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# NEURAL NETWORK BASED TORQUE CONTROL OF SWITCHED RELUCTANCE MOTOR FOR HYBRID ELECTRICAL VEHICLES

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## ABSTRACT

The switched reluctance motor (SRM) is a simple, low-cost, and robust motor suitable for variable-speed as well as servo type applications. With relatively simple converter and control requirements, the SRM is gaining an increasing attention in the drive industry. The SRM is known to be highly cost-effective and reliable due to its simple structure and the unidirectional operation of its converter. A number of power electronic converter topologies have been developed over the years exclusively for use in conjunction with SRM drives. In principle, the quest has always been for a converter with a minimum number of switches. In this proposed method, torque ripple of an SRM Drive system has been controlled with the help of Neural Network based PID controller. And also the comparison of results is made between with and without PID controller.

**KEYWORDS:** SRM Characteristics, Neural Network PID Controller, Back Propagation Neural Network, Power Converter, Simulink Model

## INTRODUCTION

With the High concern over the energy resource crisis and global warming, Hybrid Electric Vehicle (HEVs) has become the most suitable candidate for the next generation vehicle due to their lower emission, high fuel efficiency. While the permanent magnet synchronous machine (PMSM) has some drawbacks such as expensive, fragile and short constant power range where as switched reluctance motor (SRM) can be suitable for the traction motor for its robust construction, fault tolerant operation, high starting torque without the problem of excessive inrush current, and ability to extremely high-speed operation[1, 2]. Although the torque ripple is the obvious drawback of the SRM which has been studied extensively during high-speed operation, the large inertia of the vehicle can effectively smooth out the torque ripple of the SRM and the motor efficiency becomes the most important performance criterion of the vehicle drive train. The Switched Reluctance Motor (SRM) is the simplest of all electrical machines. In this motor only the stator has got windings. The rotor contains no conductors or permanent magnets [5]. It consists simply of steel laminations stacked onto a shaft. It is because of this simple mechanical construction SRMs carry the promise of low cost, which in turn has motivated a large amount of research on SRMs in the last decade [2].

### Conventional Operation of the SRM

The reluctance motor is a type of synchronous machine. It has wound field coils of a DC motor for its stator windings and has no coils or magnets on its rotor. Figure 1 shows its typical structure. It can be seen that both the stator and rotor have salient poles; hence, the machine is a doubly salient machine [14]. The rotor is aligned whenever the diametrically opposite stator poles are excited. In a magnetic circuit, the rotating part prefers to come to the minimum reluctance position at the instance of excitation. While two rotor poles are aligned to the two stator poles, another set of rotor poles is out of alignment with respect to a different set of stator poles. Then, this set of stator poles is excited to bring the rotor poles into alignment [2]. As shown in Figure 1 is an example of an ideal inductance profile of phase 'a' for an SRM with 8 stator poles and 6 rotor poles. Conventionally, it is called an 8/6 SRM. It is shown for only 60 mechanical degrees because of its periodicity. Figure 2 portrays an ideal situation while in reality the inductance and torque profiles are nonlinear functions of the current and rotor position. This ideal inductance profile of the SRM is assumed to produce torque in the conventional drives.

The rotor position is defined as the mechanical angle from the polar axis of phase 'a' to one of the interpolar axes of the rotor [2, 16]. At zero degree, the inductance of phase 'a' is the lowest and the interpolar axis of the rotor is aligned with the polar axis of phase 'a'. At the points where inductance is the highest, a set of rotor poles are in full alignment with two opposite stator poles, which composes phase '*a*'. If a phase is excited when its inductance is rising, positive torque is produced while negative torque is produced during the falling slope of the inductance [5]. The torque is proportional to the square of the phase current as given in. Hence, the direction of the current is arbitrary. This unidirectional current requirement has a distinct advantage over other motor drives requiring four-quadrant operational converter, whereas only a two-quadrant operational converter is necessary in the SRM drives. To move the rotor by 60 degrees in the counter clockwise direction, it takes four phase excitations in the sequence of '*a -b -c – d*' and one revolution of the rotor needs six sets of the same sequences. Similarly, four phase excitations in the sequence of 'd *-c -b –a*' are necessary for the movement of the rotor in the clockwise direction [2, 3].

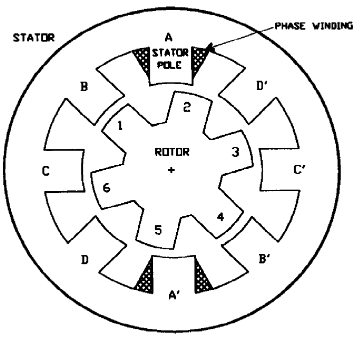


**Figure 1: Cross Section of an 8/6 SR Motor**

## Characteristics of SRM

The aligned position of a phase is defined to be the situation when the stator and rotor poles of the phase are perfectly aligned with each other ($\theta_1$-$\theta_2$), attaining the minimum reluctance position and at this position phase inductance is maximum ($L_a$) [5]. The phase inductance decreases gradually as the rotor poles move away from the aligned position in either direction. When the rotor poles are symmetrically misaligned with the stator poles of a phase ($\theta_3$-$\theta_s$), the position is said to be the unaligned position and at this position the phase has minimum inductance ($L_u$) [2, 14].

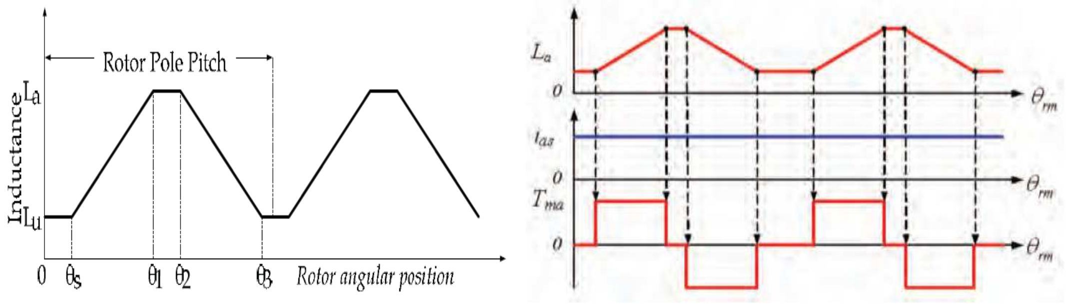


**Figure 2: Characteristics of Inductance and Torque of SRM**

## NEURAL NETWORK MODEL

A Structure of a Neural Network (NN) is a mathematical model or computational model inspired by the structure and functional aspects of biological neural systems, such as the brain. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. Figure 3 shows the typical structure of a NN. It has one input layer, one output layer and several hidden layers. In each layer, there are a certain number of nodes (neurons). The neurons in adjacent layers are connected together, while there are no connections between neurons in the same layer [10, 11].

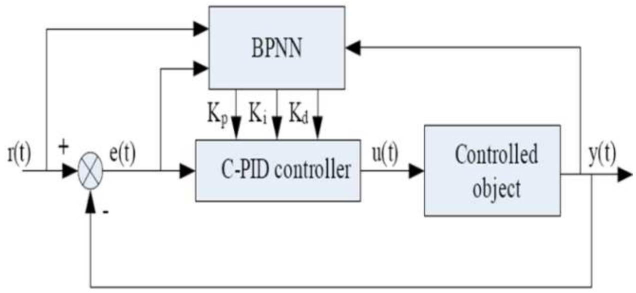


**Figure 3: Structure of a NN PID Controller**

## POWER CONVERTER

Power converter of Switched Reluctance Drive (SRD) system is comprised of a certain amount of power electronic devices with certain topological structure. The functions of power inverter are as follows:

- It works as a switch.
- Making the winding and resources on or off.
- It supplies feedback path for the stored energy of winding.
- And provides power to SR electromotor for the transformation of mechanical energy.

Its input terminal is connected to DC power, and output terminal with winding. Power converter holds important proportion in the whole SRD system, so its rationality is a key to improve the cost performance ratio [13].

### Analysis of the Main Power Circuit

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The choice also depends on the specific application [14, 15]. The number of switches required is twice the number of phases in our converter circuit. This circuit is especially suitable for high voltage, high power drives. The 4-phase SRM has '8' stator and '6' rotor poles, each phase comprises two coils wound on opposite poles and connected in series or parallel consisting of a number of electrically separated circuit or phases. These phase windings can be excited separately or together depending on the control scheme or converter. Due to the simple motor construction, an SRM requires a simple converter and it is simple to control [15, 16].

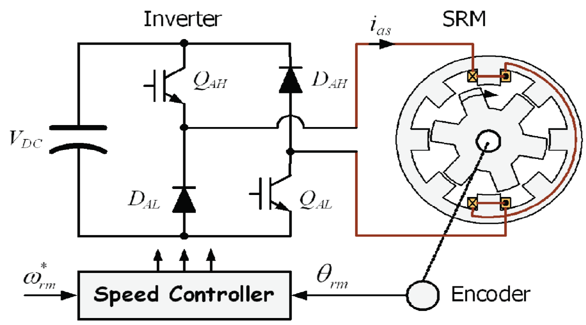


**Figure 4: 8/6 SRM with Asymmetric Half Bridge Converter**

## Converter Topology

The converter for the SRM should have the ability to provide a positive voltage loop to increase phase current, a negative voltage loop to decrease phase current, and a zero maintain the desired current level. From the existing converter topologies, the voltage loop to two most popular converter topologies for an 8/6 SRM are the asymmetric half-bridge converters shown in Figure 5. They are capable of providing the three voltage loops [4, 15]. Both converters are capable of operating in two quadrants. The switches and freewheeling diodes for both converters should be rated to withstand the supply voltage and switching transients [16]. However, the current ratings of the upper switches $T_{ac}$ and $T_{bd}$ of the shared switch half bridge converter must be determined to carry the sum of two phase currents. The upper switches $T_{ac}$ and $T_{bd}$ shown in Figure 5(a) are connected to two phase windings rather than one in the asymmetric half-bridge shown in Figure 5(b) [5, 7].

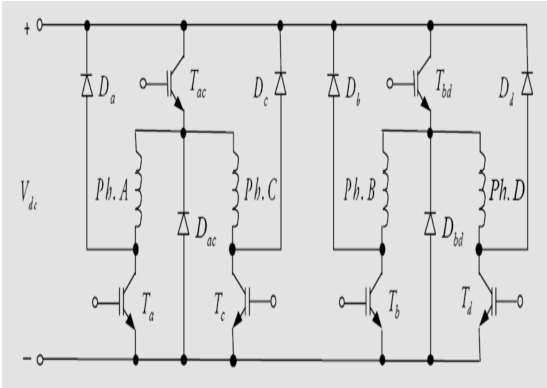


**Figure 5 (a): Shared Switch Asymmetric Half-Bridge Converter**

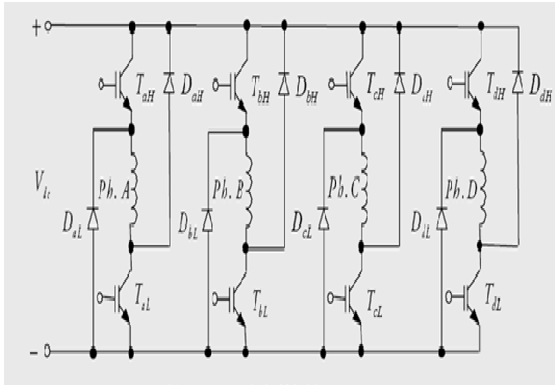


**Figure 5 (b): Asymmetric Half-Bridge Converter**

## RESULTS AND ANALYSIS

### Simulink Model without PID Controller

The simulation model of a switched reluctance motor without Proportional Integral Derivative (PID) controller is shown in figure 6. Without PID controller the simulation results posses high torque ripple, Speed regulation cannot be achieved. The above such drawbacks can be overcome by PID controller. The switched reluctance motor having '8' stator poles and '6' rotor poles are taken in to consideration for simulink process. A DC voltage of 240V is fed to the power converter circuit by the means of external battery source. Position sensor is used to sense the angle of the rotor for that instantaneous speed at which SRM is operating. Relay is used to generate a gate signal for the power converter circuit to operate.

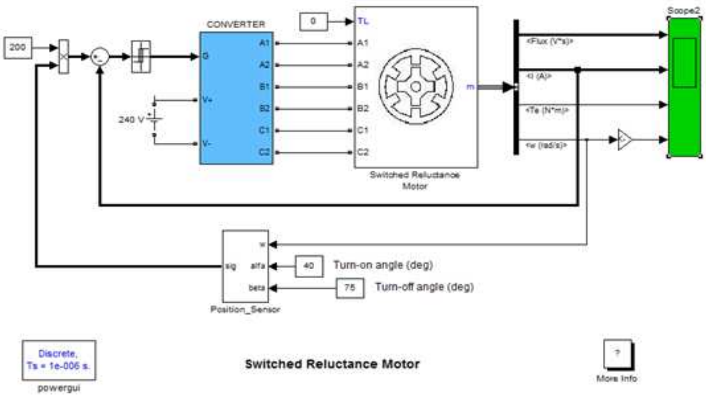


**Figure 6: Simulation Model without PID Controller**

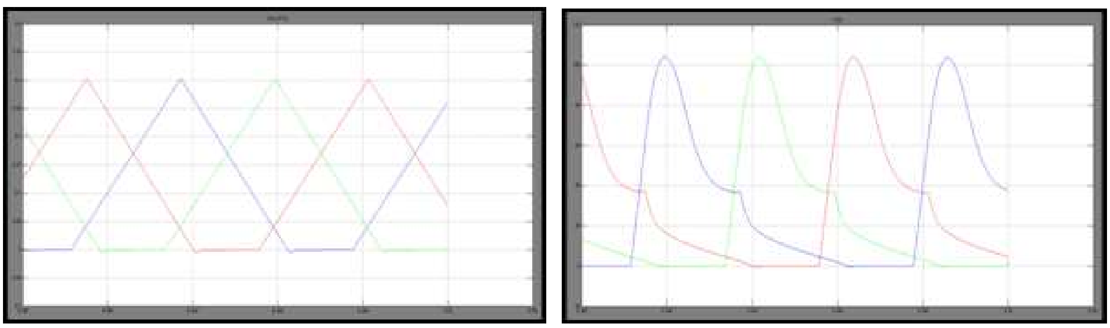

**Figure 7(a): Waveform of Flux and Current without PID Controller**

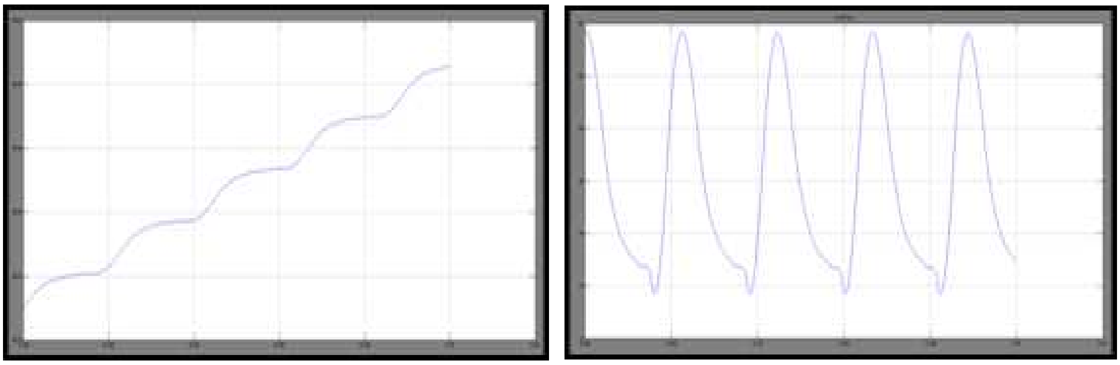

**Figure 7(b): Waveform of Torque and Speed without PID Controller**

The waveforms of the SRM without PID controller are shown in figure 7. In the figure 7 (a) the first graph shows flux Vs time deals that how the flux is developed in air gap of SRM and its steady state value of the flux is 0.3(v*s). The second graph shows the value of current.

In the figure 7 (b) first graph shows the torque of the switched reluctance motor i.e. 2.5 N*m at 1400 rpm with ripple content. The second graph shows the speed of SRM i.e., 1400 rad/s.

**Simulink Model with PID Controller**

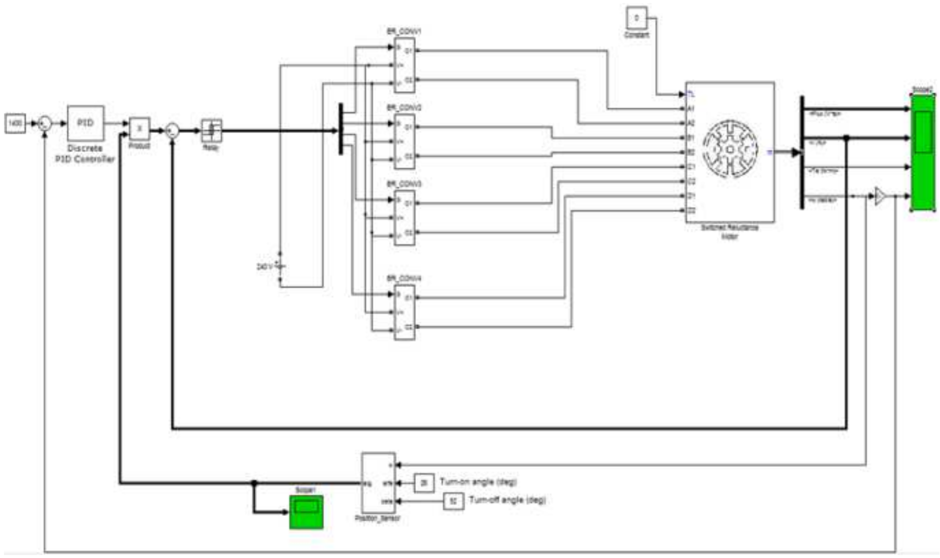


**Figure 8: Simulation Model for with PID Controller**

The simulation model of a switched reluctance motor without Proportional Integral Derivative (PID) controller is shown in figure 8. Without PID controller the simulation results will posses high torque ripple, Speed regulation cannot be achieved.

The above such drawbacks can be overcome by implementing the PID controller. The switched reluctance motor having ‘8’ stator poles and ‘6’ rotor poles is taken in to consideration for simulink process. A DC voltage of 240V is fed to the power converter circuit by the means of external battery source. Position sensor is used to sense the angle of the rotor for that instantaneous speed at which SRM is operating.

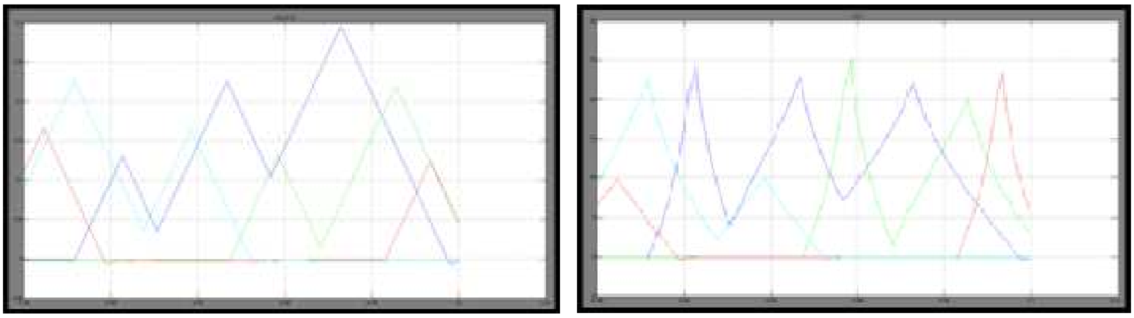

**Figure 9 (a): Waveform of Flux and Current with PID Controller**

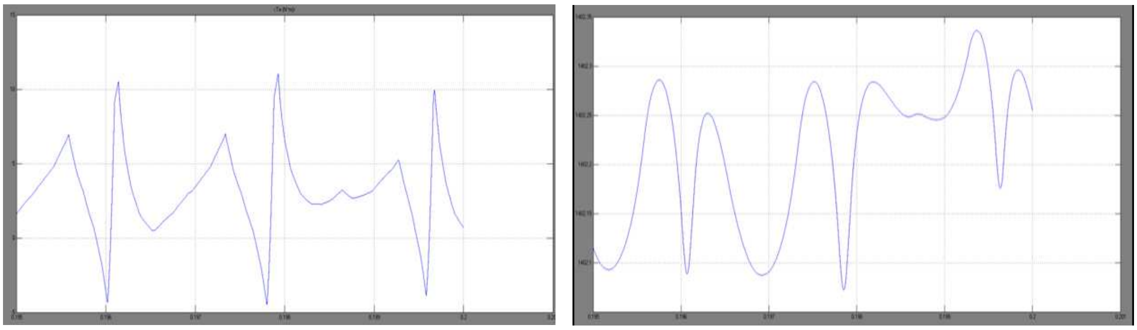

**Figure 9 (b): Waveform of Torque and Speed with PID Controller**

## CONCLUSIONS

In this paper the modeling and simulation procedure is presented for various operating conditions of SRM drive system. A Neural Network based torque controller has been presented for SRM Drive system with a minimum number of switches have been controlled torque ripple and the results are compared with and without PID controller. By implementing the PID controller for the SRM drive the torque ripple has been minimized and this drive system can be very efficient for Hybrid Electric Vehicles.

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