ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
Vol. 2, Issue 3, March 2013

Reliability of Permanent Magnet Brushless D.C. Drives Using IGBT's

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Abstract*:* Brushless DC (BLDC) motors are one of the electrical drives that are rapidly gaining popularity, due to their high efficiency, good dynamic response and low maintenance. This paper briefly reviews the fundamentals behind the motor. Within the last decade, the research and development on BLDC motor drives have been focused on the motor topology design and optimization as well as the motor control strategies. Nevertheless, most of these converter topologies employ the hard-switching technique which causes high switching losses and severe electromagnetic interference. Recently, a number of soft-switching techniques have been successfully developed. In this paper, soft switching technique using IGBT's is applied for Brushless DC Motor. Its principle of operation and simulation results will be given.

Keyword-- Permanent Magnet Machines, Hard Switching, Soft Switching, IGBT'.

I INTRODUCTION

An electronic Brushless D.C. Controller (also known as a Driver, or Electronic Speed Controller), replaces the mechanical commutation system utilized by a Brush DC Motor, and is required by most Brushless DC Motors to operate. The Brushless DC Electric motors are one of the most essential components and the driving force of industry today. The ac motors are usually less expensive, rugged and have low maintenance but hard to control. On the other hand the conventional dc motors are highly efficient and their characteristics make them suitable for use in different applications. However, one of their drawbacks is the need for a commutator and brushes, which are subjected to wear and tear and require maintenance. That's why the Permanent Magnet Machines are developed which are able to overcome all of the above limitations and to provide the requirements of a well variable speed drive. [1][2]

A Brushless DC Motor also known as a BLDC Motor, is a synchronous electric motor powered by a direct current. As the name implies, the Brushless DC Motor does not operate using brushes; rather it operates with a controller via electronic commutation. The permanent magnet machines have the feature of high torque to size ratio. They possess very good dynamic characteristics. The PMBLDC motor is fed with rectangular voltages and the windings are distributed so as to produce trapezoidal back e.m.f.

An electronic Brushless D.C. Controller (also known as a Driver, or Electronic Speed Controller), replaces the mechanical commutation system utilized by a Brush DC Motor, and is required by most Brushless DC Motors to operate. In a Brushless DC Motor controller, Hall Effect Sensors are used to identify the position of the rotor. [1][2]

For proper commutation, the current must reverse polarity every time a magnet pole passes by it, in order that the torque is unidirectional. In the DC commutator motor, the commutator and brushes perform the polarity reversal. In the brushless DC motor, the polarity reversal is performed by power MOSFETS, which must be switched in synchronism with the rotor position.

To rotate the BLDC motor, the stator windings should be energized in a sequence. The stator is normally 3-phase star connected. Each commutation sequence has one of the windings energized to positive power (current entering into the winding) and the second winding energized to negative power (current exits the winding) and third winding non-energized. It is important to know the rotor position in order to decide this energizing sequence. Rotor position is sensed using Hall Effect sensors embedded into the stator. Most of the BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor. Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
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sequence of commutation can be determined. Torque is produced by the interaction of the magnetic field produced by the stator windings and the permanent magnets.[2][7]

Fig.1 shows the block diagram of Brushless D.C Motor.

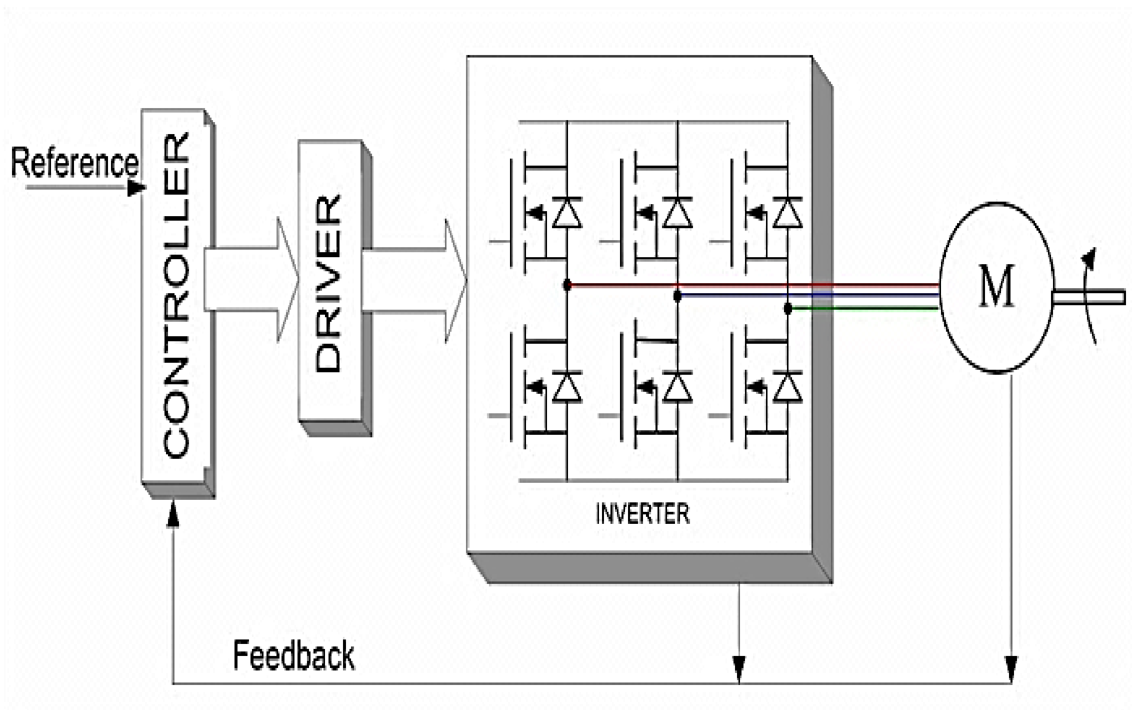

Fig.1 Block Diagram for a Brushless D.C.Motor

II HARD SWITCHING & SOFT SWITCHING

There are two ways of handling the drive current brushless D.C. motor:
i) Hard switching
ii) soft switching.
In the hard switching technique, both phase transistors are driven by the same pulsed signal: the two transistors are switched-on and switched-off at the same time. [3]
In soft switching mode the low side transistor is left ON during the phase supply and the high side transistor switches according to the pulsed signal. Traditional hard-switching inverters presented several problems during switching. During turn-on, the device current rises from zero to the load current with additional diode reverse recovery and stray capacitor charging and discharging currents on top of the load current. Typically, a current spike will occur, and the peak device power consumption is extremely high. During turn-off, the device voltage rises. Due to the leakage inductance in the loop, a voltage overshoot caused by Ldi/dt will occur, and the device voltage will exceed the dc bus voltage. This voltage overshoot can be reduced by a good circuit layout and high frequency dc bus capacitors. The turn-off loss varies among different types of devices depending upon the turn-off delay and current fall time. The power MOSFET consumes least turn-off loss. The insulated gate bipolar transistor (IGBT) turn-off loss also varies among different manufacturing processes. Some ultrafast IGBTs may have low turn-off loss close to that of power MOSFETs. The bipolar junction transistors (BJTs), in general, have a long turn-off delay time and consequently, high switching losses. Another switching problem is the voltage rise and

ISSN: 2319-8753

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fall rate, di/dt. During turn-on, the voltage falls to zero when the opposite switch turns on. During turn-off, the voltage rises to the dc bus voltage with an overshoot.[3][7]
The use of soft-switching inverter is a logical choice to serve the following purposes:
1) Eliminate switching losses
2) Reduce switching dv/dt
3) Allow high frequency switching

III MATLAB MODELS

A) Model without Soft-Switching

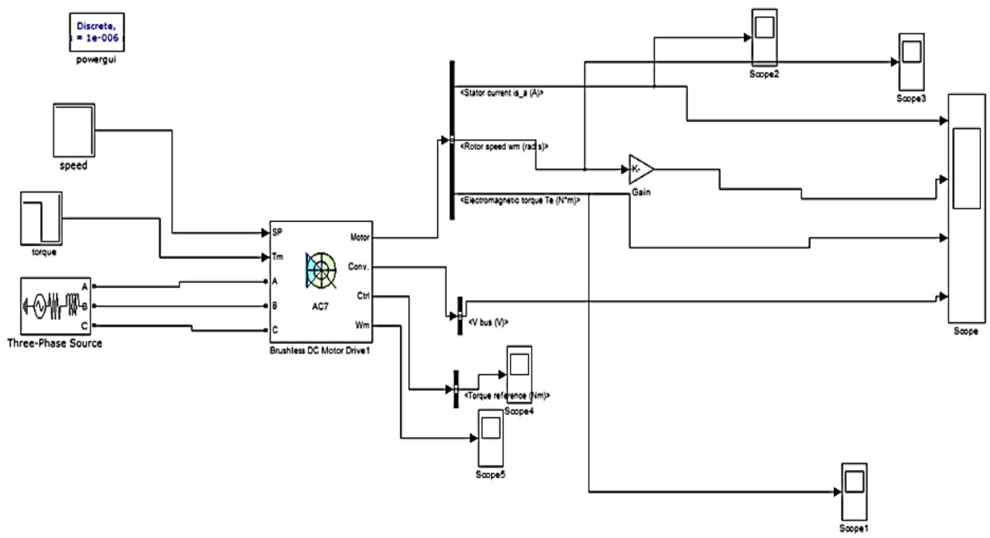

Fig.2 BLDC without soft switching

B) Model with Soft-Switching

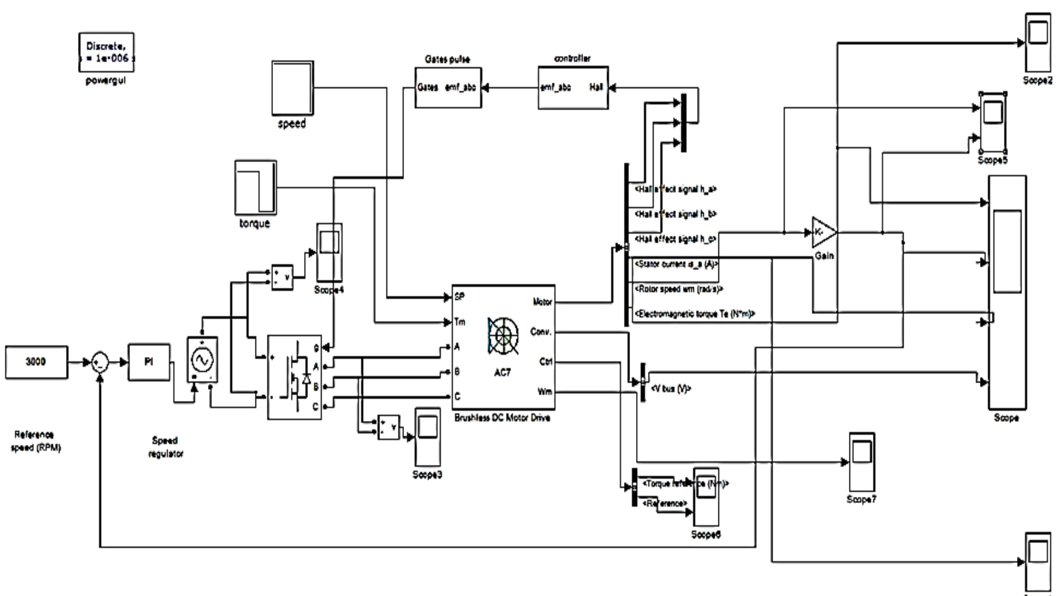

Fig.3 BLDC without soft switching

IV CIRCUIT OPERATION FOR BLDC MOTOR USING IGBT

Current is passed through one of the stator windings. Torque is generated by the tendency of the rotor to align with the excited stator pole. , if the poles a1 and a2 are energized then the rotor will align itself with these poles. Once this has occurred it is possible for the stator poles to be de-energized before the stator poles of b1 and b2 are energized. The rotor is now positioned at the stator poles b. This sequence continues through c before arriving back at the start. This sequence can also be reversed to achieve motion in the opposite direction. This sequence can be found to be unstable while in operation.[12] [13]

The direction of the torque generated is a function of the rotor position with respect to the energized phase, and is independent of the direction of current flowing through the phase winding. Continuous torque can be produced by intelligently synchronizing each phase's excitation with the rotor position. The amount of current flowing through the BLDC winding is controlled by switching on and off power electronic devices, IGBTs here, which can connect each BLDC phase to the DC bus.

The Soft switching circuit uses 3 IGBT .The IGBT act as switches to provide a series of DC pulses to the brushless dc motor. Since Brushless DC Motor frequency controls are for 3-phase motors, there are 3 IGBT, one for each phase. IGBT connects each motor terminal to the positive side of the DC supply 220 V. In that way, each terminal to terminal or line to line voltage can be either positive or negative. By controlling the switching sequence of the IGBT, the control provides a simulated 3-phase sine voltage with frequency and voltage control. The waveform is composed of DC pulses and doesn't look too much like a sine wave, but the effective value is a reasonably good simulation of a sine wave. Torque ripple of motor is reduced significantly. For a given voltage of supply, torque and speed of the motor are doubled. For a given speed of the motor, the voltage stress of switching device is reduced half; the insulation class requirement can be also reduced. BLDC (AC7) required 220 V to operate. The Soft switching circuit plays role for drive system for BLDC. From the constant block we are providing 3000 and soft switching circuit is designed to operate and switch if V_f goes above 220 v, which it is doing and exciting two phases of BLDC at a time (it can be A,B or B,C or A,C) depending upon the input signal. The speed precisely follows the acceleration ramp.[9]

V SIMULATION RESULTS

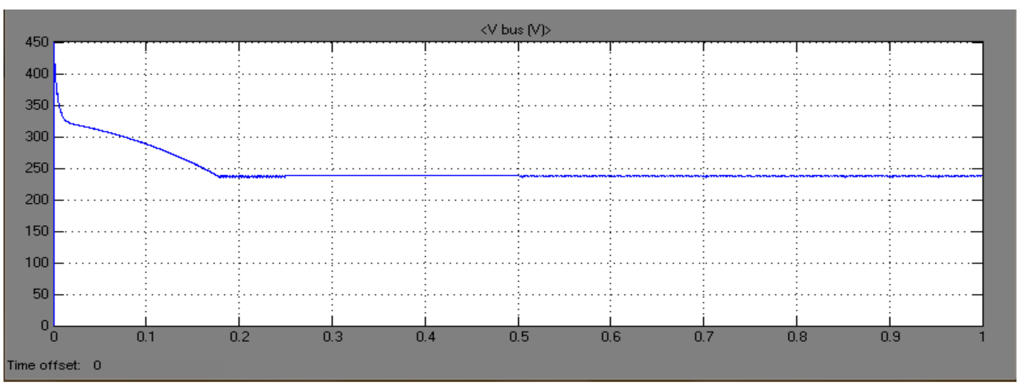

Fig.4 Voltage without Soft Switching

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
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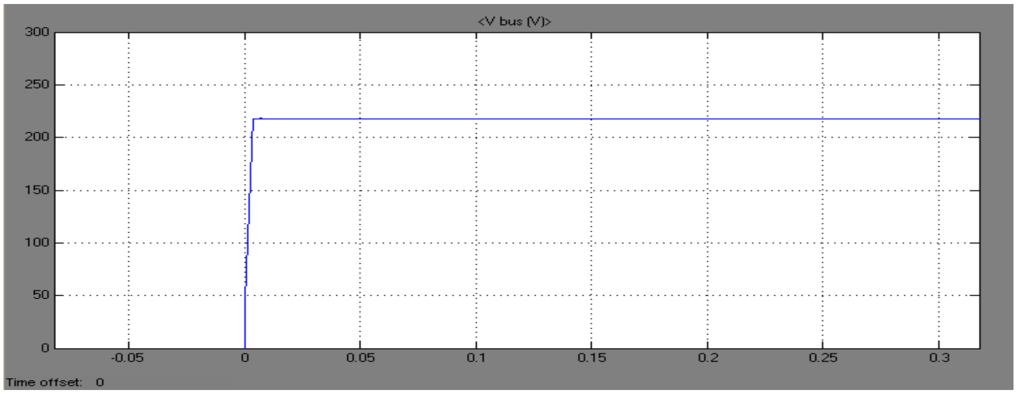

Fig.5 Voltage with Soft Switching

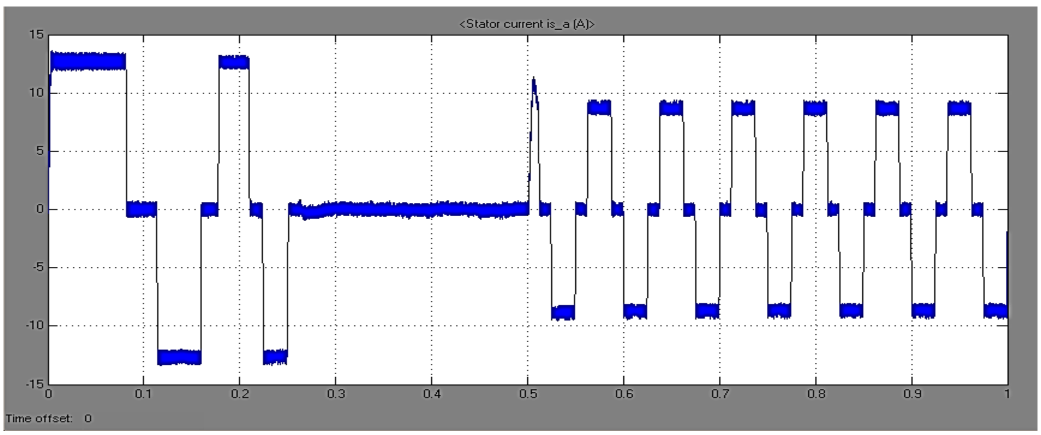

Fig.6 Stator Current without Soft Switching

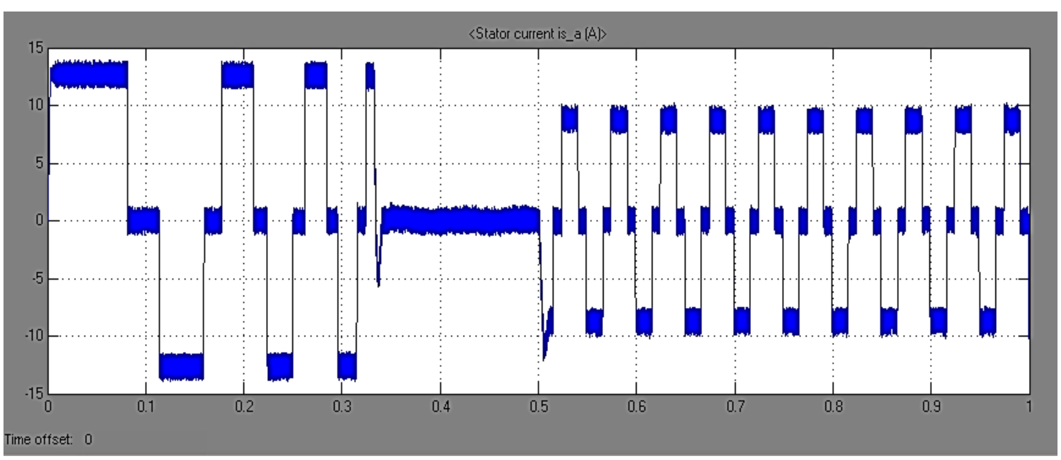

Fig.7 Stator Current with Soft Switching

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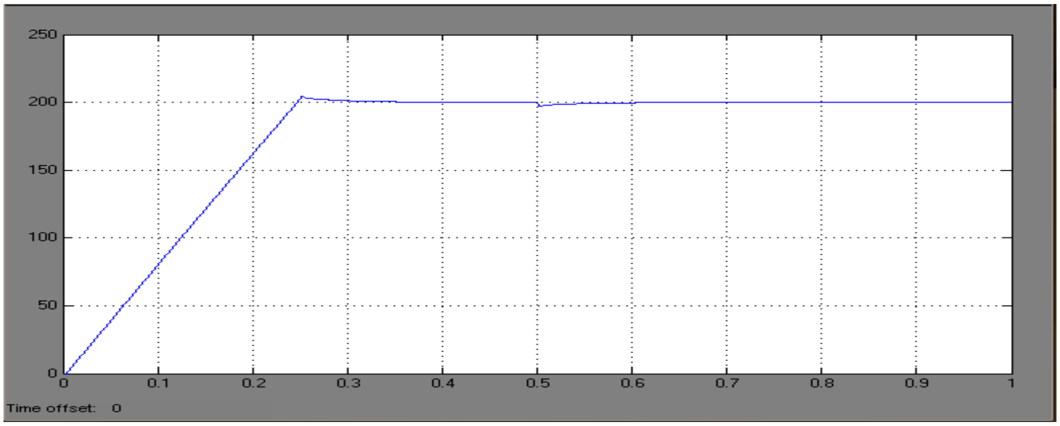

Fig.8 Rotor Speed without Soft Switching

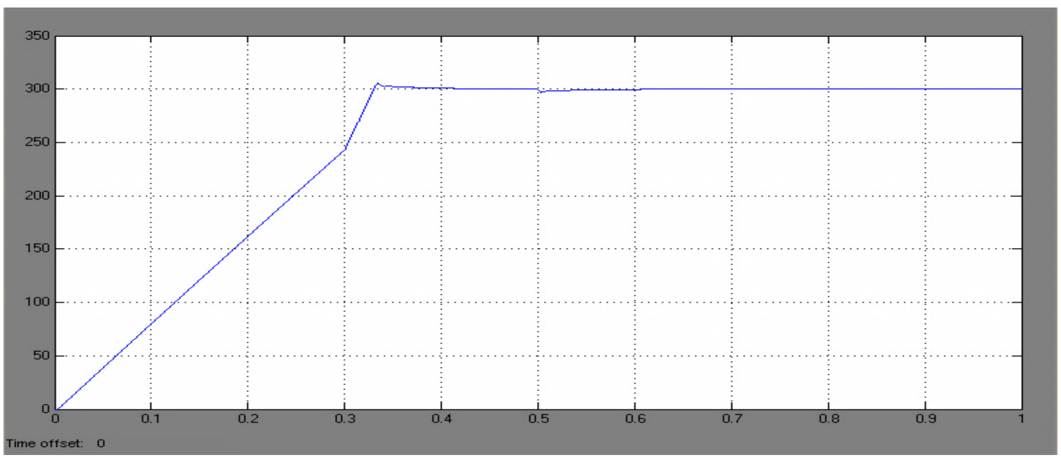

Fig.9 Rotor Speed with soft switching

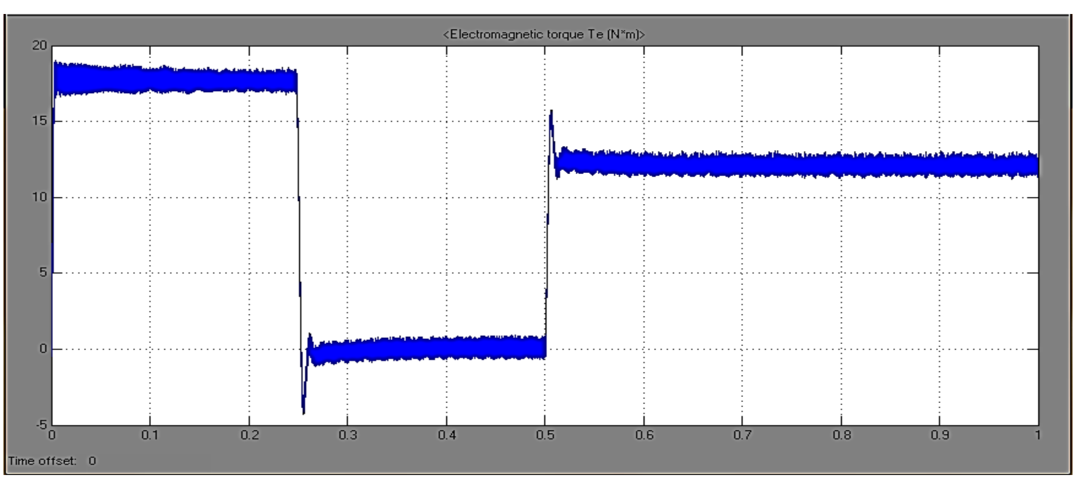

Fig.10 Torque without Soft Switching

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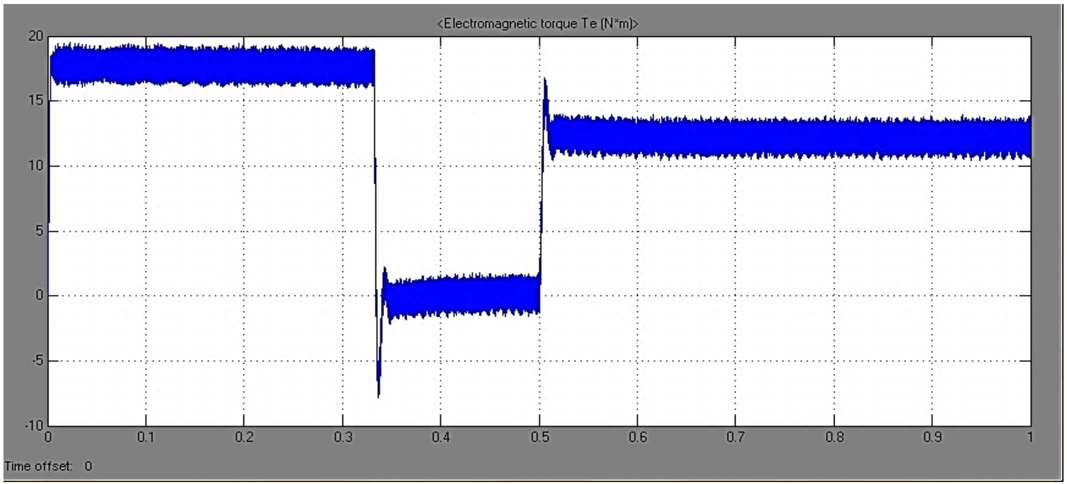

Fig.11 Torque with Soft Switching

VI CONCLUSION

A) Invetigators compared the voltage outputs of without soft switching model and IGBT soft switching model. (Fig 4 and 5)

- **a)** The voltage outputs of without soft switching model and IGBT soft switching model shows that in without soft switching the voltage decreases in interval (0, 0.18) and after that it becomes constant.
- **b)** In soft switching voltage remain constant over the whole period. There is no effect on bus voltage when motor starts with soft switching.

B) Invetigators compared the outputs of stator current of both the without soft switching model and IGBT soft switching model
at maximum current in both is 12A. (Fig. 6 and 7)

- **a)** The stator current starts increasing in interval (0,0.01), start fluctuating and becomes constant after 0.25 and remains constant until 0.5.Then it becomes proper and gives sine wave after 0.5. onwards in without soft switching model.
- **b)** The stator current with soft switching model is more sinusoidal than without soft switching model. It remains constant in interval (0.33 to 0.5).The stator current with soft switching is more stable and it gives better torque.

C) Invetigators compared the outputs of rotor speed of without soft switching model and IGBT soft switching model. (Fig.8 and 9)

- **a)** Maximum speed of without soft switching model is 200 (rad/sec) and maximum speed of with soft switching model is 300 (rad/sec). Thus rotor speed improves with soft switching using IGBT's.
- **b)** Rotor speed starts increasing from zero, after some time it become constant.

D) Invetigators compared the torque outputs of without soft switching model and IGBT soft switching model at maximum torque in both models is 19 N-m. (Fig.10 and 11)

- **a)** Torque starts , torque start increasing in interval (0, 0.01) and after that it remains constant up to 0.24 and further decreases and becomes negative. After that it again starts increasing and remains constant in interval from 0.26 to 0.5. From 0.5 it again starts increasing to maximum value and after it again decreasing and becomes constant in without soft switching.
- **b)** Torque in soft switching model starts increasing in interval (0, 0.01) and after that it remains constant up to 0.33 and further decreases and become negative. After that it again starts increasing and becomes constant in interval from 0.34 to 0.5. From 0.5 it again starts increasing to maximum value and after it again decreasing and becomes constant. From the outputs we observed that torque improves with soft switching technique.

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Above all simulation results obtained justify these facts that soft switching provides better current and voltage inputs, improvements in speed and torque, fewer losses, less heating problems and higher efficiency. That's makes it more useful as compared to hard switching.

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ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology
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