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Original scientific paper

Fully Insulated Dual Output DC-DC Converter Battery Charging System with Single Dynamo Input at the Electric Vehicle

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Abstract: Battery charging and regulation for the electrical system of electric cars or fuel cars are of great importance for the efficient operation and comfort of the vehicles. In this study, a DC-DC boost converter system that can charge two batteries isolated from each other with the same dynamo for a car is presented. With this system, it is possible to charge two different batteries at their nominal voltages at the same time by increasing the voltage of the system at the low voltage inputs that will occur. First, the circuit model and mathematical expansions that give the operating logic of the circuit are given. Then, the designed circuit model is operated between the modulation indexes of 0.2-0.5 and two different batteries are fed at their nominal voltages in isolation from each other. After the simulation studies, the current and voltage values of the circuit elements and the charging parameters of the battery are measured and the system application is carried out. According to the obtained results, although the charging circuit receives low voltage from the alternator, the two batteries can be charged to the requested level with the proposed system.

Keyword: battery charging; electric cars; fuel cars; regulation for the electrical system

1 INTRODUCTIONS

Batteries and energy storage systems play a critical role in the integration of energy sources [1]. These systems increase energy supply security by balancing fluctuations in energy production and reduce dependency on fossil fuels [2]. In addition, energy storage technologies minimize environmental impacts by increasing the efficiency and sustainability of electric power systems [3]. Battery charging systems are of critical importance for both electric vehicles (EVs) and homes [4, 5]. With the widespread use of electric vehicles, the need for efficient and reliable charging of these vehicles is increasing and important studies are being carried out in this regard [6-8]. In electric vehicles, generators or dynamos usually generate an alternating voltage that the converter converting alternating current (AC) to direct current (DC) is charging battery [9]. Regulating circuit elements are generally used in direct current (DC) sources and battery charging systems to provide high efficiency and reliability. These elements increase stability in energy conversion processes, resulting in high accuracy and low harmonic distortion in charging processes [10]. In particular, dual closed-loop DC control systems are widely used in electric vehicle charging infrastructures and are notable for their high power factor and low total harmonic distortion (THD) [10, 11]. Bidirectional AC-DC converters for electric vehicles are optimized to provide both charging and grid support (Vehicle-to-Grid, V2G) with high power density, reliability and bidirectional power flow capability. The use of wide-bandgap semiconductors (e.g. SiC and GaN) in these systems reduces energy losses while improving efficiency and thermal management [12]. At the same time, multi-input and isolated DC-DC converters offer a flexible solution that extends the life of batteries and allows independent or integrated use of energy sources [13, 14]. These developed technologies provide significant advantages over existing systems with features such as low component count, safe grounding and increased insulation levels in battery charging systems [12-14]. In order to ensure the continuity of the stored battery energy systems in vehicles and in case of failure or for vehicles with multiple electrical receivers, an insulated backup energy battery may be needed. In parallel or series connections, it is not possible to insulate the batteries from each other. Therefore, in this study, a single input dual output boost converter design has been developed for a single alternator source input insulated battery charging system. In traditional converter structures, a single battery charging opportunity can be achieved with a single switching frequency of the modulation index [15-17]. In this study, with the new converter system for the charging infrastructure of electric vehicles, multiple boost converter structures have the ability to charge two batteries simultaneously insulated from each other with a separate single operating rate and a common double non-operating time switching frequency. In this system, batteries can be charged with a single source input at different time intervals without being connected in series or parallel to each other. With this method, when one of the batteries fails in the electric battery charging system of an electric vehicle or a fossil fuel vehicle, it can be ensured that another battery can be charged. In addition, it will increase comfort and performance by providing energy from more than one battery source to receivers that require more electricity than the amperage and voltage value of a battery in electric vehicles.

2 DUAL BOOST CONVERTER BATTERY CHARGING SYSTEM

2.1 General Structure of the Power System

In the Independent Dual Battery Charging System, two different batteries that are insulated from each other with a single modulation index can be charged. Although this system uses a single voltage source, it can charge two batteries with a voltage above the input source voltage. The battery charging system for a car is given in Fig. 1.

The first part of the system is the alternator that is driven by the vehicle engine, which produces 3-phase alternating voltage. The second part of the system is the rectifier circuit that rectifies the alternator's 3-phase alternating voltage. The third part of the system is a single modulation index double boost converter that uses the full wave rectifier as the input voltage source and two batteries.

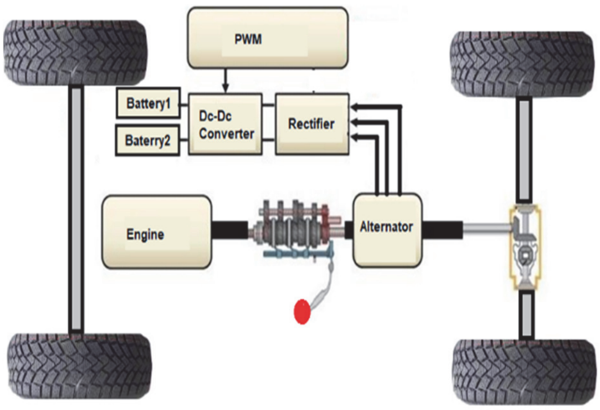


Figure 1 The battery charging system for a car

2.2 Single Input Dual Output Boost Charging Circuit

The circuit for increasing the electrical voltage produced by the alternator and passing through the rectifier is given in Fig. 2. The operating modes of the proposed isolated double boost circuit for the automobile are given in Fig. 3. The operation of the power circuit in this system is based on operating in four different power circuit modes for a single switching total time as in Fig. 3.

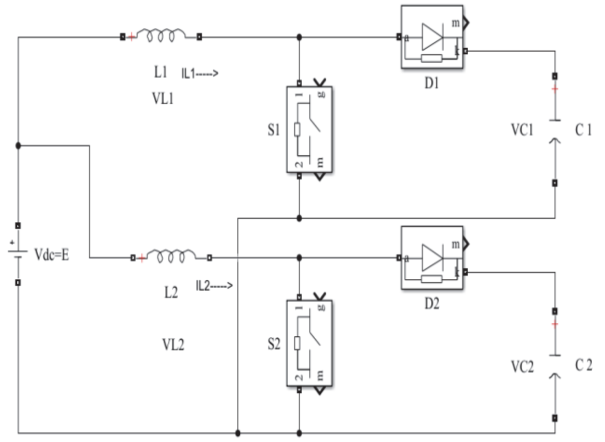


Figure 2 Single input dual output boost converter for battery charger

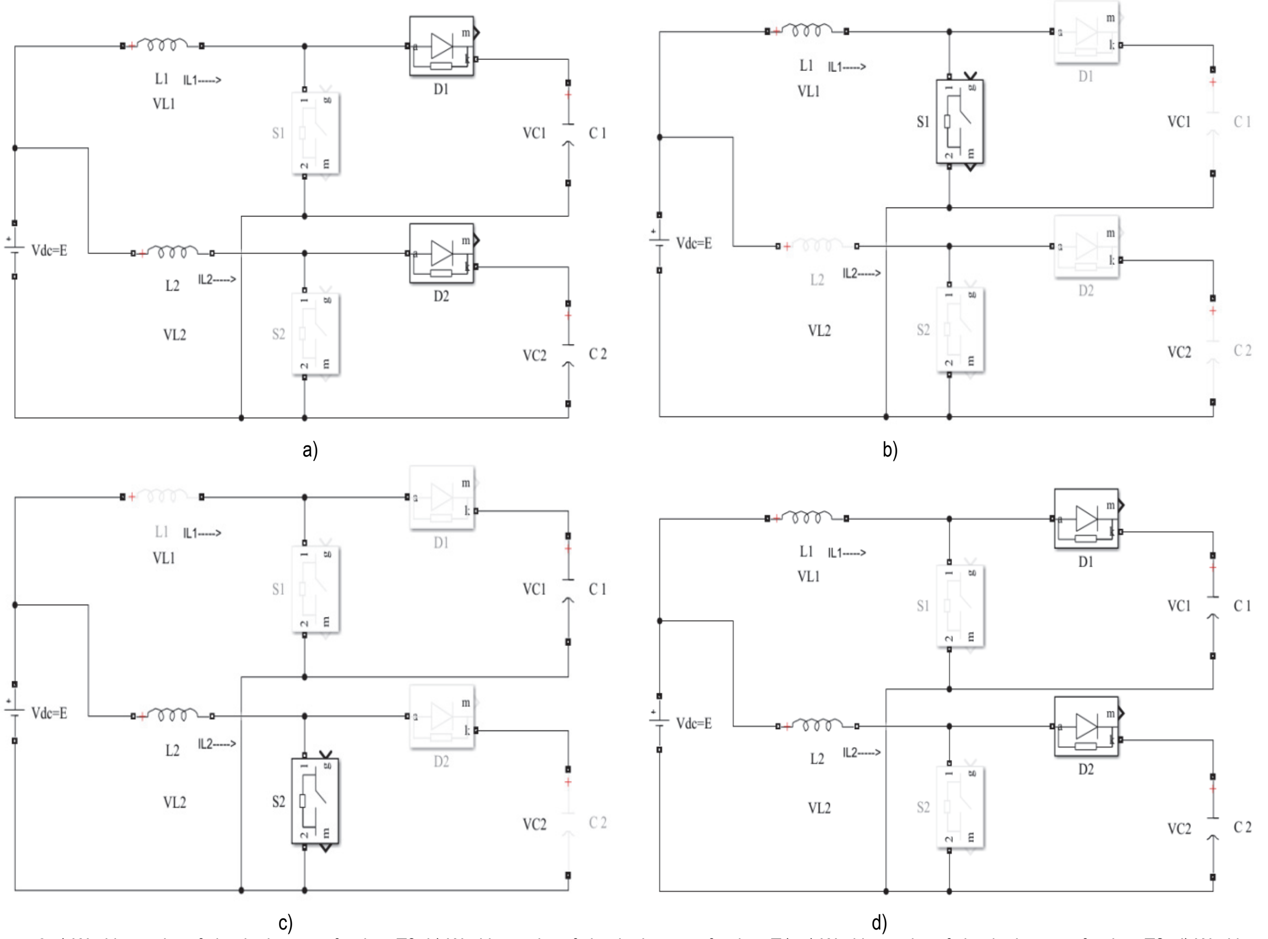
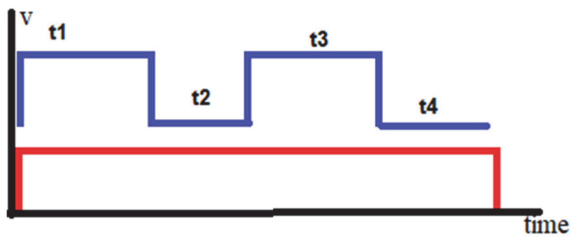


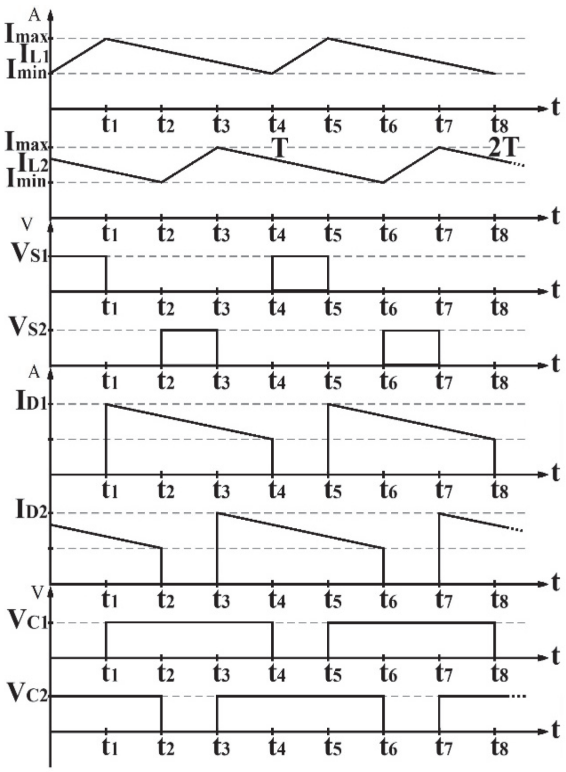
Figure 3 a) Working order of circuit elements for time T3, b) Working order of circuit elements for time T1, c) Working order of circuit elements for time T2, d) Working order of circuit elements for time T4

Table 1 Working order of circuit elements

	S1	S2	D1	D2	L1	L2	C1	C2	Alter.
T1	1	0	0	0	1	0	0	0	1
T2	0	1	0	0	0	0	0	0	1
T3	0	0	1	1	0	1	1	1	1
T4	0	0	1	1	1	0	1	1	1



a)



b)

Figure 4 a) The PWMs that control the operating times of the switches, b) Currents and voltages of circuit elements in their operating order

While Tab. 1 shows the operating order of the circuit elements of the power unit depending on the operating times of the switches, Fig. 4 shows the PWMs that control the operating times of the switches. Vi = DC Input voltage, Vc = Capacitor voltage, L = Coil inductance, D = Power switch duty ratio, T = Switching time. I_{L1} = First converter coil current, I_{L2} = Second converter coil current, V_{S1} = Power switch voltage of the first converter, V_{S2} = Power switch voltage of the socond converter, I_{D1} = First converter diode current, I_{D2} = "Second converter diode current", V_{C1} = "First converter capacitor voltage", V_{C2} = "Second converter capacitor voltage".

Current-voltage relationship of the circuit when the converter power switches are operating as below;

$$\frac{\mathrm{d}i}{\mathrm{d}t}\cdot L = Vi \rightarrow \frac{\mathrm{d}i}{\mathrm{d}t}\cdot\frac{Vi}{L} \rightarrow I_{\max} - I_{\min} = \frac{Vi}{L}DT \tag{1}$$

Current-voltage relationship for the time when the power switches are not operating as below;

$$Vi = \frac{\mathrm{d}i}{\mathrm{d}t}\cdot L + Vc \rightarrow \frac{Vi - Vc}{L} = \frac{\mathrm{d}i}{\mathrm{d}t} \tag{2}$$

$$I_{\min} - I_{\max} = \frac{Vi - Vc}{L}\cdot(2 - D)T \tag{3}$$

The relationship between output voltage and operating time is shown in the following equations.

$$\frac{Vi - Vc}{L}\cdot(2 - D)T = -\frac{Vi}{L}DT \tag{4}$$

$$Vi - Vc(2 - D) = -ViD \tag{5}$$

$$2Vi - ViD - 2Vc + VcD = -ViD \tag{6}$$

$$Vc = 2\frac{Vi}{(2 - D)} \tag{7}$$

3 SIMULATION APPLICATIONS OF BATTERY CHARGING SYSTEM

Fig. 5 shows the simulation model of the proposed system. An alternator feeds a full-wave rectifier consisting of exactly 6 diodes. The DC voltage received from the full-wave rectifier is provided by a single-input, dual-output boost converter to provide increased voltage for two different 24-volt of lithium-ion battery. There are two diodes, two coils and two capacitors in the converter circuit. $L_1 = L_2 = 1$ mH, $C_1 = C_2 = 100$ micro-Farad, $R_1 = R_2 = 5$ ohm. The switching frequency is 0.25 kHz.

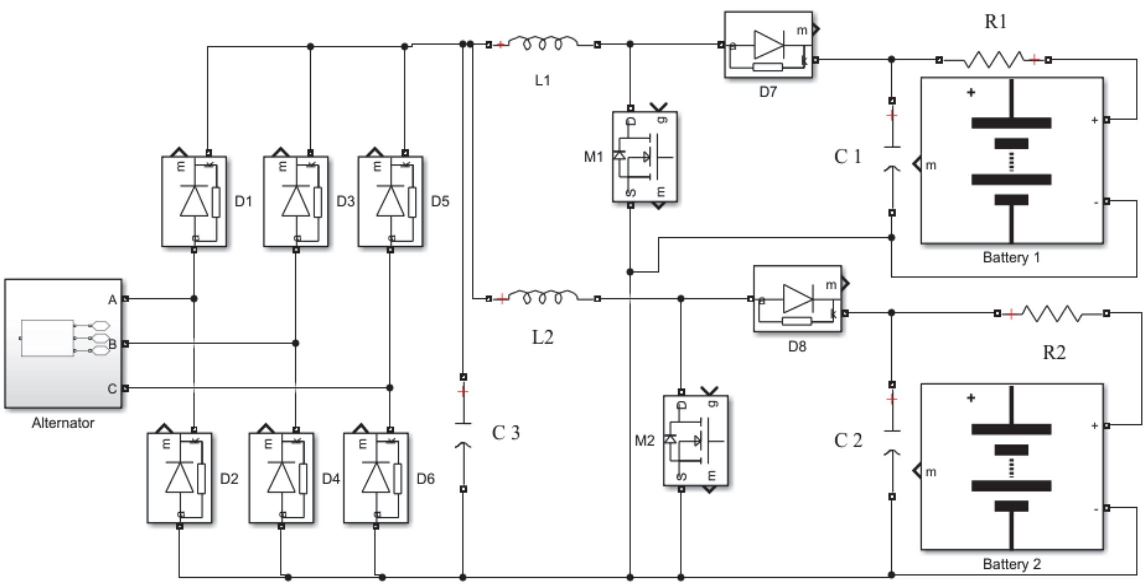


Figure 5 The simulation model of the proposed system

In order to show that the battery fed by a single alternator input is supplied at nominal voltage and above, the system has been tested with different modulation indices. The coil currents, battery charge values, converter output voltages and PWMs of the converters with power switches operating at a modulation index of 0.5 are given in Fig. 6.

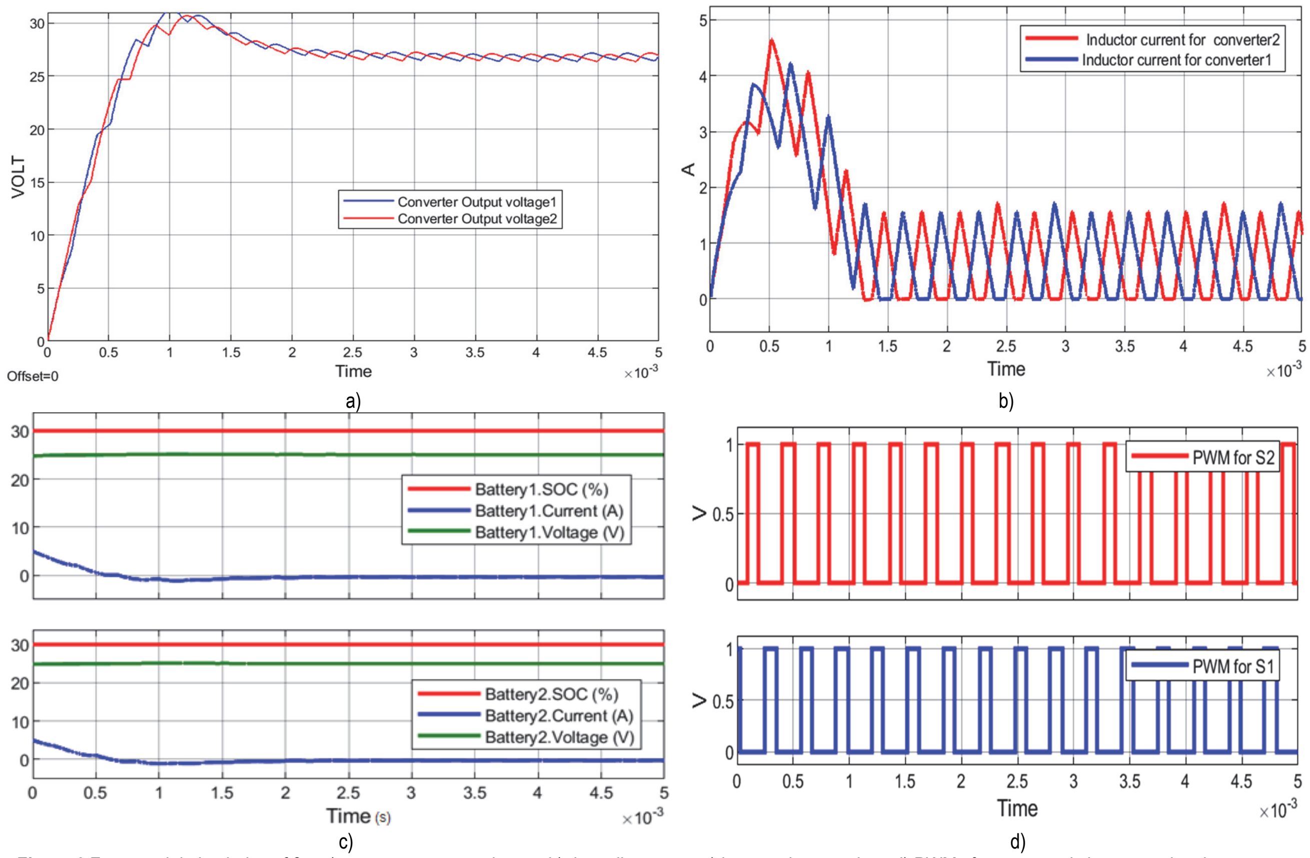
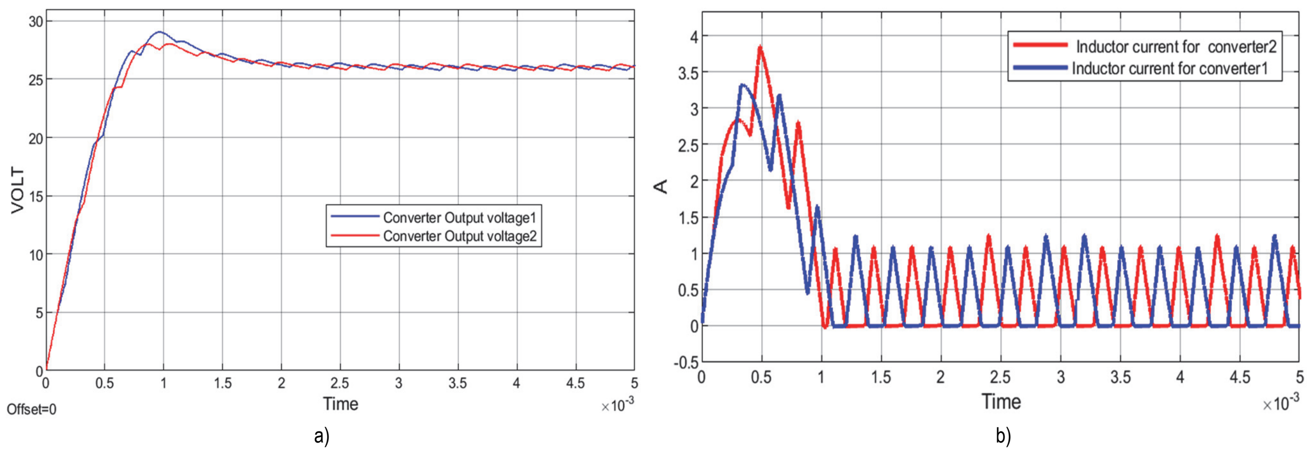
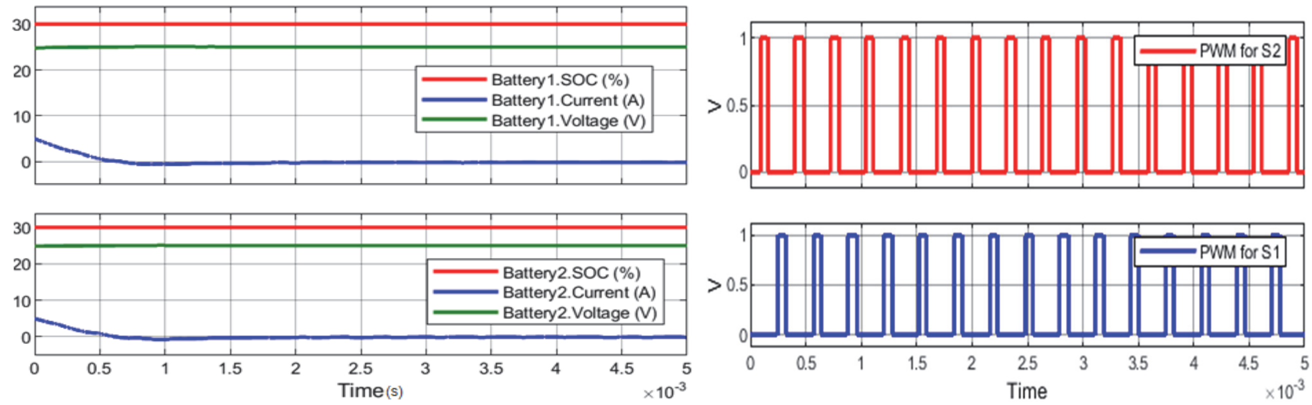


Figure 6 For a modulation index of 0.5 a) converter output voltages, b) the coil currents, c) battery charge values d) PWMs for power switches operating the converters

In Fig. 6a, the converter steps up a 20-volt dc input voltage to 27-volt levels. The changes in the peaks of the voltage waves show that the two converters store energy in their coils for different times. Fig. 6b shows the changes in coil currents of converters charging two different batteries. The maximum values of the coil currents for a modulation index of 0.5 are 1.8 A. In Fig. 6c, the battery is charged to 24-volt levels while the battery current stabilizes at zero in 1.5 milliseconds. In Fig. 6d, the PWMs controlling the power switches are shown. The system output values for a modulation index of 0.3 are given in Fig. 7.

The converter increases a 20-volt dc input voltage to 26-volt levels in Fig. 7a. Again, the changes in the peaks of the voltage waves show that the two converters store energy in their coils at different times. Fig. 7b demonstrates the changes in coil currents of converters charging two different batteries. The maximum values of the coil currents for a modulation index of 0.4 are 1.1 A. In Fig. 7c, the battery is charged with 24-volt levels when the battery current stabilizes at zero in 0.7 millisecond. In Fig. 7d, there are the PWMs for controlling the power switches.

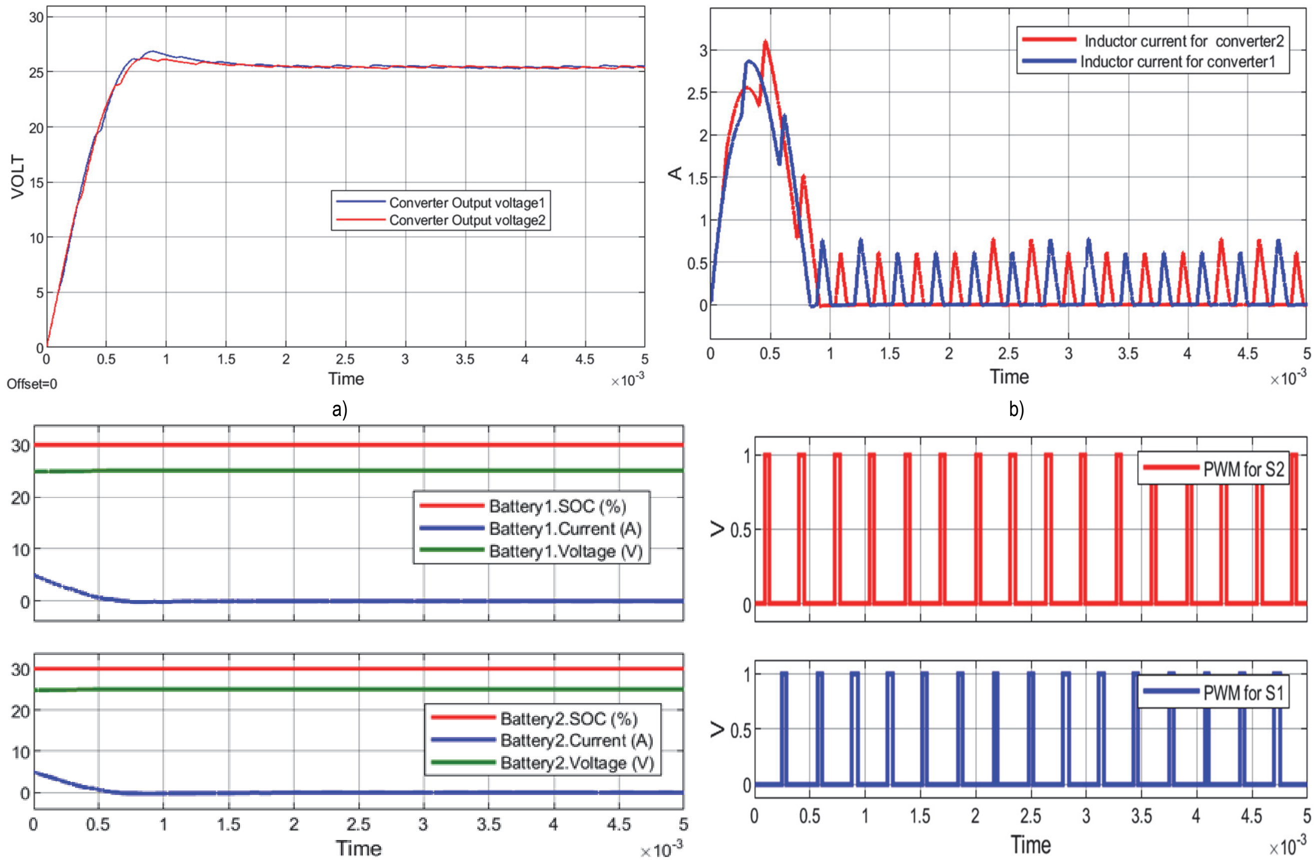




c) d)

Figure 7 At the modulation index of 0.4 a) converter of output voltages, b) the coil currents, c) battery charge values d) PWMs for power switches operating the converters

The converter steps up a 20-volt dc input voltage to 25.5-volt levels in Fig. 8a. The changes in the peaks of the voltage waves show that the two converters store energy in their coils for different times. Fig. 8b shows the changes in coil currents of converters charging two different batteries. The maximum values of the coil currents for a modulation index of 0.3 are 0.6 A. In Fig. 8c, the battery is charged to 24-volt levels while the battery current stabilizes at zero in 0.6 milliseconds. In Fig. 8d, the PWMs controlling the power switches are shown. The system output values for a modulation index of 0.2 are given in Fig. 9.



c) d)

Figure 8 At the modulation index of 0.3 a) converter of output voltages, b) the coil currents, c) battery charge values d) PWMs for power switches operating the converters

The converter increases a 20-volt dc input voltage to 25-volt levels in Fig. 9a. Again, the changes in the peaks of the voltage waves show that the two converters store energy in their coils at different times. Fig. 9b demonstrates the changes in coil currents of converters charging two different batteries. The maximum values of the coil currents for a modulation index of 0.2 are 0.4 A. In Fig. 9c, the battery is charged with 24-volt levels when the battery current stabilizes at zero in 0.5 millisecond. In Fig. 9d, there are the PWMs for controlling the power switches. The change in the current passing through the coils in the charger with the change in the modulation index is given in Fig. 10.

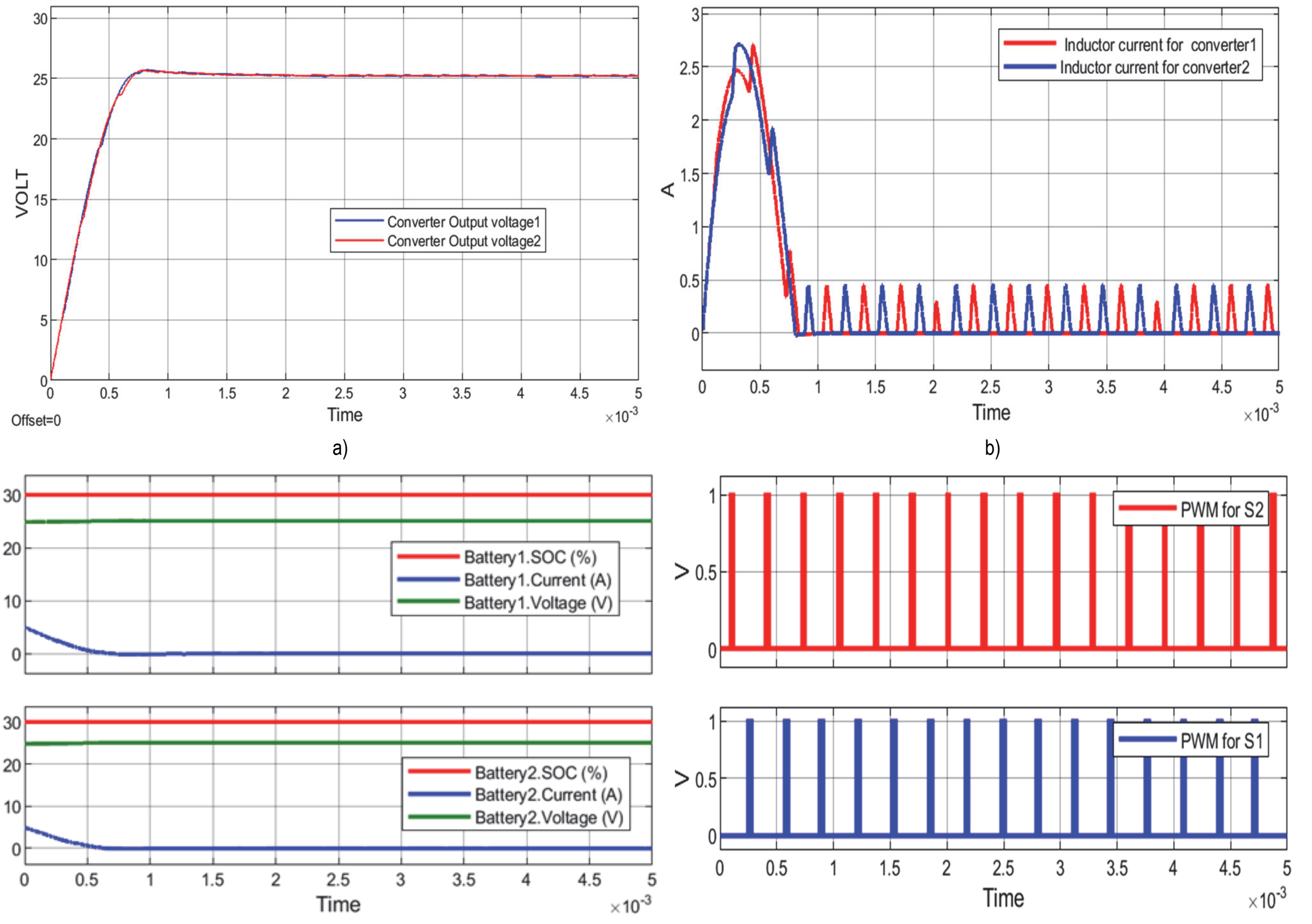


Figure 9 At the modulation index of 0.2 a) converter of output voltages, b) the coil currents, c) battery charge values d) PWMs for power switches operating the converters

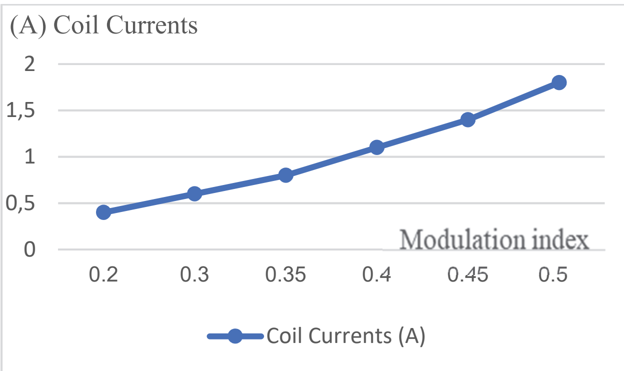


Figure 10 The change in the current passing through the coils

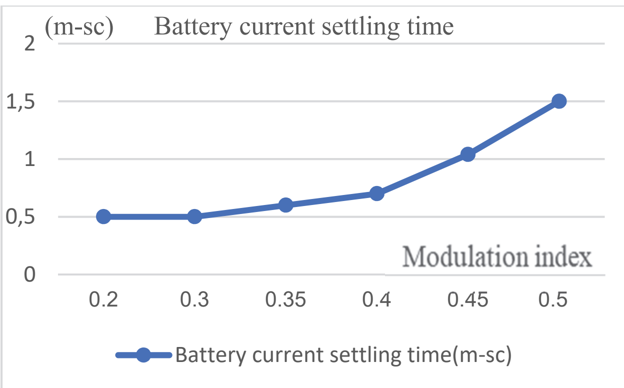


Figure 11 current stabilization at the moment of first charge in the battery

The current passing through the coils in the charging power circuit becomes 0.4 amperes when the modulation index is 0.2, and increases to 1.4 A when it is 0.45. The time it takes for the current to stabilize at the moment of first charge in the lithium-ion battery is given in Fig. 11.

After the battery reaches its nominal charge voltage, it takes 0.5 milliseconds for the battery current to stabilize at zero ampere for a modulation index of 0.2. It takes 0.5 milliseconds for the battery current to stabilize at zero ampere for a modulation index of 0.5. The change in the output voltage of the battery charger unit depending on the modulation index is given in Fig. 12.

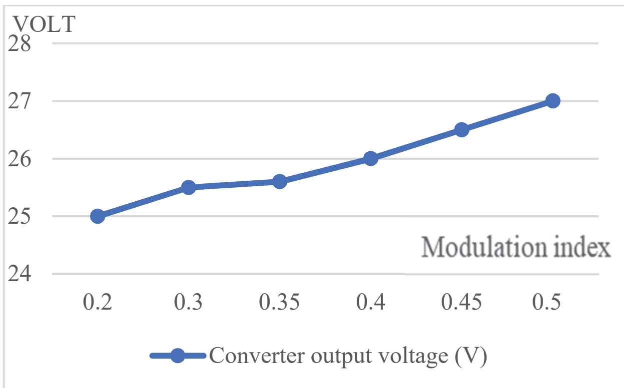


Figure 12 The change in the output voltage of the battery charger unit depending on the modulation index

The output voltage of the battery charger unit feeds the battery at 26 V for a modulation index of 0.4, while it feeds the battery at 25 V for a modulation index of 0.2.

4 DISCUSSION AND RESULTS

With the proposed method, two 24 V battery systems can be fed from a single alternator with 20 V rectifiers fed from a single input DC-DC converter and two different batteries can be fed from each other in isolation. It can be shown that voltage drops that may occur with modulation index changes can be compensated by feeding above the battery nominal voltage. The proposed charging unit ensures that a spare battery is available while charging two different batteries from the same source at the same time. If desired, it will provide the opportunity to use a battery to make the ignition that will enable the car to start, while it will also provide the opportunity to use a different battery for radio, tape and lighting systems.

5 CONCLUSION

A fully insulated dc-dc converter system capable of charging multiple batteries for automobiles and electric vehicles has been presented. First, the operating circuit structure and operating order of the system are given. Then, the system proposed with low alternator output voltages and different modulation indexes is used to charge two batteries with different nominal voltage values in isolation from each other. The converter increased a 20-volt dc input voltage to 26-volt levels. Again, the changes in the peaks of the voltage waves showed that the two converters store energy in their coils at different times. The maximum values of the coil currents for a modulation index of 0.2 were 0.4 A.

The converter stepped up a 20-volt dc input voltage to 25.5-volt levels. The changes in the peaks of the voltage waves showed that the two converters store energy in their coils for different times. The maximum values of the coil currents for a modulation index of 0.3 were 0.6 A. the battery is charged to 24-volt levels while the battery current stabilized at zero in 0.5 milliseconds. When the results obtained were examined, it was shown that the proposed system can successfully charge more than one battery in automobile type vehicles in parallel with each other.

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