A New Resonant Driver for Switched Reluctance Motor

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Abstract: *The switched reluctance motor (SRM) drive is receiving increasing attentions from various researchers as well as industry as a viable candidate for adjustable speed and servo applications. Combining the unique features of an SRM with simple and efficient power converter that is uses, a superior motor drive system emerges which may be preferable for many applications compared to other AC or DC motor drive systems. Although a number of converters have emerged over the years for SRM drives, but every single driver has its own advantages and draw backs and there has always been a trade-off between gaining some of the advantages and losing some when a new driver is invented [3]. In this paper we present a new driver for switched reluctance motor. The driver features zero-current switching. It means all the switching operations are done when the phase current is almost zero and so that it reduces the overall power loss in the switching process also using the resonance phenomenon, it provides faster rate of rise and fall of current which helps the motor to operate at higher speeds.*

Keywords: Switched Reluctance Motor, Resonant Drive Circuit, SRM Drive, Resonant Driver.

1 Introduction

The low cost simple construction of switched reluctance motor, with its features of fault tolerance and ability to stand high temperatures makes it very attractive for the automotive application [3]. The static performance of an SR motor is characterized as torque developed by a single phase for various angular rotor positions and the phase current levels. The maximum torque produced by a SRM depends on speed because the voltage generated by the motor at higher speeds reduces the amount of current that can be reached within a cycle and depends as well on the timing of the current pulses, turn-on and turn-off angles [1]. one of the hardest struggles in the SRM field is the converter design and topology. The essential features of an SRM converter are 1-Each phase of the converter must be able to conduct independent of the other phases 2- The converter should be able to demagnetize the phase before it steps into generating region if the machine is operating as a motor and should be able to excite the phase before it steps into the generating region if it is used as a generator.

There are different kinds of converters created before that we'll have a brief review of them here. Two-switch per-pole [4], (N+1) switch converter [5], bifilar converter [6],[9], C-dump converter [7], resonant converter [8] and hybrid converter [2].

In two-switch per pole, the upper transistor is used to control the amount of current flowing through the motor phase and the lower one synchronizes the proper operation of that phase with the rotor position by using the hall effect sensors. The phase excess energy is returned to the battery using the diode.

In (N+1) switch configuration, all the phases have one transistor in common (T1) and another transistor (T2) independent of the others. When T1, T2 are turned on, phase A is energized by applying the source voltage across the phase winding. The current can be limited to the set level by controlling either T1 or T2 or both. The merit of this converter is higher utilization of power devices due to the shared switch operation. Bifilar converter regenerates the stored magnetic energy to the source by using one switch and one diode per phase. This is achieved by having a bifilar winding in series with the diode with the reverse polarity. When the switched is turned on, the current flows through the phase winding and as soon as the current reaches the set value the switched is turned off and the diode being on directs the energy back to the source. The draw back of this converter is increase of complexity of the motor. It has the advantage of using fewer devices per phase.

C-dump converters have various forms but the basic principle of them all is that the energy from the off-going phase is dumped into a capacitor to achieve fast demagnetization. The conduction of the phase is initiated by turning on the series switch with the phase. During commutation period, the diode which conducts the phase energy to the dumping capacitor is forward-biased and so that transfers the phase winding energy to the capacitor. The excess energy stored in the capacitor is transferred back to the source by turning on the transistor which is connected to the power supply. In a resonant converter the energy is first dumped into a capacitor and after the phase winding current falls to zero, the stored energy resonates using the dumping capacitor and another inductance which is connected to the phase winding and is returned to the power supply faster comparing the other topologies and this could be one of the advantages of this type of drivers.

The last topology we want to have a review on is the new hybrid converter which is comprised of a capacitor charged through the resonant circuit comprising the motor phase winding inductance during the phase turn off interval. This capacitor is discharged during the next working stroke into the appropriate phase winding and so that the driver makes use of the energy stored in the previous phase commutation process. The new resonant circuit topology presented here , has the advantage of the resonant circuits, that is faster rate of rise and fall of phase current and consequently higher motor speed and also it features zero-current switching .

2 The New Converter Circuit

The new driver circuit is provided below in figure 1. Basically it resembles the (N+1) switch per phase topology. The magnetization of the first phase is done when the stator and the rotor poles overlapping period begins or in other words as soon as the phase inductance starts to increase. In this situation M1 and M3 are turned on and the phase current is established. We call it the charge cycle because the capacitor will start charging.

Capacitor C series with the phase winding inductance produces a series resonant circuit and according to these circuit characteristics we'll have a sinusoidal waveform for the phase current. In the other hand, the capacitor will be floated after being charged by the DC power supply and so that the phase current approaches zero. With the appropriate switching procedure, we can keep the phase current flowing and this will generate the positive torque we need to run the motor. As soon as the capacitor C is charged to a predefined level, M1 and M3 are turned off by the control unit and M2 is turned on. While M1 and M3 are turned off the phase inductance will change it's polarity to maintain it's current so that diode D1 will be conducting. With M2 being turned on and D1 being forward-biased, the stored energy is transferred back to the source we call this the discharge cycle. As we discussed before we have to stop the capacitor from being full-charged and this means that at the exact time the discharge cycle has to be accomplished. For that we have to know exactly when the phase is approaching zero. Generally we can divide the circuit into two main parts: 1- the voltage comparators 2- The control unit and pulse generator.

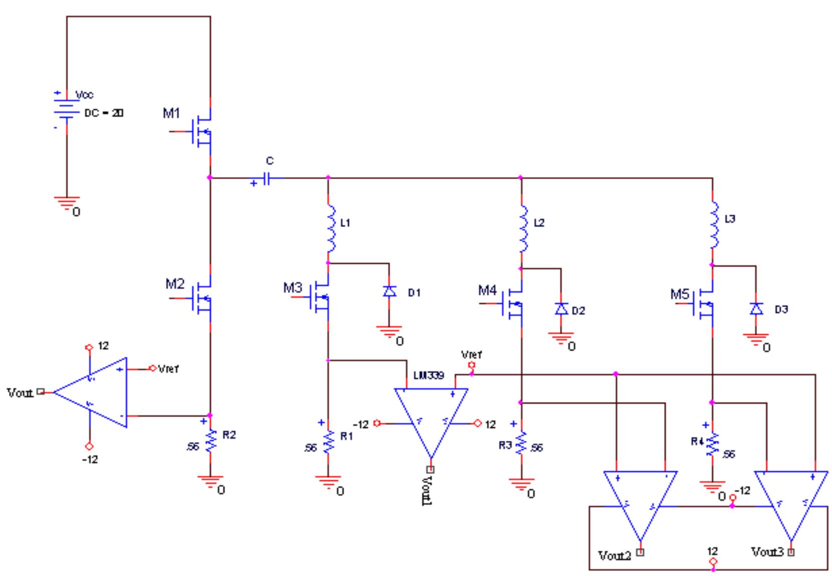


Figure 1: The new converter circuit

The system block diagram of the converter is shown in the following picture.

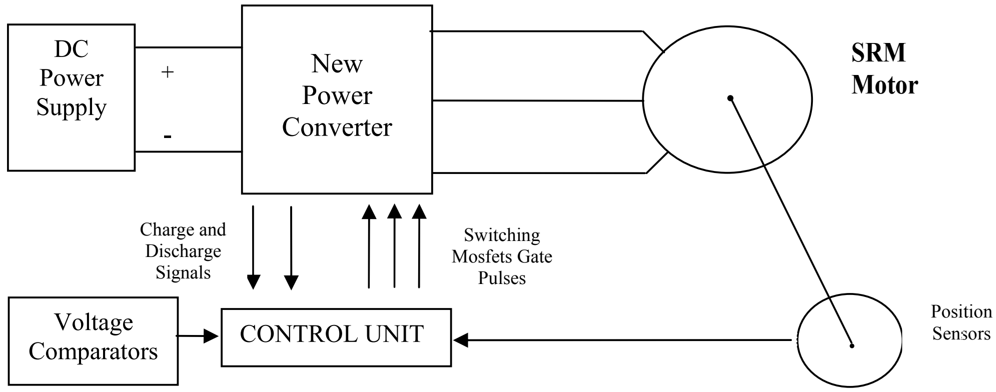


Figure 2: General Block Diagram of the Resonant Converter

3 The Voltage Comparators

We are not able to monitor the phase current, so that we need to convert it to the voltage by using the .56 Ω resistor series with the phase switch (depicted in figure 1). Meanwhile adding the resistor will not affect the circuit at all. The voltage produced across the resistor is then compared with a referenced voltage (.2V) by an opamp. If it's higher than that the output will go high otherwise it remains to zero. The generated pulse is directed to the control unit for further considerations. Figure 3 provided by the simulation results, illustrates how the output pulse is generated.

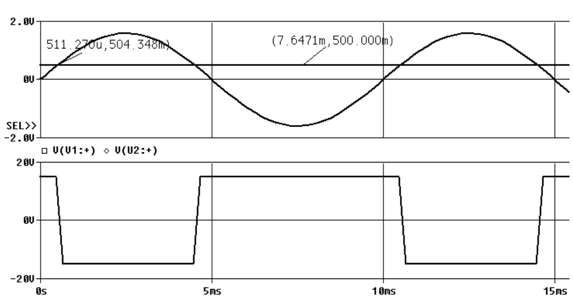
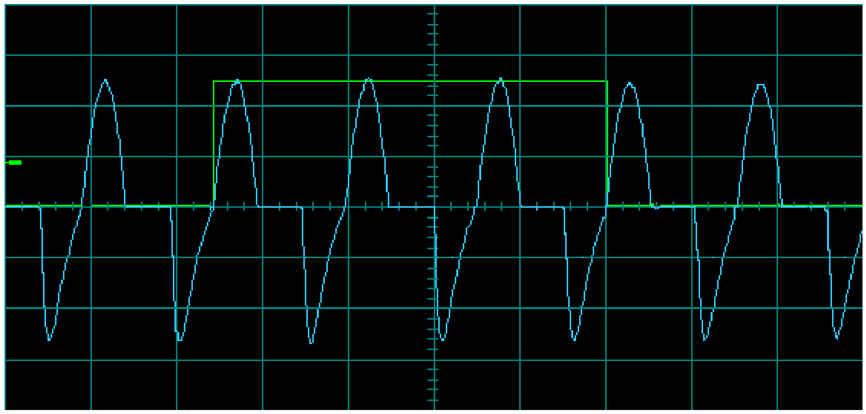


Figure 3: Voltage comparators output pulse and the phase current

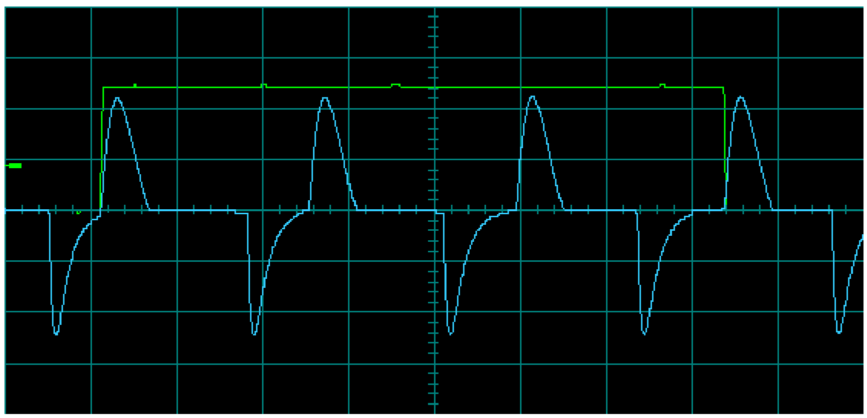
4 The Control Unit and Pulse Generator

The main part of the control unit is a micro controller (AT89C51) that controls all the operations. In order to synchronize the signals applied to M1 and M3 gates and to prevent short circuit, we need a powerful and intelligent control unit and the best choice would be 89C51 for its simplicity and usefulness. The control unit will process the input signals coming from the comparators and position sensors. As soon as overlapping between the stator and rotor poles occurs, the related signal is sent to the control unit and then charge and discharge cycle begins. We have allocated two interrupts to the charge and discharge signals. When M1 and M3 are turned on by the control unit, interrupt 1 is occurred and the charge cycle begins. The same thing happens to the discharge cycle when interrupt 0 is encountered. In one overlapping period, we could have several charge and discharge cycles which depend on the value of the capacitor used in the circuit. When the overlapping is finished no more interrupts are serviced until the next phase overlapping region arrives. For phase two, all the previous sequences will be repeated except that this time M1 and M4 will have the responsibility of capacitor charging. Corresponding to the capacitor used, the current schemes could be different. Figure 4 which has been captured with a digital oscilloscope, depicts the experimental results of two waveforms of the phase current related to their capacitors.

We know the lower the capacitor value is the higher the motor speed would be. Because for the capacitors with lower capacities, the charge and discharge cycle will be certainly faster and so the decay of the output torque would decrease.



Time (5ms/div), Volt (500mV/div)
Figure 4: A. charge and discharge of 220uF capacitor representation



Time (5ms/div), Volt (500mV/div)
Figure 4: B. charge and discharge of 1200uF capacitor representation

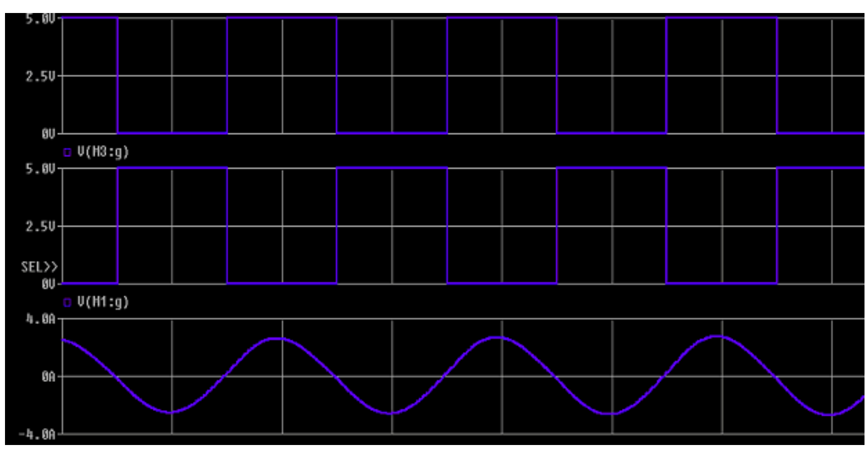


Figure 5: The Simulation of M1 and M3 gate pulses and the capacitor current waveforms

If we have a comparison between figure 4 and figure 5, we'll comprehend that the practical outputs do not exactly match the simulation results. In the simulation the phase current is completely sinusoidal but in the practical waveforms there is not such a thing. This is because the phase winding inductance has variable reluctance according to the rotor position and thereby we'll see different rate of rise and fall in the current of charge cycle comparing with the discharge cycle.

5 Conclusions

In this paper we developed and implemented a new resonant driver. The converter was successfully tested on 25W, three-phase, 12 by 8 switched reluctance motor and a detailed explanation and demonstration of the converter circuit have been presented. The practical results totally accommodate the simulations conclusions.
The concept of this driver was to speed up the time required for rising and falling the phase current. Although it featured zero-current switching that decreased the total switching power losses in the converter.

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