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A HYBRID ELECTRIC VEHICLE POWERED BY SRM DRIVE AND FEATURING A REDUCED SWITCH CONVERTER

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Abstract-A hybrid electric vehicle with an asymmetric bridge converter and a reduced switch converter is being investigated. The commonly used Asymmetric Bridge Converter has a large number of switches, which results in higher losses and negative torque current.

Due to high torque ripples, a long response time, and a long time to settle down, the results of Asymmetric Bridge Converter Control are unsatisfactory. Reduced Switch Converter control is more compact than Asymmetric Bridge Converter control and has higher speed controllability and torque performance to address this issue. With fewer components and improved system performance, the Switch Converter has been reduced.

The SRM Drive is intended to power a hybrid electric vehicle with wheels connected to the SRM shaft. Controlling the motor allows for control of the wheels and thus the HEV. The converter's design also allows for driving acceleration and braking. The motor's increase and decrease in speed are analogous to the increase and decrease in speed during acceleration and braking.

An appropriate power electronic converter and control circuit must be used to achieve the desired operation of the Switched Reluctance Machine. These devices, in combination with a number of sensors, conditioning circuits, and other components, make up an electric drive that regulates machine currents and, as a result, torque and speed. The theoretical srectangular, and power converters capable of imposing bidirectional or zero voltages and controlling unidirectional currents in each phase are required to provide such waveforms.

Each phase is magnetised, held at a reference value, and then demagnetized by these unidirectional currents. Numerous studies on the topology and control system used have been conducted as a result of the importance of these power converters. To achieve the best operating performance of the SRM, the power converter topology must be carefully chosen. The whole drive system is modelled and simulated in MATLAB/SIMULINK.

Keywords-Switched Reluctance Motor (SRM), Hybrid Electric Vehicle (HEV), Reduced Switch (RS) Converter.

I. Introduction

Increased fuel consumption for vehicles has had negative environmental consequences, and there is also a problem with diminishing fuel resources. As a result, there is a pressing need for a fuel-efficient alternative, which is known as a Hybrid Electric Vehicle. [2] & [4]. These HEVs run on electricity, which can be generated in a variety of ways, including solar, wind, fuel cells, and other renewable energy sources. A hybrid electric vehicle (HEV) can be thought of as a mobile energy storage device. [2], as there is also regeneration capability is incorporated in it.

There have been numerous advancements in this field, with Switched Reluctance Motor Drives proving to be the most effective. [1]-[7]. The rotor of an SRM is doubly-salient and singly-excited, with no conductor or permanent magnet. Since they have a high level of controllability and a simple and robust construction at a low cost, they are a good investment. They have high developed torques, high power density, and fault tolerance for high-speed driving without cogging torque.

A hybrid electric vehicle (HEV) is propelled by a battery/super capacitor (SC) that stores energy via a converter. Bridge Converters with an Asymmetrical Design [2] & [6] are generally used for this purpose. They do, however, have tail current in the phase windings and a negative torque slope in the torque characteristics. They have a higher number of switches, resulting in higher losses and lower system efficiency.The converter proposed in this paper is a Reduced Switch Converter with fewer components and better system performance.

The SRM Drive is designed to power a HEV whose wheels are connected to the SRM shaft. Controlling the motor allows control of the wheels, and thus the HEV, to be achieved. The converter design also allows for the acceleration and braking moments of driving. The increase and decrease in speed during acceleration and braking are analogous to the increase and decrease in motor speed.

II PROPOSED METHODOLOGY

A. Block Diagram of The SRM Drive Based HEV

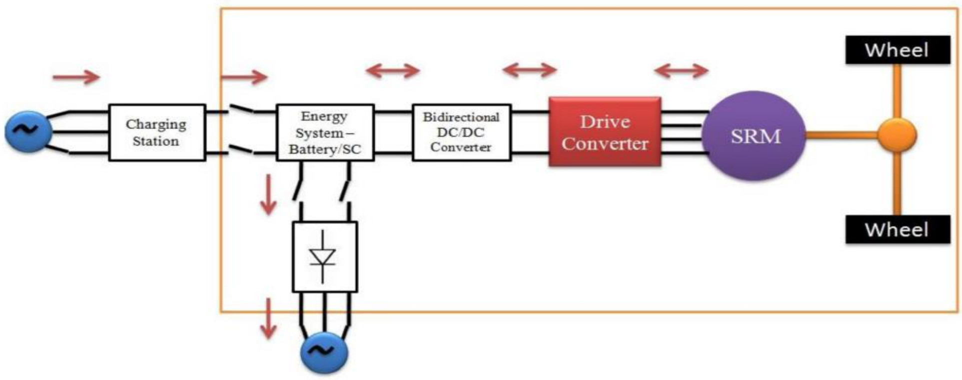

Fig. 1: Block Diagram of the SRM Drive based HEV

Electric vehicles are becoming more popular because they not only reduce reliance on oil, but they can also be used to reduce noise and pollution. For a Hybrid Electric Vehicle, there are a variety of electric-propulsion systems to choose from. Because of their numerous advantages, SRMs are gaining a lot of attention and are seen as having a lot of potential for HEV applications. However, there are a number of drawbacks that, in many cases, outweigh the benefits. Torque ripple, acoustic noise, and speed ripple are all factors to consider. Analytical modelling of the SRM in saturation is extremely difficult due to its highly nonlinear nature. The main goal of this project is to use a nonlinear controller to reduce the torque and speed ripple of a switched reluctance motor, making it suitable for HEV.The proposal of the switched reluctance motor for hybrid electric vehicle is simulated by using MATLAB Simulink model.

B.Introduction to bidirectional dc-dc converters

Many power-related systems, such as hybrid vehicles, fuel cell vehicles, renewable energy systems, and so on, have found the bidirectional DC-DC converter and energy storage to be a promising option. It not only lowers costs and increases efficiency, but it also improves the system's performance.

Fig 2 Configuration of power system in DC-DC directional

An auxiliary energy storage battery absorbs the regenerated energy fed back by the electric machine in electric vehicle applications. Furthermore, a bidirectional DC-DC converter is required to draw power from the auxiliary battery in order to boost the high-voltage bus during vehicle starting, acceleration, and hill climbing. The bidirectional dc-dc converter can be classified as buck or boost depending on where the auxiliary energy storage is located. SSC and VMC-based non-isolated high voltage gain DC-DC converters. Finally, a three-level interleaved AC–DC converter.

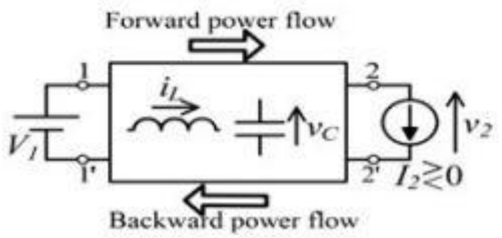

Fig 3. Illustration of bidirectional power flow

To realize the double-sided power flow in bidirectional dc-dc converters the switch cell should carry the current on both directions.

C.Converter Topology

The basic structure of a SRM Drive based HEV will be as shown in Fig.1. The Energy System is initially charged by connecting to a Charging Station. To drive the SRM, the stored energy is fed to the Drive Converter via a DC/DC Converter. During SRM's Motoring mode, the Mechanical Wheels connected to its mechanical terminals are controlled by controlling the SRM. The mechanical energy stored in the flywheels connected to SRM is fed back to the Energy Storage System through the Converters in the Regenerative Braking mode of SRM, where it can be used for some other energy consuming application.

This research work mainly concentrates on the Drive Converter part, analysing the complications of generally used Asymmetric Bridge Converter with the new Split type Converter.

1. Asymmetric Bridge Converter fed SRM

A circuit with a mechanical load, such as a HEV, controlled by an Asymmetric Bridge Converter and supplied by a battery of voltage Vb via a bidirectional DC/DC converter with a duty cycle D in the range 0-D-1. The converter's input voltage is then V=DVb, with a range of 0-V-Vb. With the help of a Bi-pole switch, this circuit can be operated in both motoring and regenerative braking modes, switching between D for driving and B for battery idle mode.

In Motoring mode, the Battery voltage is bucked in DC Converter and applied to the converter controlling SRM which drives the HEV.

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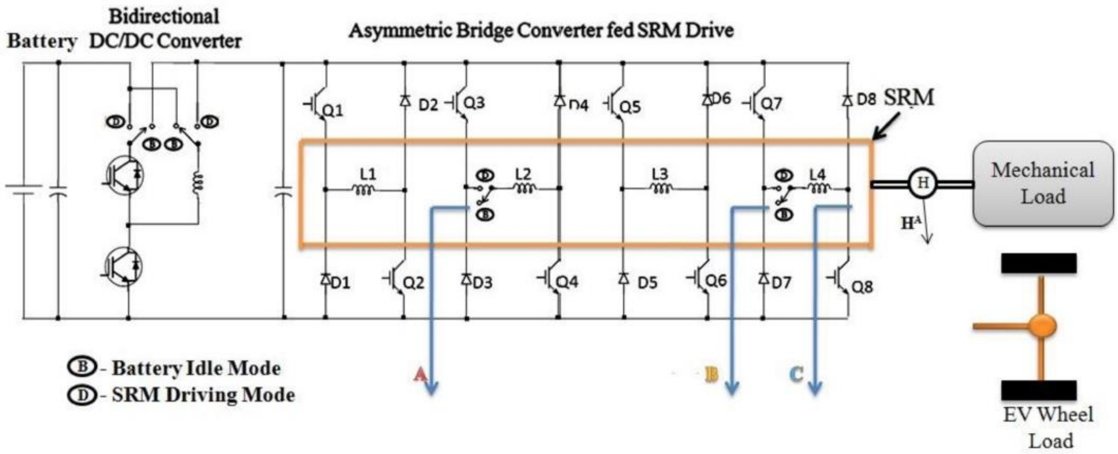

Fig.4.HEV SRM Drive by Asymmetric Bridge Converter

2. Reduced Switch Converter Fed SRM

The Reduced Switch Converter configuration with SRM Drive, as shown in Fig.5, has a much simpler design than the previous case. The number of switches has been reduced to nearly half of the circuit's original size. With the help of the Bi-pole switch, this will also operate in the Motoring and Braking modes as described above, i.e., in Motoring mode, battery voltage is applied to an RS converter fed SRM via a buck converter. By using a controller, such as a PID controller that uses current control to generate gate pulses based on variations in vehicle speed and phase current, and a speed controller to generate gate pulses based on variations in vehicle speed and phase current. The pulses are produced only when there is a change between the actual and reference values of the current or speed.

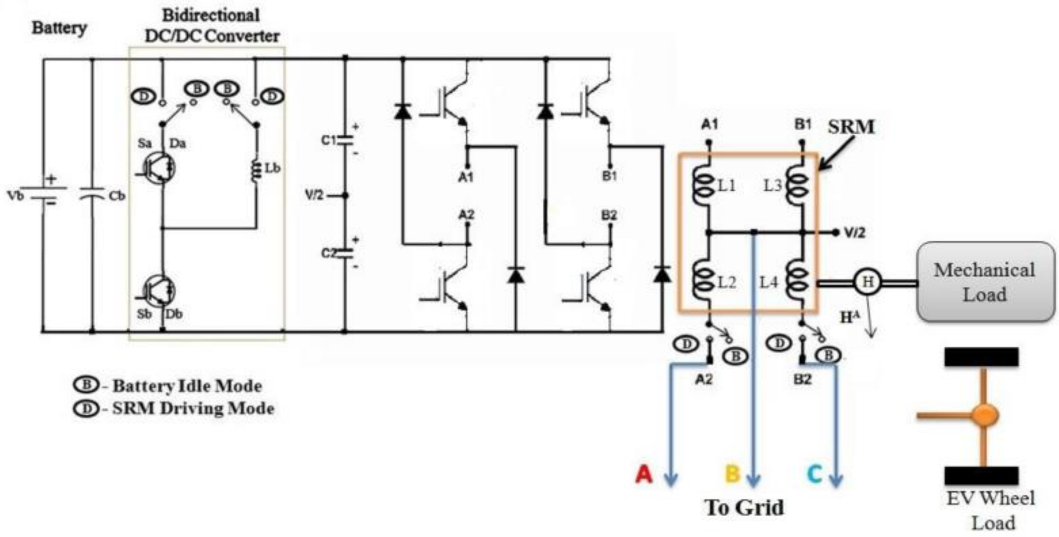

Fig 5. HEV SRM Drive by Reduced Switch Converter

3. Modes Of Operation

3.1. Motoring Mode:

In Motoring mode, the SRM can use the batteries' electrical input to drive the mechanical wheel load. Position D is maintained for the Bipole Switches.

a. Acceleration: The Accelerator of the ear is applied then the speed increases from its position.

b. Brake: The Brake of the ear is applied then the speed starts decreasing from its position.

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3.2. Regenerative Braking Mode:
The SRM can use the mechanical energy stored in its rotor during motoring mode in Regenerative Braking mode and give it back to a battery or use it for other electricity-consuming utilities.

III GOVERNING EQUA TIONS

If Vb is the Battery Voltage and D is the duty cycle of the DC/DC converter, then the phase voltage applied at winding terminals of SRM is

$$V = DV_b;\ 0 \leq D \leq 1 \qquad (1)$$

Consider the equivalent circuit of the SRM per phase as in fig.4 .

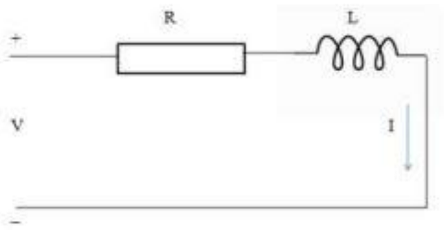

Fig 6. Per Phase Equivalent of SRM

If V is the Voltage applied, I is the phase current, L is the inductance in the phase, R is the resistance in the phase, then the phase winding terminal voltage is given as

$$V = IR + \frac{d(I)}{dt} \qquad (2)$$

But L is not constant and varies according to the rotor position, hence

$$V = IR + \frac{d(L(I,\Theta)I)}{dt} \qquad (3)$$

Where, Θ is the rotor position in degrees

The above equation can be simply written as

$$V = IR + \frac{d(\lambda(I,\Theta))}{dt} \qquad (4)$$

Since, λ = LI

Where λ(I,Θ) is the Magnetic flux in the air gap. It can also be calculated from above equation as

$$(\lambda(I,\Theta)) = \int (V - IR)dt \qquad (5)$$

The Electromagnetic developed torque can be derived from its energy as

$$Te = \frac{1}{2}(I\text{^}2 + \frac{d(L(I,\Theta)I)}{dt} \qquad (6)$$

It can also be expressed in mechanical terms as

$$Te = TL + B\omega r + J\frac{d(\omega r)}{dt} \qquad (7)$$

Where TL is the Load Torque, B is the Total Damping ration, J is the Moment of Inertia and ωr is the Rotor Speed.

Substituting eqn.1 in 5 and 6, we get

$$(\lambda(I,\Theta)) = \int (DV - IR)dt \qquad (8)$$

$$Te = \frac{1}{2}(I^2) + \int (DV - IR)dt \qquad (9)$$

Eqn 8 and 9 depicts that they depend on the duty of the DC Converter, Battery voltage and winding current.

IV SIMULATION RESULTS

A.Simulink Model Of The Asymmetric Bridge Converter Controlled SRM Drive Fed HEV

Using all the system blocks the complete schematic blocks has been developed

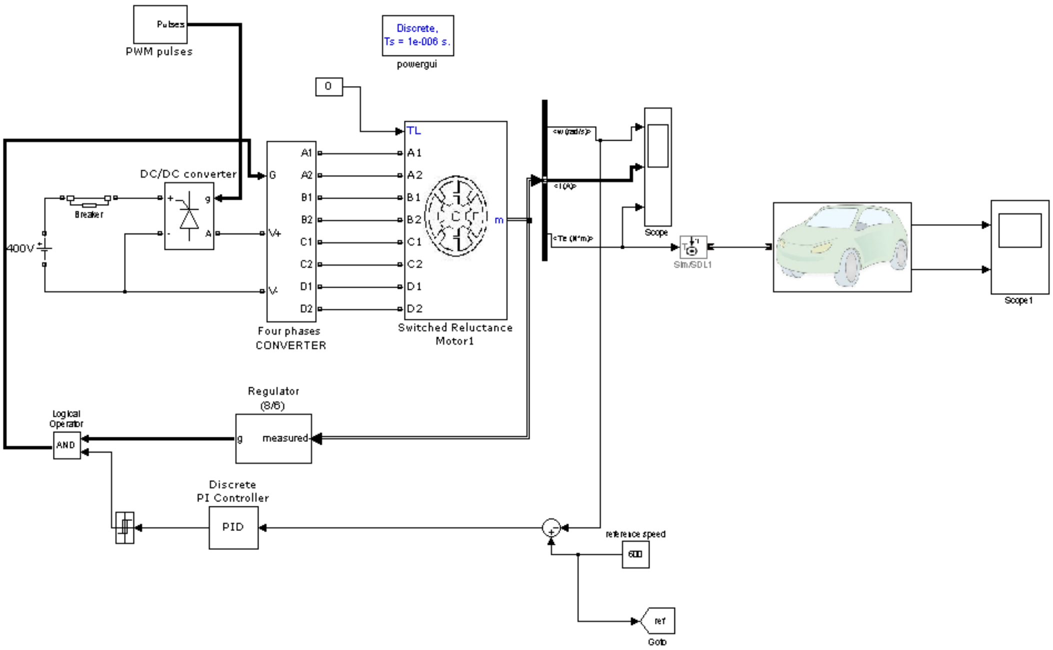

Fig 7. Simulation model of the Asymmetric Bridge Converter controlled SRM Drive driving HEV

The Converter is Controlled by a PID Controller. It has a 400V input DC supply to a DC/DC converter feeding a Asymmetric Bridge Converter whose detailed model is shown in Fig.7.

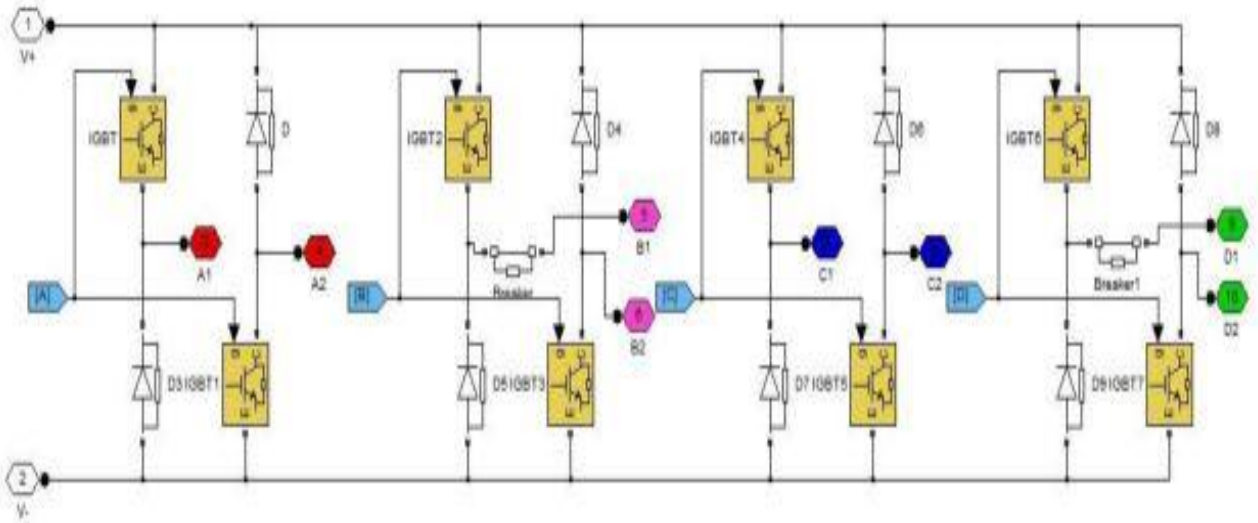

Fig 8 Asymmetric Bridge Converter controls SRM Drive whose torque output is driving a HEV model.

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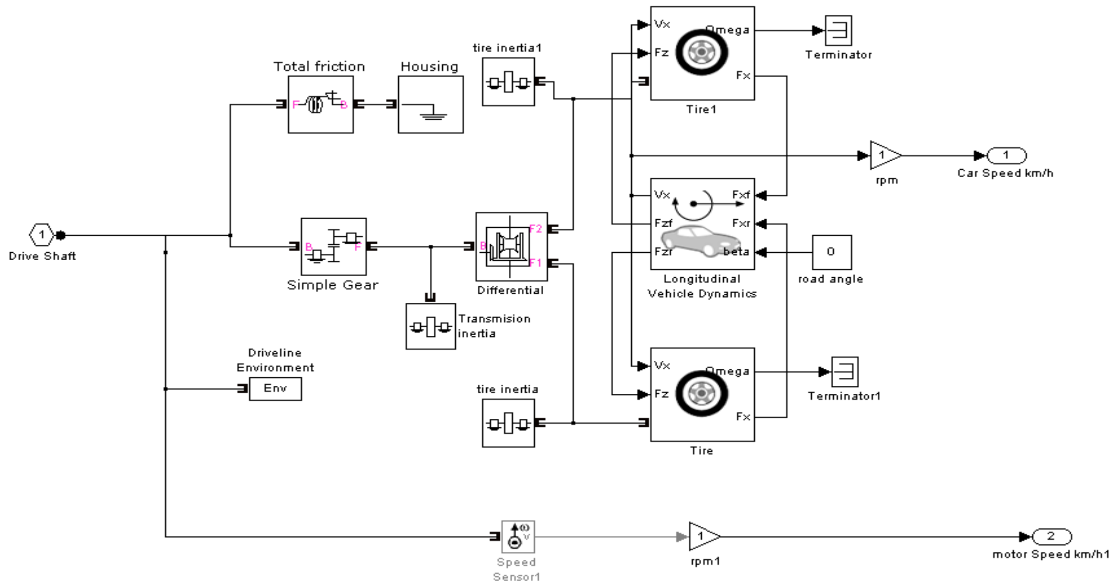

Fig 9 Simulation model of the Hybrid Electric Vehicle

The Torque of SRM is connected to shaft of the tires of a car. From the Torque command, gear ratio is calculated and the tyres rotate depending inertia produced according to gear ratio.

B.Simulation Results

The motor parameters used for simulation are given:-

Motor Specification:

An 8/6 SRM having the following ratings,

• Rated power : 7.5 kW, Rated current : 60 A, Rated voltage: 280 V,

• No of poles in the stator: 8, No of poles in the rotor: 6, Stator pole arc : 22.3 °,

• Rotor pole arc: 22.5°, No of phases: 4, No of Turns per pole: 100, Speed: 1000 rpm, Motor length: 165 mm.

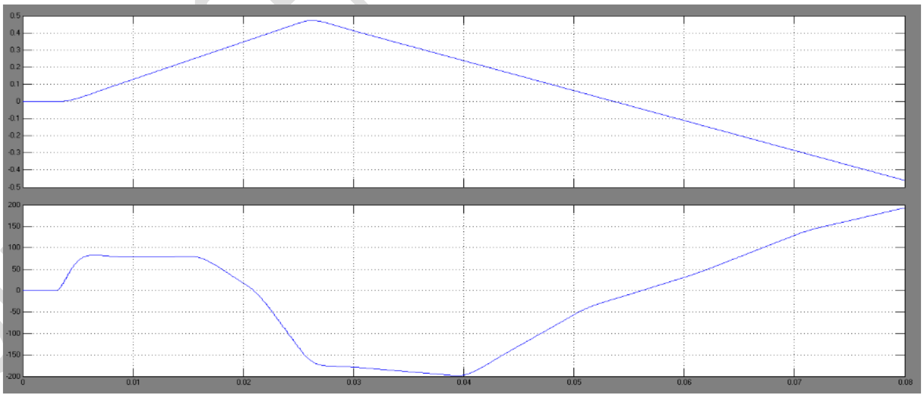

Fig.10 Simulation output of Car and Motor Speeds with Asymmetric Bridge Converter

It shows the output of the car and motor speeds when asymmetric bridge converter is used with respect to time given.

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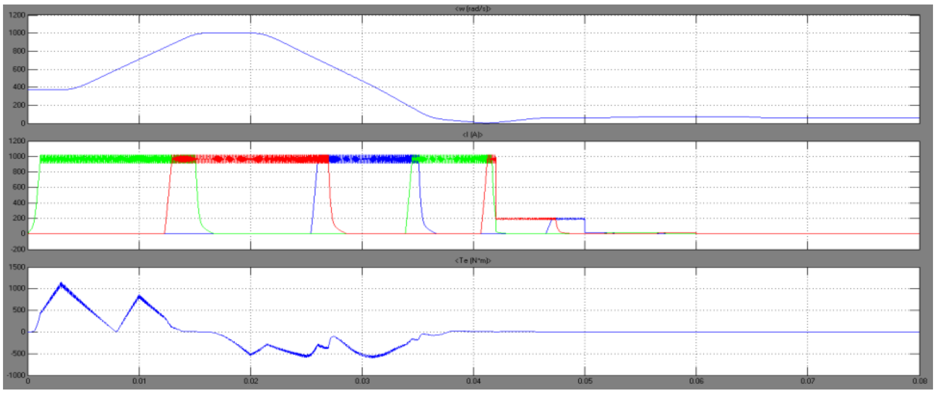

Fig.11 Simulation output of Motor Speed, Current and Torque of Asymmetric Bridge Converter

It Shows the motor speed when 1000rpm is given as the reference and current and torque is shown with respect to time.

C.Simulink Model Of The Reduced Switch Converter Controlled SRM Drive Fed HEV

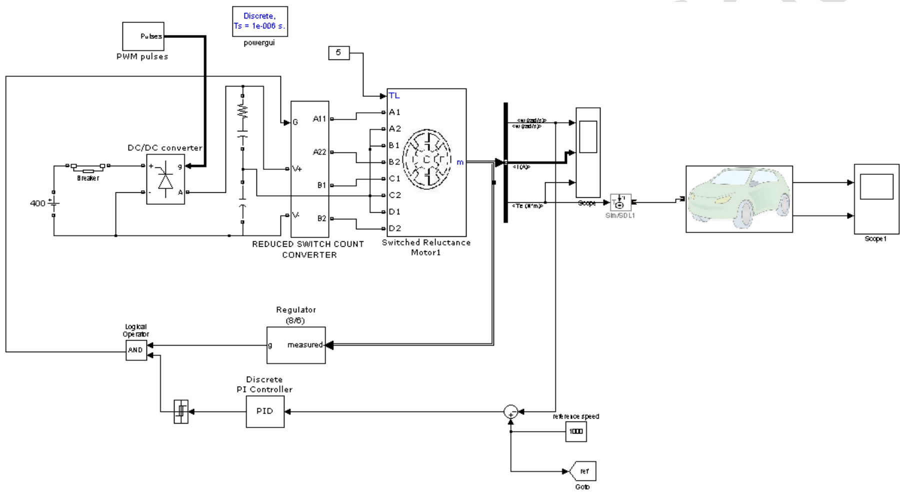

Fig 12.Simulation model of the Reduced Switch Converter fed SRM Drive driving HEV

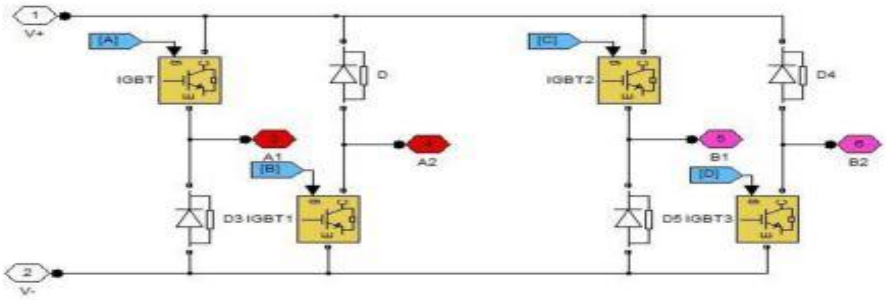

Fig 13. Simulation Block Model Of Reduced Switch Converter

To Construct the RS Converter four IGBTs and four diodes are used reducing the circuit complexity shown in Fig.13.

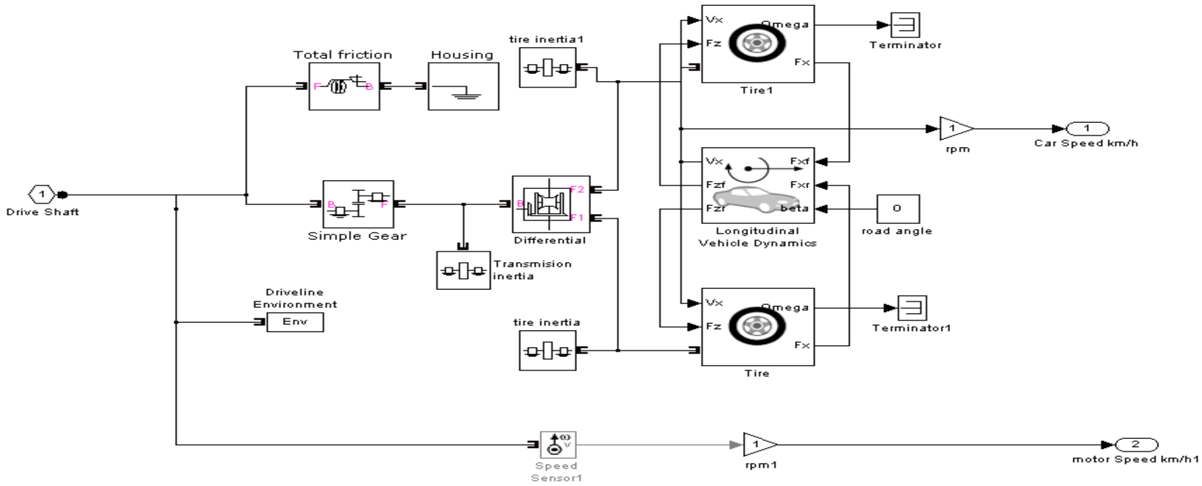

Fig 14. Simulation Block Of Hybrid Electric Vehicle

D.Simulation Results

The HEV model is shown in Fig.14 and remains unchanged. Figures 15 and 16 depict the simulation outputs. Figures 15 and 16 depict car and motor speeds at car terminals, and speed, current, and torque at motor terminals, respectively. These two graphical outputs clearly show the improvement in the characteristics. In the case of an RS Converter, the speed is more controllable.

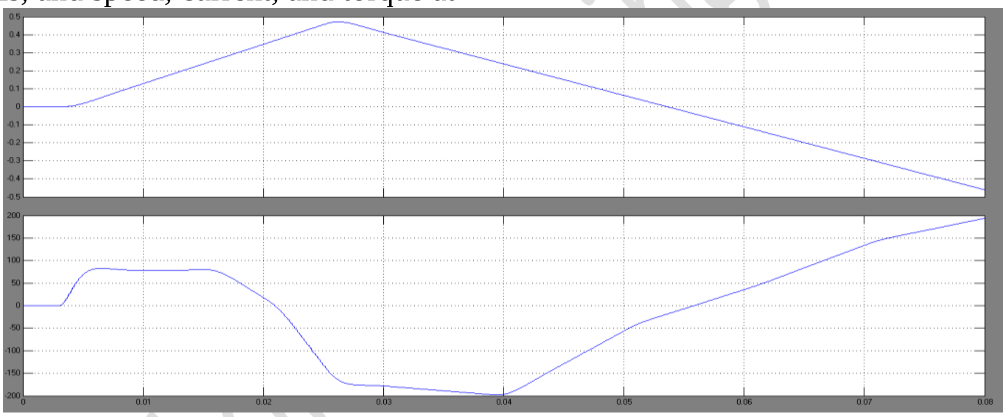

Fig.15 Simulation output of Car and Motor Speeds with RS Converter

When an asymmetric bridge converter is used, it displays the car's output and motor speeds over time. The increase and decrease in speed during acceleration and braking are analogous to the increase and decrease in motor speed.

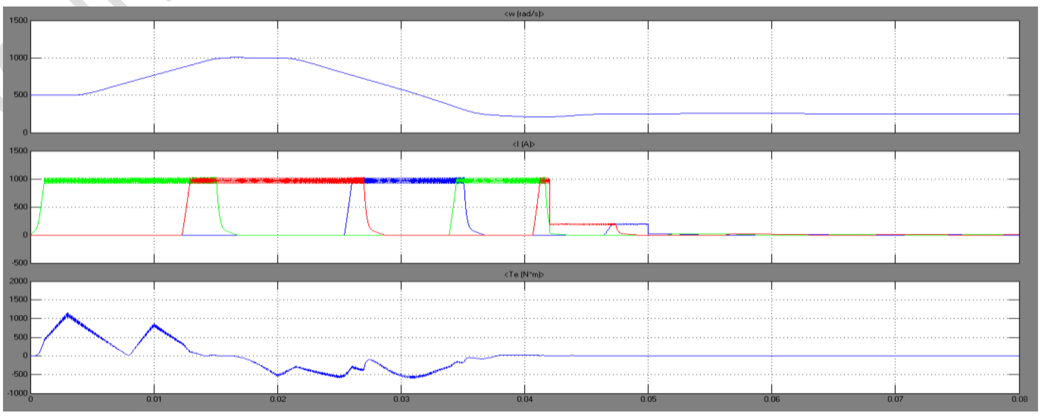

Fig.16. Simulation output of Motor Speed, Current and Torque of RS Converter

It displays the motor speed when 1000rpm is used as a reference, as well as current and torque in relation to time. The increase and decrease in speed during acceleration and braking are analogous to the increase and decrease in speed in the motor.

V Conclusion

A Hybrid Electric Vehicle with Asymmetric bridge converter along with Reduced Switch Converter are studied. The whole drive system is modelled and simulated in MATLAB/SIMULINK. The generally used Asymmetric Bridge Converter has a large number of switches, resulting in more losses and negative torque current.

The results of Asymmetric Bridge Converter Control are not satisfactory because of high torque ripples, high response time and it takes more time to settle down is too high. To overcome this problem the Reduced Switch Converter control is more compact than the Asymmetric Bridge Converter with higher speed controllability and better torque performance. Reduced Switch Converter having lesser number of components and improved system performance.

The SRM Drive is made to drive a HEV, whose wheels are coupled with shaft of SRM. So, by controlling the motor, control over the wheels and hence the HEV is achieved here. The acceleration, braking moments of the driving are also made possible with the converter design. The increase of speed during acceleration and decrease of speed during braking are analogue to the increase and decrease of speed in the motor.

The use of an appropriate power electronic converter and control circuit are essential to accomplish the desired operation of the Switched Reluctance Machine. These devices, together with several sensors, conditioning circuits and other devices, compose an electric drive responsible to control the machine currents and consequently the torque and speed. The theoretical current waveform of each phase is rectangular and, to provide such waveforms, it is necessary to use power converters able to impose bidirectional or zero voltages and control unidirectional currents in each phase. Such unidirectional currents are responsible for magnetizing, maintaining in a reference value and finally demagnetizing each phase. Thus, due to the importance of these power converters, many studies have been developed regarding the adopted topology and control system. To obtain the best operating performance of the SRM, the power converter topology must be carefully chosen.

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