

Electronic Commutation of DC Motor

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Abstract—This paper focuses on the design and implementation of electronically commutated DC MOTOR. The electronic MOSFET is used as switch. For a P pole machine in lap & wave winding configuration coils can be wound for no. of parallel path. The stator consists of slots for armature winding and the rotor has dc field winding or permanent magnet. The MOSFET switch is triggered in a specific pattern according to connection with coil using microcontroller. The speed control of the motor is very flexible. The motor can run in linear motion, discrete motion, exponential motion, linearly increasing & linearly decreasing motion. Reversal of direction of rotation is easy. Motor can run in desired speed range from minimum speed up to maximum speed. Winding of the motor is suitability connected according to V- I rating of source like lap or wave configuration.

Keywords—Electronic commutation, MOSFET switch, microcontroller triggering, A-D converter, Flexible speed control

I. INTRODUCTION

Electric motors are one the most essential components and the driving force of industry today. It is estimated that more than five billion motors are built worldwide every year. In general, there are two types of motors namely ac and dc. The ac motors are usually less expensive, rugged and have low maintenance but hard to control, on the other hand the dc motors are more expensive, but highly controllable. 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 subject to wear and require maintenance. When the task of commutator and brushes are replaced by solid-state switches, maintenance-free motors were realized and the new motor called brushless dc motors emerged. The commutation problem of dc motor limits their use. Brushless dc motors (BLDC) are one of the motor types rapidly gaining popularity. The construction of modern BLCD motors is very similar to the ac motor, known as the permanent magnet synchronous motor. BLDC motors come in single-phase [1], 2-phase and three-phase configurations [2]. Out of these, the 3-phase motors are the most popular and widely used. Much research has been done on the modeling and analysis of Brushless DC motor and many application note has been prepared by industries regarding working of BLDC motor [3],[5-11].

This paper represents exact electronic commutation of dc motor. In electronic commutation scheme for the commutation process reversal of current is achieved by MOSFET connected across the coils. The MOSFET is

connected in a specific manner shown fig.1 & triggering of MOSFET by independent microcontroller bits in a specific pattern. The no. of MOSFET switch required for N coil is $2N+2$. One MOSFET switch is connected to forward current & other to flow reverse current.

The speed is mainly depends on the switching delay of switches. So for a constant speed motor if torque is increased current also increase. So the current not exceed rated value a current sensing device is used. Current sensing device is connected to a serial ADC & ADC is communicated with microcontroller & switching delay is increased & speed is decreased correspondingly.

Forward switch on for a time period current flow in forward direction & than forward switch will off & reverse conduction switch will conduct then current flow in reverse direction in first coil & in a sequence reversal of current will take place in other coils. This switching pattern of the switches is continuing for next upcoming cycle.

II. SYSTEM DESCRIPTION

The main parts of electronic commutation dc machine

A. Stator

The stator core is made of insulated steel laminations. The thickness of the laminations and the type of steel are chosen to minimize eddy current and hysteresis losses. The magnetic path, which comprises a set of slotted steel laminations called stator core pressed into the cylindrical space inside the outer frame. The magnetic path is laminated to reduce eddy currents, reducing losses and heating. CRGO laminations of 0.5 mm thickness are used to reduce the iron losses. The stator frame is used to hold the armature windings. The coils are connected in series or parallel with MOSFET switch string for the forward & reverse conduction. The input is given at the terminals of the string at stator.

A.1 MOSFET required for Forward conduction & reverse conduction of coils

The N channel MOSFET are required for forward and reverse conduction of coils. So MOSFET should have less switching time. The rating of the MOSFET depends on peak voltage in coil. Triggering of MOSFET is using driver circuit with microcontroller bits in a specific manner.

For 24 slot 12 coils stator the connection diagram shown in fig.1 & physical installation is shown in fig.2. Gate pulse voltage is taken according to switching bit pattern. The no of MOSFET switch is 26.

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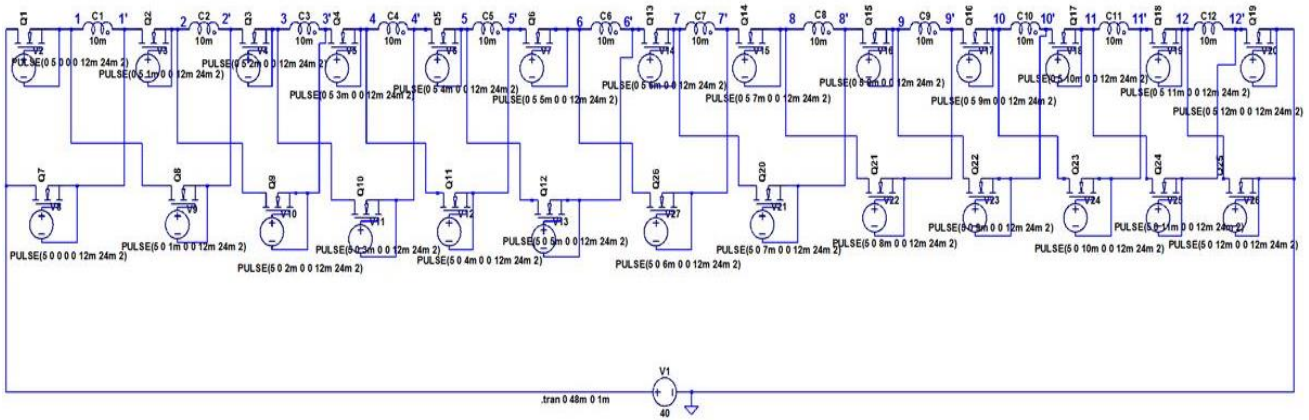


Fig.1: Coil connection with MOSFET switches for 2 pole motor.

A.2 Stator Winding (Armature Winding)

The coil side of coils are placed 180 electric degrees apart as shown in fig.2. One coil sides installed per slot. The connection of coils is in series with the MOSFET for forward and reverse conduction shown in fig.1. The coils are connected sequentially according the triggering sequence of MOSFET switch connected to coils. The positive and negative input terminals are given at two ends of coil connection. The connection shown in fig.1.

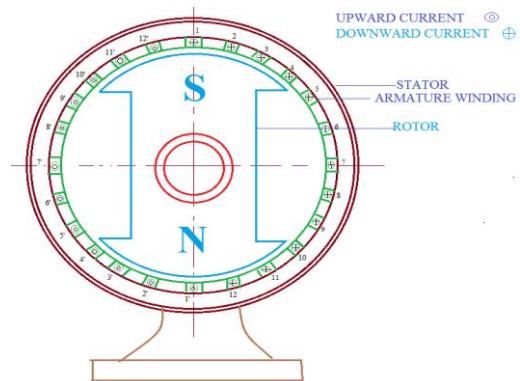


Fig.2: Physical installation of coil for a two pole motor.

A.3 Microcontroller for MOSFET switch triggering

Microcontroller is required for specific triggering pattern of electronic MOSFET switch. Coding is done in KEIL & simulated in PROTEUS using microcontroller Atmel 89C51.

B. Rotor

The rotor may salient pole rotor or cylindrical rotor. Poles are built with thin silicon steel laminations of 0.5mm to 0.8 mm thickness to reduce eddy current.

In case of high speed the rotors are manufactured from solid steel forging. The rotor is slotted to accommodate the field winding. Normally two third of the rotor periphery is slotted to accommodate the winding and the remaining one third unslotted portion acts as the pole.

The rotor is excited by direct current supply with slip ring to create magnetic field flux [4].

B.1 Rotor Windings

In electronic commutation dc motor for rotor winding field poles is made of a number of coils circuit equal no of pole pairs is energized with dc power fed through slip ring riding on the shaft or may have permanent magnetic pole. The rotor winding can be wound separately, in series or parallel with armature winding.

III. WORKING PRINCIPLE:

The working principle of electronically commutation dc motor is using electronic MOSFET switch for commutation of the coils. Coils are installed in the stator slots. Coils are connected with MOSFET switches. Triggering of MOSFET switch is using microcontroller bits shown in fig 3. For a 12 coil 24 stator slots motor coils are connected with 26 MOSFET switches shown in fig1. Gate triggering pulse is given by microcontroller bits in a specific sequential manner. Using 26 independent bits of microcontroller port P_0, P_1, P_2 & two bit of P_3 simulated in KEIL & Proteus lab center electronics. The working of the motor is explained taking simple switches at place of MOSFETs.

Case 1: Switch status for switches shown in fig.4. So the direction of the flow of current in coils is known.. Coil C1 has no current & coils C2 to C12 having negative current. The physical installation of coils is shown in fig.5. The 24 slots are shown on the stator with black color indicate upward current, yellow color indicate downward current & blank indicate no current. So this will create two magnetic poles.

Case 2: Switch status for switches shown in fig.6. So Coil C1 has positive current & coils C2 has no current & coils C3 to C12 having negative current. So rotating armature magnetic field rotates one slot in anticlockwise direction as compare to case1. The physical installation of coils is shown in fig.7. So the stator poles shifts one slot in clockwise direction & rotor will follow this.

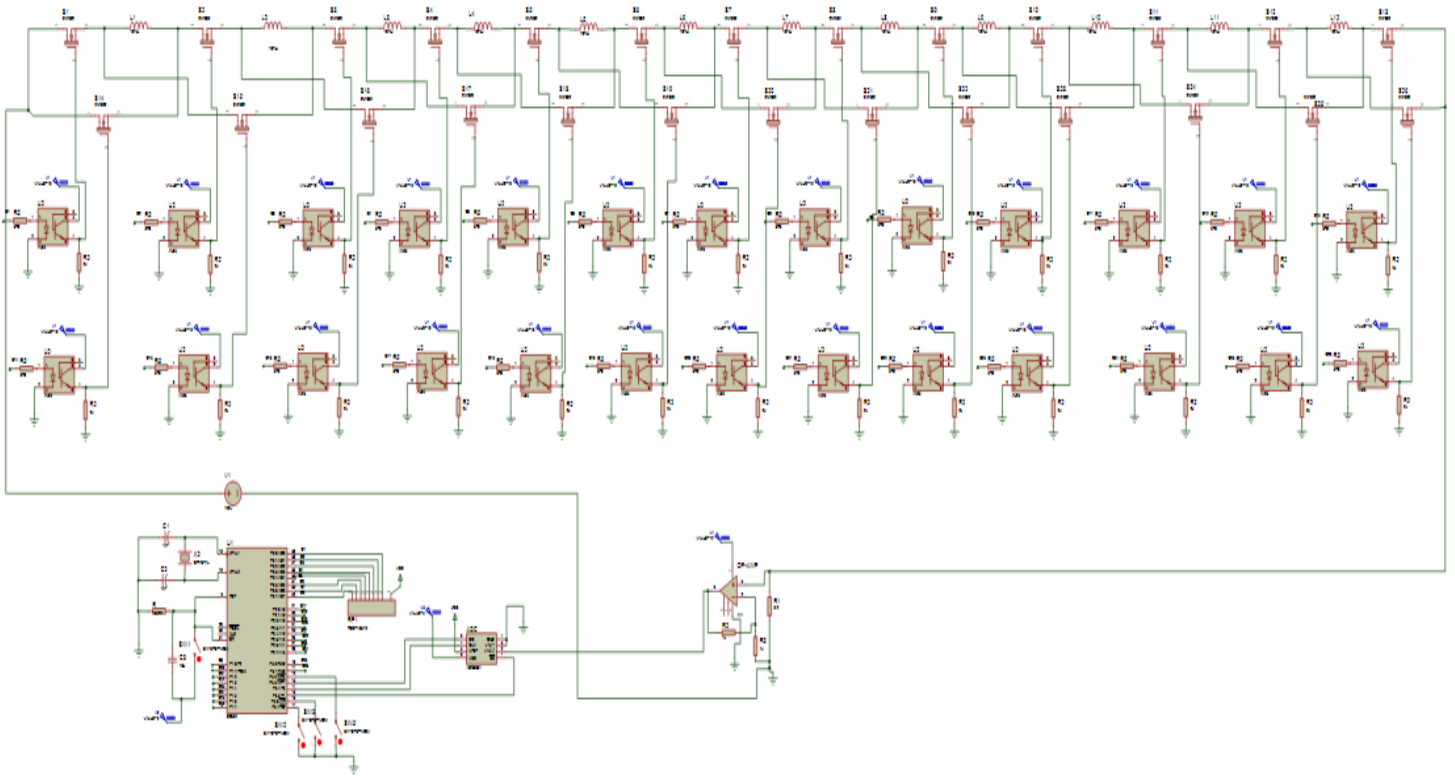


Fig.3: Circuit diagram for stator (armature) coil commutation & current sensing circuit with A-D converter.

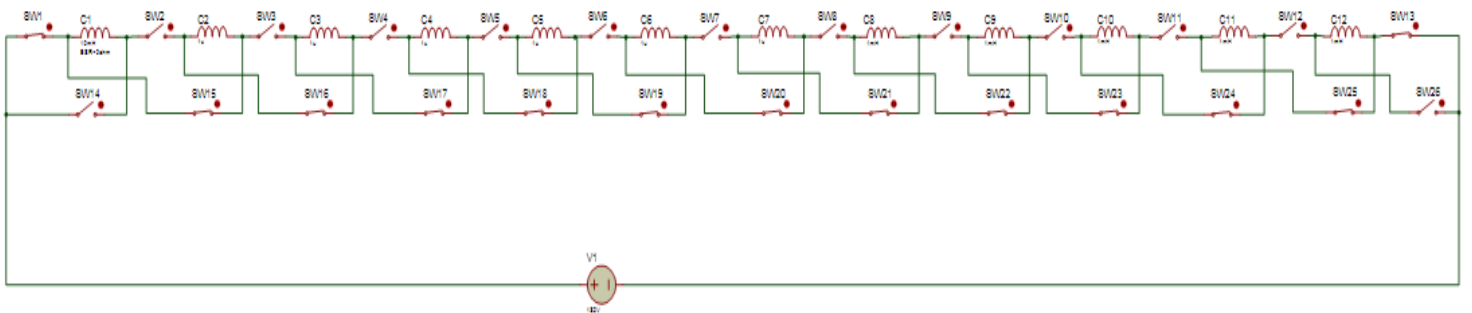


Fig.4: Circuit diagram for switch status & stator (armature) coil current flow direction for case1.

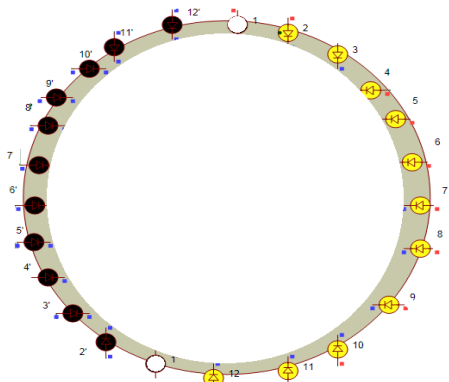


Fig.5: Physical coil installation & stator (armature) coil current flow direction for case1.

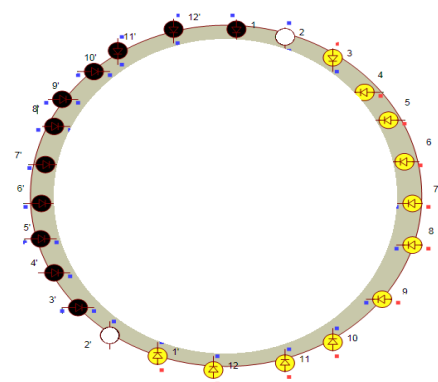


Fig.7: Physical coil installation & stator (armature) coil current flow direction for case2.

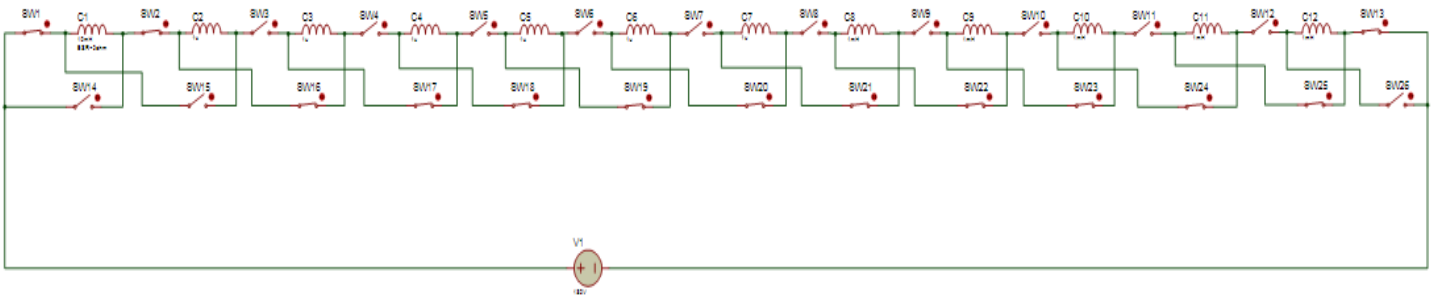


Fig.6: Circuit diagram for switch status & stator (armature) coil current flow direction for case2.

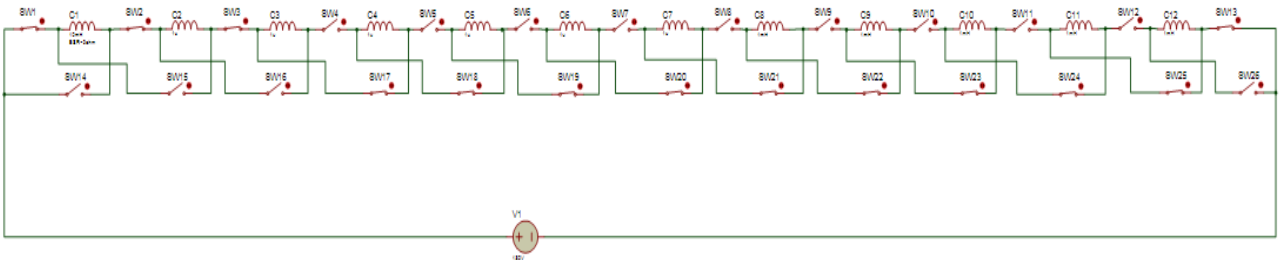


Fig.8: Circuit diagram for switch status & stator (armature) coil current flow direction for case

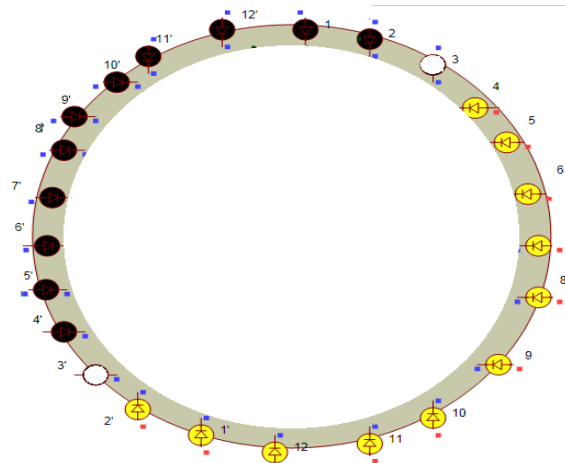


Fig.9: Physical coil installation & stator (armature) coil current flow direction for case

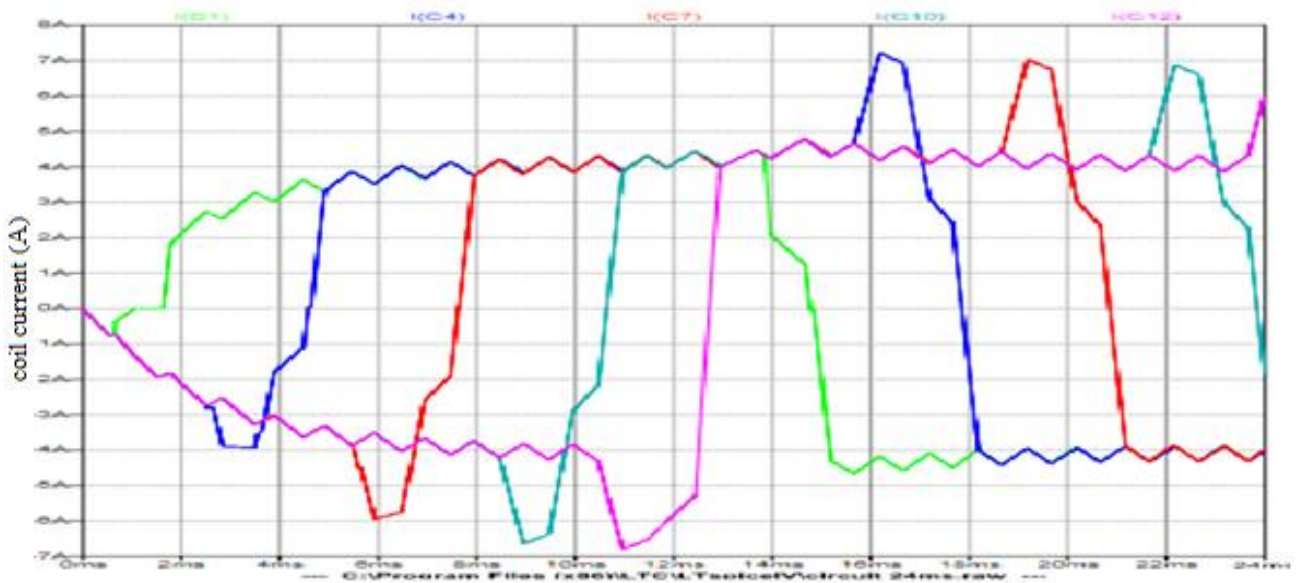


Fig.10: Current waveform in various coils C1, C4, C7, C10, and C12.

Case 3: Switch status for switches shown in fig.8. So Coil C1, C2 have positive current & coils C3 has no current & coils C4 to C12 having negative current. The physical installation of coils is shown in fig.9. So the stator poles again shifts one slot in clockwise direction & rotor will follow this.

So this sequence will be continue in upcoming cases & Case 4 to case 26 the rotor will complete one cycle & this will repeats in next cycles.

Before reversal current will zero for little time in each coil. So, current reversal of coil is reliable.

Simulation of the circuit diagram using triggering pattern of switches given above is performed in LT SPICE & PROTEUS LABCENTER ELECTRONICS software for simultaneous waveform in one figure. A Wave form of current flow is shown in fig.10 for one cycle & it repeats for next upcoming cycles. Current in coil 1 is positive for first half cycle & negative for next half cycle. Current in coil 2 lag by current in coil 1. Current in coil 2 is negative for starting time than positive for half time and again current be negative.

So the flow of current in next coil lag previous coil. Current in all coils is negative for half time period & positive for half time period. By changing direction of current flow in coils sequentially the magnetic field changes. Magnetic field is rotating in nature & field poles rotate with magnetic field. The time delay in two consequent triggering can be adjusted constant, increasing, decreasing & exponential increasing or decreasing. So speed of the motor can be obtained in desired way so motor have a flexible speed characteristic. The motor rotation can be easily reversed by microcontroller pin P3_7.

For proper visualization current waveform for coils C1, C4, C7, C10 and C12 are shown in fig.10. The value of supply voltage is taken $V_s = 180V$. Coil inductance is taken $L = 10m$ henry with series resistance of $R_a = 2\Omega$.

Time cycle is $t = 24ms$. Then the speed of rotation approximates $W_m = 41.6$ rps & 2500 rpm. So for any time 11 coils will conduct with 13 MOSFET switches. KVL equation

(I_a = Average armature current, A; P = no. of poles.
 i = Peak - peak armature current, A; Z = no. of conductors

V_{sw} = MOSFET on state drop, A = no of parallel path
 T = Motor output torque, Nm; ϕ = flux per pole, Wb)

$$V_s = 11 * E_b + (11 * I_a * R_a) + 13 * V_{sw} \quad (1)$$

The back emf in each coil is

$$E_b = \frac{Li}{t} * \frac{2}{p} = \left(\frac{P * Z * \phi}{A} * n = \frac{Li}{t} * \frac{2}{p} \right) \\ = 10m * \frac{14}{24m} = \frac{70}{12} = 5.833V \quad (2)$$

So emf in all 11 coils connected in series is 64.16V.

Voltage drop in resistance

$$I_a * R_a = 4.5 * 2 = 9V \quad (3)$$

$$V_{sw} = 1.294V \quad (4)$$

Output torque for the motor

$$T = (E_b * I_a) / W_m = \frac{64.16 * 4.5}{2\pi * 41.6} = 1.1047Nm \quad (5)$$

So for a rated constant power motor if torque is increase above a limit than speed should decrease. So in this type

IV. STARTING & SPEED CONTROL

At starting due to rotor inertia the switching speed of the coils should be low. So reduce voltage should be applied. So with the reduced voltage the switching time should be high to rotor gain sufficient speed.

1. At reduced voltage microcontroller pin P3_2=0 for little time. Then the switching time of coils will be high & rotating speed will low so rotor can easily rotate with field. After few cycles pin P3_6=0 for little time to increase speed. Then applied voltage is increased to rated value.

2. The speed is regulated by switching delay of the coils. To increase the speed microcontroller pin P3_6=0 for little time & decrease the speed microcontroller pin P3_2=0 for little time. So speed can be regulated on desired speed from minimum to maximum speed.

V. REGENERATIVE BREAKING

Regenerative braking is used at time of speed decreasing or stopping. So at this time pin P3_6 =0 make high & field excitation is increased. All switches have high gate signal so behaves like diodes. The kinetic energy of rotor can used to generate electric power & the electric power is feedback to supply source.

Motor speed can be easily controlled as torque depends on speed. So the current sensing device is used to decrease speed if current is increasing above a limit.

VI. CONCLUSION

In electronic commutation motor the working is similar to DC motor & the mechanical commutation using brush is replaced by connecting MOSFET switch. More features can be added through coding. The switching pattern for triggering can be programmed in desire way for a microcontroller. The speed can be obtained constant, discrete, linearly increasing & decreasing & exponential increasing or decreasing or any type of curvature nature. So speed of the motor can be obtained in desired way so motor have a flexible speed characteristic. There is no commutation problem & maintenance problem. Microcontroller & MOSFET switch required.

- No commutation & maintenance problem.
- Flexible speed characteristic.

- Winding configuration for no. of parallel path to adjust source V - I rating.
- Starting & speed control easy as motor can run on any desired speed.
- Highly reliable & efficient motor.
- Regenerative braking is possible.

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BIOGRAPHY



Rajendra Bhamu was born in Sujangarh, Rajasthan, India in 1993. He is pursuing his B.Tech degree in Electrical Engineering from BKBIET College, Pilani (Rajasthan), India. His interest to study for higher education at premier and reputed institute. And his research interests focus on reliable & efficient power system through electronics & automation and utilize renewable energy sources.