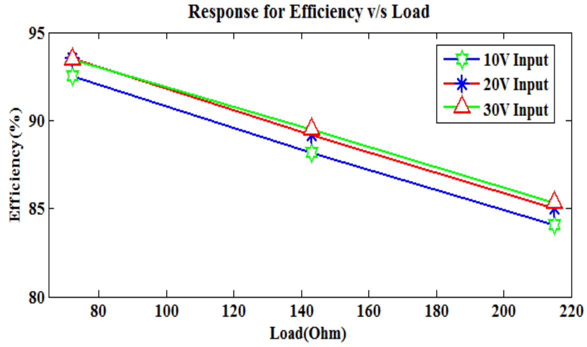

Fig. 23 Efficiency response of two phaseboost converter

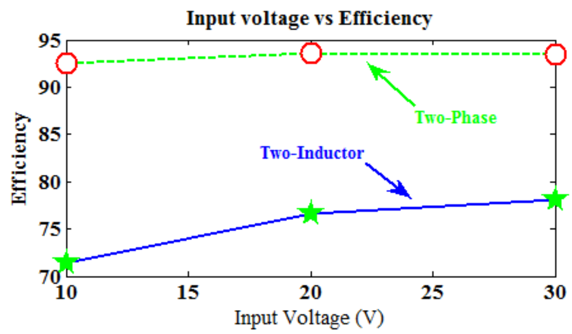

Fig. 24 Efficiency response of the both converters

From this table it is to be discussed, that how the system output voltage and efficiency varied according to the input voltage and load. The variation in output voltage and efficiency is shown in Fig. 20 toFig. 24.

CONCLUSIONS

For all values of input voltage two phase boost converter gives nearly same output voltage at all load. In-case of two inductor output voltage increases rapidly by increasing input voltage and load. The output voltage is more in case of two-inductor boost converter in comparison to two-phase boost converter and gives nearly double output voltage. At low load both converters have good efficiency. By increasing the input voltage efficiency is increased in two-inductor and constant in case of two-phase converter. Efficiency of two-phase boost converter is higher than the two-inductor boost converter at any load and voltage.

In future it can be used to provide power for the electrical vehicles. Two-phase gives good performance at every level of the load. It reduces the space of storage and number of the battery to save the economy.

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