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Speed Control of Radial Flux BLDC Motor by Using Closed Loop Control for Electric Vehicle

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ABSTRACT: Compact motor with high torque and wide speed range is the primary requirement for in-wheel electric vehicle application. Radial flux permanent magnet (RFPM) brushlessdirect current (BLDC) motors are an interesting solution for electric vehicles, because of their shape, flexibility, compactness,robustness, high efficiency, wide speed range and high torque. In this paper, RFPM BLDC motor is proposed. It hassingle side configuration with 24 stator poles and 36 permanentmagnets (PM) on rotor disc. In most of the applications of RFPMBLDC motor, the speed control is very important. To achieveaccurate speed control, closed loop control using microcontrolleris proposed in this paper. Microcontroller is used to drive themotor by sensing rotor position using Hall sensors. The effectivebraking scheme is also proposed. To verify the performance ofthe proposed RFPM BLDC motor, simulation is carried out andresults are presented.

A prototype of RFPM BLDC motor isdesigned in order to validate the performance of the motor.Index Terms—Radial flux machine, BLDC motor, closed loop control, electric vehicle, microcontroller, permanentmagnet motor.

I. INTRODUCTION

With every factory unit becoming computerized, mechanized and increasingly dependent on electric energy, motors with features such as space conservation, highefficiency and flexibility are being considered for commercial applications. As the hybrid drives entered the automobileindustry, the demand for high efficiency also increased. Thisrequirement is fulfilled by Radial flux permanent magnet(RFPM) brushless direct current (BLDC) motor. The researchis directed much more seriously towards this field. Theresearch is being done in the areas of design, control andthermal aspects etc. With the advent of technology, permanentmagnet (PM) materials such as are cheaper as compareThe researchis directed much more seriously towards this field. Theresearch is being done in the areas of design, control andthermal aspects etc. With the advent of technology, permanentmagnet (PM) materials such as NdFeB are cheaper as compareto old materials and concepts as well as new applications hasplaced permanent magnet machines in a prominent position[1]. The inherent features of Radial flux BLDC, such as highefficiency, high compactness and wide operation speed range,make these machines suitable for direct drive applications[2].
In direct drive applications like electric vehicle, the directcoupling of the shafts of the machine and application gives compactness to the circuit. This compactness is also a reason
Of elimination of gearbox. Furthermore, PM machines have amagnetized motor. Thus, the PM motors use low electricalenergy which, in turn, make it highly efficient. The ability of these machines to work at lower speeds makes themapplicable for direct drive low speed applications. High speedsare also achievable which gives these machines a wide speedrange. Such characteristics are desirable in electric vehiclewhere space is also a critical factor.The main focus of this paper is to operate RFPM BLDCmotor by closed loop control. To have a wide speed operationand closed loop control, a microcontroller is used.Basic working of BLDC motor and proposed scheme toachieve closed loop action is discussed in this paper. Motorshould also possess good braking operation which will besuitable in electric vehicle. Hence, apart from speed control,braking operation of motor by triggering any one switch fromupper group and lower group of inverter is achieved.However, to study the behavior

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of motor during loadingcondition, simulation is carried out at various load torque.Machine design is briefly discussed. Finally, other Applications where RFPM BLDC motor can be used are also discussed.

II. TOPOLOGIES

BLDC motors are constructed in two ways, namely, radialflux motor and axial flux motors. In radial flux motors, themagnetic field travels radially across the air gap betweenstator and rotor. Torque is produced when the radiallytravelling magnetic field interacts with the axially flowingcurrent. A detailed study of the different topologies of axial

flux machines is presented in.In Radial flux motors, the magnetic field between stator androtor travels axially. When this radially travelling magneticfield interacts with the radially travelling current, torque isproduced. The air gap is adjustable during and even afterassembly. In radial flux motors, retention of the magnetsagainst centrifugal force on the rotor is required but there is nosuch requirement in axial flux motors. Some importantfeatures of axial flux motors over radial flux motor arediscussed in[3].

BLDC motorsrequires information about the rotor position to generate gatesignals for its power electronic controller. This is shown inFig.1. The commutation is done electrically for which it isimportant to know the rotor position. Usually three Hallsensors are placed at 90 degree in space. When the magnetpoles of rotor come to Hall sensor, the signal is generated byHall sensor as in, which is used to trigger theappropriate next phase winding of stator. Position controlusing Hall sensor is well explained in.According to the four steps, the commutation sequence isperformed. The motor phases are supposed to conduct for 90electrical degrees one time per cycle. The one phase is onlyconducted at one time. The Hall sensor signal has the risingedge and the falling edge for each phase. That is, the fourtrigger signals are generated per cycle. Using these triggersignals, motor control is carried out.

III. CLOSED LOOP CONTROL

The RFPM BLDC motors work over a wide range of speed. This property makes it useful for robotics, factory automation, vehicular applications etc. Motor speed can beadjusted by speed control systems. Generally, a speed control system consists of speed feedback system, a motor, an inverter, a controller and a speed setting device. A properlydesigned closed loop controller makes the system immune to changes in parameters. Proportional integral (PI) controllercan be used to make a closed loop speed control of the motor.Speed of the BLDC motor is directly proportional to theapplied voltage. Any diversion of actual speed from referencespeed will be given as an error signal to PI controller whichtakes appropriate corrective action to change the duty cycle ofapplied gate signal.A Hall sensor can also use as a speed sensing device.The difference between the reference speed and actual speed isfed to the PI controller as the error signal. The values ofproportional and integral gain are set such that the overshoot And the settling time to reach steady state should be as low aspossible so as to have a better motor operation.

IV. PROPOSED SCHEME

The proposed scheme presented in Fig. 3 shows that singlephase AC supply is converted into DC supply using singlephase bridge rectifier. The DC power from rectifier is supplied

To the Single phase bridge inverter which can give variablevoltage and frequency. The Single phase AC output frominverter is then fed to the RF BLDC motor.Hall sensors detect the rotor position and provide positionsignal to the controller which energizes the appropriatewinding of the Single phase motor and motor starts running atωr speed. To have a closed loop control, the reference speedωr^* is fixed at particular value. This value is compared with theactual speed with the help of comparator. Error signalgenerated by comparator is then given to the controller whichtakes corrective action and gives the triggering pulses to therectifier circuit. Hence, the output voltage of the rectifier willchange according to the reference speed and motor will regainits set speed.

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V. DESIGN OF MOTOR

There are many construction topologies in Radial fluxmachine; amongst them single rotor, single stator structure is fabricated. The flux from permanent magnets which aremounted on the rotor, flows through the air gap, then throughelectromagnets which are mounted on stator and back to therotor, this completes the closed path of the flux. Procedure ofthe motor is well explained in.

V. MICROCONTROLLER

The assembly of microcontrollerdsPIC33EP256MC202 (3.3V, 18F) with Hall sensor circuitry. The Hallsensor output is in millivolt; hence, a signal conditioningcircuit is used to convert this millivolt signal to the acceptable.
Level of voltage for microcontroller.This microcontroller is a twenty eight pin integratedcircuit. 26th -21st pins are used to generate pulse widthmodulation (PWM) signals and these signals are fed to thedriver circuit of the inverter. Microcontroller receive analogsignal from Hall sensor. Using analog to digital (ADC)module of controller, these analog signals are converted intodigital form. A program written for closed loop speed controlof motor is fetched in this controller. If the speed of motordrops below the reference speed, the controller changes thepulse width of the switches used in inverter and motor willreturn to its reference speed.

VII. SIMULATION STUDY

To study the performance of RF BLDC motor, simulationis carried out in PROTEUS (Version8) environment for different operating conditions.

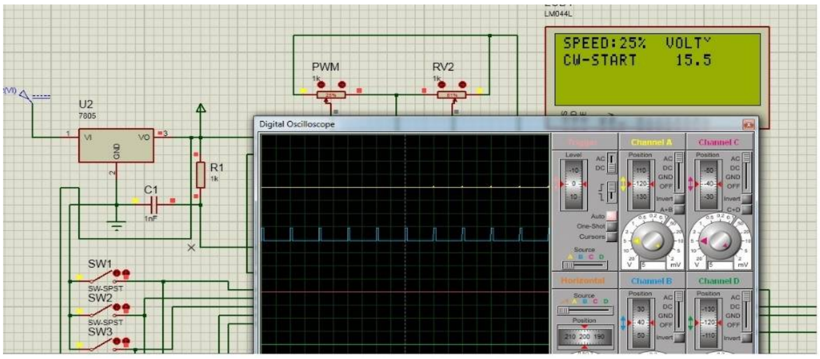

Fig.1 Speed on 25% in PWM

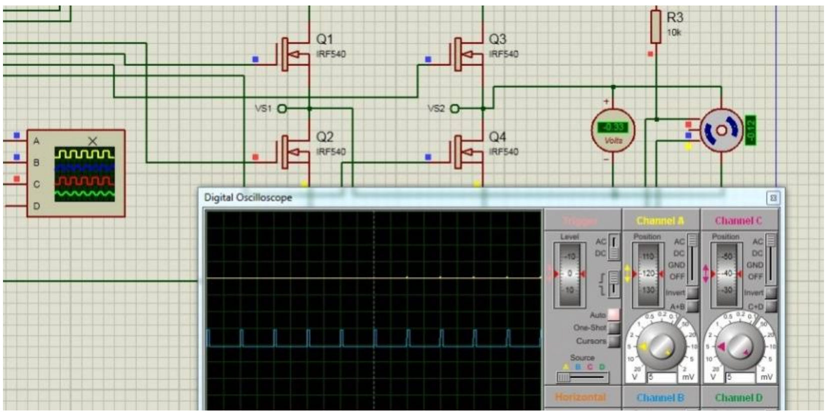

Fig.2 Motor Voltage Variation at 25% PWM Speed

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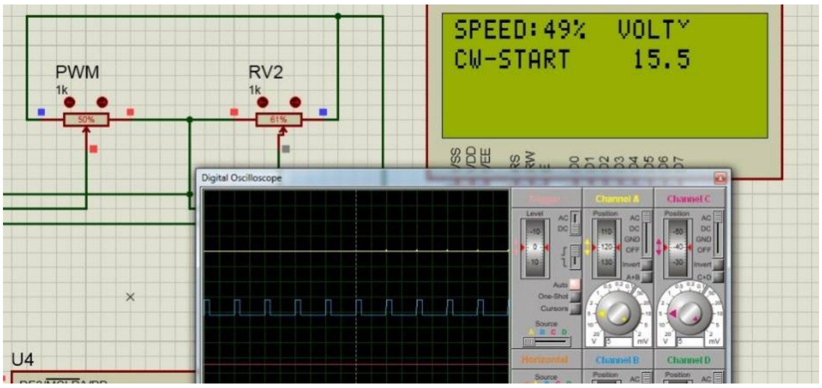

Fig.3 Speed on 50% in PWM

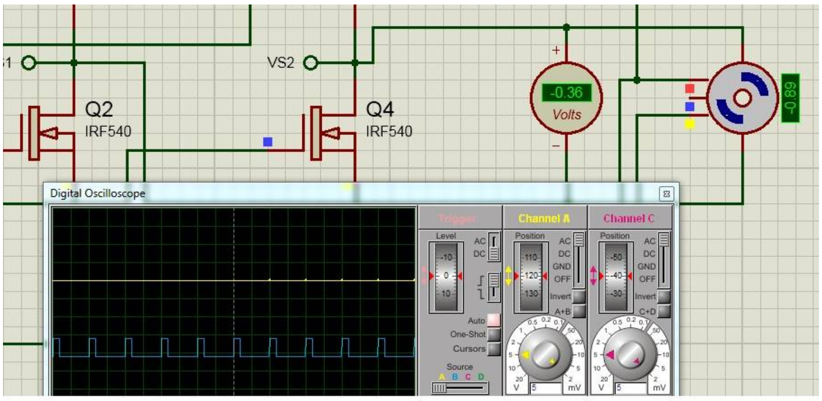

Fig.4 Motor Voltage Variation at 50% PWM Speed

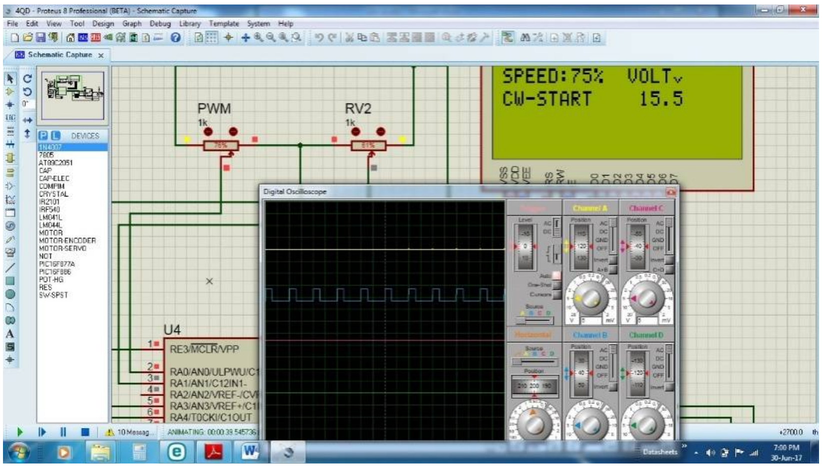

Fig.5 Speed on 75% PWM

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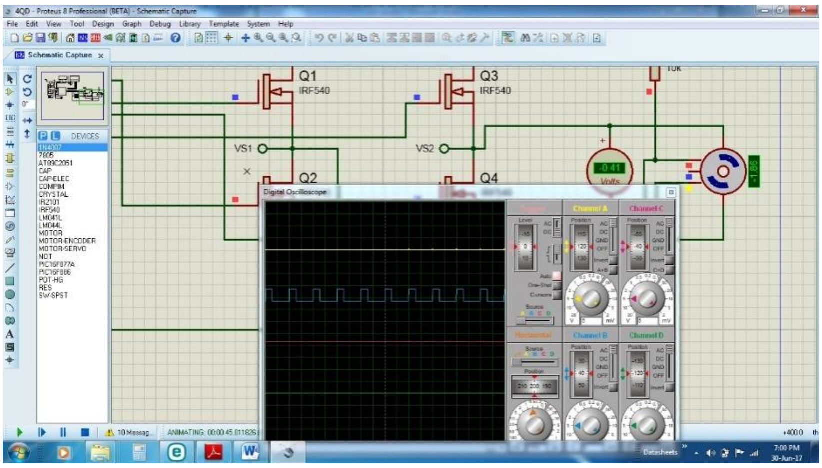

Fig.6Motor Voltage Variation at 75% PWM Speed

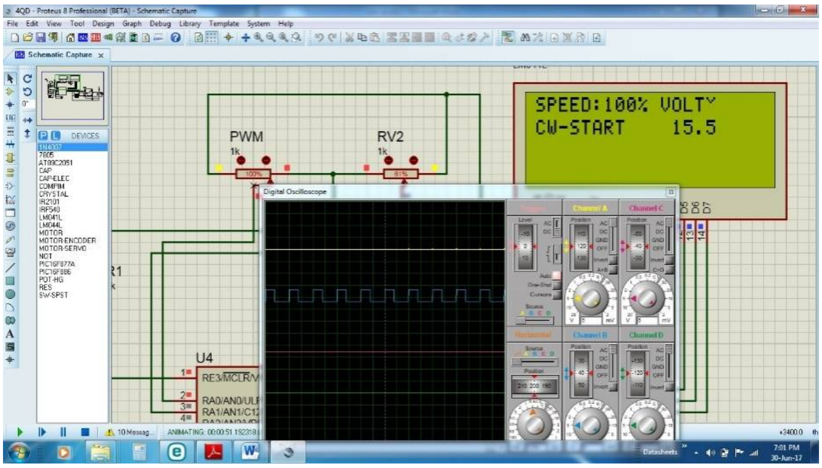

Fig.7 Speed on 100% PWM

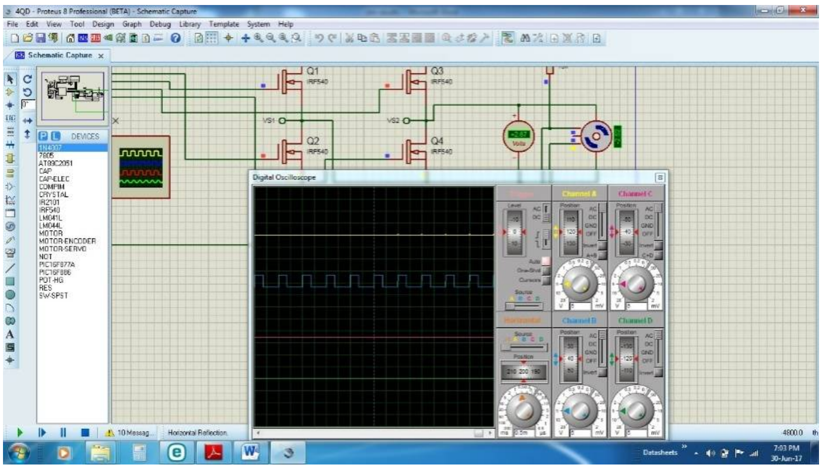

Fig.6Motor Voltage Variation at 75% PWM Speed

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The above Fig. shows PROTEUS result is out at 25%-100% Speed of PWM technique. According to the speed variation the motor voltage is also changes. The motor result is taken as negative in clockwise rotation and positive at anticlockwise direction of motor rotation. The Q1 and Q4 switch is operate at anticlockwise direction, the result is taken by motor variation voltage. The Q2 and Q3 switch is operate at clockwise direction, and result is taken at software. The fig.1 shows the PWM speed variation at 25%of PWM speed according that in Fig.2 taken result is out at motor voltage variation.We are going to check the different result of speed in different parentage of duty cycle in PWM, According that the motor voltage is vary that is given a simulation. If the at 50% duty cycle of Speed is rotate at 1500 RPM in the first half then in second half is double at 3000 RPM. If that result is not come then hall effect feedback is work and corrected by using closed loop control system. It sense the speed of variation by microcontroller PIC and give the signal to the control system there Hall effect senser control the speed of RFBLDC motor.

VIII. BRAKING OPERATION

Simple dynamic braking operation can be achieved by continuously energizing the windings of the respective Hallstate among any one of the six Hall states. By continuously energizing the windings, a steady magnetic stator poles established. Rotating rotor poles try to align themselves with the steady magnetic stator poles. Hence, after some rotations, motor stops. However, for safe braking and for achieving thedesired deceleration rate, the switching frequency or the duty

Cycle can be adjusted.If the upper switch Q1 of phase A and lower switch Q2 ofphase C triggered continuously by controller then statorwindings of phase A and phase C acquired N pole and S polerespectively. South Pole of PM rotor try to align with NorthPole of stator and same wise, the North Pole of rotor alignwith South Pole of stator. Hence, motor come to rest as shownin. No external dc supply required in this brakingoperation and fast braking of motor is achieved.Apart from this, unlike plugging, motor will not run inreverse direction. Electric braking brings the vehicle at verylow speed and when mechanical brakes are applied motorcomes to rest. Hence, less frictional losses and the brakingoperation required low maintenance.

IX. APPLICATIONS

PM synchronous machines are fast becoming popular dueto the rise in low speed applications. The recent developmentsin electrical vehicle and renewable energy, direct driveselectrical machines are becoming the need of the hour.Majority of applications have requirements in terms ofhigh efficiency, saving of space, economic feasibility amongstother characteristics. RFPM BLDC motors fulfill theserequirements. Their disc shape, multistage capability and hightorque density are added advantages. The three most importantapplications are listed below.However, three applications may be the most relevantincluding electric vehicle due to the numbers of documentsand amount of research a review of the literature reveals in thesearch for information about axial flux machines: wind power,electric vehicles, blowers and elevation.

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A. Electric Vehicles

Shape flexibility, compactness, robustness, highefficiency, and high torque make RFPM BLDC motors apt forelectrical vehicles. The motor can be directly coupled to orinside the drive wheels. Axial flux machines are an interestingsolution, where the motor is directly coupled to, or inside, thedrive wheels

B. Blowers

In RFPM BLDC motor is fabricated for blowers invacuum cleaners. Motor design and velocity control of theself-tuning fuzzy proportional-differential-integral (PID)control and a soft-switching mechanism combined with thesensorless drive method have been effectively demonstratedfor blowers in vacuum cleaners using slim sensor less RFPMBLDC.

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X. CONCLUSION

The availability of rare earth permanent magnet materialsat low cost with high energy product allows rethinking ofmany traditional drive problems. Attractive features of an RFBLDC motors are good solution for the application likeelectric vehicle. Single side, RF BLDC motor hasbeen designed and fabricated for electric vehicle application.For steady and accurate operation, closed loop control ofmotor using Hall sensor is good solution and implementedusing microcontroller. Braking of motor and its advantagesover other braking technique, leads to the effective brakingcontrol of motor. Simulation study is carried out at differentoperating conditions. The simulation results prove theeffectiveness of proposed scheme.RF BLDC motor is also very much suited for applicationlike elevator, because of their disc like shape. Performance ofthe motor after reduction in the stator coils can also be tested.Further torque control loop can be added and the performanceof drive can be tested under the different torque conditions.

APPENDIX

1. Motor voltage = 24V
2. Rated Speed = 1500 rpm
3. Stator phase resistance Rs = 12 ohm
4. Stator phase inductance Ls = 0.005 H
5. Torque Constant = 4 N.m / A_peak
6. Pole pairs = 2

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