Simulation Modelling of Sensor less Speed Control of BLDC Motor Using Artificial Neural Network

Dr.T.Govindaraj and S.Vishnu

Abstract: This project presents an intelligent speed controller for BLDC motor, based on a single artificial neuron. Artificial neural network-based motor controllers require no offline training, which is both time consuming and requires extensive knowledge of motor behavior for the specific drive system. In addition, drive behavior is measured with the help of Back Emf sensing. This method of Back Emf sensing is used for providing the controlled gate pulse to the MOSFET switches. In existing method used Hall Sensor. The proposed drive system overcomes the limitations of Hall Sensors using back Emf control and using ANN control algorithm, is robust under varying operating parameters, and is easily adaptable to various drive systems. Drive efficiency is verified in simulation as well as experimentally.

Keywords*: *Artificial neural network (ANN), Brushless DC motor (BLDC), back Emf control.

I INTRODUCTION

The Brushless DC motor (BLDC) is a synchronous electric motor which is power driven by direct-current electricity (DC) and which has an electronically controlled commutation system, instead of a mechanical commutation system based on brushes. In such motors, current and torque, voltage and rpm are linearly related [1]. In BLDC motor, there are two sub-types used which are the Stepper Motor type that may have more poles on the stator and the Reluctance Motor. In a conventional (brushed) DC motor, the brushes make mechanical contact with a set of electrical contacts on the rotor or also called the commutator, forming an electrical circuit between the DC electrical source and the armature coil-windings.

As the armature rotates on axis, the stationary brushes come into contact with different sections of the rotating commutator. The commutator and brush system form a set of electrical switches, each firing in sequence, such that electrical-power always flows through the armature coil closest to the permanent magnet that is used as a stationary stator [2]. In a BLDC motor, the electromagnets do not move; but, the permanent magnets rotate and the armature remains static. This gets around the problem of how to transfer current to a moving armature. The method which is the brush-system/commutator assembly is replaced by an electronic controller is used.

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The controller performs the same power distribution found in a brushed DC motor, but using a solid-state circuit rather than a commutator/brush system. In this motor, the mechanical "rotating switch" or commutator/brush gear assembly is replaced by an external electronic switch synchronized to the rotor's position. Brushless motors are typically 85-90% efficient, whereas DC motors with brush gear are typically 75-80% efficient. BLDC motors also have several advantages over brushed DC motors, including higher efficiency and reliability, reduced noise, longer lifetime caused by no brush erosion in it; elimination of ionizing sparks from the commutator, and overall reduction of electromagnetic interference (EMI)[1-2]. With no windings on the rotor, they are not subjected to centrifugal forces, and because the electromagnets are located around the perimeter, the electromagnets can be cooled by conduction to the motor casing, requiring no airflow inside the motor for cooling.

This means that the motor's internals can be entirely enclosed and protected from dirt or other foreign matter. The maximum power that can be applied to a BLDC motor is exceptionally high, limited almost exclusively by heat, which can damage the magnets. BLDC motors are considered to be more efficient than brushed DC motors. This means that for the same input power, a BLDC motor will convert more electrical power into mechanical power than a brushed motor, mostly due to the absence of friction of brushes. The enhanced efficiency is greatest in the no-load and low-load region of the motor's performance curve [3]. Under high mechanical loads, BLDC motors and high quality brushed motors are comparable in efficiency. Brushless DC motors are commonly used where precise speed control is necessary, as in computer disk drives or in video cassette recorders, the spindles within CD, and etc.

Brushless dc (BLDC) motors have been desired for small horsepower control motors due to their high efficiency, silent operation, compact form, reliability, and low maintenance. However, the control complexity for variable speed control and the high cost of the electric drive hold back the widespread use of brushless dc motor. Over the last decade, continuing technology development in power semiconductors, microprocessors/logic ICs, adjustable speed drivers (ASDs) control schemes and permanent-magnet brushless electric motor production have combined to enable reliable, cost-effective solution for a broad range of adjustable speed applications.

Brushless DC motor has a rotor with permanent magnets and a stator with windings [5]. It is essentially a DC motor turned inside out. The brushes and commutator have been eliminated and the windings are connected to the control electronics. The control electronics replace the function of the commutator and energize the proper winding. The motor has less inertia, therefore easier to start and stop. BLDC motors are potentially cleaner, faster, more efficient, less noisy and more reliable[1]-[20]. The Brushless DC motor is driven by rectangular or trapezoidal voltage strokes coupled with the given rotor position. The voltage strokes must be properly aligned between the phases, so that the angle between the stator flux and the rotor flux is kept close to 90 to get the maximum developed torque. BLDC motors often incorporate either internal or external position sensors to sense the actual rotor position or its position can also be detected without sensors[21]-[36].

II CONTROL ALGORITHM

Conventionally, proportional–integral (PI)[6] and proportional–integral–derivative (PID) speed controllers have been utilized to meet these control challenges controller has an advantages that it is very simple, inexpensive, have applications in most systems, faster response.

But the disadvantages are the set point offset, delay if gain is lower. So this P Controller needs the gain adjustment. Then the PI controller is preferred [9]. And it has an advantages that there is no offset, have applications in many processes. The disadvantage of this controller are more costly, little complex, slow response, oscillations and overshoot

In PID controller it has no offset, faster, no or very less oscillations, and it has low overshoot. It has disadvantages that it was costly and it is used for limited applications, it is more difficult to configure and tune the functions. FLC (fuzzy logic controllers) -based systems typically require extensive initial tuning and may impose significant computational burden. So, here I go with Artificial Neural Network and sensor less speed control of BLDC motor

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II (A) ARTIFICIAL NEURAL NETWORKS (ANN)

This project presents an ANN-based controller for the BLDC motor drive which requires minimal offline training yet precisely and accurately follows command speed with insensitivity to load and parameter variations. The system is simplified to a single artificial neuron (SAN) to minimize complexity and computational burden requirements. By using sensor less speed measuring system we can find out the Speed error and conditionally used at each iteration to adaptively modify the SAN parameters to produce the precise command torque to minimize speed error. BLDC is widely used because of its high mechanical power density, simplicity and cost effectiveness. A mathematical model of the drive system is developed to analyse the performance of the proposed drive.

ANNs are mathematical systems consisting of many weighted interconnected operation elements (neurons). A processing element is an equation, which is often termed a transfer function. This processing element receives signals from other neurons; combines and converts them; and produces a numerical result. In general, processing elements roughly correspond to real neurons, they are interconnected via a network and this structure constitutes neural networks.

$$x = \sum_{i=1}^{N} A_i W_i + \theta \qquad (1)$$

Equation 1 shows Single Artificial Neuron. The structure of ANNs contains three main elements neurons, the connection providing input and output route, and connection weights indicating the strength of these connections. Typically, the architecture (structure) of an ANN is formed and weight values required to optimize the accuracy of the outputs are determined using one of several mathematical algorithms. The ANNs unravel a relationship between the input variables and estimated variables by determining the weights using previous examples. In other words, ANNs are "trained". Once these relationships are determined (in other words, once the network is trained), an ANN can be operated with new data and estimations can be produced.

The performance of a network is measured by the aimed signal and error criterion. The error margin is obtained by the comparison of the output of the network and the aimed output. A back-propagation algorithm is used to adjust the weights in such a way to reduce the error margin. The network is trained by repeating this processing many times. The aim of training is to reach an optimum solution based on performance measurements. ANNs have an extensive range of applications in real life problems. They are currently used successfully in many industries.

III PROPOSED BLOCK DIAGRAM

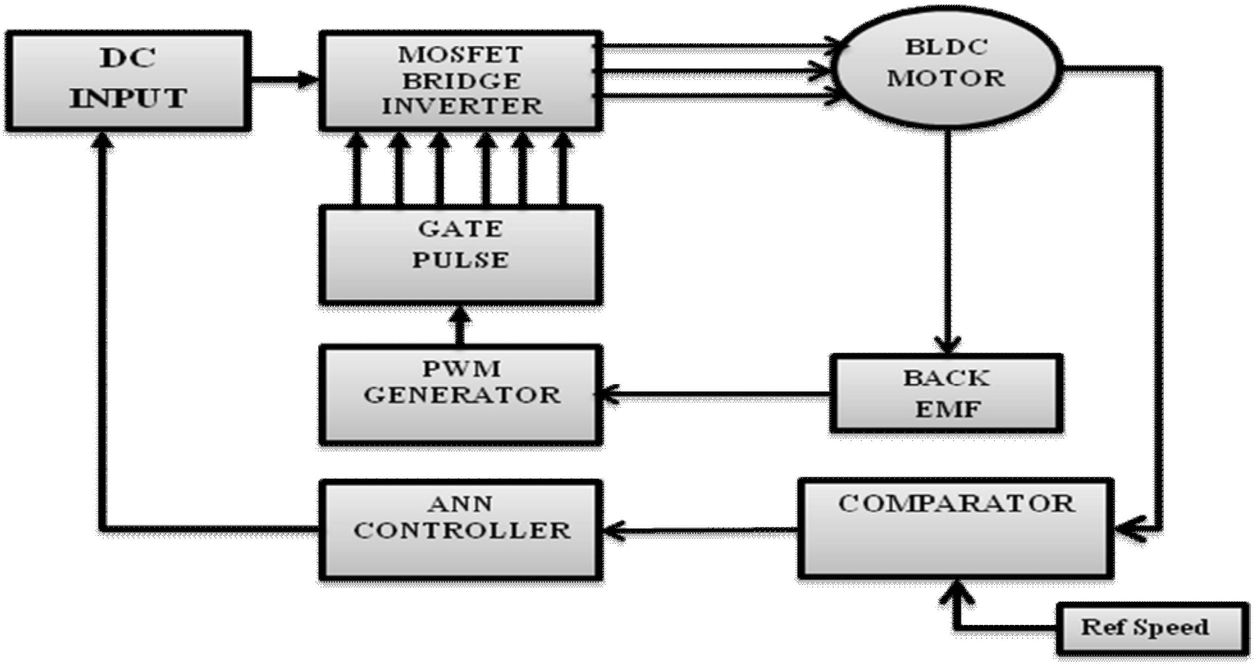


Figure 3.1 Block Diagram of Speed Control of BLDC motor

III (A) Methodology

Figure 3.1 shows block diagram of Sensor less speed control of BLDC motor. DC input is given to the inverter. This will generates three phase output which can be fed to the BLDC motor. PWM generator generates controlled gate pulse from the Back Emf of the motor. Then the controlled voltage can be generates by using ANN controller by comparing actual speed and reference speed. BLDC motors are a type of synchronous motor. This means the magnetic field generated by the stator and the magnetic field generated by the rotor rotates at the same frequency. BLDC motors do not experience the "slip" that is normally seen in induction motors. BLDC motors come in single-phase, 2-phase and 3-phase configurations. Corresponding to its type, the stator has the same number of windings. Out of these, 3-phase motors are the most popular and widely used. This application note focuses on 3-phase motors.

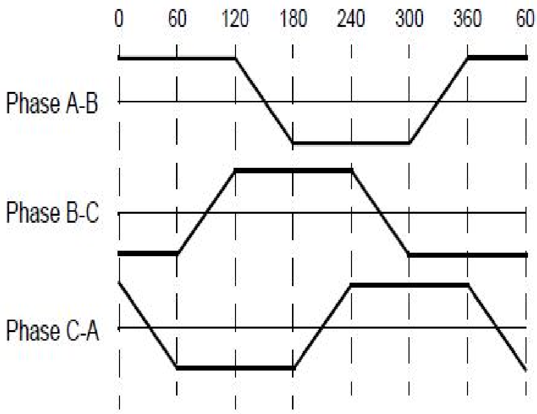
Stator

The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are axially cut along the inner periphery. Traditionally, the stator resembles that of an induction motor; however, the windings are distributed in a different manner. Most BLDC motors have three stator windings connected in star fashion. Each of these windings are constructed with numerous coils interconnected to form a winding. One or more coils are placed in the slots and they are interconnected to make a winding. Each of these windings are distributed over the stator periphery to form an even number of poles.

There are two types of stator windings variants: trapezoidal and sinusoidal motors. This differentiation is made on the basis of the interconnection of coils in the stator windings to give the different types of back Electromotive Force (EMF). As their names indicate, the trapezoidal motor gives a back EMF in trapezoidal fashion and the sinusoidal motor's back EMF is sinusoidal, as shown in Figure 3.2 and 3.3. In addition to the back EMF, the phase current also has trapezoidal and sinusoidal variations in the respective types of motor. This makes the torque output by a sinusoidal motor smoother than that of a trapezoidal motor. However, this comes with an extra cost, as the sinusoidal motors take extra winding interconnections because of the coils distribution on the stator periphery, thereby increasing the copper intake by the stator windings.

Rotor

The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles. Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make the rotor. Ferrite magnets are traditionally used to make permanent magnets. As the technology advances, rare earth alloy magnets are gaining popularity.



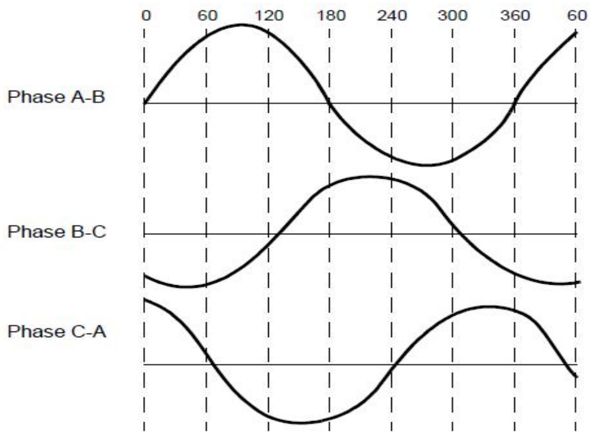


Figure 3.2 Trapezoidal back emf

Figure 3.3 Sinusoidal back Emf

IV CIRCUIT DIAGRAM

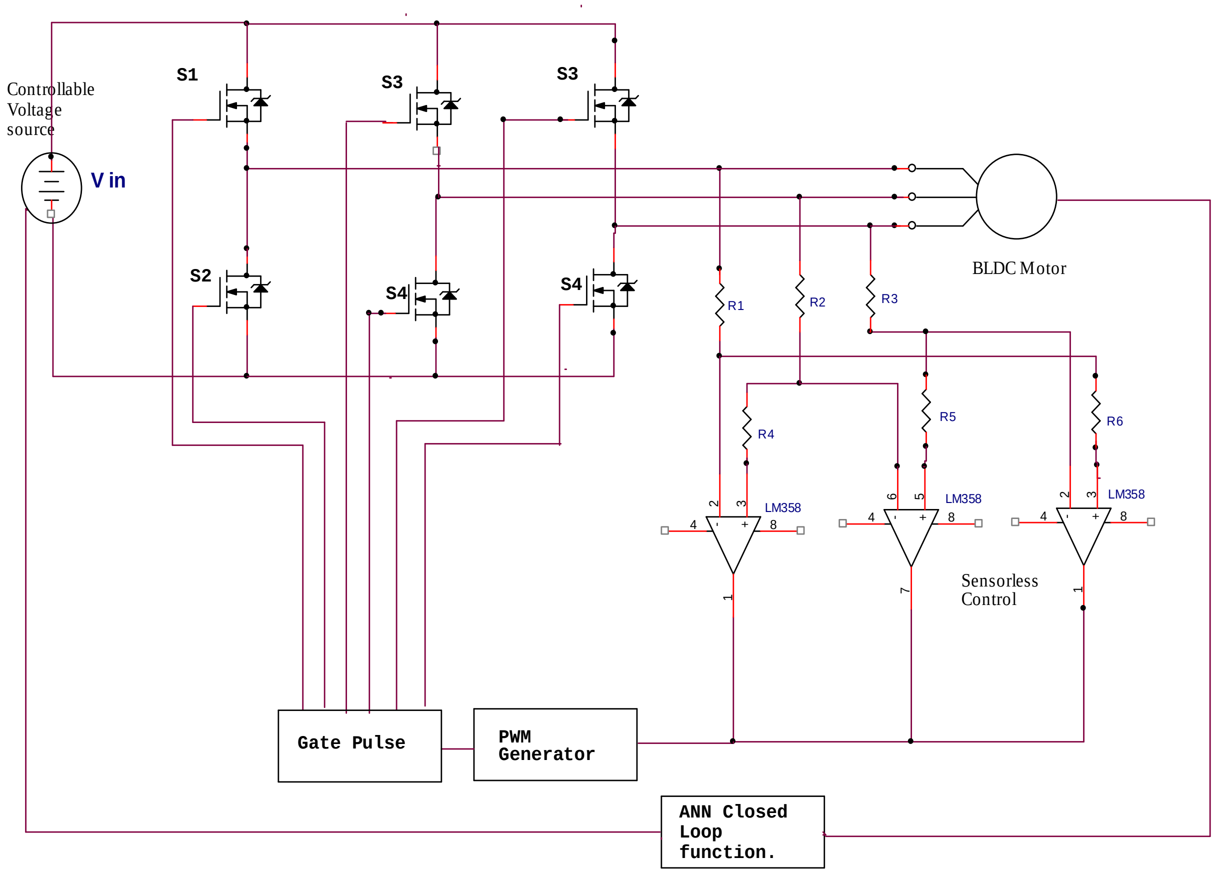


Figure 4.1 Circuit Diagram

IV (A) Circuit Explanation

Figure 4.1 shows circuit diagram of Speed control of BLDC Motor. It shows when the dc input voltage is given to the MOSFET controlled switches it will generated three phase output and it will given to the BLDC motor. Back Emf will be generated in the motor. This will be taken as an advantage for such operation for generating controlled gate pulse from the PWM generator. Then the Speed can be sensed and it can be fed to ANN controller. This will found error signal and corrected then the output of the controller is given to input voltage. Drive parameters can be measured using simulation Diagram.

The sensor less drive is based on the detection of the Back Electro Magnetic Force (BEMF) induced by the movement of a permanent magnet rotor in front of stator

winding. This method also requires the use of a trapezoidal signal in order to have a zero crossing of the BEMF. For a given fixed motor design (number of stator winding turns, mechanical rotor characteristics and rotor magnet characteristics) the BEMF Amplitude is proportional to the rotor speed. The sensor less method uses the zero crossing of
BEMF to synchronize phase commutations. To detect BEMF the specific 120° six-step drive is used. "120° six-step drive" forces zero current twice in each phase during a six step period. This allows BEMF zero crossing to be detected and read.

$$\textbf{Back Emf, } NlrB = \omega \qquad (2)$$

Where, N = number of windings per phase
l = length of the rotor
r = internal radius of the rotor
B = rotor magnetic field
ω = angular velocity

Because the controller must direct the rotor rotation, the controller requires some means of determining the rotor's orientation/position (relative to the stator coils.) Some designs use Hall Effect sensors or a rotary encoder to directly measure the rotor's position. Others measure the back EMF in the undriven coils to infer the rotor position, eliminating the need for separate Hall Effect sensors, and therefore are often called sensor less controllers. Controllers that sense rotor position based on back-EMF have extra challenges in initiating motion because no back-EMF is produced when the rotor is stationary. This is usually accomplished by beginning rotation from an arbitrary phase, and then skipping to the correct phase if it is found to be wrong. This can cause the motor to run briefly backwards, adding even more complexity to the startup sequence. Other sensors less controllers are capable of measuring winding saturation caused by the position of the magnets to infer the rotor position.

5. SIMULATION CIRCUIT DIAGRAM

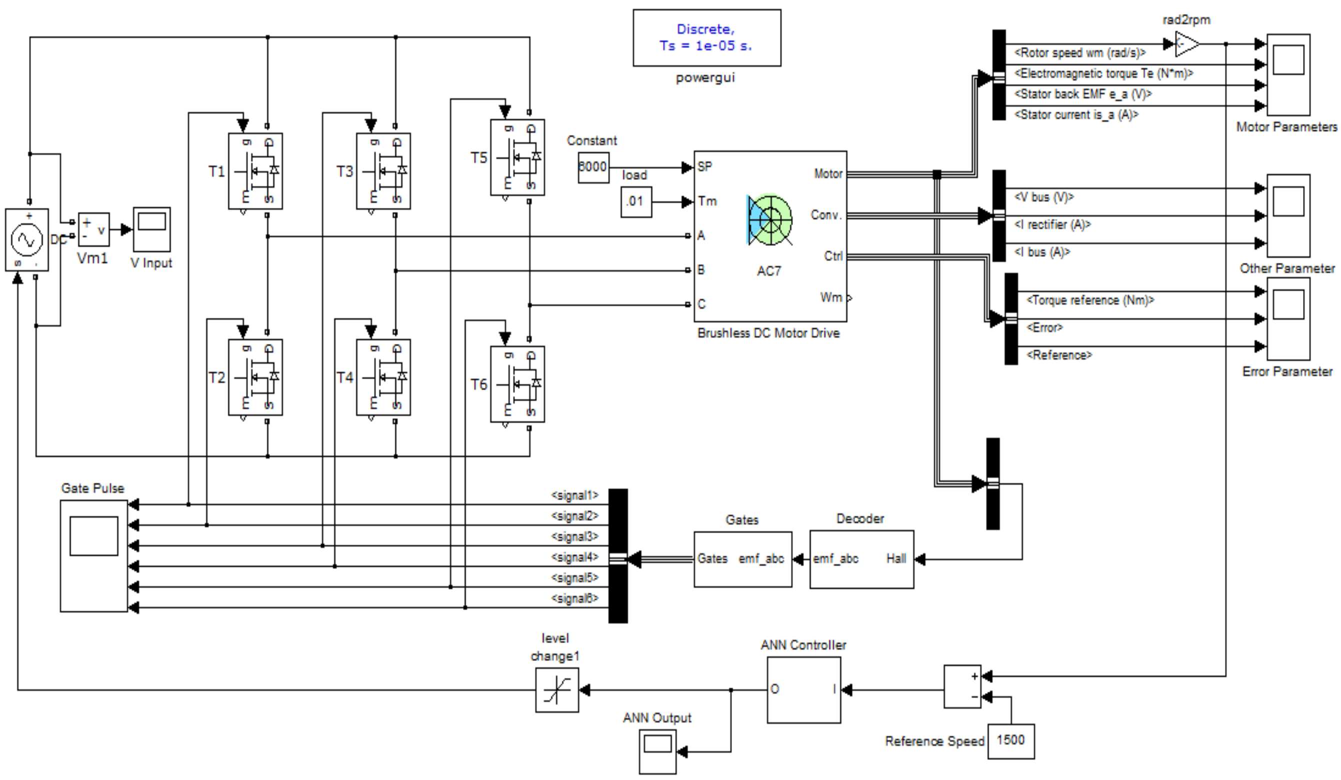


Figure 5.1 Simulation Circuit Diagram

(A) Simulation Results

Figure 5.1 shows simulation circuit diagram of the proposed system. The Simulation can be done by using MATLAB Simulink. Simulink, developed by Math Works, is a commercial tool for modeling, simulating and analyzing multi domain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in control theory and digital signal processing for multi domain simulation and design.

The following figure shows simulation results of Input voltage, Stator Back Emf, Stator current, Electromagnetic Torque, Gate Pulse waveform, Motor Speed and ANN output.

5.1 INPUT VOLTAGE

Figure 5.2 shows input voltage corresponds to the output speed. Error can be corrected.

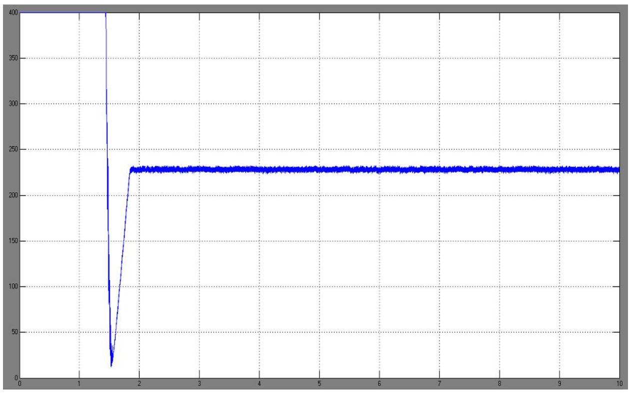


Figure 5.2 Input voltage

5.2 ELECTROMAGNETIC TORQUE

Figure 5.3 shows Electromagnetic Torque.

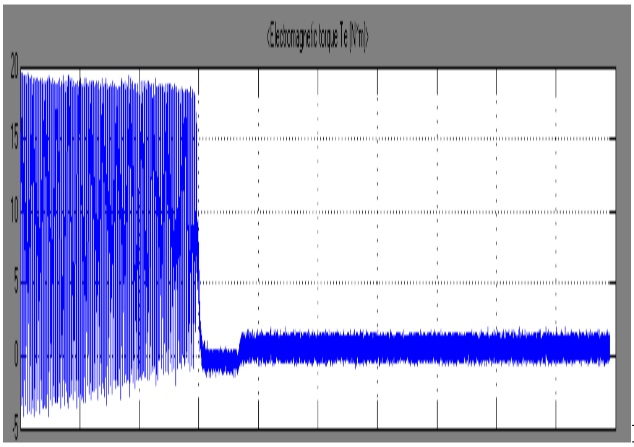


Figure 5.3 Electromagnetic Torque

5.3 STATOR BACK EMF

Figure 5.4 shows Stator Back Emf

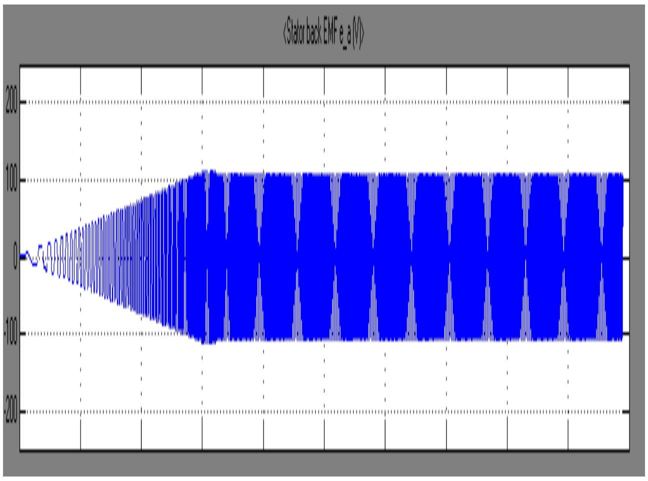


Figure 5.4 Stator Back Emf

5.4 STATOR CURRENT

Figure 5.5 shows Electromagnetic Torque.

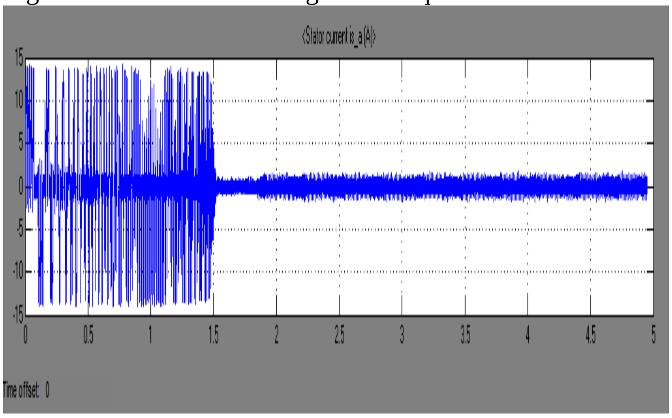


Figure 5.5 Stator Current

5.5 ANN OUTPUT

Fig 5.6 Shows ANN Output

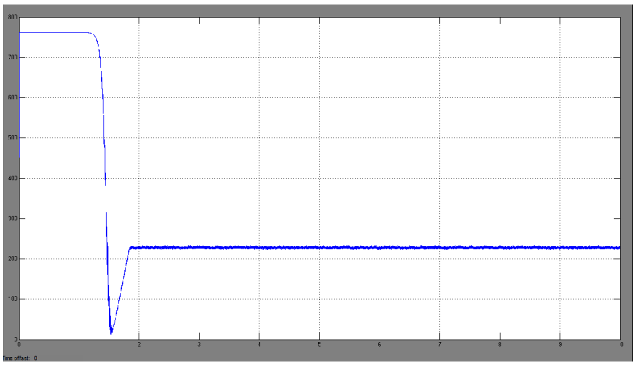


Figure 5.6 ANN Output

5.6GATE PULSE WAVEFORM

Fig 5.7 Shows Gate Pulse Waveform

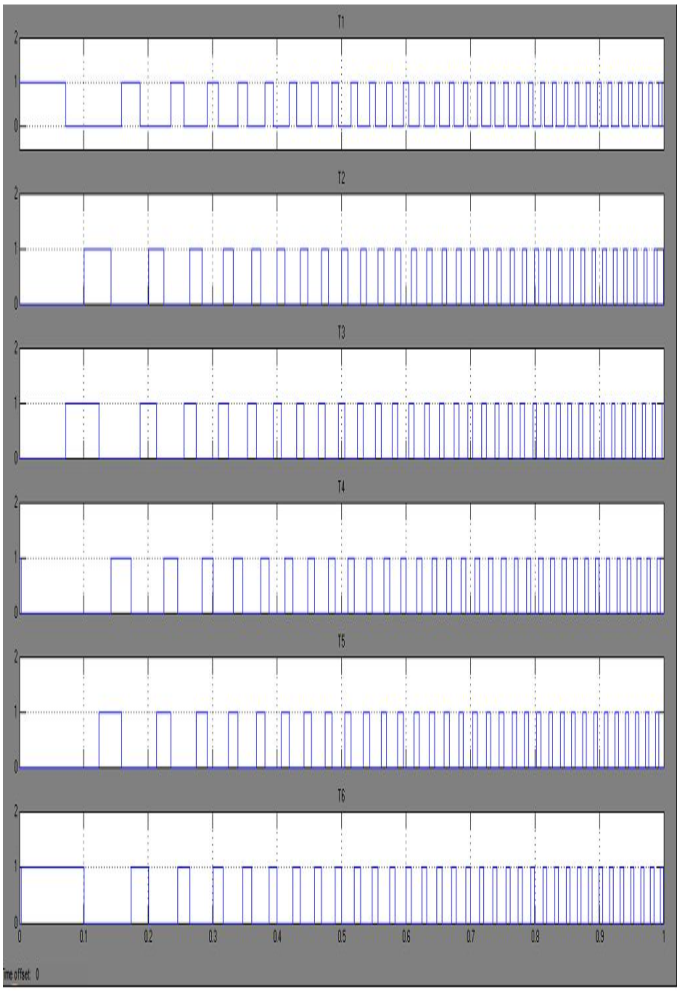


Figure 5.7 Gate Pulse Waveform

5.7 MOTOR SPEED

Fig 5.8 shows Motor Speed

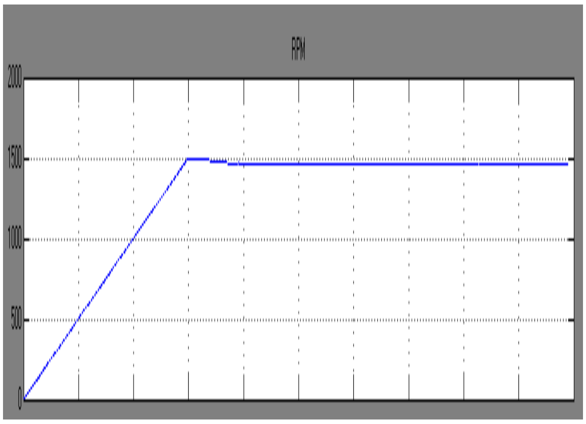


Figure 5.8 Motor Speed

6. Conclusion

In view of the pulsation of three-phase BLDC motor with non-ideal back EMF, a new current control method is proposed. The PWM_ON_PWM pattern is used to eliminate the diode freewheeling of inactive phase. When the motor works at low speed, the torque ripple is restrained by speeding up the turn- ON phase current through increasing the duty cycle of PWM. When the motor works at high speed, overlapping commutation scheme is used. The commutation times are given by the current controller in low and high speeds. Aiming at the non-ideal back EMF, the duty cycle is calculated in the current controller by measuring the angular position, speed, and the offline measured back EMF. Here I used Artificial Neural Network technique of SAN controller. By using this, the motor rpm is fed to the ANN and the regulated input voltage is generated automatically according to the output.

7. References

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