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# Brushless DC Motor Current control scheme Operated by Four Switch Three Phase Inverter

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**Abstract: This is a result paper on brushless DC motor driven by four switch three phase inverter. This paper describes the design of a low cost three phase inverter brushless dc motor (BLDC) drive. For effective use of the developed system, a direct current controlled Pulse width modulation scheme is designed and implemented. Operation of the four-switch three phase inverter BLDC motor drive and the developed control scheme and experimental results prove the effectiveness of the circuit**.

***Keywords -*** ***Brushless DC (BLDC) motor drive, four-switch three phase inverter, Metal Oxide Semiconductor Field Effect Transistor (MOSFET) , Pulse Width Modulation( PWM).***

## I. INTRODUCTION

Brushless DC (BLDC) motor finds variety of uses and applications in almost all industries such as aerospace, military, household products and automobile industry etc. BLDC motor has higher efficiency high torque, increased power density and ease of control and maintenance. Torque developed by BLDC motor is almost constant. Previously a conventional BLDC motor is driven by a six switch three phase inverter. Conventional method of six switch three phase inverter (Fig.1) has more cost and losses. In this result paper four switch three phase technique (Fig. 2) is use to reduce cost and losses by reducing the no of power switches, switching driver circuit.[1],[2]

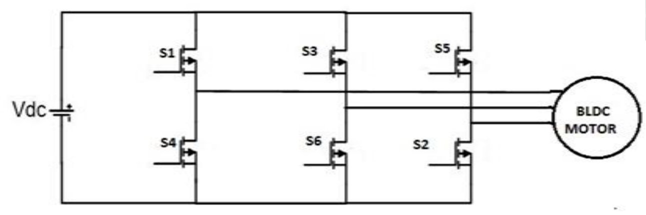


Fig 1. Six switch three phase inverter circuit

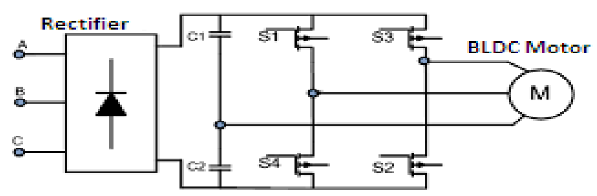


Fig 2. Four switch three phase inverter circuit

## II. SYSTEM ARCHITECTURE

### *A. Arduino Controller*

Arduino boards are uses a variety of microprocessors and controllers. Arduino boards are equipped with sets of digital and analog input/output (I/O) points that may be interfaced to various expansion boards (shields) and other circuits. Boards feature serial communications interfaces, including Universal Serial Bus (USB) on some models, which are also used for loading programs as per the application [3]

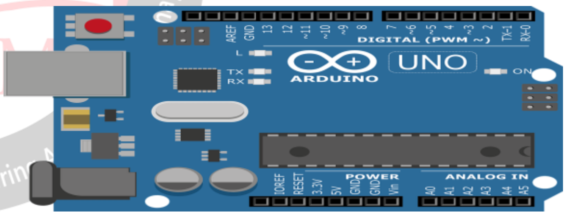


Fig.3. Arduino ATmega 328P

### *B. Brushless DC Motor*

A brushless DC motor also called as an electronically commutated motor (ECM motor) or synchronous DC motor, is a synchronous motor use a direct current electric power supply. For operation BLDC uses an electronic closed loop controller to switch DC currents to the motor winding producing magnetic fields which effectively rotate in space and which the permanent magnet rotor follows same.[9]

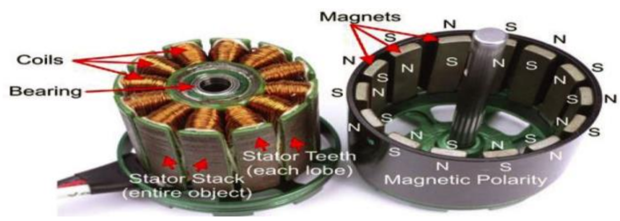


Fig.4. Brushless DC Motor

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### *C. Opto Couplers*

Opto-couplers are made up of a light emitting equipment's and it is a light sensitive device, all components are packed in single component, but there is no electrical connection between the two it has just a beam of light. Light emitter device is always an LED and light sensitive device may be a photodiode, phototransistor, or more sensitive devices such as thyristors, triacs etc. An optocoupler has two circuits to exchange signals yet remain electrically isolated. This is used for protection of circuit.

### *D. IRF Z44 MOSFET*

IRFZ44 is a third generation power Metal Oxide Semiconductor Field Effect Transistor (MOSFET) which has the best combination of fast switching, ruggedized device design, low on-resistance and cost-effective. TO-220AB package is universally used for commercial and industrial applications at power dissipation levels to approximately 50 W.

## III. WORKING AND RESULTS OF PROJECT

Arduino UNO pins 2, 3 and 4 are ATmega328P microcontroller external Optotriac IC interrupt pins PCINT18, PCINT19 and PCINT20 respectively. Optocoupler is a device that is used to activate any device by using LED glowing, this glowing occurs internally in IC. In Optocoupler, an LED and an IC 2101 together with proper way to sense with high gain. When we give supply to Optocoupler the internal Optical is turn on by the light get from the LED. Internally That LED and transistor are isolated from each other. Isolation between both provides high protection from AC supply. Major reason to use optocoupler is for protection from AC. There are different types of the optocoupler, in which some use with a fully DC circuit and some use with AC circuit. When a DC supply given to the optocoupler input, then the internal LED glows and activates internal component.

Signals from optocoupler are used to give command to gate driver circuit .The four PWM signals auto turn on the four switches in the inverter. The PWM waveforms are generated by using Arduino controller .The voltage PWM scheme for FSTPI must have six commutations. [4]

Those signals are (S,0), (1,0), (1,S), (S,1), (0,1) and (0,S). Symbols are commutation signals of two controllable phases (phase A and B). "S" indicates the high side and low side power devices in the same leg are OPEN. "1" means the high side power device in this phase is switching in PWM and "0" means the low side device in this phase is switching in PWM. This data, controller controls the duty cycle of the PWM pulses which corresponds to the voltage amplitude required to maintain the desired speed and BLDC motor speed control is operated by PWM signals. The circuit diagram for the BLDC motor powered by the FSTPI is shown in Fig.1.The power inverter is equipped with 4 MOSFET switches, S1, S2, S3 and S4 capacitors and dc link capacitors. The two phases 'a' and 'b' are connected to the two legs of the inverter and the third phase 'c' of the motor is connected to the center point of dc link capacitors, C1 and C2. Capacitor C1 and C2 are equal and the voltages across the two capacitors are equal. A Brushless DC motor has operation such that at a time only two phases are active and conducting current while the third phase is inactive.[5]

The Back Electromotive Force should have trapezoidal shape with 120° conduction and 60° non conducting regions and the quasi square wave currents are needed to generate constant output torque so, it required to have accurate rotor position. It can be obtained by three hall sensor signals. However, in the four-switch inverter, there are two legs (with two switches in each leg) which are connected to two motor winding and third phase of the motor is always connect to the third phase midpoint of the dc -link capacitors, so that a small amount of current is always flowing. One upper side and one low side power switches must be turned on but not simultaneously in the same leg, and this supply is fed to the BLDC motor.

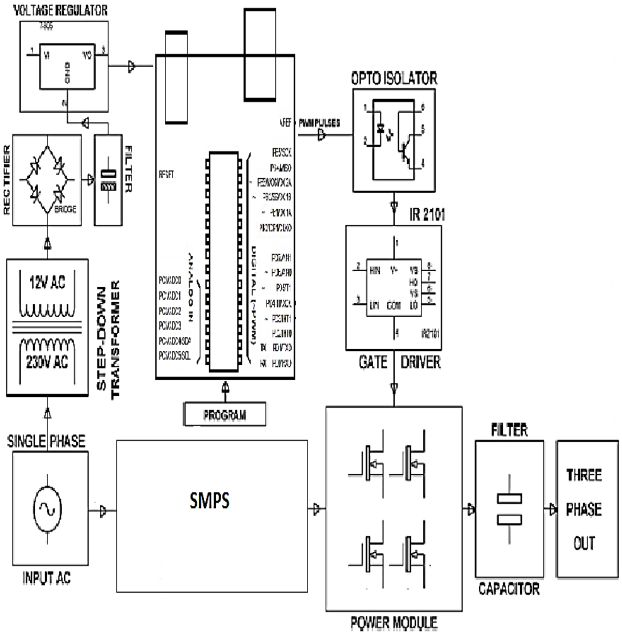


Fig.5. System Architecture

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## IV. Simulation and Hardware Results

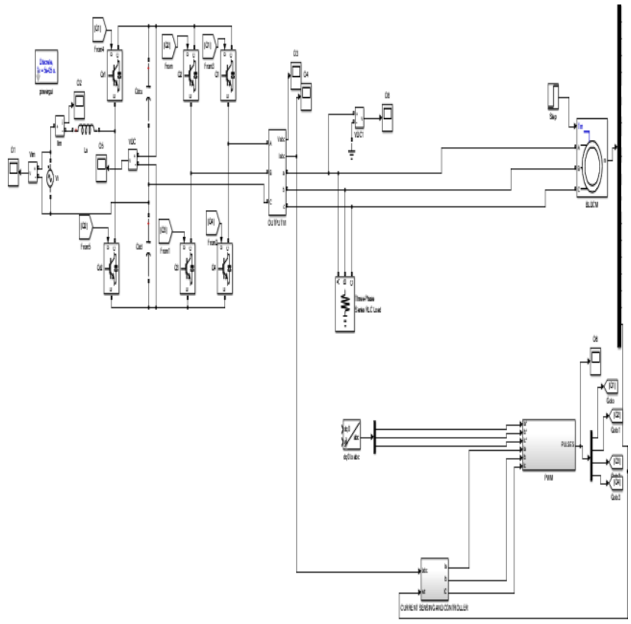

Fig.6. Matlab/SIMULINK

Fig.6. Matlab/SIMULINK Scheme of the System Simulation of the total closed-loop system with PI controller is performed using MATLAB/SIMULINK software in order to verify the system as well as predict to any unexpected behavior which may occur during operation. The MATLAB/SIMULINK schematic of the BLDC Motor drive is shown in Fig. 5. The system includes FSTPI, BLDC Motor and pulse generator for generating PWM signals with varied duty ratio based on the decoded Hall signals.

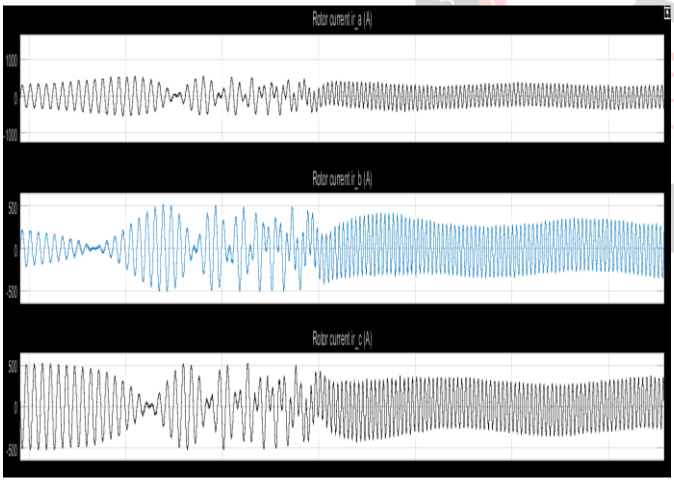

Fig.7. Current Waveforms for Rotor Phase A, B, C.

Fig.7. shows the current waveform of rotor phase A, B and C. BLDC motor parameters are those: the motor rated voltage 12 V, the rated current 1.5A, the phase resistance 1.05Ω.Since the motor is unloaded current value is very small and back EMF value is 2 V at speed of 1600 RPM.

System is validated with experimental setup, microcontroller ATmega328P is used as suitable development board, IR 2101 is used as a gate driver circuit. Fig.8 shows installed setup and Fig 9 shows the Stator voltage waveforms across the phases.

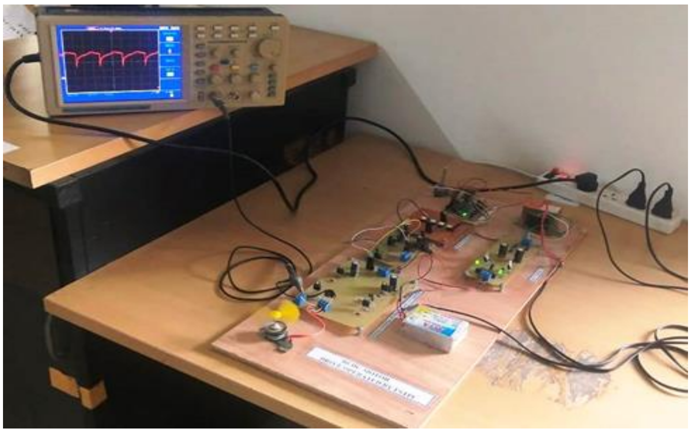

Fig.8. Experimental Setup

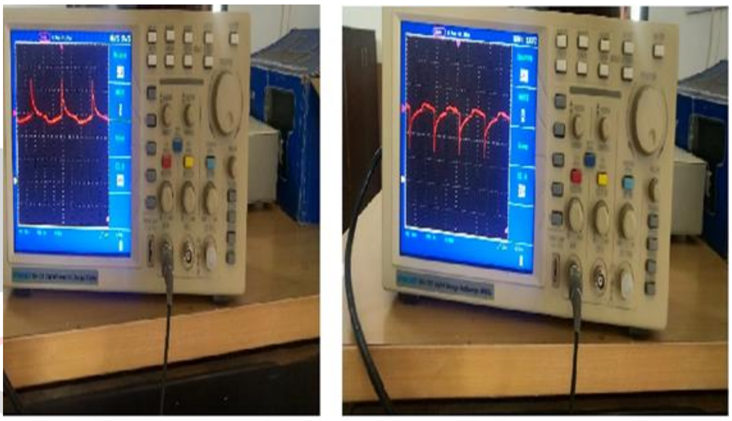

Fig.9 Waveform of Stator Voltage across Phases

| Sr. No | Current (A) | Speed (RPM) | Torque (mN-M) |
|---|---|---|---|
| 1 | 0.1 | 416 | 12.14 |
| 2 | 0.2 | 558 | 24.29 |
| 3 | 0.3 | 716 | 36.44 |
| 4 | 0.4 | 820 | 48.58 |

Table No I. Current, Speed & Torque Reading

Table No-I shows different speed and torque readings of experimental setup. Torque is calculated by following equation.

$$Ʈ = \frac{8.3 * Ia}{Kv} \quad (I)$$

Where, Ʈ is torque in NM, Ia is current in ampere; Kv is a velocity constant in RMS/V.

MOSFET Conduction Losses

MOSFET Conduction losses can be calculated by,

$$P_{Cond} = I^2_{RMS} * R_{DS(ON)} * D \quad [6] \quad (II)$$

Where, I is in ampere, R is in ohm and D is duty cycle.

In Four switches three phase inverter experimental setup we use IRFZ44 as a switch, and from equation no II,

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conduction losses in single MOSFET switch is calculated as follows for all readings of Table No I.

For Reading No 1

$P_{Cond} = (0.1)^2 *(17.5\ m\Omega) *(0.27)$ mW

$P_{Cond} = 0.12$ mW (III)

For Reading No 2

$P_{Cond} = (0.2)^2 *(17.5\ m\Omega) *(0.43)$ mW

$P_{Cond} = 0.30$ mW (IV)

For Reading No 3

$P_{Cond} = (0.3)^2 *(17.5\ m\Omega) *(0.55)$ mW

$P_{Cond} = 0.86$ mW (V)

For Reading No 4

$P_{Cond} = (0.4)^2 *(17.5\ m\Omega) *(0.70)$ mW

$P_{Cond} = 1.96$ mW (VI)

From equation III, IV, V and VI conduction losses of single MOSFET at different speed is calculated. Following Table No II shows the comparison of conduction losses between four switch and six switch inverter circuit.

| Reading No. | FSTPI Losses (mW) | SSTPI Losses (mW) | Difference (mW) |
|---|---|---|---|
| 1 | 0.12* 4 = 0.48 | 0.12* 6 = 0.72 | 0.24 |
| 2 | 0.30* 4 = 1.2 | 0.30* 6 = 1.8 | 0.60 |
| 3 | 0.86* 4 = 3.44 | 0.86* 6 = 5.16 | 1.72 |
| 4 | 1.96*4 = 7.84 | 1.96* 6= 11.76 | 3.92 |

Table No. II Conduction Losses in FSTPI & SSTPI

From above Table No II we can say that the conduction losses in six switch three phase inverter circuit is more compared to four switch three phase inverter circuit.

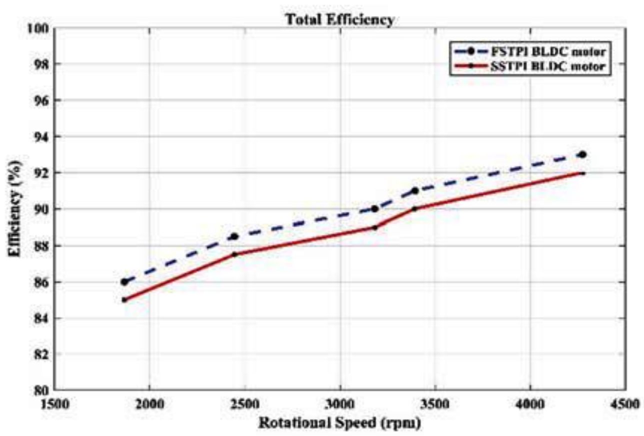


Fig.10 Efficiency Comparison of SSTPI and FSTPI [7]

From above Fig. 10 which shows the comparison between Efficiency of BLDC motor operated by SSTPI and FSTPI [7] we can say that the FSTPI circuit has more efficiency compared to SSTPI circuit.

## V. Conclusion

Brushless DC motor has major characteristics such as high efficiency, high power factor, high torque, low maintenance and ease of control; it can be widely use in variable speed drives and various industrial applications. A simulation and hardware result validates proposed system. The major advantages of the proposed system are

1. More Simplified circuit.
2. Switching losses are less as compared to SSTPI.
3. Implementation of the proposed system less expensive.

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