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Fuzzy Implementation for Two BLDC Using Three Phase Inverter

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Abstract: ***This project proposes an implementation which is capable to operate two brushless DC Motors (BLDC) using a three phase inverter and controlled by fuzzy logic method. Conventional parallel connection method used in this application for the single DC voltage applied to both motors can operate only at the same speed and have a high risk of loss of synchronism. On the other hand, the proposed topology can employ the conventional six bridge power module without any modification or addition and operate two motors at the different speeds using the superposition principle. In other inverter topologies, the number of switches increases or implementation of inverter is complicated. The analysis of the proposed system is presented and the control method to independently operate two motors is proposed. It is verified through experimental results.***

Keywords: Three Phase Inverter, BLDC Motor, Fuzzy Logic, Matlab

1. Introduction

The conventional energy conversion system consists of energy conversion circuits and energy conversion machine. To operate several machines from a single source, energy conversion circuits of the same number of machines are required. In this case, the system becomes complicated due to sharing ac or dc link and the cost increases as the number of circuits. In a drive system for two motors of the low power ratings, a power module which has higher current rating is less expensive than low rating ones. However, driving two motors using one inverter has the limitation of single operating speed and may cause loss of synchronism when it comes to synchronous machines. In the applications that do not require precise control as in fans, dual motor single inverter system can reduce cost highly. Therefore, control method that guarantees stable operation while having the benefit of reduction in the number of power devices is necessary.

For induction machines, various topologies and control methods have been researched. Multiple induction machine drive system using a modified current source inverter (CSI) was introduced. Many research treated parallel connection of induction machines. Various series and parallel connections of multi-phase machines are researched.

Many researches on a dual BLDC single inverter system have focused on parallel connection of two motors. 'average phase current technique' that controls one equivalent motor whose phase current and rotor position are the average values of two parallel connected motors was proposed. In one research, the controller selects the motor under higher load as master motor and only controls the master motor. And, only the q-axis currents of both motors are controlled, while the d-axis currents remain uncontrolled. These methods cause inaccuracies in control and divergence in the system since only control the portion of whole system and do not care the other parts. And in parallel connection method where the voltage of single frequency and magnitude is applied to both motors, the two motors operate only at the same speed and have a high risk of loss of synchronism when there is a large discrepancy between two rotor positions.

Researches on the other inverter topologies were also conducted. 2-leg inverter where each leg has three switches was proposed in some research. And, 5-leg inverter with ten switches are required than that of 6-bridge inverter. Furthermore, implementation of new inverter is complicated because the conventional power module does not offer the topology.

This project proposed a novel topology for dual motor single inverter systems and its control method. The proposed topology consists of two BLDCs and a single conventional 6-bridge inverter. The proposed control method enables two BLDCs to be controlled independently and to rotate at different speeds.

1.1. Proposed Topology

The proposed topology is shown in Fig. 1. Two c-phases of each motor are connected each other and the rest of the stator windings are connected to inverter leg A, B, C and neutral point N. The dc bus voltage is divided by two motors. As a result, the input voltages of two motors are different from each other and the two motors can operate different speeds.

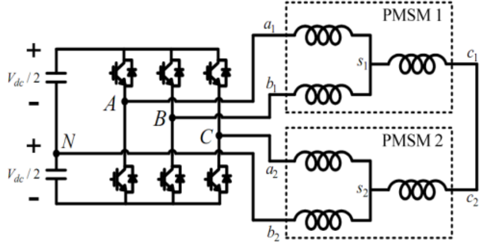


Figure 1.1(a) Proposed topology

The operation of proposed topology can be described by the superposition principle. The stator current of one motor affects the other motor since c-phases of each motor are connected. Fig. 1.1 shows the current flowing through each stator winding when phase currents of only one motor flow. The subscripts a, b, and c indicate each phase of motor, respectively, and the subscripts 1 and 2 imply each motor. k1 and k2 are the ratios of the c-phase current of one motor that is divided into a and b-phases of the other motor. Consequently, sum of the currents of Fig. 1.1 (a) and (b) flows through the motors.

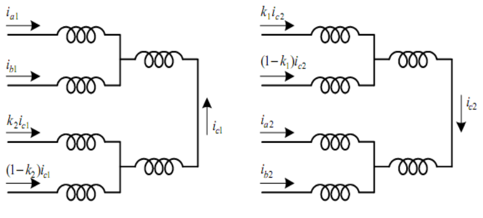


Figure 1.1(b) Current distribution where phase currents of only one motor flow

1.2. Control For Proposed Topology

The proportional and integral (PI) controllers are used for speed controller as in a conventional single motor single inverter system. To apply aforementioned superposition principle, d and q-axis current references are the outputs of the speed controller and they are transformed into a, b, and c phase quantities. Then, the current command generator outputs A, B, and C leg current references using the a, b, and c phase current references as shown in Fig. 1.1(a) and (b). Three fuzzy controllers are used as current controller as shown in Fig. 5.The proposed controller requires three current sensors for feedback while typical motor drive system requires two ones per motor.

When the current command generator outputs current references, k1 and k2 are required to be determined. Z is the stator impedance, |Zx| is the magnitude of Z, and x is each frequency component. After I1, I2, ω1, and ω2 have been determined according to speed, torque, k1 and K2 are calculated. They make peak value of maximum voltage among (3), (4), and (5) minimize. The peak ones of maximum voltage according to k1 and k2 are shown in Fig. 6.

1.3. Existing Limitations

1. In parallel connection method where the voltage of single frequency and magnitude is applied to both motors, the two motors operate only at the same speed and have a high risk of loss of synchronism when there is a large discrepancy between two rotor positions.
2. The conventional 6-bridge inverter is used.

1.4. Proposed Merits

1. The proposed control method enables two BLDCs to be controlled independently and to rotate at different speeds.
2. In proposed topology, two c-phases of each motor are connected each other and the rest of the stator windings are connected to three inverter legs and neutral point, respectively.

2. Block Diagram & Explanation

2.1 AC Supply

This is a normal 440V, 50Hz, three phase voltage. This voltage is used to supply the thyristors i.e., the MOSFETs. This voltage primarily depends on the MOSFETs ratings and the load. For high power applications this voltage proportionately increases to supply the required load current levels.

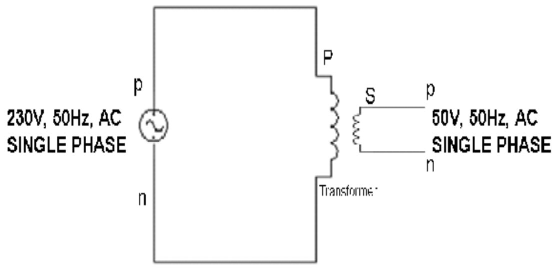
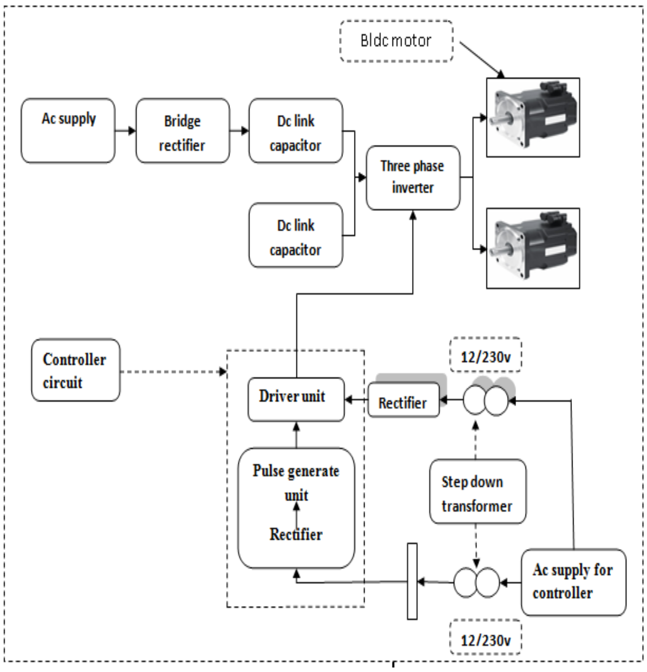


Fig 2.1(a) AC supply

Since the proposed project reduces the supply voltage harmonics, a perfect sine wave is obtained. The next level of block requires a split voltage to make the inverter function, summing up these voltages later. Hence this makes it mandatory to give a supply same in magnitude and frequency. The voltage level required for the specified MOSFETs ratings is 50V, 50Hz, three phase AC supply. So, it becomes mandatory to step down the available 440V to 50V, without changing the frequency and phase. Hence a Step-Down Transformer or an auto-transformer Is used to supply the vital voltage



2.2 Rectifier

A **rectifier** is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as **rectification**. Rectifiers have many uses, but are often found serving as components of DC power supplies and high-voltage direct current power transmission systems. Rectification may serve in roles other than to generate direct current for use as a source of power. In gas heating systems flame rectification is used to detect presence of flame. Because of the alternating nature of the input AC sine wave, the process of rectification alone produces a DC current that, though unidirectional, consists of pulses of current. Many applications of rectifiers, such as power supplies for radio, television and computer equipment, require a steady constant DC current (as would be produced by a battery). In these applications the output of the rectifier is smoothed by an electronic filter to produce a steady current.

3. DC Link Capacitors

These capacitors are designed for use on DC supplies and are intended to protect the network from momentary voltage spikes and surges and for filtering out AC ripple.

3.1 Construction

The self-healing capacitor elements are enclosed in a cylindrical aluminum case, which is filled with a vegetable oil based gel (resin, solid matter) that is non- toxic, biodegradable, and environmentally friendly. The case is fitted with an overpressure disconnected and an M12 mounting stud, which is also used for the protective conductor connection.

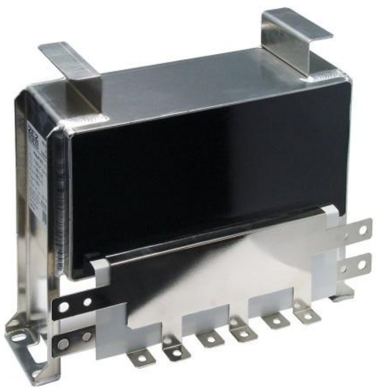


Figure 3.1 Self-Healing Capacitor

3.2 Construction

The self-healing, dry-type, capacitor elements are produced using specially structured, segmented, metalized PP film which ensures low self-inductance, high rupture resistance and high reliability. These elements are enclosed in a rectangular steel case, which is filled with vegetable-oil based gel (resin, solid matter) that is non-toxic, biodegradable, and environmentally friendly. Overpressure disconnects or is not considered necessary. The capacitor top is sealed with self-extinguishing PU resin. The terminals design (arrangement) provides very low self-inductance.

A DC link exists between a rectifier and an inverter, for example, in a VFD or phase converter. On one end, the utility connection is rectified into a high voltage DC. On the other end, that DC is switched to generate a new AC power waveform. It's a link because it connects the input and output stages. The term "DC link" is also used to describe the decoupling capacitor in the DC link. I assume that this is what you're asking about. The switching network on the output side generates very large transients at the switching frequency. The DC link capacitor helps to keep these transients from radiating back to the input.

3.4 Applications

- Hybrid vehicles
- Wind & Solar power plants
- Electric energy generation from sea waves
- Medical & Industrial equipment
- Car electronics
- Railway and turbines (generator)

4. Three Phase Inverter

4.1 Three-Phase Inverter Equivalent Circuit

Each leg (Red, Yellow, and Blue) is delayed by 120 Degrees. A three-phase inverter with star connected load is shown below

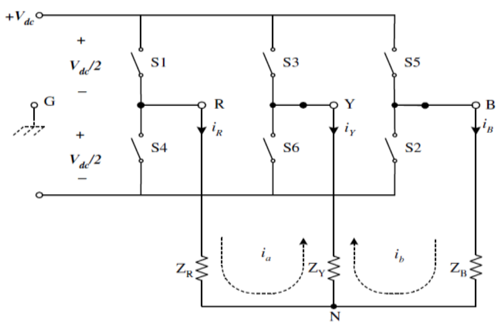
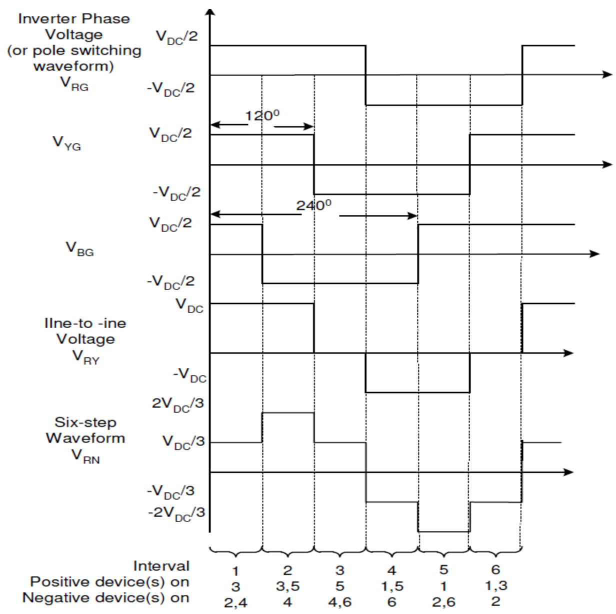


Figure 4.1(a) Three-Phase Inverter Equivalent Circuit

Three Phase Inverter Waveform



Quasi-square wave operation voltage waveforms

5. Fuzzy Logic

Fuzzy logic is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large, networked, multi-channel pc or workstation-based data acquisition and control systems. It can be implemented in hardware, software, or a combination of both. Fl provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information.[21] Fl's approach to control problems mimics how a person would make decisions, only much faster.

Fuzzy Logic incorporates a simple, rule-based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically. The FL model is empirically-based, relying on an operator's experience rather than their technical understanding of the system. For example, rather than dealing with temperature control in terms such as "SP =500F", "T <1000F", or "210C <TEMP <220C", terms like "IF (process is too cool) AND (process is getting colder) THEN (add heat to the process)" or "IF (process is too hot) AND (process is heating rapidly) THEN (cool the process quickly)" are used. These terms are imprecise and yet very descriptive of what must actually happen. Consider what you do in the shower if the temperature is too cold: you will make the water comfortable very quickly with little trouble. FL is capable of mimicking this type of behavior but at very high rate.

Fuzzy Logic requires some numerical parameters in order to operate such as what is considered significant error and significant rate-of-change-of-error, but exact values of these numbers are usually not critical unless very responsive performance is required in which case empirical tuning would determine them. For example, a simple temperature control system could use a single temperature feedback sensor whose data is subtracted from the command signal to compute "error" and then time-differentiated to yield the error slope or rate-of-change-of-error, hereafter called "error-dot". Error might have units of degs F and a small error considered to be 2F while a large error is 5F. The "error-dot" might then have units of degs/min with a small error-dot being 5F/min and a large one being 15F/min. These values don't have to be symmetrical and can be "tweaked" once the system is operating in order to optimize performance. Generally, FL is so forgiving that the system will probably work the first time without any tweaking.

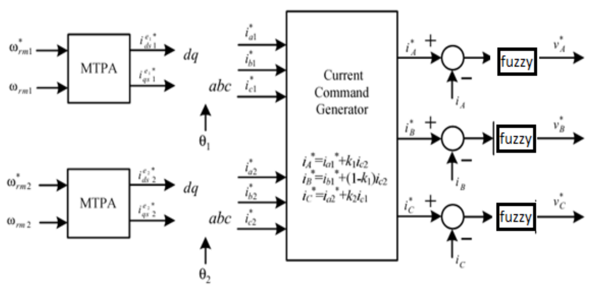


Figure 5 Proposed Control Block Diagram

5.1 Fuzzy Logic Controller

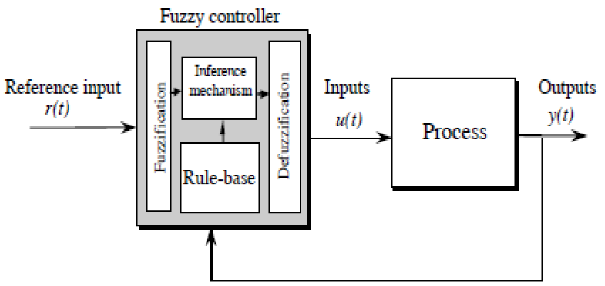


Figure 5.1 Fuzzy controller

Fuzzy Logic Uses

FL offers several unique features that make it a particularly good choice for many control problems.

1) It is inherently robust since it does not require precise, noise-free inputs and can be programmed to fail safely if a feedback sensor quits or is destroyed. The output control is a smooth control function despite a wide range of input variations.

2) Since the FL controller processes user-defined rules governing the target control system, it can be modified and tweaked easily to improve or drastically alter system performance. New sensors can easily be incorporated into the system simply by generating appropriate governing rules.

3) FL is not limited to a few feedback inputs and one or two control outputs, nor is it necessary to measure or compute rate-of-change parameters in order for it to be implemented. Any sensor data that provides some indication of a system's actions and reactions is sufficient. This allows the sensors to be inexpensive and imprecise thus keeping the overall system cost and complexity low.

4) Because of the rule-based operation, any reasonable number of inputs can be processed (1-8 or more) and numerous outputs (1-4 or more) generated.

5) FL can control nonlinear systems that would be difficult or impossible to model mathematically.

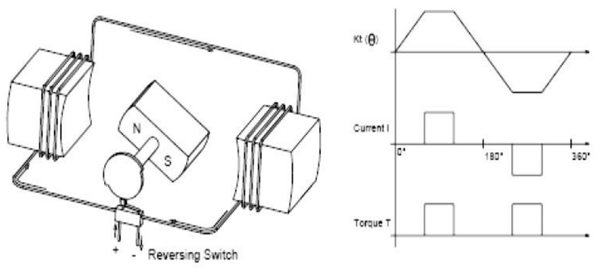
6. Brushless DC Motor

6.1 Principle

BLDC motors are basically inside-out DC motors. In a DC motor the stator is a permanent magnet. The rotor has the windings, which are excited with a current.

The current in the rotor is reversed to create a rotating or moving electric field by means of a split commutator and brushes. On the other hand, in a BLDC motor the windings are on the stator and the rotor is a permanent magnet. Hence the term inside-out DC motor.

Many motor types can be considered brushless; including stepper and AC-induction motors, but the term "brushless" is given to a group of motors that act similarly to DC brush type motors without the limitations of a physical commutator. To build a brushless motor, the current-carrying coils must be taken off the rotating mechanism. In their place, the permanent magnet will be allowed to rotate within the case. The current still needs to be switched based on rotary position; here, shows a reversing switch is activated by a cam.



(a) (b)

Figure 6.1 Basic operation of BLDC motor and Waveform of current and torque of basic BLDC motor

This orientation follows the same basic principle of rotary motors; the torque produced by the rotor varies trapezoidal with respect to the angle of the field. As the angle θ increases, the torque drops to an unusable level.

Because of this, the reversible switch could have three states: positive current flow, negative current flow, and open circuit. In this configuration, the torque based on rotary position will vary as the current is switched.

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7. Simulation Results

7.1 General

Simulation has become a very powerful tool on the industry application as well as in academics, nowadays. It is now essential for an electrical engineer to understand the concept of simulation and learn its use in various applications. Simulation is one of the best ways to study the system or circuit behavior without damaging it .The tools for doing the simulation in various fields are available in the market for engineering professionals.

Many industries are spending a considerable amount of time and money in doing simulation before manufacturing their product. In most of the research and development (R&D) work, the simulation plays a very important role. Without simulation it is quiet impossible to proceed further. It should be noted that in power electronics, computer simulation and a proof of concept hardware prototype in the laboratory are complimentary to each other. However computer simulation must not be considered as a substitute for hardware prototype. The objective of this chapter is to describe simulation of impedance source inverter with R, R-L and RLE loads using MATLAB tool.

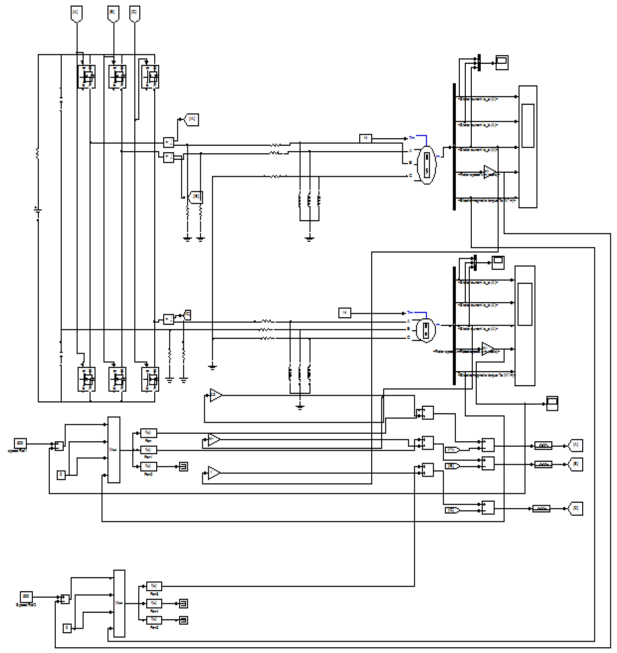
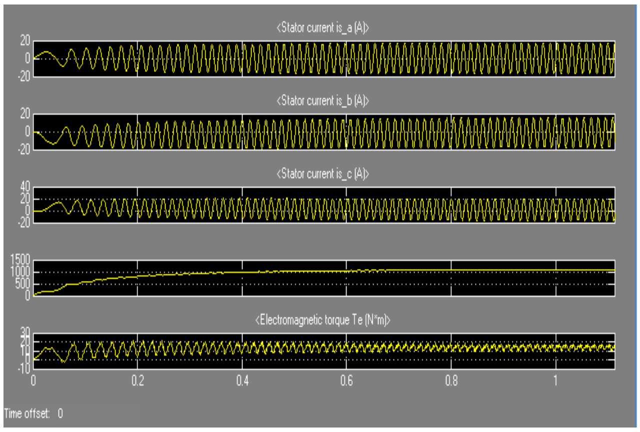
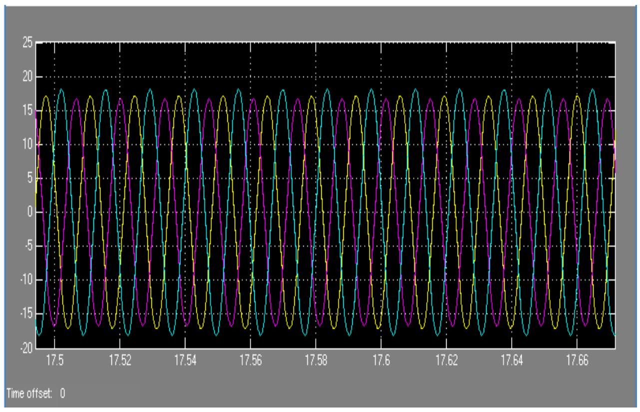


Figure 7.1 Simulation Diagram

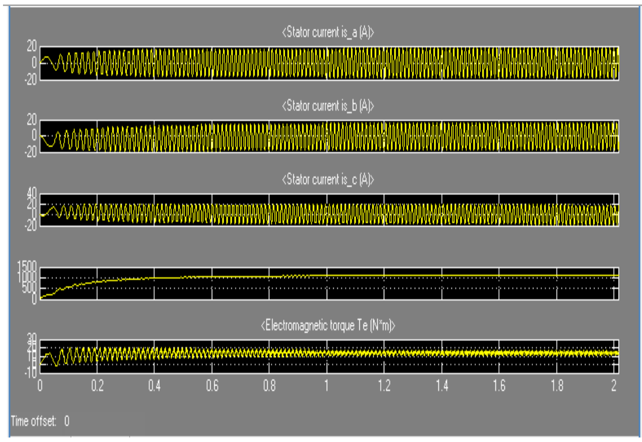
7.2 Motor 1 Torque Wave Form



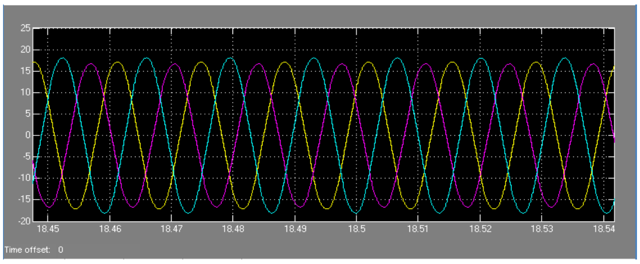
Motor 1 ABC Current Wave Form



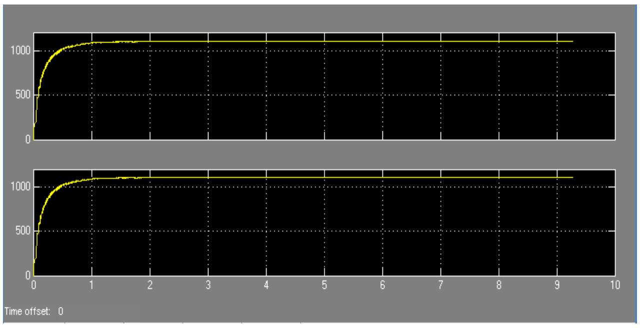
Motor 2 Torque Wave Form



Motor 2 ABC Current Waveform



Motor 1&2 RPM at Constant Speed



8. Conclusion

This project proposes implementation which is capable to operate two Brushless DC Motor(BLDC) using a three phase inverter and controlled by fuzzy logic method. In proposed topology, two c-phases of each motor are connected each other and the rest of the stator windings are connected to three inverter legs and neutral point, respectively, and the conventional 6-bridgeinverter is used.

By superposition principle, two motors can work at different speeds as well as at the same speed. The proposed control method includes the command generator which makes current references using superposition and two motors are controlled with minimum voltage.

The proposed topology and its control method are demonstrated through simulation results.

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