

DC-DC converter in isolation Fed DC motor for bidirectional use in electric vehicles

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Abstract

Fossil fuel use and carbon dioxide (CO₂) and nitrogen oxide (NO_x) emissions have increased due to the growing use of conventional automobiles. Because they can lessen reliance on fossil fuels and contribute to lower vehicle emissions, electric vehicles (EVs) offer a viable substitute. However, battery capacity, charging time, and energy consumption have a significant impact on EV performance. A large portion of the vehicle's kinetic energy is transformed into heat and lost through the braking system during traditional braking. Recovering the battery's stored energy while braking is the primary goal of this research.

The electrical energy transfer between the battery and DC motor is managed by a bidirectional DC-DC converter. While the motor functions as a generator during braking and the recovered electrical energy is returned to the battery via the bidirectional converter, energy is transferred from the battery to the motor during acceleration. The suggested regenerative braking system can extend an electric vehicle's useful driving range while also increasing energy efficiency and minimizing energy losses.

Keywords: nitrogen oxides (NO_x), carbon dioxide (CO₂), bidirectional DC-DC converter. EV performance and electric vehicles

1. Introduction:

According to the International Energy Agency, a significant portion of the world's oil consumption is attributed to the transportation sector. Compared to traditional fossil-fuel vehicles, electric vehicles (EVs) are becoming a more environmentally friendly option[1]. EVs have lower operating costs, low emissions, excellent efficiency, and minimal noise. The main energy-storage devices found in contemporary electric cars are batteries.

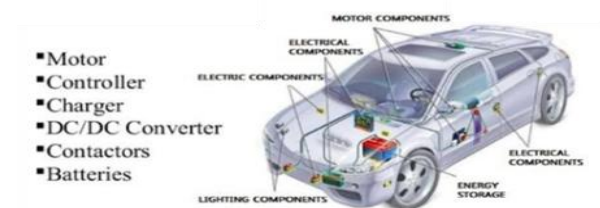


Fig.1. Electric Vehicle

Energy is transferred from the battery to the motor during acceleration, and it is returned to the battery during regenerative braking. Voltage matching and power flow between the battery and motor are managed by a bidirectional DC-DC converter. The proposed work uses MATLAB/Simulink simulations to show regenerative braking and energy recovery[2].

2. Project Objective:

"To recover the stored energy in battery during the braking operation" is our primary motto. The transportation industry accounts for over 64% of the world's oil consumption. CO₂ and NO_x emissions have been controlled as a result of rising fossil fuel demand and climate change[3]. Electric vehicles (EVs) have the potential to lessen the threat posed by climate change. However, there is still much room for improvement in the EV charging system[4]. A reduction in charging time is a crucial prerequisite for making EVs user-friendly. This has led to the demonstration of a bidirectional DC-DC converter that feeds a DC motor and recovers energy by regenerative braking.

3. Existing System:

In a traditional electric car, the battery provides electrical energy to the motor, which generates mechanical power to move the car. The traditional braking system uses friction to transform the vehicle's kinetic energy into heat while braking, which lowers the motor speed. Basic or typical EV systems do not effectively control the bidirectional flow of energy between the battery and motor, even though some may have regenerative braking. In general, a unidirectional DC-DC converter permits energy to move from the battery to the motor, but it does not offer an effective way to return energy during braking[5]. As a result, rather than being stored back in the battery, a significant amount of the available braking energy is lost.

3.1. Disadvantages:

In a traditional electric car, the battery provides electrical energy to the motor, which generates mechanical power to move the car. The traditional braking system uses friction to transform the vehicle's kinetic energy into heat while braking, which

lowers the motor speed. Basic or typical EV systems do not effectively control the bidirectional flow of energy between the battery and motor, even though some may have regenerative braking[6]. In general, a unidirectional DC-DC converter permits energy to move from the battery to the motor, but it does not offer an effective way to return energy during braking. As a result, rather than being stored back in the battery, a significant amount of the available braking energy is lost.

4. Proposed System:

Regenerative braking and energy recovery are accomplished by the suggested method through a bidirectional DC-DC converter between the battery and DC motor[7]. The battery powers the DC motor via the converter when the car is operating normally. Electrical energy is transferred from the battery to the motor when the car accelerates. The DC motor functions as a generator during braking or deceleration, transforming the mechanical and kinetic energy of the car into electrical energy[8]. This recovered electrical energy is managed by a bidirectional DC-DC converter, which then returns it to the battery for charge. An appropriate control strategy adjusts the converter based on the motor's operating conditions. As a result, some braking energy is recovered and stored in the battery for later use rather than being entirely lost as heat.

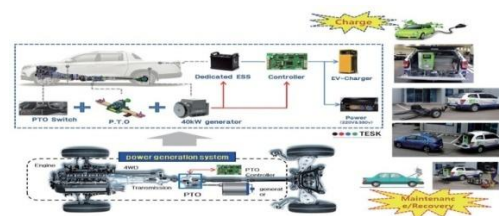


Fig.2. Power Generation of Electrical Vehicle

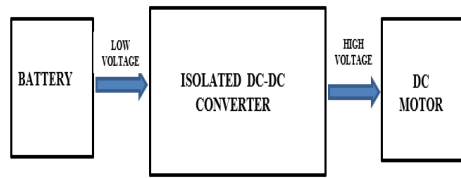


Fig.3. Block Diagram of proposed system

4.1. Working process:

4.1.1.Lithium-Ion Battery: Electric vehicles and electrical equipment frequently employ lithium-ion batteries, which are rechargeable energy storage devices[9]. An anode, cathode, separator, electrolyte, and current collectors make up this system. Li-ion batteries have a long service life, little self-discharge, and a high energy density. The DC-DC converter and motor in this project are powered by the battery when they are in use.

4.1.2. Converter DC-DC: The battery voltage is controlled and transformed into the necessary motor voltage using a DC-DC converter. It can run in boost mode to raise voltage or buck mode to lower it[10]. During regenerative braking, bidirectional converters enable power to move from the battery to the motor and back. Additionally, they enhance overall drive performance and offer regulated power flow.

4.1.3. DC Device: A DC motor generates the torque needed to propel the car by converting electrical energy into mechanical energy. The field and armature windings of an independently excited DC motor are separate, enabling independent control[11]. By changing the field voltage or armature voltage, its speed can be adjusted. The motor functions as a generator and transforms mechanical energy into electrical

energy during regenerative braking.

4.2 Benefits:

1. Retains braking energy in the battery after recovering it.
2. Increases the EV's overall energy efficiency.
3. Reuses collected energy to extend the effective driving range.
4. Lowers the energy loss from traditional braking.
5. Because regenerative braking aids in deceleration, it lessens mechanical brake wear.
6. Enables the battery and motor to exchange power in both directions.

5. Working Principle:

There are two primary modes of operation for the system:

5.1. Acceleration and Motoring: DC Motor → Bidirectional DC-DC Converter → Battery The bidirectional converter receives electrical energy from the battery. The DC motor's voltage and current are controlled by the converter[12]. The vehicle is propelled by the motor, which transforms electrical energy into mechanical energy.

5.2. Braking that Regenerates: DC Motor → Battery → Bidirectional DC-DC Converter

The motor functions as a generator as the car slows down. The moving vehicle's kinetic energy is transformed into electrical energy. Energy that would otherwise be lost is recovered by the bidirectional converter, which regulates the electrical energy produced and returns it to the battery.

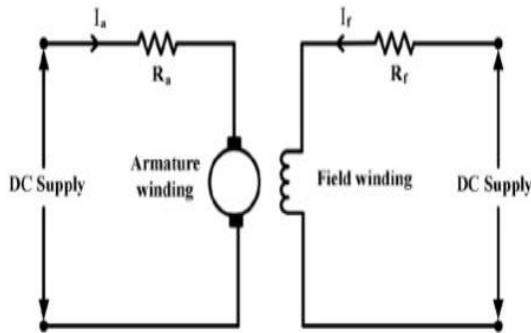
6. The process of implementation:

Separately Excited DC Motor: In a separately excited DC motor, the armature and field windings get separate main supplies. The main characteristic that sets these types of DC motors apart is that the armature current does not flow via the field windings since the field winding is driven by an independent external DC supply[13].

We can infer from the torque equation of motors that:

$$T_g = K_a \phi I_a$$

Therefore, in this instance, the torque can be altered by changing the field flux (ϕ), regardless of the armature current (I_a). The individually excited DC motor is shown in the image below.



6.1. Characteristics of Motor :

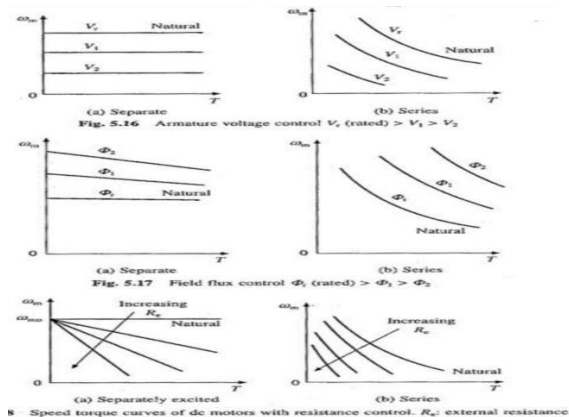


Fig.4. Characteristics of Motor

6.2. Electrical Generator:

Electromagnetic induction is the basis for how electric generators operate. Between the poles of a horseshoe-shaped magnet[14], a conductor coil—a copper coil tightly coiled over a metal core—rotates quickly. An armature is made up of the conductor coil and its core.

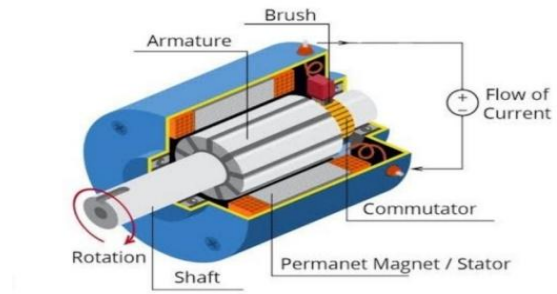


Fig.5. Electrical Generator

Over all efficiency of motor = power input + losses

$$E_a = K_a \phi \omega_m$$

$$E_a = V_t - I_a R_a$$

$$T = K_a \phi I_a$$

$$\omega_m = \frac{V_t - I_a R_a}{K_a \phi} = \frac{V_t}{K_a \phi} - \frac{R_a}{(K_a \phi)^2} T$$

$$\eta = \frac{\text{output power}}{\text{Input power}}$$

Regenerative braking is used when an electric vehicle is in the free wheel running phase and the battery is in the discharging mode. By utilizing an electric motor's capacity to function as a generator[15], regenerative braking uses the energy used to slow down a car to assist replenish batteries. The transformer receives the generated voltage.

Circuit Diagram:

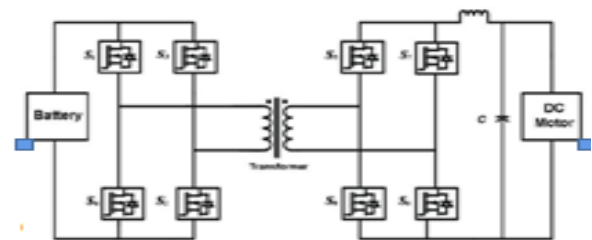


Fig.6. Ckt diagram of transformer

6.3. Isolation Transformer: An isolated DC-DC converter that electrically separates the input and output sides using a high-frequency transformer is called a dual active

bridge converter[16]. The transformer may step up or step down the voltage and offers galvanic isolation. Additionally, it permits bidirectional power transfer, which makes it appropriate for regenerative braking and battery charging in electric vehicles. Ground loops, electrical noise, and safety issues between the two sides are all lessened by the isolation.

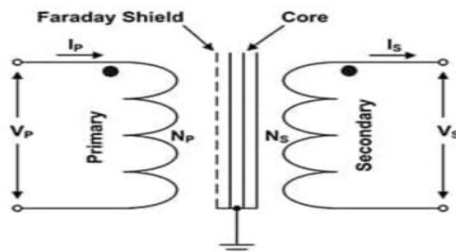


Fig.7. Isolation Transformer

Around the shared magnetic core, the secondary winding has N_{S/N_S} turns and the main winding has N_{P/N_P} turns. The number of turns in each winding determines the voltage ratio between the primary and secondary windings. The connection is provided by:

$$V_s = N_s/N_p * V_p$$

6.4. Transformer Operation: A step-down transformer is produced when the secondary voltage is lower due to the primary winding having more turns than the secondary. A step-up transformer is produced when the secondary voltage is higher due to the secondary having more turns than the primary[17]. The input and output voltages of an isolation transformer are almost equal since both windings typically have the same number of turns. Apparent power (VA), which is derived from RMS voltage and current, is used to express transformer capacity. To lessen capacitive coupling and lower electrical transients and common-

mode noise, a Faraday shield is positioned between the windings.

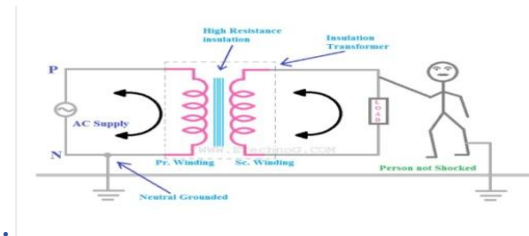


Fig.8. Transformer Working

6.5.MOSFET: A thin oxide layer electrically isolates the gate from the semiconductor channel of a MOSFET, an insulated-gate field-effect transistor. The current that flows between the source and drain terminals is managed by this voltage-controlled device. The MOSFET has a very high input resistance and requires very little gate current since the gate is shielded. DC-DC converters and other switching and power-electronic applications frequently use MOSFETs. To avoid damaging the gadget, the insulated gate must be handled carefully and protected from static charge accumulation.

Basic MOSFET Structure and Symbol :

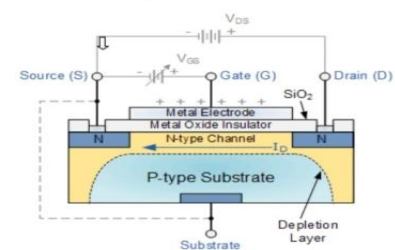


Fig.9. Structure of MOSFET

6.5.1.MOSFET Construction: MOSFETs regulate charge carriers in the drain-source channel by means of an electric field generated by the gate voltage. A small layer of insulating oxide separates the gate from the semiconductor, resulting in extremely

high input resistance[18]. There are enhancement and depletion varieties of n-channel and p-channel MOSFETs.

6.5.2. Enhancement-Mode MOSFET: Since there is no conducting channel when $V_{GS}=0$, an enhancement MOSFET is typically OFF. A positive gate voltage higher than the threshold voltage activates an n-channel MOSFET. A negative gate voltage activates a p-channel MOSFET.

6.5.3. Depletion and Enhancement Types:

A depletion-mode MOSFET needs gate voltage to decrease or halt conduction, and it is typically ON. An enhancement-mode MOSFET needs gate voltage to create conduction and is typically OFF. Therefore, enhancement MOSFETs behave like ordinarily open switches, but depletion MOSFETs behave like usually closed switches[19].

6.5.4. Power Converters: To regulate electrical power, power converters quickly switch semiconductor devices. AC-DC, AC-AC, DC-DC, and DC-AC converters are the four fundamental varieties. Power supply, motor drives, battery systems, and electric cars all make extensive use of them.

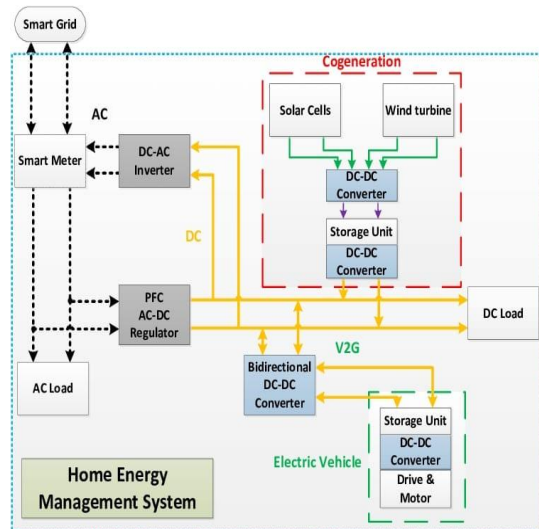


Fig.10. Converters

7. Single-phase full bridge inverter:

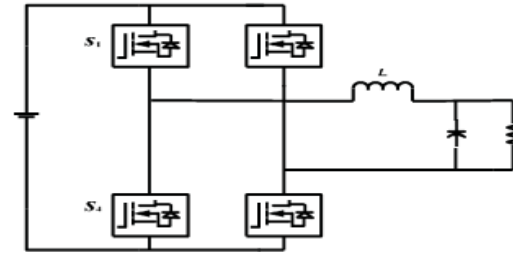


Fig.11. Single Phase Full Bridge Inverter

7.1. Full-Bridge Inverter: Using four regulated switches and four freewheeling diodes, a full-bridge inverter transforms DC power into AC power. The voltage polarity across the load is alternately reversed by operating the switches in pairs. One polarity is produced by switches T1 and T2, and the opposite is produced by switches T3 and T4. It is frequently utilized in power-electronic systems, isolated DC-DC converters, and motor drives.

7.2. Full-Bridge Rectifier: Compared to a half-bridge rectifier, a full-bridge rectifier produces a DC output with less ripple. During the positive and negative half-cycles, four switching devices or diodes conduct in the proper pairs. Even when the input voltage changes polarity, current may still flow through inductive loads. The average DC output is higher and smoother with the bridge design.

7.3. DC-DC Converters: To match battery voltage with DC-link and motor needs, DC-DC converters are frequently utilized in EVs and HEVs. They provide controlled energy transfer between various energy-storage systems and can increase or decrease voltage. They facilitate energy recovery during regenerative braking and provide power to the traction motor during acceleration. High efficiency, dependability, low weight, small size, low EMI, and low voltage/current ripple should all be features of EV converters.

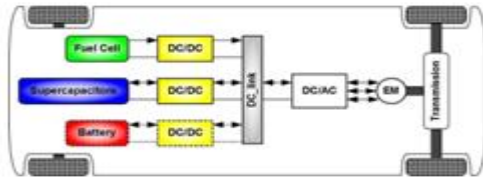
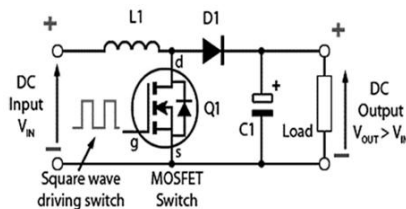


Fig.12. DC-DC Converters

By sharing energy and power requirements, a hybrid energy storage system that combines fuel cells, batteries, and supercapacitors can extend battery life. EVs need high-power DC-DC converters to control the voltage between the motor drive and energy storage system. Vehicle characteristics including speed, acceleration, weight, torque, and peak power all affect the converter rating. A DC-DC converter uses inductors, transformers, or capacitors to temporarily store and release energy in order to modify a DC voltage level. In order to send energy to the motor during acceleration and return recovered brake energy to the battery during regenerative braking, a bidirectional DC-DC converter permits power to flow in both ways.



8.DC Converter Operation Principle:

A three-phase voltage supply and a Star-Delta transformer are used in the MATLAB/Simulink model of the EV charging system. To charge the EV battery, AC electricity is transformed into DC power using a three-level bridge converter. DC-voltage and current controllers are used by the control system to regulate the DC bus voltage and reactive current[18]. The converter currents are controlled by a phase-

locked loop in a d-q transformation. In order to maintain steady and regulated charging, the current regulator produces the necessary voltage magnitude and phase.

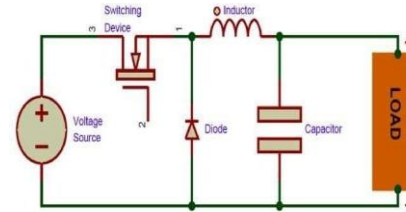


Fig.13. Buck Converter

9. Boost Converter: A boost converter is a DC-DC power converter that lowers the output current while raising the input voltage to a higher output voltage. In order to store and transfer energy during switching operation, it typically consists of a semiconductor switch, diode, inductor, and capacitor. Boost converters are common in EV power systems and can be powered by batteries, solar panels, rectifiers, or DC generators. Aside from converter losses, a rise in output voltage causes a comparable decrease in output current since input and output power are roughly conserved.

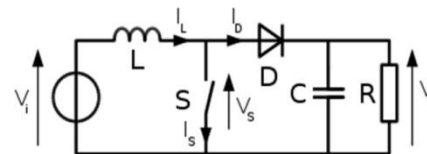


Fig.14. Boost Converter

In order for a boost converter to function, energy must be stored in the inductor during the switch's ON state and released during its OFF state. The inductor's stored magnetic energy increases when the switch is turned on. The inductor flips polarity when the switch is off, transferring stored energy to the capacitor and load via the diode[19]. This energy is stored by the capacitor, which keeps the output voltage greater than the input voltage. Rapid repetition of the

switching operation results in a regulated increased output voltage and continuous energy transmission.

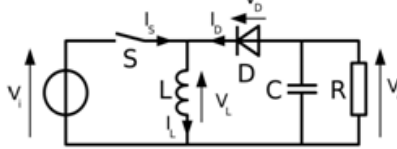


Fig.15. Boost Converter

Buck-Boost Converter Operation: Depending on the switching duty cycle, a buck-boost converter can raise or lower the input voltage. The inductor receives energy from the input source during the ON state, while the load receives energy from the capacitor. The diode transfers the inductor's stored energy to the capacitor and load when it is in the OFF state. The output voltage and input voltage have the opposite polarity in an inverting topology. The switching transistor's duty cycle regulates the output voltage.

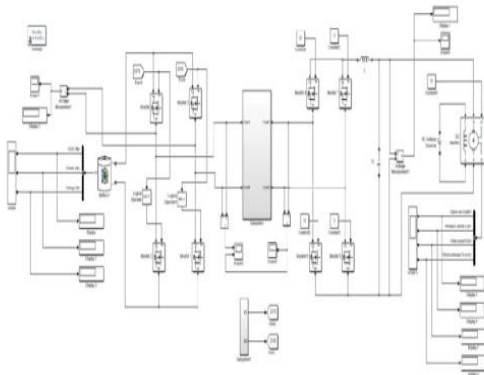


Fig.16.Simulation Results

Isolated DC-DC Converter Fed DC Motor Simulation for Bidirectional Electric Car Use. For bidirectional electric vehicles, the full simulation of an isolated dc-dc converter fed dc motor is displayed. An isolated dc-dc converter uses Simulink components such as a battery, a full bridge inverter, an isolation transformer, a full bridge rectifier, and a separately activated DC motor.

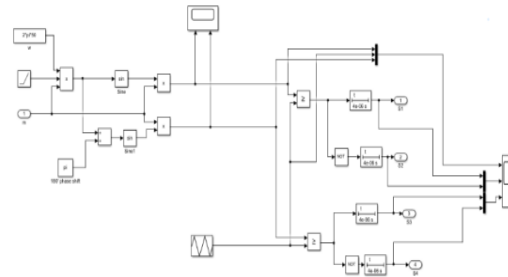


Fig.17.SPWM Technique

The PWM technique known as sinusoidal pulse width modulation (SPWM) is used in inverters to transform DC voltage into an AC output that resembles a sine wave. It is produced by controlling the pulse widths by comparing a high-frequency triangle carrier signal with a sinusoidal reference signal[20]. A regulated AC output voltage is produced by varying the pulse width in accordance with the sine wave's instantaneous amplitude. The ratio of the carrier frequency to the sinusoidal reference frequency determines how many pulses there are. Because of its straightforward implementation, excellent dynamic responsiveness, and decreased harmonic distortion, SPWM is frequently employed in power-electronic converters.

$$M_R = \frac{\text{frequency of carrier waveform}}{\text{Frequency of the modulating waveform}}$$

10.Results and discussion:

The inverter receives its dc input from the battery. This dc input voltage is transformed into an ac output voltage. The SPWM technique is used to activate the switches. This voltage level is increased by the transformer, which also isolates the dc-dc converter's input and output. Ac voltage is transformed into dc voltage using a rectifier[19]. The simulation model of an isolated dc-dc converter and the simulated results are used in the design of the L and C filter, which is intended to eliminate

harmonic. This paper incorporates two quadrant topology and solely explains the motoring mode.

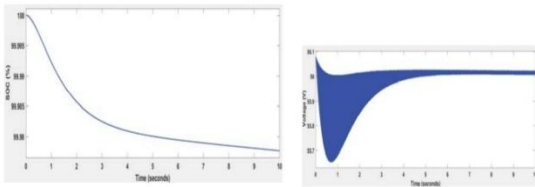


Fig.18. SOC of battery Fig.19 Battery storage

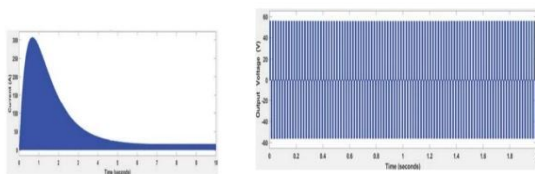


Fig.20.Battery current Fig. 21. Transformer primary voltage

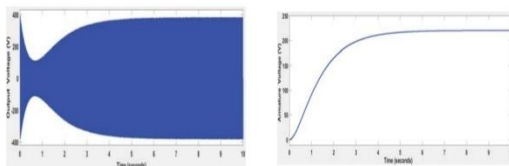


Fig.22.Trasformer secondary voltage
Fig.23.Ammature voltage of DC motor

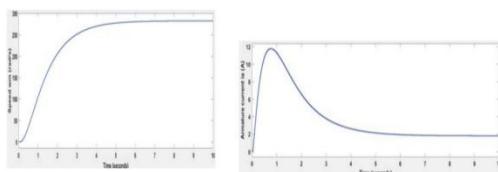


Fig.24.Speed of DC motor Fig.25.Ammature current of DC motor
Eight simulation result graphs showing the transient performance of a battery-powered DC motor system are shown in this image.
1. Battery performance: Displays a transient current peak, varying storage levels, and a decreasing State of Charge (SOC)[20].

2. Transformer voltages: Shows a secondary AC voltage that increases over time in addition to a constant primary AC voltage.
3. DC motor dynamics: Shows an exponential increase in the motor's rotational speed and armature voltage.
4. Armature current: During motor startup, it records a high initial spike that gradually decreases to steady-state.

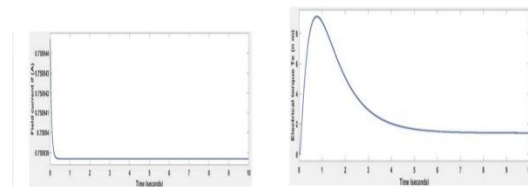


Fig.26. Field current of dc motor Fig.27. Electrical torque of dc motor

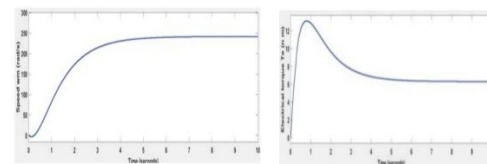


Fig.28. Speed of dc motor with load Fig.29. Electrical torque of dc motor with load

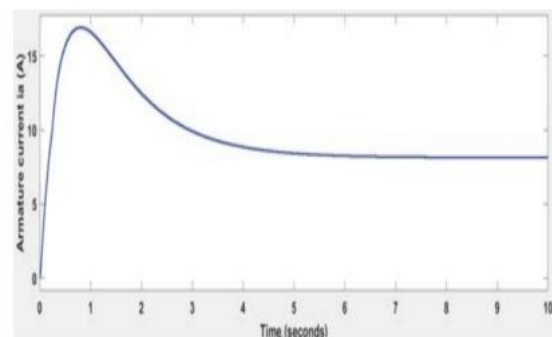


Fig. 30. Armature current of DC motor with load
Isolated Dc-Dc Converter FED DC Motor for Bidirectional Electric Vehicular Application

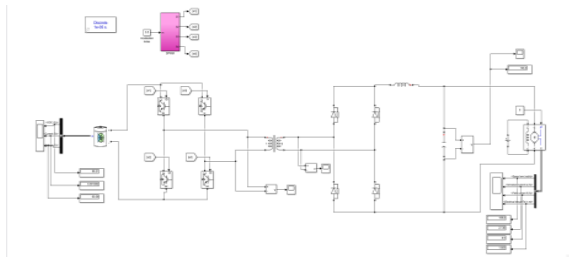
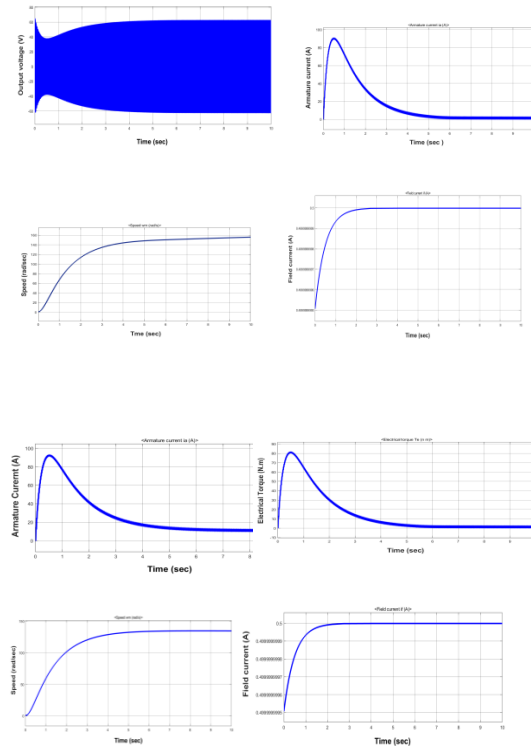
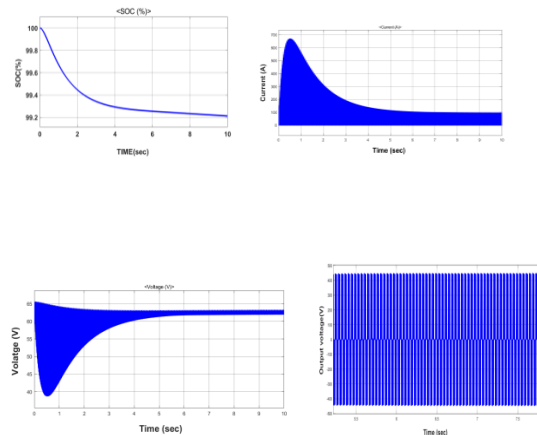


Fig.31. The result of Isolated DC-DC Converter Fed DC Motor For Bidirectional Electric vehicle is as shown.

The circuit design and simulation waveforms for an isolated DC-DC converter feeding a DC motor for bidirectional electric vehicle applications are shown in this image.

1. Motor under load: Shows the armature current, electrical torque, and motor speed's transient reactions under load.
2. No-load vs. loaded characteristics: Provides a comparison of electrical torque and field current parameters at initial startup.
3. Circuit architecture: The isolated DC-DC converter topology connected to the DC motor drive is depicted in a Simulink schematic layout.
4. System dynamics: Shows typical torque and current surges at startup, which settle into steady-state functioning when speed levels down.



Ten simulation waveform graphs that show the transient electrical and mechanical properties of a power electronic converter and DC motor drive system are included in this graphic.

1. Energy storage behavior: Shows how, over a 10-second period, the state-of-charge (SOC) percentage rapidly decreases along with the matching battery output current profile.
2. AC waveform dynamics: Captures alternating voltage waveforms, describing the voltage transitions and high-frequency switching envelopes of the transformer stages in the system.
3. Motor starter characteristics: As the motor accelerates from a standstill, it exhibits a traditional exponential rise in both rotational speed and armature voltage.
4. Transient peak responses: Shows the same abrupt initial surges and subsequent decline profiles for the electrical torque and armature current of the motor during startup.

11. Advantages:

1. High voltage isolation from several hundred to thousand volts is a feature of isolated DC-DC converters.
2. They give the load a distinct DC source because of their great noise and interface blocking capabilities.
3. Reduce costs and increase system effectiveness.
4. To help balance increases in the demand for electricity, the energy stored in automobile batteries is pushed back to the power grid.

12. Conclusion :

This work presents a battery-operated isolated DC-DC converter, or DABC fed DC motor, for use in bidirectional electric vehicles. Through simulation utilizing the MATLAB/SIMULINK environment, the system's performance has been confirmed. The dual active bridge uses a transformer to isolate the input and output sides and guaranty user safety, whereas the conventional Buck-Boost converter needs an extra isolation circuit for charging and discharging mode. Future research might incorporate a bidirectional isolated DC-DC converter into the suggested system, and MATLAB/Simulink could be used to study its performance.

13. Future Scope:

The current EV batteries can only store energy within a certain range when operating, but with improved implementation in the future, they will be able to do so. More electricity can be stored in the battery to power the cars. In the future, electric vehicles will become even more efficient. Adding sophisticated control, monitoring, and energy-management tools can improve the system even more. The bidirectional converter can be controlled in real time using a microcontroller or DSP-based control system. It is possible to

continuously monitor battery voltage, current, motor speed, braking force, recovered energy, and state of charge (SOC). Regenerative braking performance can be enhanced by sophisticated control algorithms like PID, fuzzy logic, or model predictive control. To avoid overcharging and excessive current during energy recovery, a battery-management system can also be incorporated. Future iterations may include intelligent energy-management algorithms, supercapacitor-assisted energy storage, regenerative braking optimization, and Internet of Things-based monitoring.

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