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PLUG-IN HYBRID ELECTRIC VEHICLES WITH FLEXIBLE ENERGY CONVERSION INTEGRATED WITH A MULTILEVEL CONVERTER FOR SRM MOTOR DRIVES

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ABSTRACT

For plug-in hybrid electric vehicle (PHEV) applications, this study provides an integrated multilevel converter of switching reluctance motors (SRMs) supplied by a modular front-end circuit. The front-end circuit's switches may be turned on and off to create a variety of working modes. The battery bank is used in generator driving mode to increase the phase voltage for quick excitation and demagnetization. The converter is redesigned as a four-level converter while the battery is driving it. The torque capability is increased by using the capacitor as an extra charge capacitor to provide multilayer voltage outputs. The suggested drive's working modes are described, and a detailed analysis of the phase current and voltage is done. The regenerative current in braking mode and the demagnetization current in driving mode automatically accomplish battery charge. Furthermore, while the car is at a stop, the battery may be charged using the suggested converter and an external AC source or generator. The power flow between the generator and battery is coordinated by the SRM-based PHEV, allowing it to run at various rates. MATLAB/Simulink simulation validate the efficacy of the suggested converter configuration.

1.INTRODUCTION

Due to the growing exhaust gas emissions in metropolitan areas and the quick depletion of fossil fuels, electric cars, or EVs, have garnered more attention throughout the years. Hybrid electric cars (HEVs) and plug-in hybrid electric vehicles (PHEVs) provide higher flexibility and more potential than pure battery-powered vehicles. Permanent-magnet synchronous motors (PMSMs) are a common motor drive technology for hybrid or plug-in hybrid electric vehicles (HEVs). However, since their magnets are usually made of rare-earth elements, their mass manufacturing market use is limited. Therefore, there has been a desire for alternative technologies to provide rare-earth-less or rare-earth-free solutions. Without any rotor windings or permanent magnets, switched reluctance motors (SRMs) are recognized for having a more straightforward and durable design. They are a more affordable motor drive choice than PMSMs and may provide a longer service life in tough situations. Furthermore, SRMs are regarded as a competitive option for HEV and PHEV electric propulsions because of other intrinsic benefits including high efficiency, high reliability, outstanding fault-tolerance ability, and strong beginning torque in first accelerations. For safety-critical applications, position sensor-less control techniques and fault tolerance schemes are developed to increase the dependability of the SRM system. New direct torque control systems have been developed to address this problem by reducing the SRM torque ripple. Additionally, a few cutting-edge solutions have been put out to increase motor efficiency and reduce vibration in automotive applications.
For PHEV applications, an integrated SRM converter architecture with many functionalities has not yet been created. In general, electric vehicle traction drives need a small, dependable inverter/converter. Some novel SRM-based converter topologies have been developed. We introduce a new three-phase SRM drive that can be used for both grid and ICE charging. Since this converter is based on a Cdump converter, which lacks fault tolerance because of non-isolated phases in the converter circuit, quick excitation and fast demagnetization cannot be accomplished. SRM drives use a dc/dc converter, and to improve the SRM winding current and speed dynamic responses, a voltage-boost controller is included in. DC/DC converters often include inductors and capacitors, which lower the power density. For use in solely battery-powered vehicle applications, a driving/charging SRM drive with a modified Miller converter and three-phase intelligent power modules is offered; however, fault-tolerance is not included. For flexible battery charging and discharging, an asymmetric bridge converter and a bidirectional front-end dc/dc converter are combined to form an SRM drive. Additionally, the control schemes are designed with superior regenerative braking, accelerating, and deceleration capabilities. For EV applications, a four-phase SRM drive powered by a split converter is proposed to enable versatile charging functionalities using both dc and ac sources. To connect for the new converter, the four phase windings are divided and their midpoints are taken out. It is not appropriate for three-phase motor drive applications, however, since multilevel voltage cannot be reached under driving circumstances. In order to increase the dc-link voltage for a high negative bias in the demagnetization mode, a new passive boost power converter for SRM is presented. This power converter adds a passive circuit to the front-end of a traditional asymmetrical converter. The power converter with the function of higher voltage is built by utilizing an extra capacitor for high-speed operations in order to produce a quick current buildup and sufficient demagnetization. A single switch per phase in an SRM converter allows it to provide a high demagnetization voltage, which raises the motor drive's output torque. It cannot, however, accomplish rapid excitation since it is intended for low-cost applications. The development of a quasi-three-level converter for SRM drives reduces the rising and falling periods of the current. Compared to traditional converters, this converter requires twice as many power switches, which significantly increases the cost and complexity of the motor drive. A brand-new SRM dual-voltage drive is shown here. It makes it possible for an SRM to run off either low-voltage battery power or ac mains without the need for a transformer to convert between the two voltage levels.It is also suggested to use a different low-cost battery-powered SRM drive that has charging and driving capabilities. Without the need of additional charging devices or external converters, the motor windings directly charge the battery.
In order to support PHEV applications, this work offers a novel integrated multilevel converter of SRM supplied by a modular front-end circuit. Differential working modes are obtained by varying the on-off states of the switches in the front-end circuit. The battery bank raises the phase voltage in generator driving mode to facilitate quick excitation and demagnetization. The extra charge capacitor helps to accomplish quick excitation and demagnetization in battery driving mode, when the converter reconfigures as a four-level converter. The multilayer voltage enhances the torque capabilities. Motoring and braking actions effectively charge the battery. Furthermore, flexible battery charging is possible even in standstill situations. By adjusting the switching components in the drive circuit, the energy conversion between the generator, battery bank, external AC source, and traction motor is accomplished in a flexible manner. The paper's primary benefits and contributions in comparison to the current systems are:

1. By using a simplified front-end circuit (fewer power devices and a simpler control algorithm), an integrated multilevel converter for PHEV applications is built;

2. The proposed system's modularized structure makes it more compact and appropriate for the intended applications. Eight asymmetric half bridge arms make up the suggested converter, and each bridge arm has an IGBT and a diode.

The modularized construction is simple to build and replace for industrial applications. Without the need for an additional capacitor or inductor, the suggested converter combines the generator and battery bank using only two IGBTs and two diodes. As a result, the suggested converter has a higher power density and is more compact. It may be extended to accommodate multi-phase SRMs and larger power applications.

3. The suggested converter architecture enables the achievement of several functions and operation modes.

4. Demagnetization and excitation go more quickly without generating torque ripples.

5. There is a 2–4% increase in drive system efficiency.

The efficiency and benefits of the suggested drive are confirmed by modeling and tests conducted on a three-phase 12/8 SRM with the use of the front-end circuit. The structure of this document is as follows: A detailed analysis of the SRM drives' working concept is provided in Section II. An integrated multilayer converter for SRM-based PHEV traction drives is suggested in Section III. The benefits of using the frontend circuit are shown, along with an analysis of the operating modes, current, and voltage.

2. INTRODUCTION TO SRM

This chapter covers the Switched Reluctance Motor's (SRM) construction, operation, operating principle, frequency modification of inductance, energy design, and mathematical modeling. In addition, a number of converter topologies, rotor position sensors, SRM control elements, benefits, drawbacks, and applications are covered. This chapter also includes the comprehensive literature review of the reference articles as well as the issues found in the review. Modern businesses rely heavily on electrical drives. The SRM drive is a novel kind of electrical drive that has been developed and is being actively watched throughout the past 20 years. The SRM drive has now matured to the point that it can be utilized in industry as an effective brushless drive with a large speed range, cost benefits, and built-in simplicity and toughness. The SRM is not a novel idea, however, since early proponents of electromagnetic engines were aware of its principles. Nevertheless, their efforts to construct a motor were thwarted by the inadequate mechanical and electromagnetic designs, as well as the lack of appropriate switching mechanisms. The invention of thyristors in the 1960s sparked a renewed interest in switched field devices. The first SRM drive system using the novel technology was commercially accessible in the early 1980s thanks to research conducted by a team from Nottingham and Leeds Universities in the United Kingdom. Applications using 10 W and medium power drives have showed a resurgence of interest in this machine in recent years. A number of benefits are making such a machine an appealing option for applications requiring variable speed. The most notable of them is the motor's basic design, which has brushes and no windings on the rotor and coils on the stator.

2.1 BASICS OF SRM

The electric machine with two salient poles and one excited system. It is a piece of electrodynamic and electromagnetically charged equipment. Similar to a single energized variable 3 reluctance stepper motor is the SRM's operating concept. On the other hand, compared to stepper motors, variable reluctance motors need distinct design processes and control schemes. A rotor position sensor is necessary for SRM stepper motors, but not for Variable Reluctance (VR) stepper motors. While VR stepper motors are designed to spin in stages, SRMs are meant to revolve continuously. In an SRM, there are no windings on the rotor teeth and concentrated windings on the stator poles. Due to the following characteristics, SRM is currently being used in changeable speed drives more often.

1. This motor has a straightforward design, with focused coils on the stator and no winding on the rotor.

2. Because of the rotor's robust structure and lack of winding, it can operate at high speeds (about 2u105 RPM).

3. Stator windings are simply and effectively cooled.

4. For a particular machine rating, the motor dimensions are reduced due to efficient stator cooling.

5. Because an SRM may be run from unidirectional drive circuits, micro and power electronics are less expensive.

6. When one or more phases are disconnected from the circuit as a result of the same problem, SRM functions well, even at decreased output.

2.2 CONSTRUCTION OF SRM

Stator The stator is made up of silicon steel stamping with inward projected poles. The number of poles of the stator can be either in an even or an odd. Most of the motors have even number of stator poles. All these poles carry field coils (or) stator windings. The field coils of opposite poles are connected in series such that the Magneto Motive Force (MMF) is additive and hence they are called as “phase windings”. Phase windings are connected to the terminals of the motor. Rotor The rotor is also made up of silicon steel stamping with outward projected poles. The rotor shaft carries a Rotor Position Sensor (RPS). The turning on and off operation of the various devices of the power semiconductor switching circuit are influenced by the signals obtained from the rotor position sensor. Number of poles on the rotor is different from the number of stator poles.

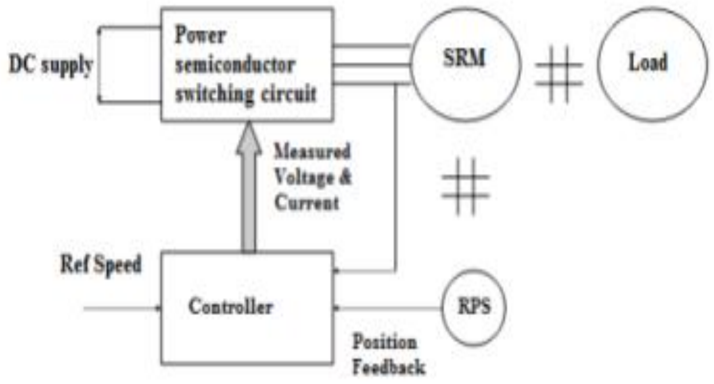


Figure 2.1 Block diagram of SRM

2.3 Block diagram of SRM

Figure 2.1 displays the SRM block diagram. The power semiconductor switching circuit, which is coupled to the different phase windings of the SRM, receives a DC supply. The controller receives signals from the RPS, which is fixed atop an SRM shaft, indicating the rotor's position in relation to the reference axis.

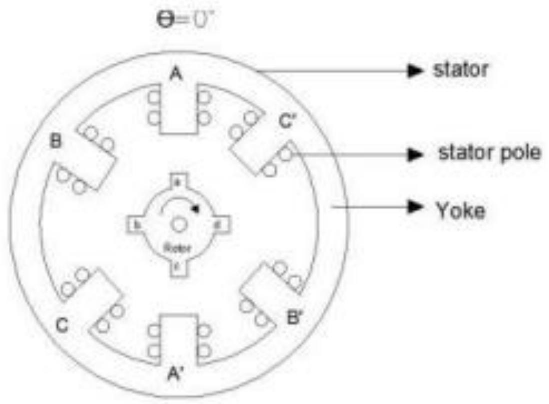


Figure 2.2 Basic structure of three phase 6/4 SRM

2.4 FREQUENCY VARIATION OF THE INDUCTANCE OF SRM

Let's see the rotor's salient pole count. The inductance is maximized because the rotor and stator pole axes are aligned. It is stated as The coil's inductance is reduced when the stator pole axis is not aligned. The stator phase winding's inductance varies in cycles throughout a single rotor rotation, as shown.

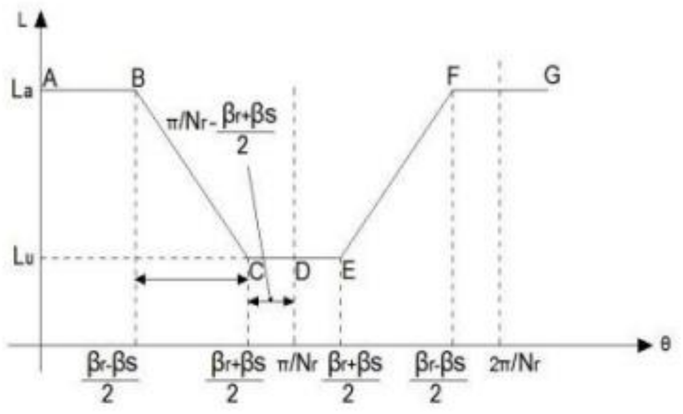


Figure 2.3 Frequency variation of the inductance of each phase winding of SRM

From the Figure 2.3, the following observations are made. From point A TO B

$$AB = \frac{\beta_r - \beta_s}{2}$$

'θ' varies from 0 to $\frac{\beta_r - \beta_s}{2}$; $= L_a$

From point B to C

$$BC = \frac{\beta_r - \beta_s}{2}) - \frac{\beta_r - \beta_s}{2}$$

$$BC = \beta_s$$

As θ varies from $\left(\frac{\beta_r - \beta_s}{2}\right)$ $\frac{\beta_r - \beta_s}{2}$, $\frac{\partial L}{\partial \theta}$ exists and is negative

From point C to D

$$CD = \frac{\pi}{N_r} - \frac{\beta_r + \beta_s}{2}$$

'θ' varies from $(\frac{\beta_r + \beta_s}{2})$ to $\frac{\pi}{N_r}$; L L_u; $\frac{\partial L}{\partial \theta} = 0$

From point D to E

$$DE = \frac{2\pi}{N_r} - \frac{\pi}{N_r} \quad \left(\frac{\beta_r + \beta_s}{2}\right)$$

'θ' varies from $\frac{\pi}{N_r}$ to $\frac{\beta_r + \beta_s}{2}$; L L_α; $\frac{\partial L}{\partial \theta}$

'θ' varies from $\frac{\pi}{N_r}$ to $\frac{\beta_r + \beta_s}{2}$; L L_u; $\frac{\partial L}{\partial \theta}$

From point E to F

$$EF = \frac{\beta_r - \beta_s}{2}) - \frac{\beta_r + \beta_s}{2} = -\beta_s$$

θ varies from $\frac{\beta_r + \beta_s}{2}$ to $\frac{\beta_r - \beta_s}{2}$

$\frac{\partial L}{\partial \theta}$ exists and is positive.

3.MULTILEVEL CONVERTER

INVERTER:

An electrical device called an inverter changes direct current (DC) to alternating current (AC); with the right transformers, switching, and control circuits, the converted AC may be at any desired voltage and frequency. Static inverters are utilized in many different applications, ranging from big electric utility high-voltage direct current applications that transfer bulk power to tiny computer switching power supplies. Static inverters are characterized by their lack of moving components. When supplying AC power from DC sources, such solar panels or batteries, inverters are often used. An electronic oscillator with high power is what the electrical inverter is. The reason for the term "inverted" is because the first mechanical AC to DC converters were designed to operate in reverse, or "inverted," in order to convert DC to AC. An inverter works in the opposite way as a rectifier.

INVERTER WITH CASCADED H-BRIDGES

Figure 3.1 shows the single-phase construction of an m-level cascaded inverter. Every individual DC source (SDCS) is linked to a single-phase full-bridge inverter, often known as an H-bridge inverter. By using various combinations of the four switches, S1, S2, S3, and S4, to link the dc source to the ac output, each inverter level may produce one of three voltage outputs: +Vdc, 0Vdc, and –Vdc. Switches S1 and S4 must be switched on in order to acquire +Vdc, whereas switches S2 and S3 must be turned on in order to receive –Vdc. The output voltage is zero when S1 and S2 or S3 and S4 are turned on. The synthesized voltage waveform is equal to the sum of the ac outputs of all the full-bridge inverter levels whose ac outputs are coupled in series.

$$V(\omega t) = \frac{4V_{dc}}{\pi} \sum_n \left[\cos(n\theta_1) + \cos(n\theta_2) + \ldots + \cos(n\theta_s)\right] \frac{\sin(n\omega t)}{n}, \quad \text{where } n = 1, 3, 5, 7, \ldots$$

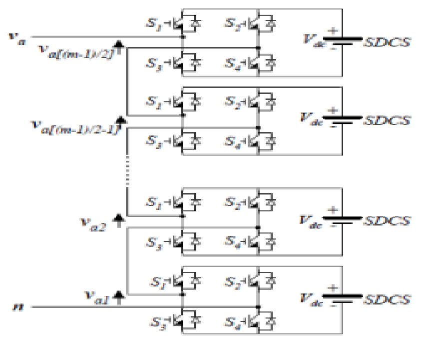
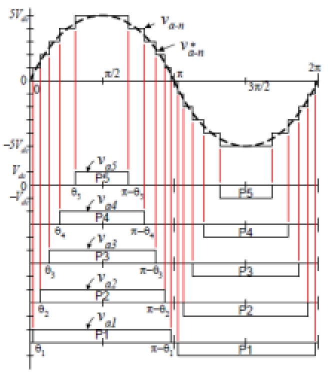


Fig3.1: Single-phase structure of a multilevel cascaded H-bridges inverter



Output phase voltage waveform of an 11-level cascade inverter with 5 separate dc sources.

4.OPERATING PRINCIPLE OF SRM DRIVES

In SRM drives, a traditional asymmetrical half-bridge converter is often used because of its superior fault-tolerant design, phase isolation, and stability. In the phase turn-on zone, it often adopts a soft-chopping mode to minimize the torque ripple and switching loss [49]. A phase operates in the excitation mode when a positive dc-link voltage energizes the phase winding. A negative dc-link voltage affects the phase while it is in the demagnetization or regenerative braking mode. When the current flows through the inductance ascending zone, it produces a positive torque; conversely, when the current flows through the inductance descending region, it produces a negative torque.

By varying the turn-on and turn-off angles, the direction of the electromagnetic torque may be directly regulated. The demagnetization current in the inductance falling zone causes a negative torque to be created at high speeds, which reduces the driving performance. On the other hand, when the demagnetization voltage is raised and the turn-off angle is lag-set to expand the effective current area for output torque enhancement, no negative torque may occur. The block diagram of a speed-controlled SRM drive using a current regulation system is shown in Fig. 4.1.

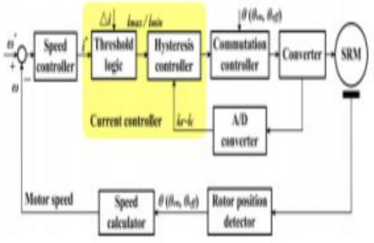
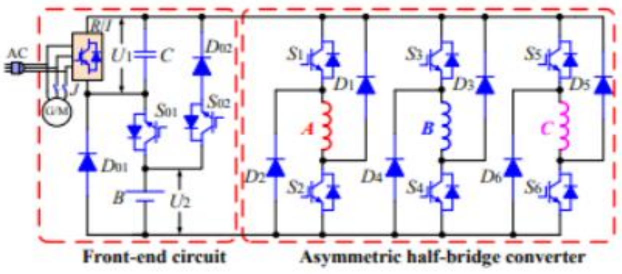
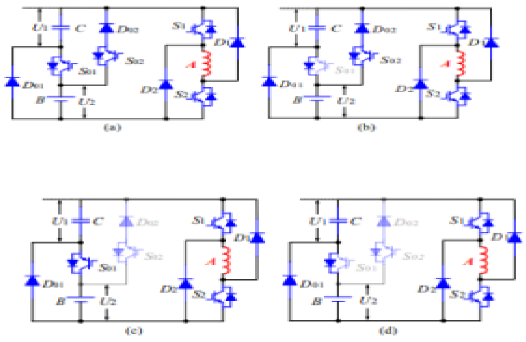


Fig. 4.1 Block diagram of the speed-controlled SRM system

5. PROPOSED INTEGRATED MULTILEVEL CONVERTER FOR PHEVS

Integrated Multilevel Converter Proposed As seen in Fig. 2, the suggested power converter is built using a front-end circuit and a traditional asymmetrical half-bridge converter. A battery bank (B), an IGBT bridge rectifier/inverter (R/I), a capacitor (C), and an ac electric machine (G/M) make up the front-end circuit. In addition, two IGBTs (S01 and S02), two diodes (D01 and D02), and a relay (J) are combined to provide various working modes. An internal quick recovery anti-parallel diode is included in the IGBTs utilized in the converter. In the proposed motor drive, the capacitor C is also used to elevate the dc-link voltage for the battery driving operations, and battery bank B is used to interface the generator's power source to accomplish the multilevel voltage. The switch S01's anti-parallel diode allows the demagnetization and braking currents to return straight to the power source, facilitating battery charge. The suggested converter's four working modes are seen in Fig. 3. These modes may be selectively selected by adjusting the on and off states of the switching devices (S01 and S02) in the front-end circuit.





6.SIMULATION RESULTS

6.1 SIMULATION CIRCUITS

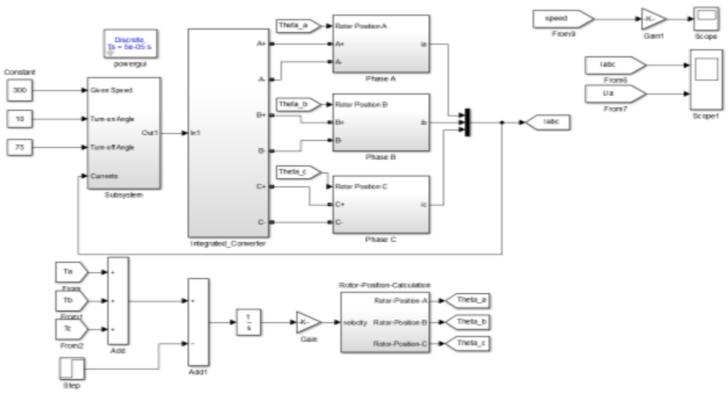


Fig 6.1. Simulation model of the SRM Drive

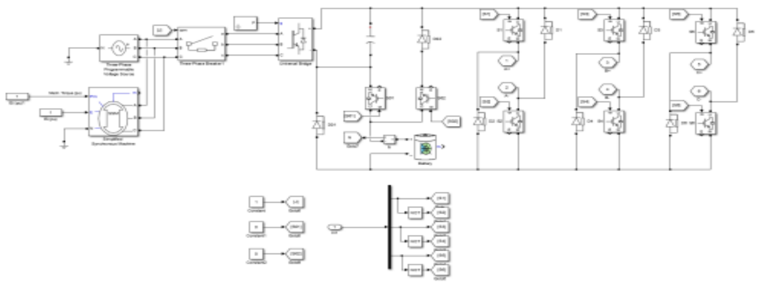
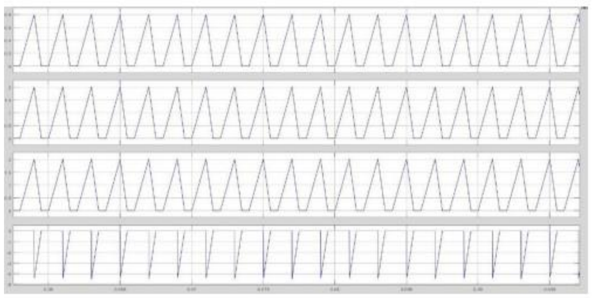


Fig 6.2. Simulation model of proposed converter

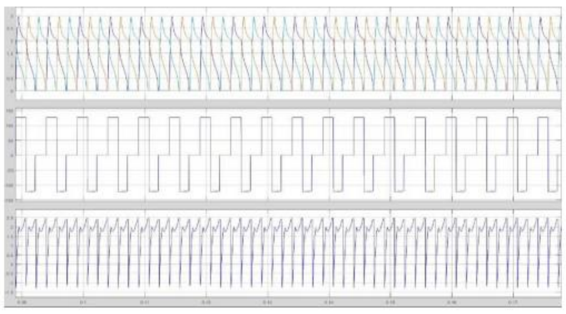
6.2 SIMULATION RESULTS

Output waveforms during high speed & low speed operations: driven by Battery, Generator, Dual source

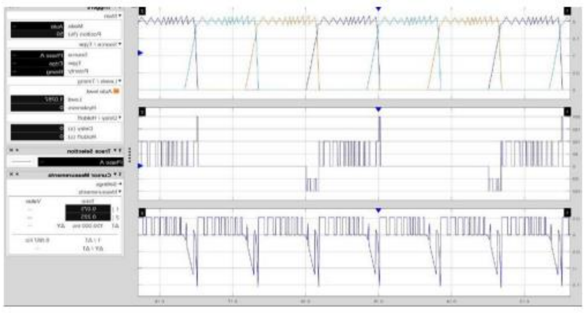
Case i) SRM by charging



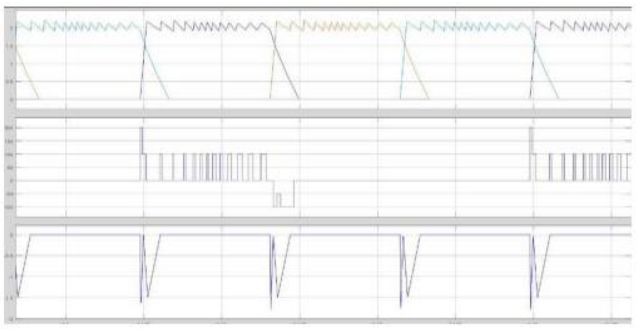
Case ii) SRM by dual source



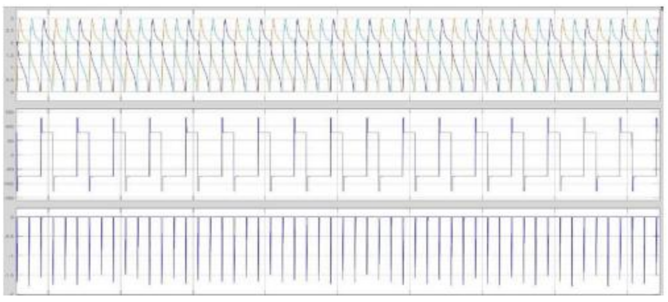
Case iii) SRM by battery



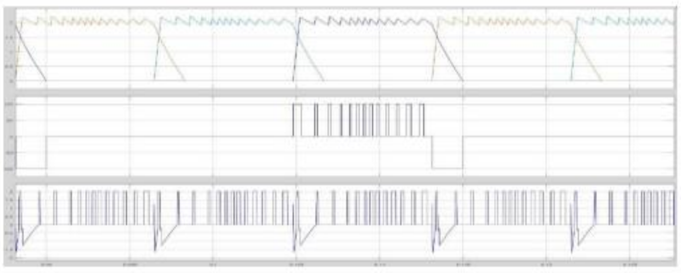
Case iv) SRM by generator



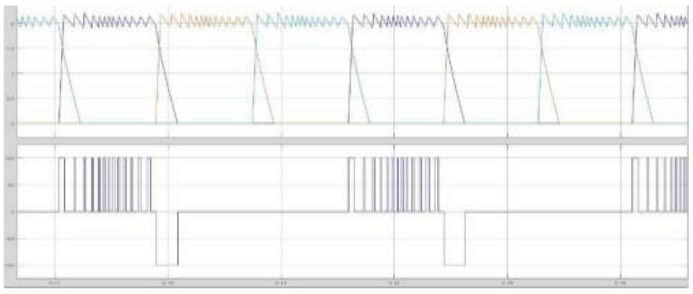
Case v) SRM 2 by generator



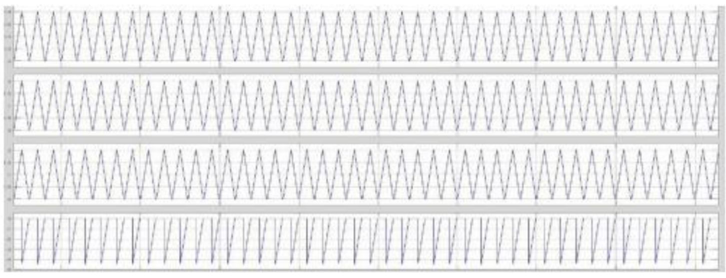
Case vi) SRM 1 by dual source



Case vii) Conventional converte



Case viii) SRM by charging



7.CONCLUSION

For PHEV applications, a novel SRM drive powered by a modular front-end circuit is suggested in this research. By adjusting the switches in the front-end circuit's on-off state, multimode and multilevel voltages may be produced. The voltage and current in various operating stages are thoroughly examined, and the suggested converter's excitation and demagnetization modes are described. An enhanced front-end circuit is used for multilevel voltage and multimode operations, using fewer power components and a simpler control algorithm than the current systems. In comparison to traditional converters, the excitation and demagnetization are accelerated. Multilevel voltages increase the torque capabilities without generating torque ripples. The efficiency of the motor system is increased. Additionally, the battery may be flexible charged without using off-board charging facilities whether the vehicle is in stationary, driving, or braking circumstances.

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