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POWER LOSS REDUCTION IN PWM INVERTERS OF INDUCTION MOTOR DRIVES BASED ON SOFT SWITCHING TECHNIQUE

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ABSTRACT

Performance of the systems equipped with PWM inverters can be improved through increasing frequency of switching. However, frequency improvement made some troubles in the system such as electromagnetic interactions or interferences (EMI) and increased power loss. Generally in the inverters working based on PWM method, the losses of switching are so high, where the load is induction. But, in the presented method, it is possible to minimize the switching losses. In this investigation, by adding Snubber circuit in the driver circuit, switching losses significantly reduced. The results obtained from simulation showed that soft switching inverter is more efficient than hard switching inverter in terms of reduction of switching losses.

Keywords: PWM inverter, Electromagnetic interactions, Soft switching, Power loss, Induction motor, Snubber circuit.

1. INTRODUCTION

Regarding the fact that electric motors are among the major tools in industry, the provision and presentation of machines owning the least maintenance costs and the most efficiency as well as control capability is of the critical objectives for respective researchers and experts. The rotation rate of rotary field in induction motors is a function of source frequency and the number of stator poles. Before the advance of power electronic elements, changing the frequency of induction motors was not feasible. And, it constrained the application of these motors. There are different methods for changing the speed of induction motors. Yet, the most widely used method is PWM technique or Pulse-Width Modulation. In this technique, a DC wave can be connected and disconnected periodically and based on speed. Accordingly, it is possible to control the average input power of the motor. Based on examinations, we can improve the performance of systems using PWM inverters. Using the topologies of inverters by hard switching technique resulted in considerable switching losses, electromagnetic interference, and the reduction of the inverter efficiency. The type of switching in which the voltage of feeding source is completely placed on transistors and resistors when each phase switch is called hard switching. In this method, considerable losses occur on switches which are highly effective in reducing the efficiency of inverter. If switching is done when we have zero voltage or current, then the losses on switches will be removed. This type of switching is defined as soft switching. In these inverters, using

other elements leads to resonance at the time switching circuit and reduces current to zero. This frequency increase can result in the increase of switching losses [1-3].

The idea of using ZVS and ZCS modes in three-phase inverters is done via Spatial Vector Modulation or Pulse-Width Modulation (PWM). That is, a small time is allocated to direct the secondary switches in the interval of turning on and off the two main switches of the inverter. The secondary switches are turned on so that circuit works in resonance state in a fraction of the main period. Then, Zero Voltage Switching (ZVS) when switching on and Zero Current Switching (ZCS) when switching off will be possible for the main switches. In the inverters working by PWM method, the losses of switching the switches are high since the load is induction. But, in the presented method, it is possible to minimize the switching losses. In this paper, it is demonstrated that as Snubber circuit is added, we can significantly reduce switching losses [4].

2. SIMULATION METHOD

To simplify the analysis of this perspective, the following assumptions are assumed:

The entrance filter capacitor (C_i) is big enough. Then, dc voltage (V_d) is presumed constant. All resonance inductor and capacitors are together where Cr is the amount of stray capacitance, IGBT, and the external capacitance added. And, L_r is significantly smaller than the inductance of motor. Hence, load current can be considered as the short length of stator switching. The schematic view of the inverter is shown in Figure 1 with respect to the secondary switches.

Figure-1. The schematic view of soft switching inverter using Snubber
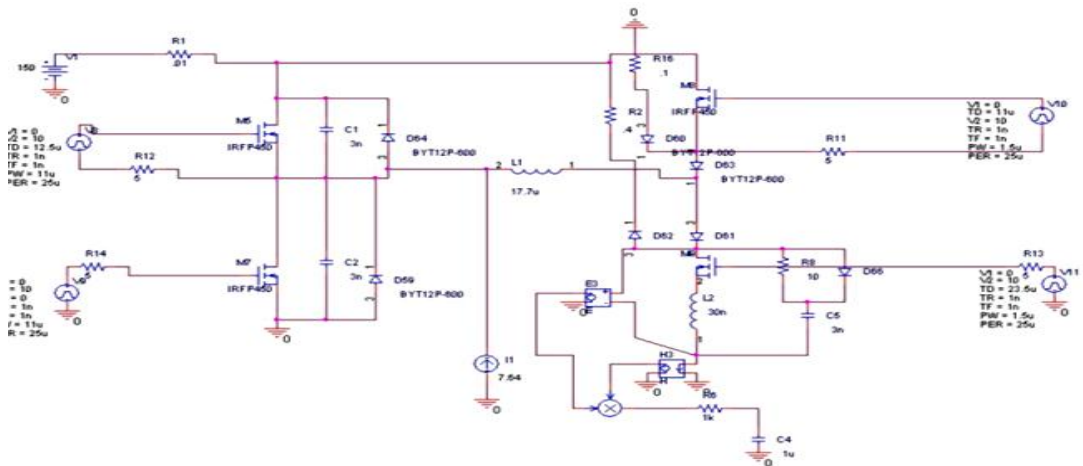
One of the methods for reducing extra voltage in the switch is to use Snubber networks [5]. A variety of Snubbers used in the inverters include RC, RL and (or) RCD Snubber. RC and RCD Snubbers lead to the reduction of switching losses and decrease of voltage changes rate when transistors are off. This can be used in this simulation. In Figure 2, Snubber network and the way it is connected to respective circuit are illustrated [6, 7].

Figure-2. Snubber network and the way it is connected to respective circuit
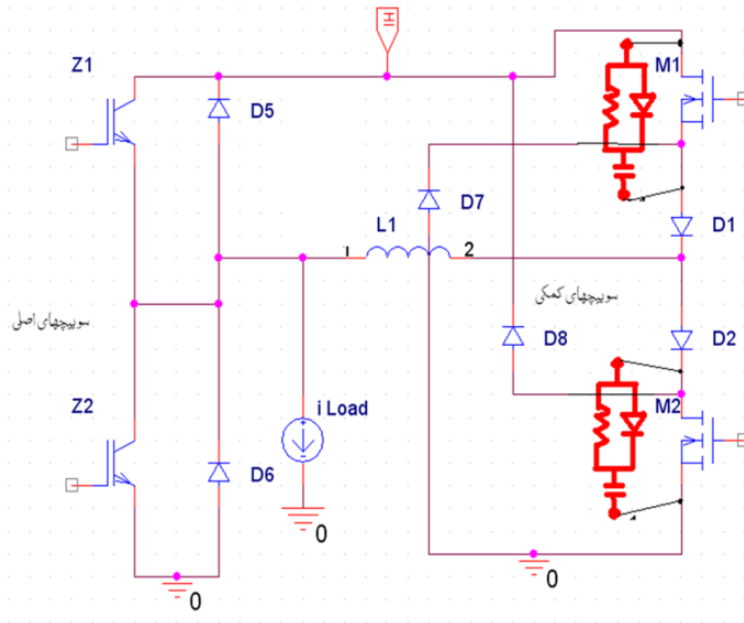
3. MEASURING AND CALCULATING SWITCHING LOSSES

Losses in power inverters usually consist of two parts: Conduction Losses and Switching Losses. To estimate the former, the instantaneous power lost at each switch is calculated based on its instantaneous voltage and current. And, finally, the average value of the instantaneous power is estimated. The voltage and current of power switches depend on the voltage-current characteristic of the switch. The accurate calculation of semi-conductor losses is required for designing a reliable system which uses the smallest power switches possible. In case of using PWM switching pattern for controlling inverter, power switches are usually switched on and off by high frequency. The currents of diode and transistors are highly complex. Power losses in the inverters can be calculated by the direct analysis of the shape of current waves of switches, computer modeling, mathematical calculations, and so on. Different methods are also presented for this which is generally based on the mathematical analysis of the wave shape of current in power switches [8].

Using mathematical equations to calculate the losses usually accompany approximations. Accordingly, it is possible to sample the voltage and current and calculate instantaneous power using *P=VI*. Average power is also determined by integrating the above equation. For instance, in some calculations, it is assumed that the load current is completely a sine current. And, its harmonics are ignored. Besides, due to the complexity of the actual model of power switches, models are replaced with completely approximate models in most of the switches calculations. As a result, there is partially significant difference between the calculated values and the actual values. In case of computer modeling of power inverters, a relatively accurate model of power switches can be applied.

Several methods are presented for the computer modeling of inverters. It is really a boring and time-consuming work to calculate the equations of power inverters state for each certain topology. As a result, it is not possible to directly simulate the state equations of these models using calculation software like MATLAB [9].

Switching Function can be used as the powerful tool of analyzing power models. In this method, power inverters are modeled based on their output wave rather than their circuit topology. It was possible to define the actual characteristics of each certain switch, in this method. And, it is no longer required to calculate the system state equations for its simulation. Due to the simplicity of the model applied, the issue of conversion is resolved and the times required for simulation is effectively reduced. Another property of the method is that it is possible to generalize it to other power inverters [10, 11].

4. VOLTAGE AND CURRENT WAVEFORM BEFORE AND AFTER ADDING SNUBBER

To observe the effect of adding Snubber in the circuit, we assume that the secondary switches include a leakage induction. Then, we will see that the switching losses of switches will considerably increase. In fact, the higher losses occur at the time of start-up. To show the effect of adding the Snubber circuit which prevents from the instantaneous changes of switch voltage, the shape of voltage and current waves of the secondary switch is presented in Figures 3 and 4 after and before adding Snubber.

Figure-3. The shape of voltage and current waves of the secondary switch before adding Snubber
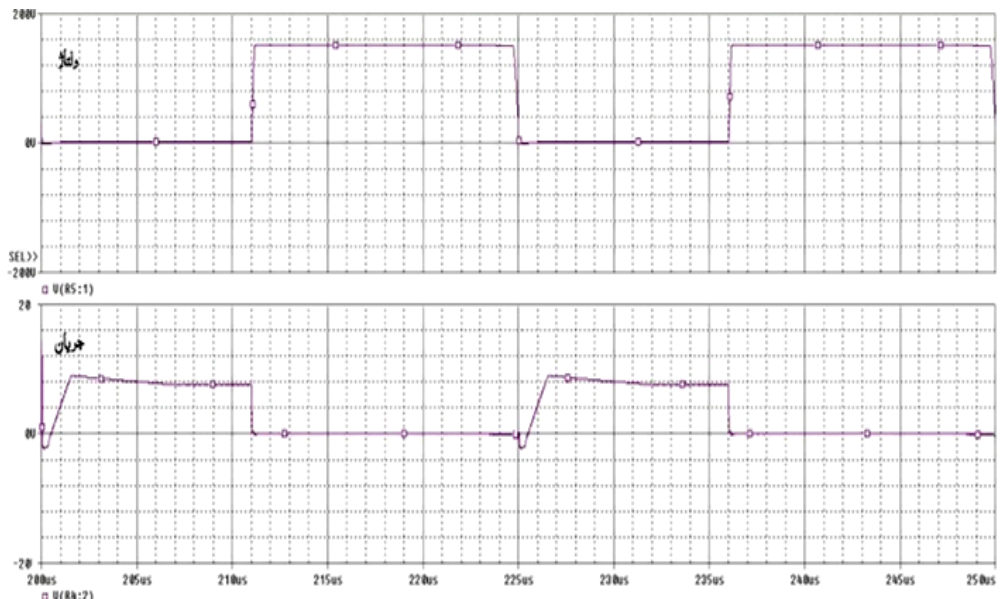
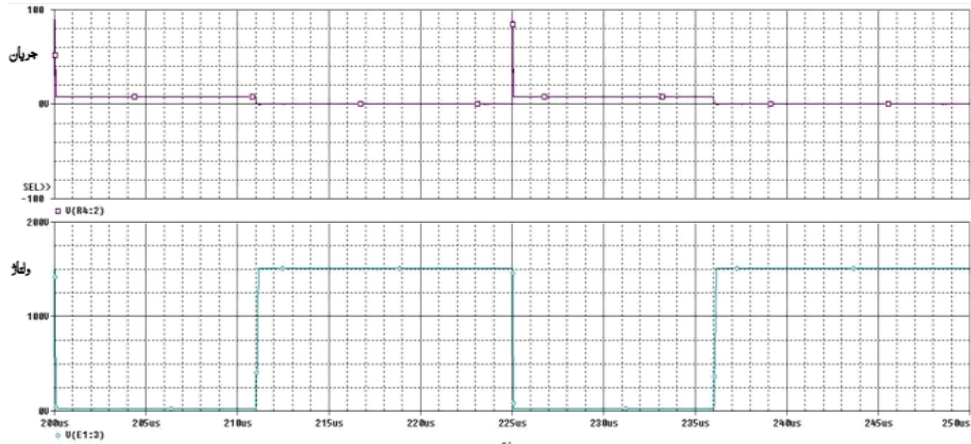**Figure-4.** The shape of voltage and current waves of the secondary switch after adding Snubber
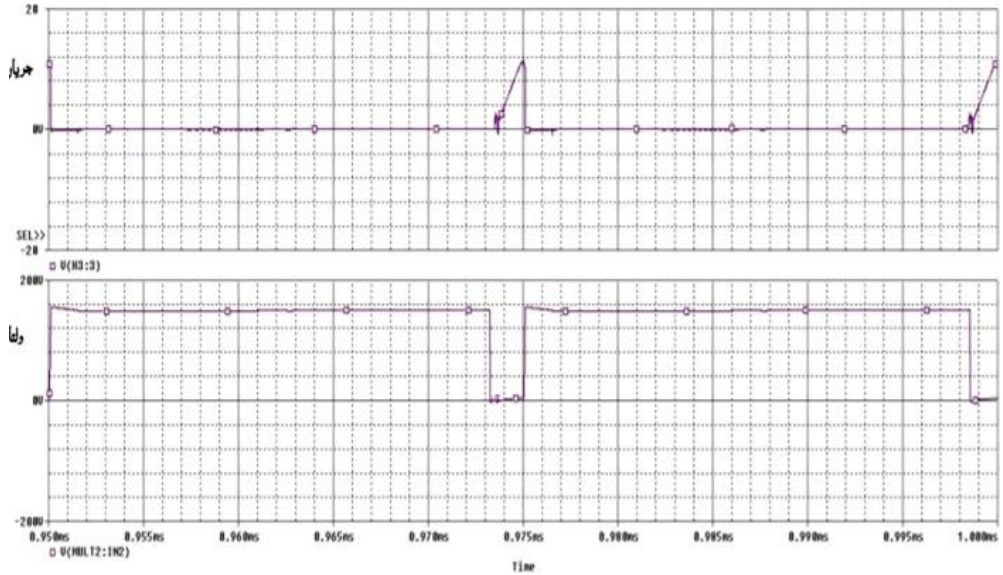
In this figure, smaller changes in the secondary switch voltage after adding Snubber can be clearly seen. With respect to the reduction of voltage frequencies and the direct relationship between the losses and voltage-current product, it is shown that Snubber circuit results in the decrease of switch losses. To prove the reduction of the main switches losses as the secondary switches are added, the shape of voltage and current waves at the both ends of the main switch in two types of hard and soft switching (before and after adding secondary switches) are represented in Figures 5 and 6.

Figure-5. The shape of voltage and current waves of the main switch after adding Snubber

Figure-6. The shape of voltage and current waves of the secondary switch after adding Snubber

It is seen that high peak values of voltage and current lead to the considerable increase of instantaneous power. The average values of losses before and after adding switch are measured then and the shape of their waves are shown. In this simulation, measuring average power is first sampled from the switch voltage and current. Then, it enters into a multiplier or analogue and its average is measured. As seen in the following figures, the average switching losses of switch connection and disconnection percentage has reached a stable value. As observed, the value is more compared to the time when we did not use Snubber. Hence, using Snubber has resulted in the reduction of the secondary switches losses in the start-up moment. Selecting Snubber elements is done with respect to the value of switching frequency and the maximum current of each switch as well as the leakage induction.

5. COMPARING SWITCHING IN PWM INVERTER CIRCUIT EQUIPPED SNUBBER

In this simulation, a diode-resistor-capacitor Snubber (10Ω and 1nF) and a high frequency diode were used. In Figure 7, resistor and capacitor R6-C4 was applied to calculate average instantaneous power measured. Simulating inverter circuit losses without using Snubber is illustrated in Figure 8.

Figure-7. Resistor and capacitor for measuring average power
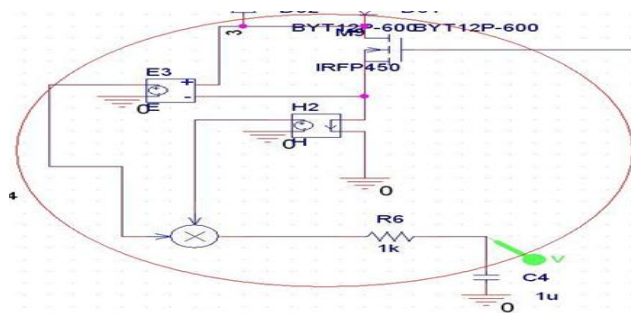
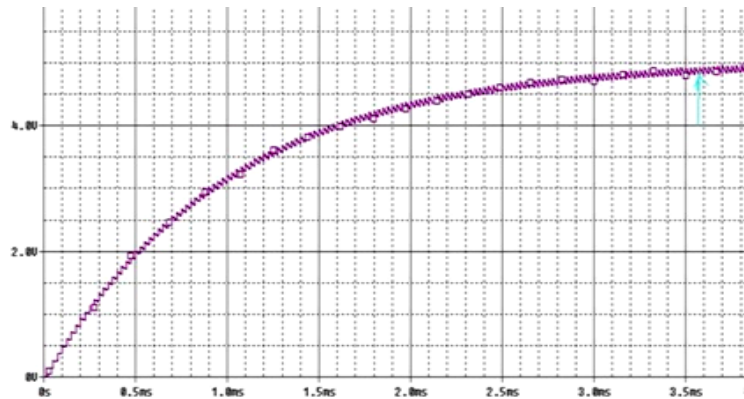**Figure-8.** The switching losses of the inverter without using Snubber
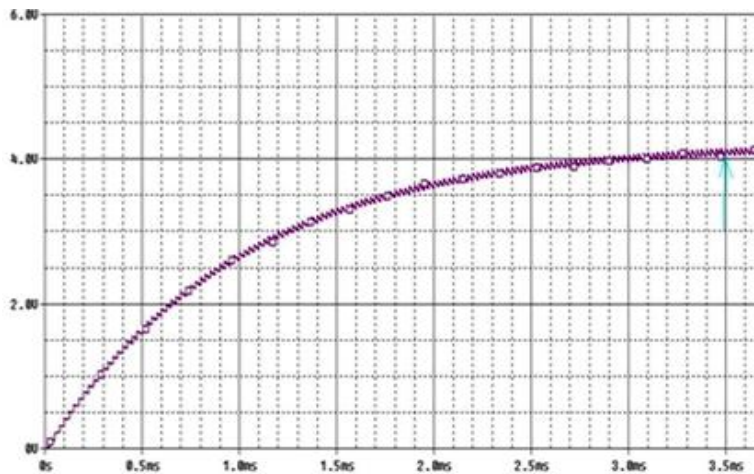

Figure-9. Switching losses in inverter using Snubber

In Figure 9, the simulation of soft switching inverter using Snubber is illustrated in terms of switching losses. The comparison between Figures 8 and 9 demonstrates that the switching losses in the inverter are reduced using secondary switch and Snubber.

6. CONCLUSION

In comparison with hard switching technique, the soft switching technique of PWM inverter leads to the reduction of switching losses. Yet, the switching losses are again considerable. However, they can be decreased using Snubber circuit. The soft switching of PWM inverter was compared together with Snubber circuit. Regarding the results of the presented simulation, it was demonstrated that soft switching inverter using Snubber circuit has better potential for reducing switching losses compared to soft switching inverter.

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