Versatile Dual Input - Dual Output Converter for Electrical Vehicles

Joys Kasi[1], Dr. Manish Kumar Srivastava[2]

[1]M. Tech Scholar, Electrical Engineering (Control and Instrumentation), Department of Electrical Engineering, Sam Higginbottom University of Agriculture, Technology and Sciences.

[2]Associate Professor, PhD, Electrical Engineering, Department of Electrical Engineering, Sam Higginbottom University of Agriculture, Technology and Sciences

Abstract: ***The advancement of electric vehicle (EV) technology necessitates the development of efficient and versatile power conversion systems. This project presents the design and implementation of a multifunctional non - isolated dual input - dual output (DIDO) converter specifically for EV applications. The converter aims to seamlessly integrate multiple power sources, such as batteries and super capacitors, and provide multiple outputs to cater to the diverse power requirements of various EV subsystems. The proposed converter enhances overall energy utilization, improves power management, and reduces system complexity, contributing to extended driving ranges and better vehicle performance. Through advanced power electronics techniques, robust control strategies, and comprehensive thermal management, the project aims to achieve high efficiency, reliability, and adaptability. Extensive prototyping and testing will validate the converter's performance in real - world scenarios, positioning it as a critical component in the next generation of electric vehicles, thereby supporting the transition to sustainable and efficient automotive technologies. In conclusion, the development of a multifunctional non - isolated dual input - dual output converter represents a significant advancement in EV power management. By efficiently integrating multiple power sources and providing versatile output capabilities, this project aims to significantly enhance the performance, reliability, and efficiency of electric vehicles. The innovative design and thorough testing of this converter have the potential to make it a critical component in the next generation of EVs, driving the transition towards more sustainable and efficient automotive technologies. This project not only contributes to the advancement of EV technology but also supports broader efforts to promote sustainable transportation solutions.***

Keywords: Hybrid electric vehicles, Boost Converter, Buck Converter, dc–dc power converters, digital control

1. Introduction

In recent years, different efforts have been undertaken to reduce emissions and improve the performance of the transportation sector, employing the development of new fuels and the electrification of transport. The latter is a promising approach with potential benefits in improving energy security by diversifying the energy sources and fostering economic growth by creating new advanced industries focused on vehicular technologies such as battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), and hydrogen fuel - cell electric vehicles (HFCEVs). Most importantly, its technology is environment friendly since renewable energy is integrated into the power system. A typical electric vehicle powertrain architecture includes a battery pack, a motor drive (motor inverter and electric motor), and sometimes a bidirectional dc–dc power converter between the battery and the inverter converter is justified in each of the component.

Battery system: Battery cells for EVs are usually connected in series to meet the voltage requirements of the power inverter. However, this connection exponentially increases the probability of failure of the battery pack [1]. In addition, the performance of the whole battery pack is limited by the weakest cell, which requires an oversizing of the power inverter and the electric motor to ensure peak power delivery at the lowest and the highest state of charge (SoC) of the battery pack [2]. Thus, a boost dc–dc converter optimises the battery size, avoiding oversizing the motor drive, which results in a cost reduction. To increase the use of EVs, many countries have introduced fuel economy regulations [3]. Historically, the average EV lithium - ion battery price dropped from 800/kWh.

Power inverter: A power inverter directly connected to the battery system does not have the same performance at all modulation indices (MI), and it is more efficient and produces better waveforms at higher MI values. When the motor reaches the base speed, the motor phase voltage remains constant using an MI=1 which produces an efficient operation of the inverter [4]. Nevertheless, for values below the base speed, the phase voltage of the motor is increased proportionally to the speed, which produces an inverter operation in low - efficiency zones. Thus, a boost dc–dc converter is used to control the voltage at the input of the inverter according to the motor speed and optimize the efficiency of the inverter (high values of 1) in a wider range of operating speeds [5].

Electric motor: The most - used traction motors in commercial EVs are the induction machine (IM) and the permanent magnet synchronous machine (PMSM) [6]. All these machines in the EV applications have been designed to exhibit torque/power - speed characteristics. This figure shows that the motor operating zone with high efficiency at high speeds is achieved with high voltage on the dc bus. However, with this dc bus voltage, the motor would not be operating in an efficient area like the low speeds reached in the city. Thus, the motor dynamic is governed by the input voltage and current of the inverter [7]. Still, if the inverter is directly connected to a battery, its input voltage will be variable and not controlled. Hence, with a dc–dc converter between the battery and the inverter, the dc voltage bus in the

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inverter input could be optimized based on the motor speed to maximize the electric motor efficiency.

2. Literature Review

1. Li et al., 2023: Li and his team focused on the application of DIDO converters in electric bicycles. Their research highlighted the need for efficient and compact power management systems in enhancing the performance and range of electric bicycles. The study demonstrated that DIDO converters could effectively manage energy from batteries and regenerative braking, ensuring optimal performance and energy efficiency. The findings indicated that integrating DIDO converters into electric bicycles could significantly extend their range and reduce charging frequency, making them more practical for daily use.

2. Mehta et al., 2023: Mehta and his team explored the role of DIDO converters in optimizing the energy efficiency of electric heavy - duty vehicles. Their research focused on the power management needs of vehicles used in construction, mining, and other heavy industries. The study demonstrated that DIDO converters could significantly enhance the energy efficiency and operational range of electric heavy - duty vehicles by managing power from multiple sources. The findings highlighted the potential of DIDO converters to support the transition to sustainable heavy - duty transportation solutions.

3. Hussain et al., 2022: Hussain's research investigated the application of DIDO converters in improving the performance of electric recreational boats. The study focused on the power management needs of electric boats, including energy storage and auxiliary power requirements. The findings demonstrated that DIDO converters could significantly enhance the energy efficiency and operational range of electric boats, making them more practical for recreational use and reducing their environmental impact.

4. Chakraborty et al., 2022: Chakraborty's research focused on the use of DIDO converters in improving the performance of off - road electric vehicles. The study highlighted the unique power management challenges faced by off - road EVs, including variable terrain and power demands. The findings demonstrated that DIDO converters could effectively manage power from batteries and regenerative braking, enhancing the performance and reliability of off - road EVs. This research emphasized the potential of DIDO converters in expanding the applications of electric transportation beyond urban environments.

5. Kaur et al., 2022: Kaur's research examined the integration of DIDO converters with energy storage systems in electric boats. The study aimed to address the challenges of energy management in marine applications, where reliability and efficiency are critical. The findings showed that DIDO converters could significantly enhance the performance and range of electric boats by efficiently managing power from batteries and renewable energy sources. This research underscored the potential of DIDO converters to contribute to the development of sustainable maritime transportation.

3. System Design Methodology

DC - DC Converter Basics

A DC - to - DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically, the output produced is at a different voltage level than the input. In addition, DC - to - DC converters are used to provide noise isolation, power bus regulation, etc. This is a summary of some of the popular DC - to - DC converter topologies.

Buck Converter Step - Down Converter

In this circuit the transistor turning ON will put voltage V_{in} on one end of the inductor. This voltage will tend to cause the inductor current to rise. When the transistor is OFF, the current will continue flowing through the inductor but now flowing through the diode [8].

We initially assume that the current through the inductor does not reach zero, thus the voltage at V_x will now be only the voltage across the conducting diode during the full OFF time. The average voltage at V_x will depend on the average ON time of the transistor provided the inductor current is continuous.

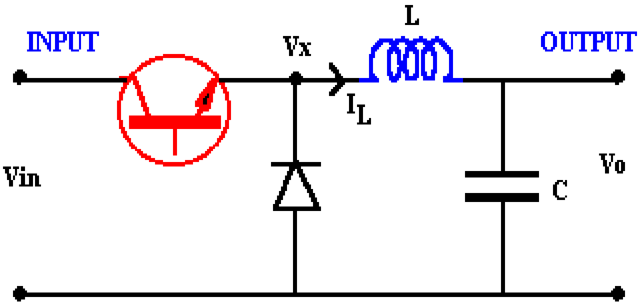


Figure 1: Buck Converter

To analyze the voltages of this circuit let us consider the changes in the inductor current over one cycle [9]. From the relation

$$V_x - V_o = L\frac{di}{dt} \qquad (1)$$

the change of current satisfies

$$di = \int_{ON}(V_x - V_o)dt + \int_{OFF}(V_x - V_o)dt \qquad (2)$$

For steady state operation the current at the start and end of a period T will not change. To get a simple relation between voltages we assume no voltage drop across transistor or diode while ON and a perfect switch change. Thus during the ON time $V_x = V_{in}$ and in the OFF $V_x = 0$. Thus

$$0 = di = \int_0^{t_{on}}(Vin - Vo)dt + \int_{t_{on}}^{t_{on}+t_{off}}(-Vo)dt \qquad (3)$$

which simplifies to

$$(Vin - Vo)t_{on} - Vo\, t_{off} = 0 \qquad (4)$$

or

$$\frac{Vo}{Vin} = \frac{t_{on}}{T} \qquad (5)$$

and defining "duty ratio" as

$$D = \frac{t_{on}}{T} \tag{6}$$

the voltage relationship becomes Vo=D Vin Since the circuit is lossless and the input and output powers must match on the average V_o I_o = V_{in} I_{in}. Thus the average input and output current must satisfy I_{in} =D I_o These relations are based on the assumption that the inductor current does not reach zero [11].

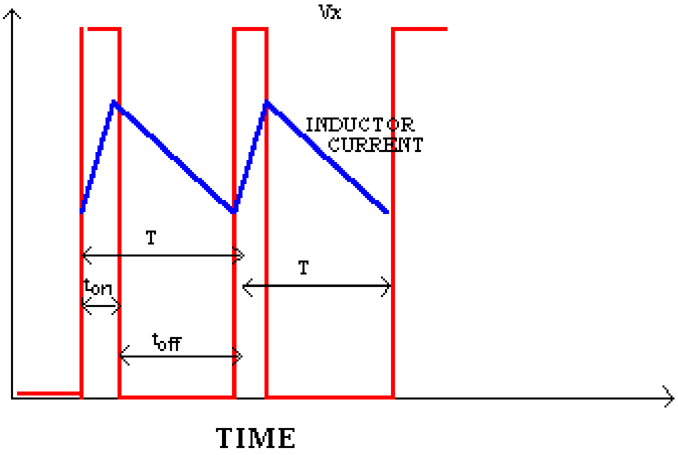


Figure 2: Voltage and current changes w. r. t. Time

Transition between continuous and discontinuous

When the current in the inductor L remains always positive then either the transistor T1 or the diode D1 must be conducting. For continuous conduction the voltage V_x is either V_{in} or 0. If the inductor current ever goes to zero then the output voltage will not be forced to either of these conditions. At this transition point the current just reaches zero as seen in Figure (buck booster boundery). During the ON time V_{in} - V_{out} is across the inductor thus

$$I_L(peak) = (Vin - Vout) \cdot \frac{t_{ON}}{L} \tag{7}$$

The average current which must match the output current satisfies

$$I_L(average\ at\ transition) = \frac{I_L(peak)}{2} = (Vin - Vout)\frac{dT}{2L} = Iout(transition) \tag{8}$$

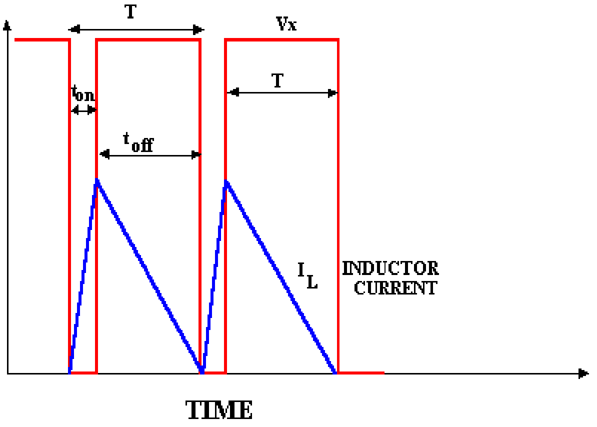


Figure 3: Buck Converter at Boundary

If the input voltage is constant the output current at the transition point satisfies

$$Iout(transition) = Vin\frac{(1-d)d}{2L}T \tag{9}$$

Voltage Ratio of Buck Converter

As for the continuous conduction analysis we use the fact that the integral of voltage across the inductor is zero over a cycle of switching T. The transistor OFF time is now divided into segments of diode conduction d_dT and zero conduction d_oT. The inductor average voltage thus gives

$$(V_{in} - V_o)\ DT + (-V_o)\ \square_d T = 0 \tag{10}$$

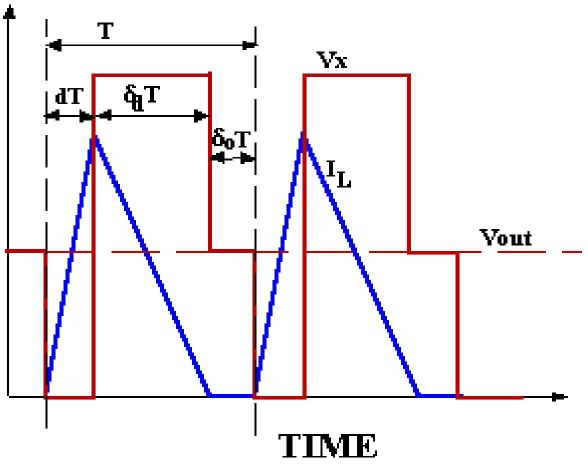


Figure 4: Buck Converter - Discontinuous Conduction

$$\therefore \frac{Vout}{Vin} = \frac{d}{d + \delta_d} \tag{11}$$

for the case $d + \delta_d < 1$. To resolve the value of δ_d consider the output current which is half the peak when averaged over the conduction times $d + \delta_d$

$$Iout = \frac{I_L(peak)}{2} d + \delta_d \tag{12}$$

Considering the change of current during the diode conduction time

$$I_L(peak) = \frac{V_0(\delta_d T)}{L} \tag{13}$$

Thus from (6) and (7) we can get

$$I_{out} = \frac{V_0 \delta_d T \cdot (d + \delta_d)}{2L} \tag{14}$$

using the relationship in (5)

$$Iout = \frac{Vin\ d\ \delta_d T}{2L} \tag{15}$$

and solving for the diode conduction

The output voltage is thus given as

$$\frac{Vout}{Vin} = \frac{d^2}{d^2 + (\frac{2L\ Iout}{Vin\ T})} \tag{17}$$

defining k = 2L/ (V_{in} T), we can see the effect of discontinuous current on the voltage ratio of the converter.

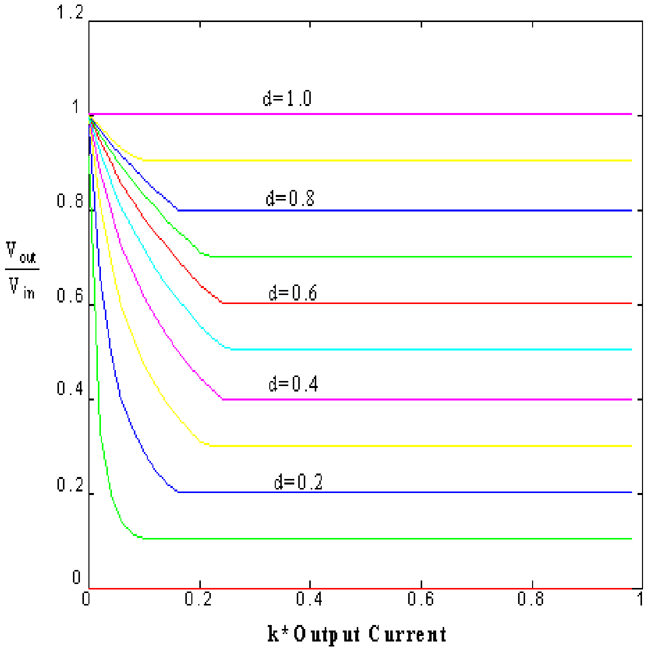


Figure 5: Output Voltage vs Current

As seen in the figure, once the output current is high enough, the voltage ratio depends only on the duty ratio "d". At low currents the discontinuous operation tends to increase the output voltage of the converter towards V_{in}.

Boost Converter Step - Up Converter

The schematic in Fig.6 shows the basic boost converter. This circuit is used when a higher output voltage than input is required [12].

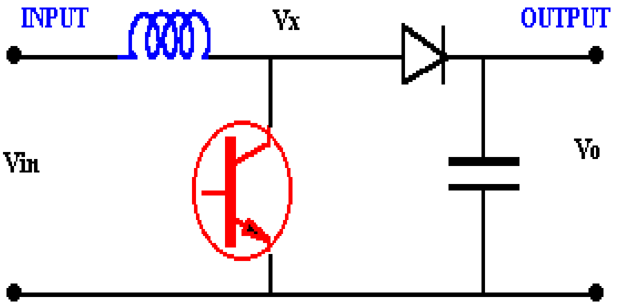


Figure 6: Boost Converter Circuit

While the transistor is ON $V_x = V_{in}$, and the OFF state the inductor current flows through the diode giving $V_x = V_o$. For this analysis it is assumed that the inductor current always remains flowing (continuous conduction). The voltage across the inductor is shown in Fig.7 and the average must be zero for the average current to remain in steady state

$$Vin\, t_{on} + (Vin - Vo)t_{off} = 0 \quad (18)$$

This can be rearranged as

$$\frac{Vo}{Vin} = \frac{T}{t_{off}} = \frac{1}{(1-D)} \quad (19)$$

and for a lossless circuit the power balance ensures

$$\frac{Io}{Iin} = (1-D) \quad (20)$$

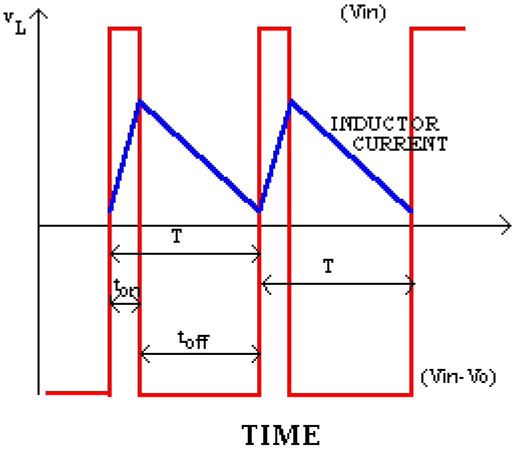


Figure 7: Voltage and current waveforms

Since the duty ratio "D" is between 0 and 1 the output voltage must always be higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage [13].

Buck - Boost Converter

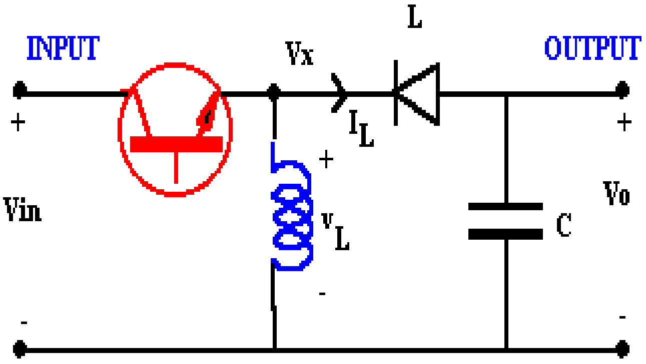


Figure 8: schematic for buck - boost converter

With continuous conduction for the Buck - Boost converter $V_x = V_{in}$ when the transistor is ON and $V_x = V_o$ when the transistor is OFF. For zero net current change over a period the average voltage across the inductor is zero

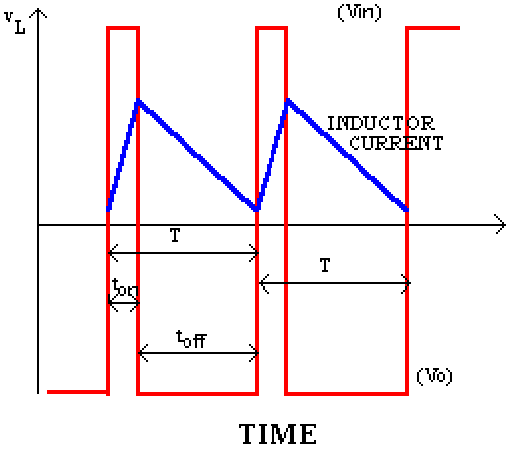


Figure 9: Waveforms for buck - boost converter

$$Vin\,t_{ON} + Vo\,t_{OFF} = 0 \tag{21}$$

which gives the voltage ratio

$$\frac{Vo}{Vin} = -\frac{D}{(1-D)} \tag{22}$$

and the corresponding current

$$\frac{Io}{Iin} = -\frac{(1-D)}{D} \tag{23}$$

Since the duty ratio "D" is between 0 and 1 the output voltage can vary between lower or higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage [14].

Converter Comparison

The voltage ratios achievable by the DC - DC converters is summarised in Fig.10. Notice that only the buck converter shows a linear relationship between the control (duty ratio) and output voltage. The buck - boost can reduce or increase the voltage ratio with unit gain for a duty ratio of 50%.

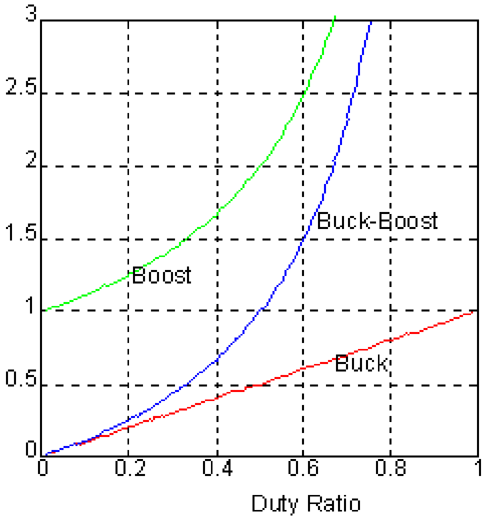


Figure 10: Comparison of Voltage ratio

CUK Converter

The buck, boost and buck - boost converters all transferred energy between input and output using the inductor, analysis is based of voltage balance across the inductor. The CUK converter uses capacitive energy transfer and analysis is based on current balance of the capacitor. The circuit in Fig. below (CUK converter) is derived from DUALITY principle on the buck - boost converter [15].

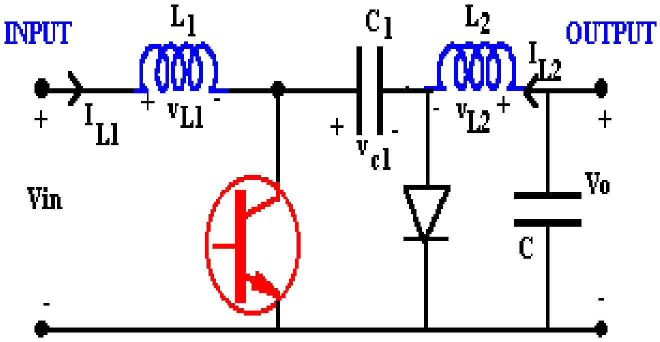


Figure 11: CUK Converter

If we assume that the current through the inductors is essentially ripple free we can examine the charge balance for the capacitor C1. For the transistor ON the circuit becomes and the current in C1 is I_{L1}. When the transistor is OFF, the diode conducts and the current in C1 becomes I_{L2}.

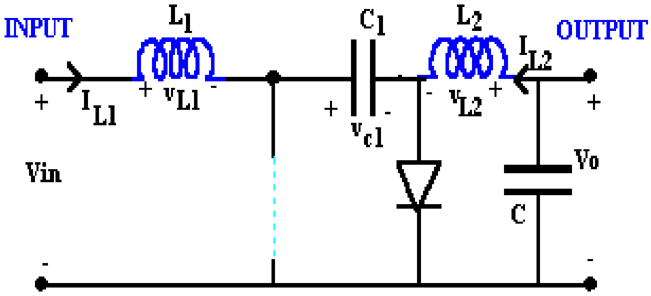


Figure 12: CUK "OFF - STATE"

Since the steady state assumes no net capacitor voltage rise, the net current is zero

$$I_{L1}t_{ON} + (-I_{L2})t_{OFF} = 0 \tag{24}$$

which implies

$$\frac{I_{L2}}{I_{L1}} = \frac{(1-D)}{D} \tag{25}$$

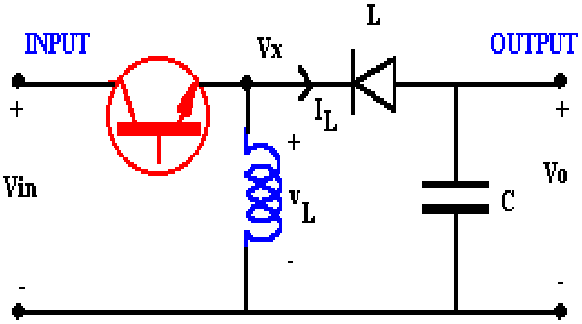
The inductor currents match the input and output currents, thus using the power conservation rule

$$\frac{Vo}{Vin} = -\frac{D}{(1-D)} \tag{26}$$

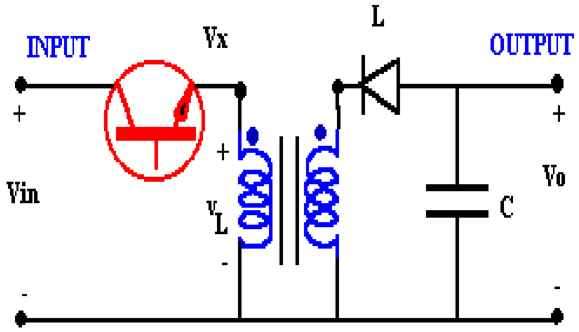
Thus the voltage ratio is the same as the buck - boost converter. The advantage of the CUK converter is that the input and output inductors create a smooth current at both sides of the converter while the buck, boost and buck - boost have at least one side with pulsed current [16].

Flyback Converter

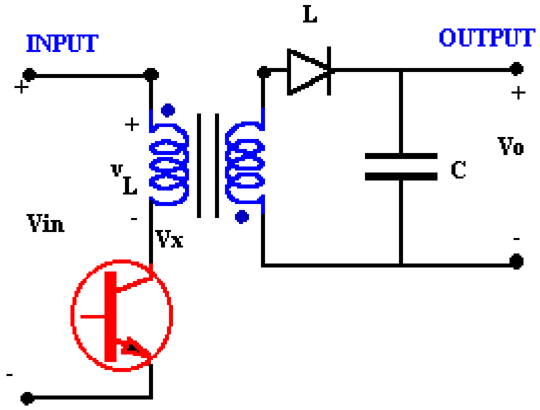
The flyback converter can be developed as an extension of the Buck - Boost converter. Fig (a) shows the basic converter; Fig (b) (replacing inductor by transformer) replaces the inductor by a transformer. The buck - boost converter works by storing energy in the inductor during the ON phase and releasing it to the output during the OFF phase. With the transformer the energy storage is in the magnetization of the transformer core. To increase the stored energy a gapped core is often used. In Fig (c) the isolated output is clarified by removal of the common reference of the input and output circuits [17].



(a) **Figure 13:** Buck - Boost Converter



(b) **Figure 14:** Replacing inductor by transformer



(c) **Figure 15:** Fly back converter re - configured

Forward Converter

The concept behind the forward converter is that of the ideal transformer converting the input AC voltage to an isolated secondary output voltage [18]. For the circuit in Fig. (forward converter), when the transistor is ON, Vin appears across the primary and then generates

$$Vx = \frac{N_1}{N_2} Vin \tag{27}$$

The diode D1 on the secondary ensures that only positive voltages are applied to the output circuit while D2 provides a circulating path for inductor current if the transformer voltage is zero or negative.

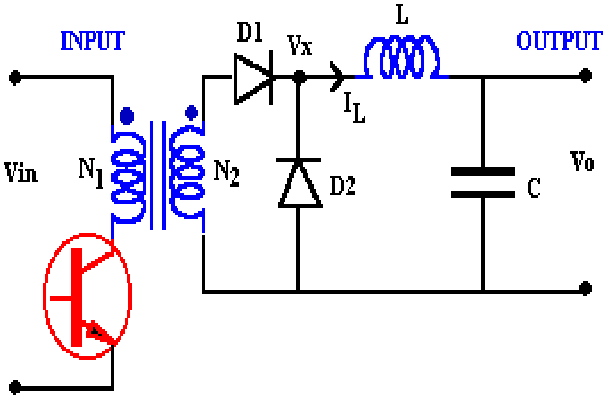


Figure 16: Forward Converter

The problem with the operation of the circuit in Fig above (forward converter) is that only positive voltage is applied across the core, thus flux can only increase with the application of the supply. The flux will increase until the core saturates when the magnetising current increases significantly and circuit failure occurs. The transformer can only sustain operation when there is no significant DC component to the input voltage. While the switch is ON there is positive voltage across the core and the flux increases. When the switch turns OFF we need to supply negative voltage to reset the core flux. The circuit in Fig. below shows a tertiary winding with a diode connection to permit reverse current. Note that the "dot" convention for the tertiary winding is opposite those of the other windings. When the switch turns OFF current was flowing in a "dot" terminal. The core inductance act to continue current in a dotted terminal.

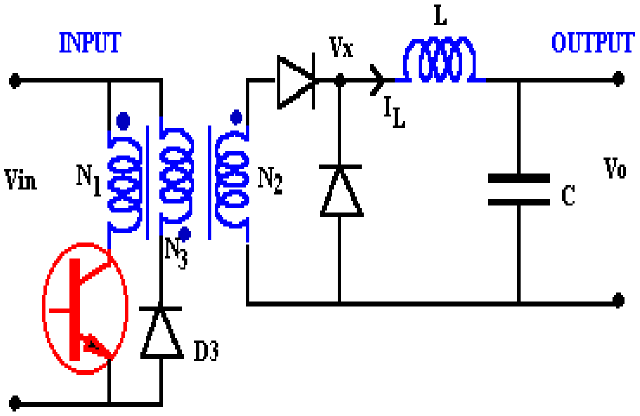


Figure 17: Forward converter with tertiary winding

Boost Converter

A boost converter is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching - mode power supply containing at least two semiconductor switches and at least one energy storage element. Filters made of capacitors are normally added to the output of the converter to reduce output voltage ripple. Power can also come from DC sources such as batteries, solar panels, rectifiers and DC generators [19]. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step - up converter since it "steps up" the source voltage. Since power ($P = VI$ or $P = UI$ in Europe) must be conserved, the output current is lower than the source current [20].

A boost converter may also be referred to as a 'Joule thief'. This term is usually used only with very low power battery applications, and is aimed at the ability of a boost converter to 'steal' the remaining energy in a battery. This energy would otherwise be wasted since a normal load wouldn't be able to handle the battery's low voltage.

This energy would otherwise remain untapped because in most low - frequency applications, currents will not flow through a load without a significant difference of potential between the two poles of the source (voltage.)

Operating principle

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. When being charged it acts as a load and absorbs energy (somewhat like a resistor), when being discharged, it acts as an energy source (somewhat like a battery). The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages.

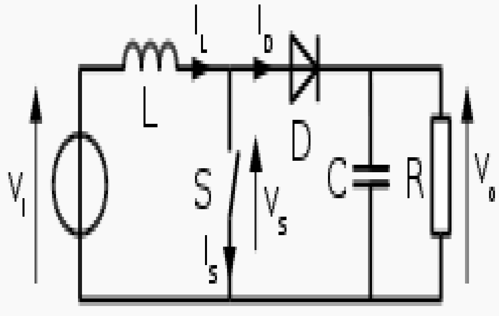


Figure 18: Boost converter schematic

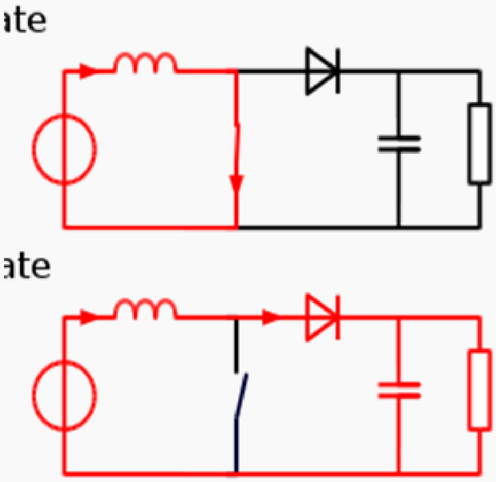


Figure 19: The two configurations of a boost converter, depending on the state of the switch S.

The basic principle of a Boost converter consists of 2 distinct states.

- in the On - state, the switch S (see figure) is closed, resulting in an increase in the inductor current;
- In the Off - state, the switch is open and the only path offered to inductor current is through the flyback diode D, the capacitor C and the load R. This result in transferring the energy accumulated during the On - state into the capacitor.

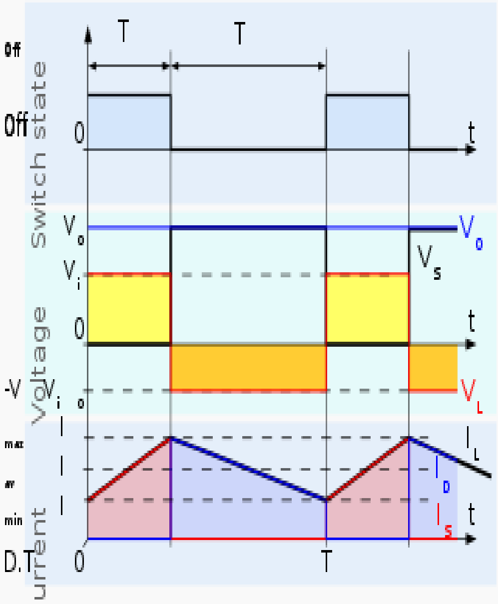


Figure 20: Waveforms of current and voltage in a boost converter operating in continuous mode.

During the On - state, the switch S is closed, which makes the input voltage (V_i) appear across the inductor, which causes a change in current (I_L) flowing through the inductor during a time period (t) by the formula:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L}$$

At the end of the On - state, the increase of I_L is therefore:

$$\Delta I_{L_{On}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L} V_i$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is on. Therefore, D ranges between 0 (S is never on) and 1 (S is always on) [21].

During the Off - state, the switch S is open, so the inductor current flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remain constant, the evolution of I_L is:

$$V_i - V_o = L\frac{dI_L}{dt}$$

Therefore, the variation of I_L during the Off - period is:

$$\Delta I_{L_{Off}} = \int_0^{(1-D)T} \frac{(V_i - V_o)\,dt}{L} = \frac{(V_i - V_o)(1-D)T}{L}$$

As we consider that the converter operates in steady - state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in the inductor is given by:

$$E = \frac{1}{2} L I_L^2$$

So, the inductor current has to be the same at the start and end of the commutation cycle. This means the overall change in the current (the sum of the changes) is zero [22]:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = 0$$

Substituting $\Delta I_{L_{On}}$ and $\Delta I_{L_{Off}}$ by their expressions yields:

$$\Delta I_{L_{On}} + \Delta I_{L_{Off}} = \frac{V_i D T}{L} + \frac{(V_i - V_o)(1 - D) T}{L} = 0$$

This can be written as:

$$\frac{V_o}{V_i} = \frac{1}{1 - D}$$

Which in turns reveals the duty cycle to be

$$D = 1 - \frac{V_i}{V_o}$$

From the above expression it can be seen that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a *step - up* converter [23].

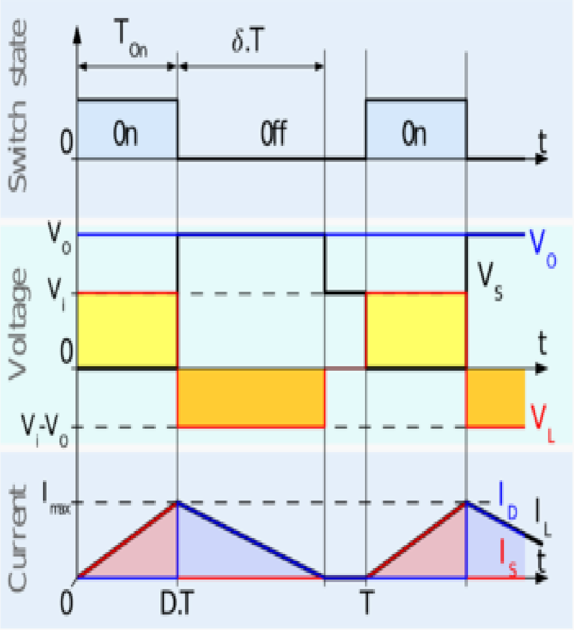


Figure 21: Waveforms of current and voltage in a boost converter operating in discontinuous mode.

As the inductor current at the beginning of the cycle is zero, its maximum value $I_{L_{Max}}$ (at $t = DT$) is

$$I_{L_{Max}} = \frac{V_i D T}{L}$$

During the off - period, I_L falls to zero after δT:

$$I_{L_{Max}} + \frac{(V_i - V_o)\,\delta T}{L} = 0$$

Using the two previous equations, δ is:

$$\delta = \frac{V_i D}{V_o - V_i}$$

The load current I_o is equal to the average diode current (I_D). As can be seen on figure 4, the diode current is equal to the inductor current during the off - state. Therefore, the output current can be written as:

$$I_o = \bar{I_D} = \frac{I_{L_{max}}}{2} \delta$$

Replacing I_{Lmax} and δ by their respective expressions yields:

$$I_o = \frac{V_i D T}{2L} \cdot \frac{V_i D}{V_o - V_i} = \frac{V_i^2 D^2 T}{2L\,(V_o - V_i)}$$

Therefore, the output voltage gain can be written as flow:

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2 L I_o}$$

Compared to the expression of the output voltage for the continuous mode, this expression is much more complicated. Furthermore, in discontinuous operation, the output voltage gain not only depends on the duty cycle, but also on the inductor value, the input voltage, the switching frequency, and the output current [24].

Space Vector PWM

The Space Vector PWM generation module accepts modulation index commands and generates the appropriate gate drive waveforms for each PWM cycle [25]. This section describes the operation and configuration of the SVPWM module. A three - phase 2 - level inverter with dc link configuration can have eight possible switching states, which generates output voltage of the inverter. Each inverter switching state generates a voltage Space Vector (V1 to V6 active vectors [26], V7 and V8 zero voltage vectors) in the Space Vector plane. The magnitude of each active vector (V1to V6) is 2/3 Vdc (dc bus voltage) [27 - 29].

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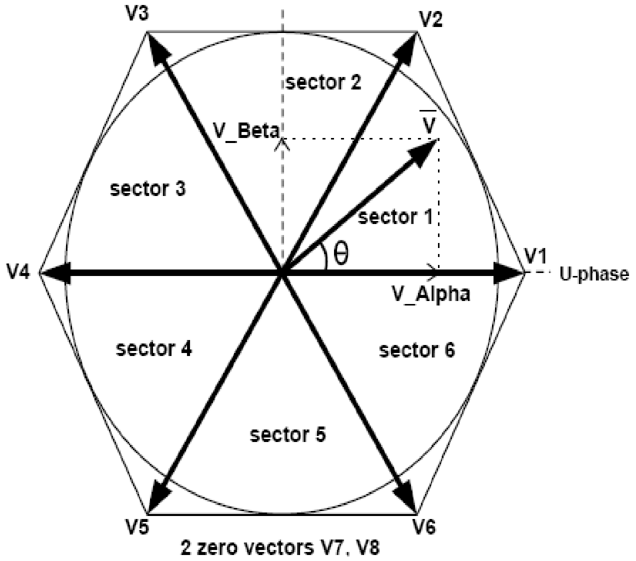

Figure 22: Space Vector Diagram

The Space Vector PWM (SVPWM) module inputs modulation index commands (U_Alpha and U_Beta) which are orthogonal signals (Alpha and Beta) as shown in Figure. The gain characteristic of the SVPWM module is given in Figure. The vertical axis of Figure represents the normalized peak motor phase voltage (V/Vdc) and the horizontal axis represents the normalized modulation index (M) [30 - 32]. The inverter fundamental line - to - line Rms output voltage (Vline) can be approximated (linear range) by the following equation:

$$Vline = Umag * Mod\_Scl * Vdc / \sqrt{6} / 2^{25}$$

Where dc bus voltage (Vdc) is in volts

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The maximum achievable modulation (Umag_L) in the linear operating range is given by:

$$Umag\_L = 2^{25} * \sqrt{3} / Mod\_Scl$$

Over modulation occurs when modulation Umag>Umag_L. This corresponds to the condition where the voltage vector in (Figure: voltage vector rescaling) increases beyond the hexagon boundary [33 - 35]. Under such circumstance, the Space Vector PWM algorithm will rescale the magnitude of the voltage vector to fit within the Hexagon limit. The magnitude of the voltage vector is restricted within the Hexagon; however, the phase angle (θ) is always preserved. The transfer gain (Figure: transfer characteristics) of the PWM modulator reduces and becomes non - linear in the over modulation region [36].

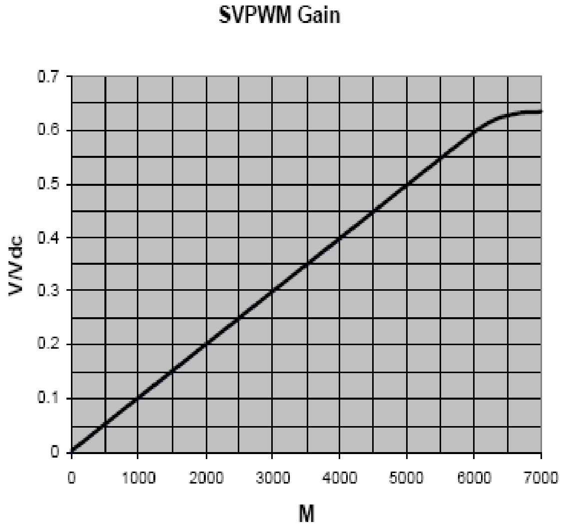

Figure 23: Transfer Characteristics

Simulation Circuit Designs

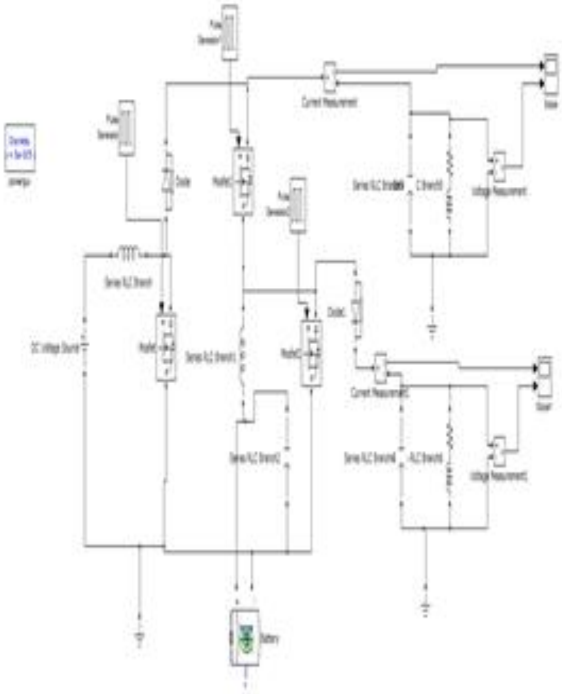

Figure 24: Circuit for open loop simulation circuit

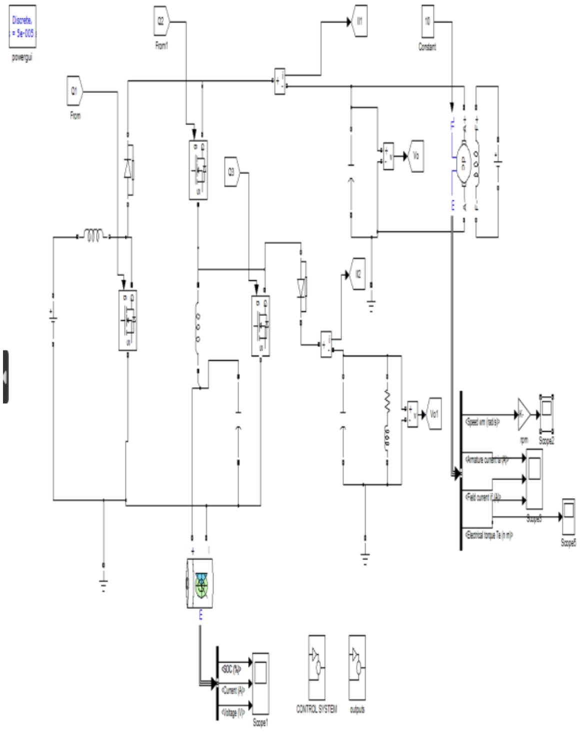

Figure 25: Circuit for motor case simulation circuit

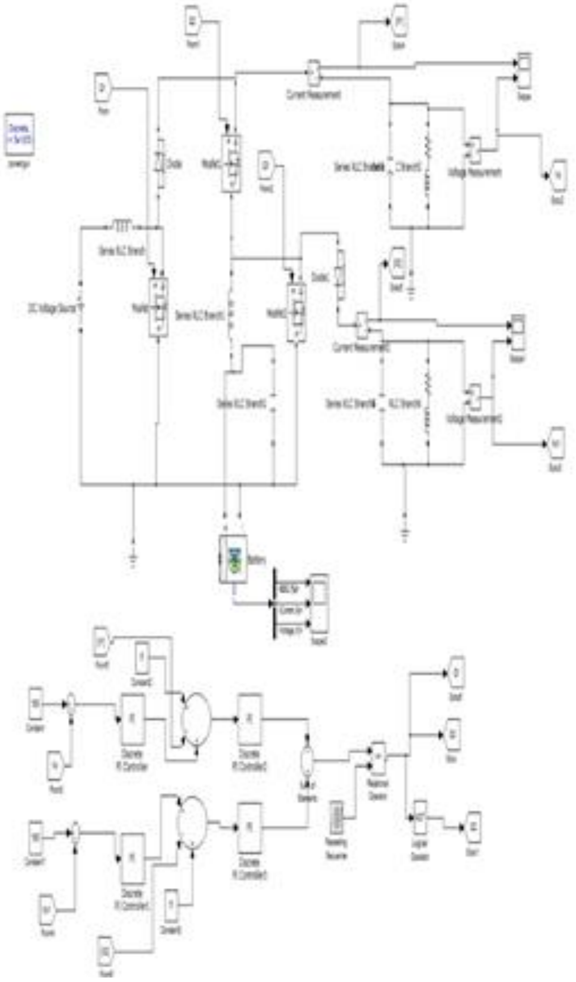

Figure 26: Circuit for closed loop simulation circuit

Simulation Results

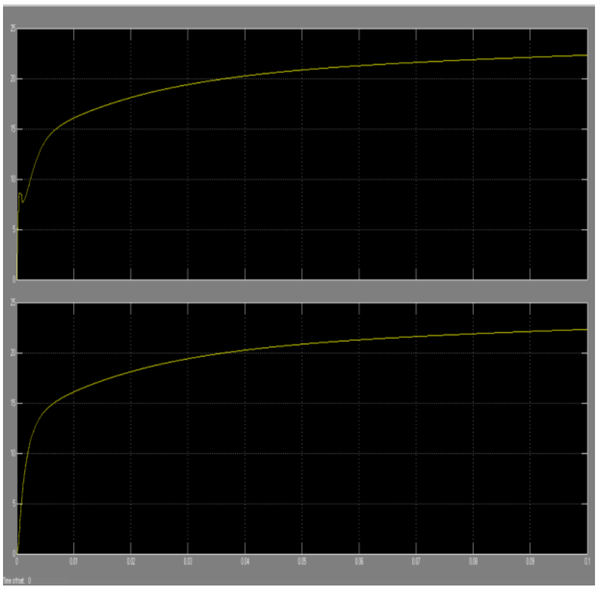

Figure 27: Open Loop

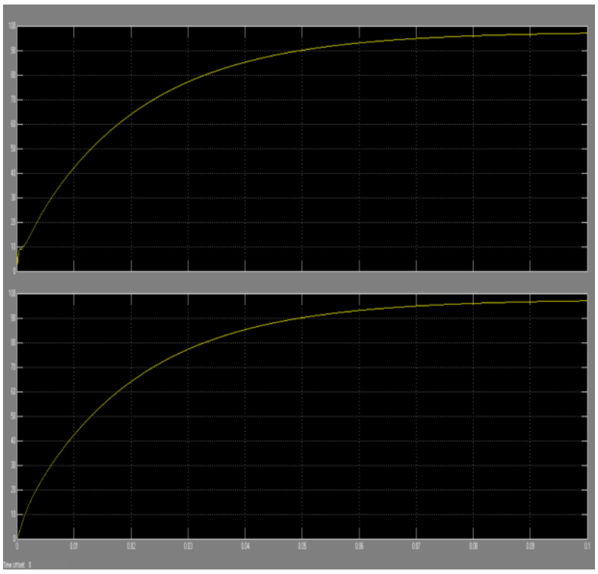

Figure 28: Closed Loop

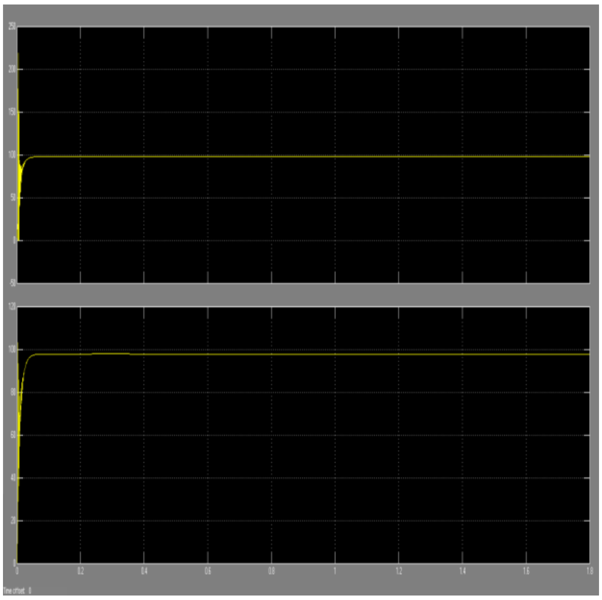

Figure 29: motor case a) Speed

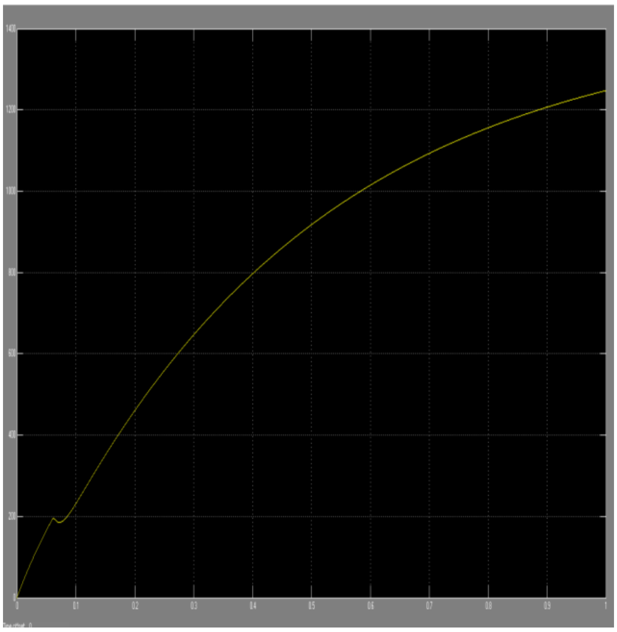

Figure 30: b) Armature current

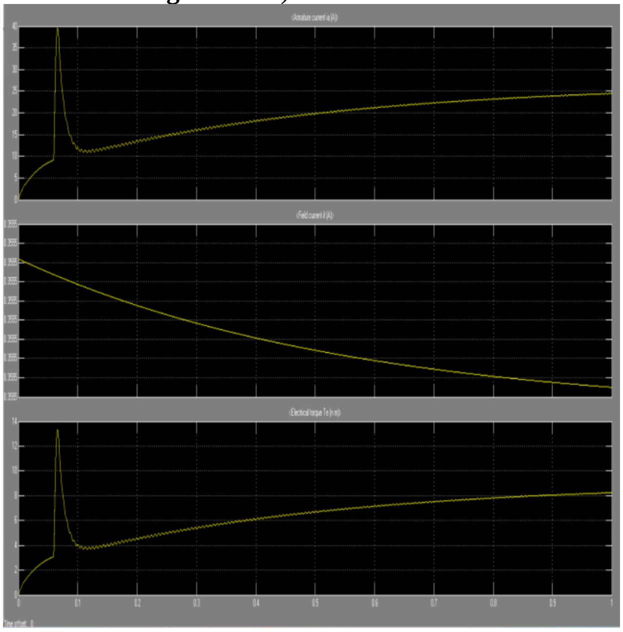

Figure 31: c) Field Current

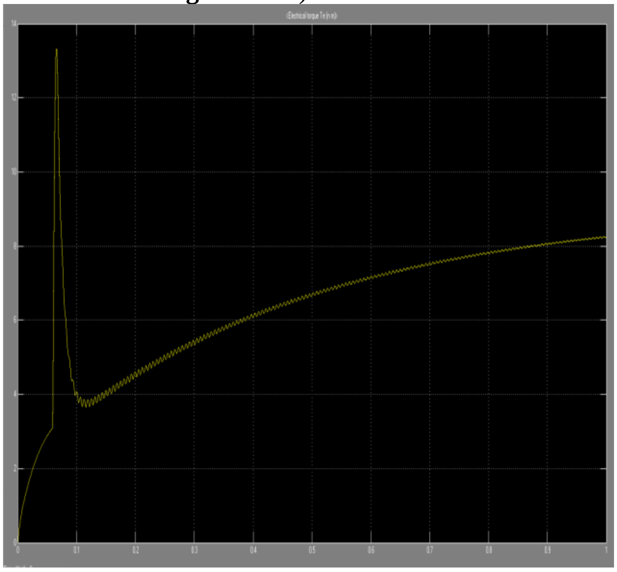

Figure 32: d) torque

4. Conclusion

A single - stage four - port (FPC) buck - boost converter for hybridizing diversified energy resources for EV has been proposed in this paper. Compared to the existing buck - boost converter topologies in the literature, this converter has the advantages of a) producing buck, boost, buck - boost output even without the use of an additional transformer b) having bidirectional power flow capability with reduced component count c) handling multiple resources of different voltage and current capacity. Mathematical analysis has been carried out to illustrate the functionalities of the proposed converter.

A simple control algorithm has been adopted to budget the power flow between the input sources. Finally, the operation of this converter has been verified through a low voltage prototype model. Experimental results validate the feasibility of the proposed four - port buck - boost topology

5. Future Scope

The future scope for Versatile Dual Input – Dual Output converters in electric vehicles is vast and multi - faceted. These converters are poised to play a critical role in the advancement of EV technology by improving energy management, enhancing reliability, supporting renewable energy integration, and enabling new functionalities such as V2G. Continued research and development in this area will further unlock their potential, contributing to the broader adoption and evolution of electric vehicles.

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