ADVANCING ELECTRIC VEHICLE PROPULSION: MULTI-FUNCTIONAL CONVERTER-BASED SWITCHED RELUCTANCE MOTOR DRIVE

#1 DR.ARRAMARAJU PRASAD RAJU, Professor & Principal,
#2VOLLEPE KARUNAKAR,
#3ASIRI RAVITEJA,
Department of Electrical and Electronics Engineering,
SREE CHAITANYA INSTITUTE OF TECHNOLOGICAL SCIENCES, KARIMNAGAR, TS.

ABSTRACT: Switching reluctance motors are reliable and easy to use, making them a common choice for powering electric cars. This article provides step-by-step instructions for building a switching reluctance motor–based multipurpose power converter that can start, halt, and recharge an electric vehicle. Given the right controls, a single power electronic converter can charge the battery bank, regenerative braking, and drive all at once. Consequently, the cost of the power electronic interface is not too high. The switching reluctance motor (SRM) can be operated in either an open or closed loop configuration, depending on the user's preference. This necessitates initial control of voltage and current. Because phase changes can only take place in the negative torque area, redirection is a real possibility. When charging the battery, a bridgeless rectifier converter is created by combining the two-phase windings of the SRM with the basic power components of an integrated power converter. Consequently, a smaller number of inductors and charging devices are needed. The effectiveness of the control mechanisms is validated across all modes using the results of MATLAB/Simulink simulations.

KEYWORDS: Bi-directional converter ,Common high side switch ,converter ,EV charging, Re-generative braking, Switched reluctance motor

1.INTRODUCTION

Electric vehicle (EV) propulsion frequently employs switching reluctance motors (SRMs) owing to their notable attributes, including elevated starting torque, adaptable control, and accurate operation. Furthermore, they have gained recognition for their ability to withstand and recover from critical situations . Numerous SRM power converter configurations have been demonstrated to operate most efficiently with this technology. R-dump, C-dump, C-dump with drifting transistors, asymmetric, series, and parallel converters are among the topologies.

Utilizing fewer component topologies to drive SRM has been shown to result in consistent and accurate performance . Individuals prefer compact, energy-efficient power switches that offer a variety of power-changing options. A typical requirement for modifying the control system of EV switching reluctance actuators is the implementation of an unsymmetrical half-bridge converter . A converter of this nature has been purposefully engineered to function and recuperate energy from the brakes. Recalibration of the battery requires an autonomous converter. An integrated power converter with a single-phase active rectifier for charging operations, a three-phase common high side toggling asymmetric half-bridge converter, and a buck front-side DC to DC converter are all components of superior converters .

The boost converter has the capability to increase and modulate the bus voltage, in addition to returning the energy stored in the winding to the energy source, when it is operating in drive mode . Battery charge converters are critical components of electric vehicles (EVs). There are a total of four driving and charging controls on this converter. In order to fabricate a modified common high side switch converter, a three-phase intelligent power module is implemented . There is a possibility that charging them could improve the efficacy of this converter. A bidirectional buck/boost converter and a common high-side switched asymmetric half bridge converter comprise this converter. Acceleration/deceleration, reversible driving, and halting are executed flawlessly .

A contemporary converter comprises battery cells, a switched reluctance motor (SRM), a capacitor housing energy storage components, and a buck circuit, as reference [22] specifies. Elevated excitation and demagnetization voltages facilitate an extensive array of driving techniques. depicts a hybrid drive with a multitude of connections organized in a layered fashion.

The battery management system and converter system illustrated in reference are capable of efficiently regulating the electricity flow from the generator to the motor, battery bank, and AC grid. With the aid of a double-break adaptor, both alternating current (AC) and direct current (DC) devices can be chargeds. As a result, the aforementioned topologies lack the capability to integrate charging, halting, and driving functions into a solitary converter while maintaining adequate current control.

2.CONVERTER CONFIGURATIONS

Topology of the multi-functional converter

The development of a multifunctional converter has begun. By reprocessing batteries, this converter can be utilized to charge batteries and regulate velocities in both open and closed cycles while in motion. The front voltage is regulated by a buck type DC to DC converter, whereas the phase is induced by a conventional high-side switch-based asymmetric converter. In order to regulate the speed within a closed loop, the necessary voltage is supplied by a front-side DC-DC converter that is activated.

Using a standard high-side switch asymmetric converter, the current in the SRM is regulated. Connected between the rotor and the energy source, the energy is supplied via the identical low excitation converter. In order to recharge the battery, the phase windings of the SRM and the dual sides of the converter function as charging displays. The inverter charges the batteries and supplies power to the engine in this mode. The interconnections between each component of the versatile converter under consideration are illustrated in Figure 1.

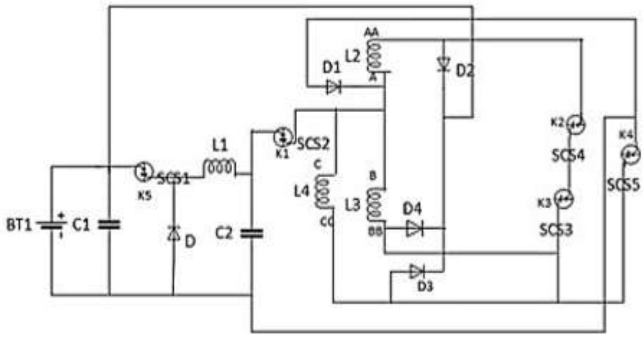


Figure 1. Multi-functional power converter

Driving mode

As illustrated in Figure 2, phases A and B are energized, liberated from a state of immobility, and demagnetized during the driving mode. The current flow and conductors are indistinguishable in Figure 3. Equation (1) signifies the phase-A voltage, whereas equations (2) and (3) illustrate, respectively, the notion of increasing inductance.

$$U\ bus = Rik + Link\ \frac{di_k}{dt} + ik\ w\frac{\partial L(\theta, i_k)}{\partial \theta} \quad (1)$$

$$Linc = L(\theta, i_k) + i_k \frac{\partial L(\theta, i_k)}{\partial ik} \quad (2)$$

$$For\ Off\ state, 0 = Ri_k + L_{inc}\frac{di_k}{dt} + i_k w\frac{\partial L(\theta, i_k)}{\partial \theta} \quad (3)$$

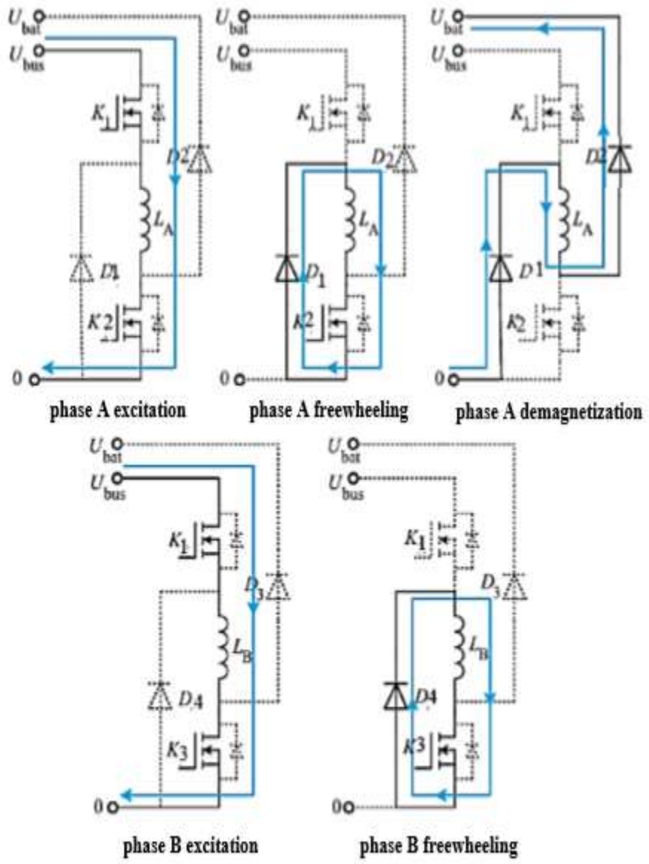


Figure 2. Illustration of phase excitation and de-magnetization

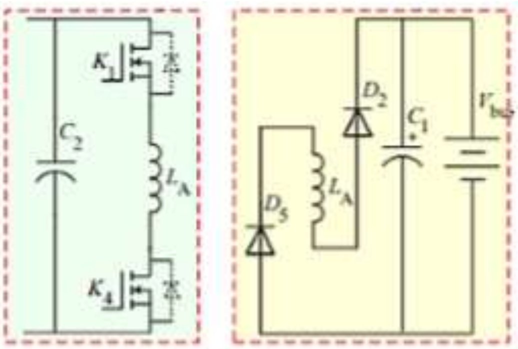


Figure 3. Operation states of under battery regenerative braking

Regenerative braking operation

An SRM drive is operational in regenerative halting mode and is capable of generating electrical energy. In order to generate the current required for renewal, one approach is to restrict the angle of stimulation for each phase, as illustrated in Figure 4. When phase-A excitation is deactivated, the generated current flows freely through diodes D1 and D2, thereby facilitating battery charging. The circuits for the propulsion and generation modes are illustrated in Figure 5.

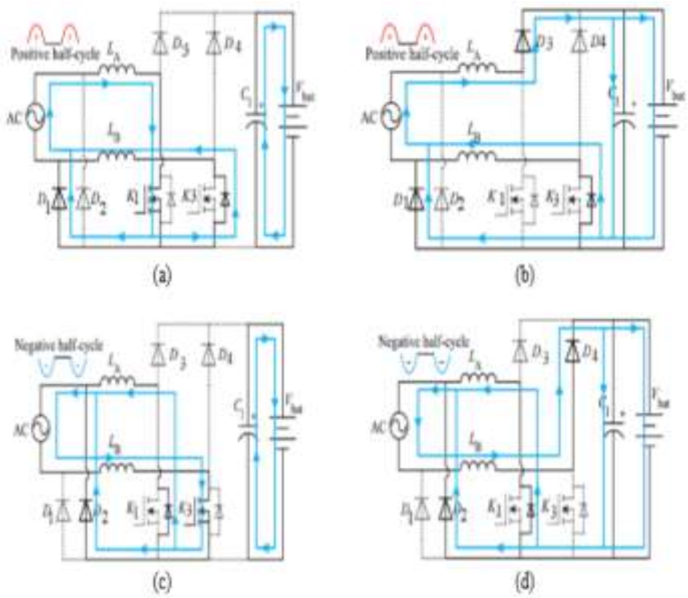


Figure 4. Illustration of sub-modes of charging operation (a) mode 1, (b) mode 2, (c) mode 3, and (d) mode 4

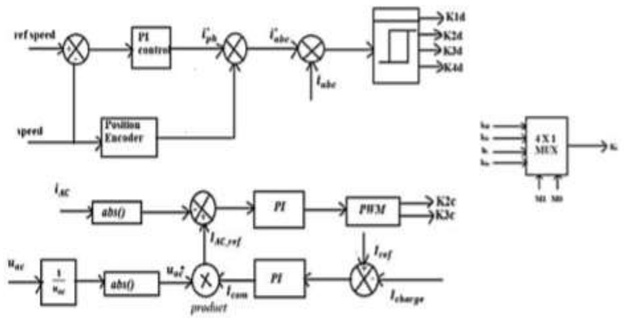


Figure 5. Control structure for driving and charging operations

Battery charging operation

With the exception of K1 and K3, the A and B phase windings can remain energized when all power switches are deactivated. Physically, the rotor will be secured in this particular location. Mode 1 involves discharging the capacitor into the battery, disabling components K1 and K3, and charging the source inductor. Modes 3 and 4 exhibit comparable behavior to modes 1 and 2, respectively, when the power supply voltage experiences an adverse half cycle.

3.CONTROL STRATEGIES

The closed-loop drive mode control of the CHSAHBC modifies the buck converter's duty cycle to one and regulates the closed-loop speed. The current magnitude order is computed by the proportional integral (PI) controller through a comparison of the discrepancy between the reference and observed velocities, as illustrated in

Figure 5. When it comes to phase stimulation, the rotor position sensor determines the sequence. Subsequently, the measured current is compared to a command for an instantaneous reference current. The defect is detected by the hysteresis current control, which then generates gate pulses for the switches in each phase.

Figure 5 depicts the charging current feedback loop, which is alternatively referred to as the outer loop. In order to rectify the imbalance that exists between the reference and feedback charge currents, a proportional-integral (PI) controller is applied. In addition, power factor correction (PFC) is the responsibility of the secondary cycle. Multiplying the actual value of the AC source voltage UAC by the outer loop control instruction Icom yields the IAC_ref. In order to rectify the tracking error that arises between the reference value, IAC_ref, and the measured AC input current, iAC, a supplementary PI controller is implemented. The pulse-width modulation (PWM) signals that are generated are subsequently employed to activate both power switches simultaneously.

4.SIMULATION RESULTS

The utilization of a Simulink model within a 6/4 structure SRM drive to evaluate the efficacy of control mechanisms and a multifunctional converter across various operating modes is illustrated in Figure 6. As illustrated in Figure 7, the speed control functions in open loop drive mode. As illustrated in Figure 7(a), the phase currents were in equilibrium, the speed fluctuated in response to the voltage supplied to the buck converter, and the level of torque noise was exceptionally minimal. A broad range of speed fluctuations can be accomplished without subjecting the converter to excessive stress, as illustrated in Figure 7(b).

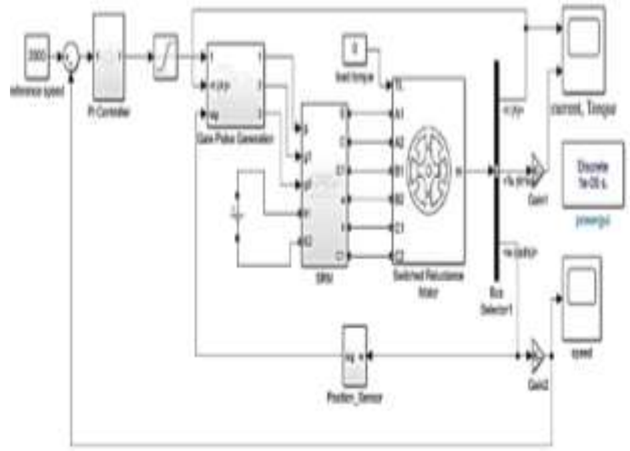
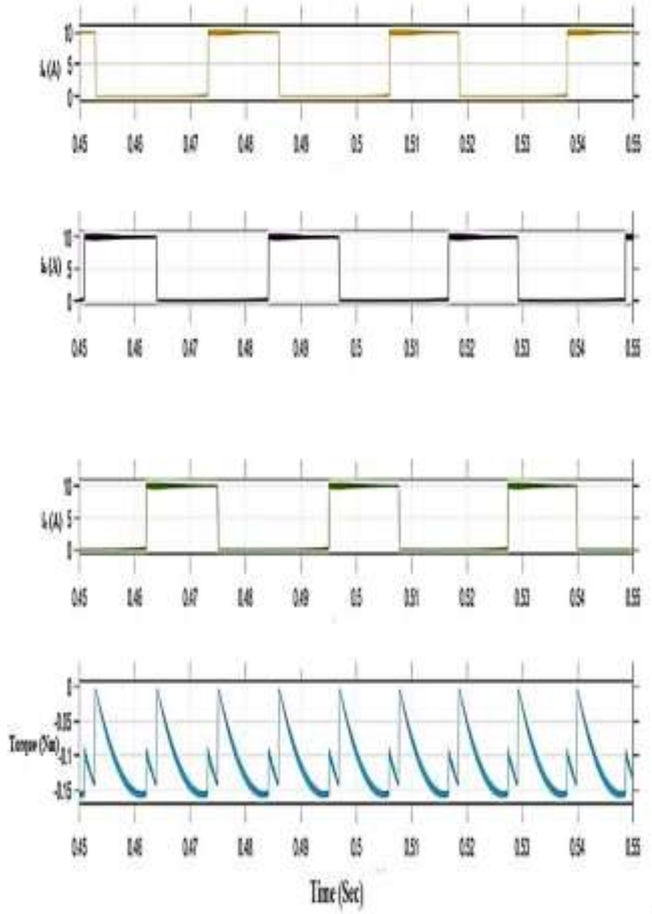
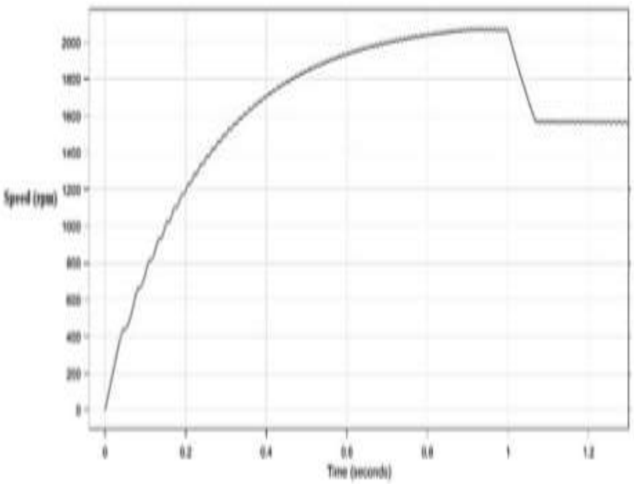


Figure 6. SIMULINK schematic of multi-functional converter based SRM drive



(a)



(b)

Figure 7. Open loop driving operation (a) phase currents and torque for 2000 rpm and (b) speed response forstep change in speed command

Figure 8 illustrates the outcomes of the simulation that was employed to regulate the closed loop driving mode. An equivalent circulation of currents secured each stage within its confines. When the current quantities are proportional to the speed order as depicted in Figure 8(a), it is evident that the torque undergoes a discernible variation of 0.1 N-m. The rapid correlation between torque and torque phase currents is illustrated in Figure 8(b). An exceptionally rapid response time of 0.004 seconds was identified. An alteration in torque induces an instantaneous response in the currents throughout all phases. A pace control system that functions in a closed loop is illustrated in Figure 9. It attains its utmost velocity in 1.4 seconds and can decelerate marginally in less than 1 second. Regenerative braking is accomplished through the storage of energy in the windings via a battery.

As the torque is restricted to the negative zone, Figure 10 illustrates the controller's phase adjustment. Furthermore, it has been demonstrated that activating the regeneration function substantially increases the currents. A reduction rate of 500 revolutions per minute is achieved in less than one second. The simulation outcomes pertaining to source voltage, current, and ground voltage are illustrated in Figure 11. As shown in Figure 11(a), the voltage and current of the battery during charging are depicted. A transitory change occurred in the established procedures. The converter is responsible for supplying the charger with the necessary voltage and current to function. The synchronization between the current flowing through the source and the supply voltage is illustrated in Figure 11(b).

This demonstrates the charging process's power factor of unity. The adapter facilitates efficient charge in this fashion. The controller ensures that the conventional current monitoring is accurate. This finding suggests that the charging control functions optimally when the source current exhibits a total harmonic distortion (THD) of 0.9%. By supplying the voltage and current required to charge the battery, the converter effectively doubles its capacity. A comparison of the construction and operation of contemporary integrated converters is presented in Table 1.

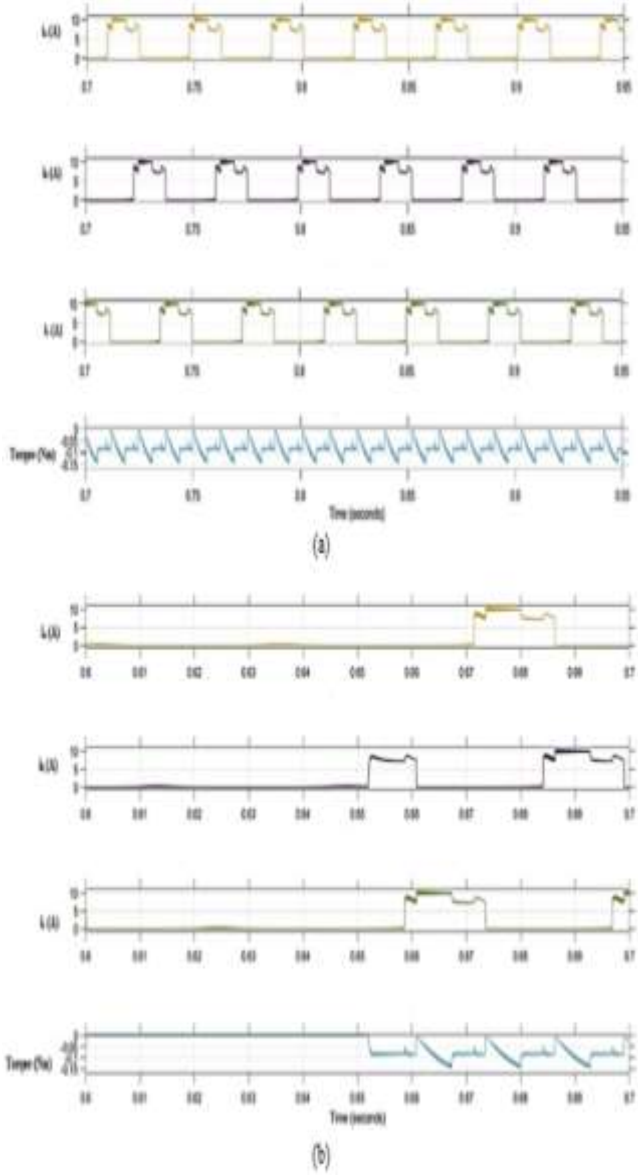


Figure 8. Steady state and transient waveforms for closed loop driving mode: (a) phase currents,

developed torque and rotor speed; and (b) transient torque response

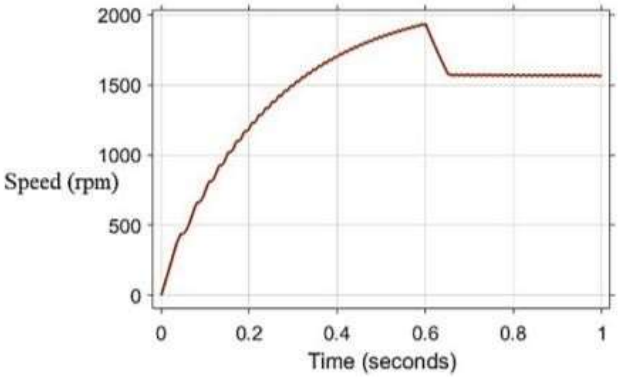


Figure 9. Tracking of speed command in closed loop operation

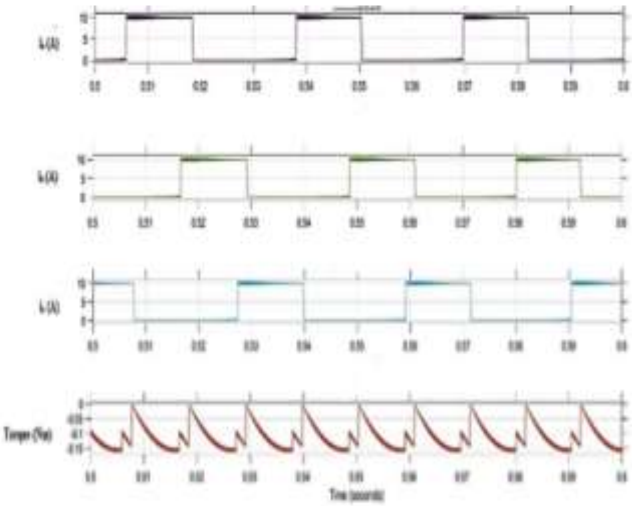


Figure 10. Phase currents and developed torque for regenerative braking mode operation

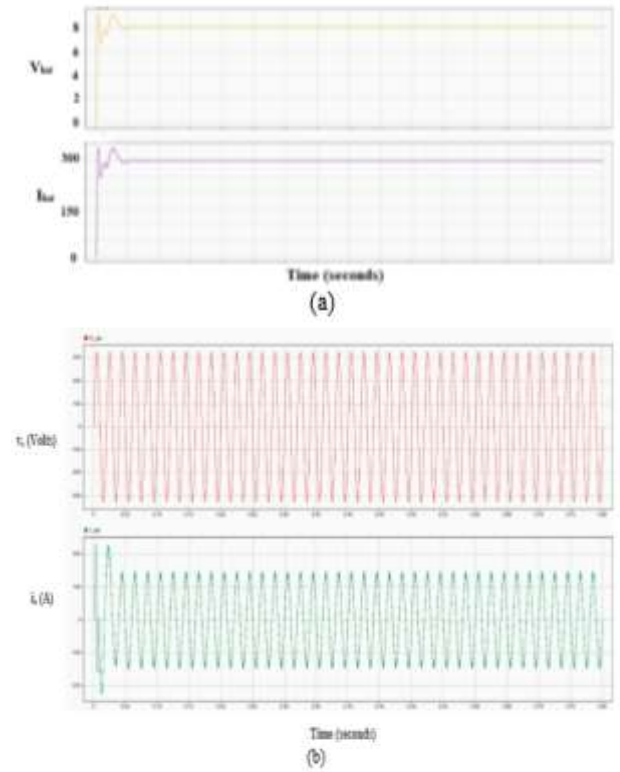


Figure 11. Charging process (a) battery voltage and current and (b) source voltage and current

Table 1. Comparison among integrated converter topologies

Topology	Proposed	[12]	[16]	[18]	[21]
Inherent regeneration capability	Yes	No	No	No	No
Single phase charging	Yes	No	No	No	Yes
Power factor correction	Yes	No	No	Yes	Yes

5.CONCLUSION

The power converter is an integral component of the propulsion system of an electric vehicle, facilitating charging, regenerative deceleration, and propulsion. For phase excitation control during regenerative deceleration, current management during rapid battery charging, and closed and open loop speed control during driving mode, control techniques were developed. The results of each mode's simulation validate that the converter was constructed and managed appropriately. By leveraging SRM technology, this results in an electric vehicle power electronic system that is both exceptionally efficient and economical.

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