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MODELLING AND SIMULATION OF FOUR QUADRANT OPERATION AND CONTROL OF THREE PHASE BLDC MOTOR FOR ELECTRIC VEHICLES WITH PI AND PID

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ABSTRACT

Brushless DC motors are gaining a lot of popularity whether it is aerospace, military, household or traction applications. Due to the constraint of fuel resources, the world requires highly efficient electric vehicle drives for transportation needs. This paper proposes The four quadrant operation is simulated for the electric drive with maximum efficiency keeping in mind the fuel constraint. The battery is charged during the regenerative mode and the speed control using the closed loop control is performed. The proposed method requires the minimum hardware and the operation can be controlled in all the four quadrants. During the regenerative mode, the kinetic energy is returned via the bi-directional converter to charge the battery. The abovementioned proposal could be applied in electric vehicle downhill run by controlling the speeding in gravitational action where the speed becomes more than the reference speed. The practical implementation is under progress for the proposed method. A comparative analysis is carried out with PI and PID Controller in this work with simulation results.

INTRODUCTION

Brushless DC motors are gaining a lot of popularity whether it is aerospace, military, household or traction applications. Due to the constraint of fuel resources, the world requires highly efficient electric vehicle drives for transportation needs. The BLDC motor has a longer lifespan, higher efficiency, and compact size making it the most sought after motor in electric vehicle drive applications. The continuous attempt to reduce environmental pollution has given an impetus to the market of electric vehicles (EVs) [1]–[3]. As the fuel resources are depleting, the energy efficient electric drives are likely to replace vehicles running with fossil fuels. Being different from the ICE (internal combustion engine), EVs are the least burden to the environment. Any motor drive system which can be recharged from any external electricity source is known as a plug-in electric vehicle (EV). The complete electric vehicle drive model is described in [14], [16]. There are still some disadvantages of EV drives like overall lower efficiency, huge dimension, and the cost of storage devices etc. The technique of performing the four quadrant operation is proposed in [4] where its battery is charged during the regenerative braking but the system here has two energy sources, one is driving the motor and other is storing the energy using the rectifier during braking. It is proposed in this paper that only one battery is enough to drive the motor and at the same time to recover the kinetic energy of the motor using regenerative mode. This proposal reduces the cost of an extra rectifier and an additional battery. In [5] the four quadrant operation is performed without utilizing the kinetic energy of the motor. During braking, the motor kinetic energy is wasted in resistive losses this makes the system highly inefficient. In the world where there is fuel constraint, this system is not helping in that cause. In [12] four quadrant sensorless control of the electronically commutated motor is done without

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utilizing the motor kinetic energy in regenerative braking. The battery capacity puts a limitation to the EVs in the form of mileage or distance covered. Regenerative braking is just one of the ways to increase the efficiency of the drive. During regenerative mode, the energy of the drive system which is in the form of kinetic energy can be used to charge the battery during deceleration and downhill run to slow down the vehicle

This paper proposes a simple method of four quadrant operation in which the energy of the motor is utilized to charge the battery during braking. This method of efficient utilization of power can be done through bidirectional DC-DC converter and VSI. There is just one energy source and it is efficiently utilizing the motor kinetic energy by charging the battery using the VSI. The VSI operates as a rectifier during the braking mode and the rectified voltage is boosted to charge the battery.

The most commonly used topology [2]-[3] for a threephase BLDC motor is shown in Fig. 1. The three phase inverter is fed by DC source through VSI. Depicted in the figure, the stage following the capacitor consists of six insulated gate bipolar transistors (IGBT) switches which have antiparallel diodes connected across it. Instead of IGBTs, switch-like MOSFET can also be used as it inherently has antiparallel diode but the problem with the MOSFET is the ON-state voltage drop. For the low voltage, application MOSFET can also be used. Typically, the BLDC motor has trapezoidal back EMF waveform. To get constant power output the current is injected during the 120° period of constant back EMF. The injection of current is controlled through the two switches of different legs at a time in the inverter. Therefore at a time, only two switches operate. Unlike the DC motor, the commutation is controlled here through the switches. The current injection in each phase should be properly aligned with the back EMF to get the rotor flux and stator flux angle close to 90° for maximum torque production. The switching sequences of the MOSFET switches are shown in Fig. 2 for both forward motoring and reverse motoring. These three phases produce constant dc voltage for 360° during regenerative braking. It becomes important to know the rotor position so that the energization of the stator winding is in sequence. The position of the rotor can be detected using internal and external position sensor or it can be detected without the help of sensors [6]-[8]. In this paper, hall sensors are used to detect the rotor position. These sensors are embedded in the stator and according to the sensor output, the switches are triggered. Applying the KVL during any interval for BLDC motor as only two phases are conducting the equation becomes (1) where I_c is the phase current and R_c is the per phase resistance.

$$V_d = 2(E_b + I_c R_c)$$

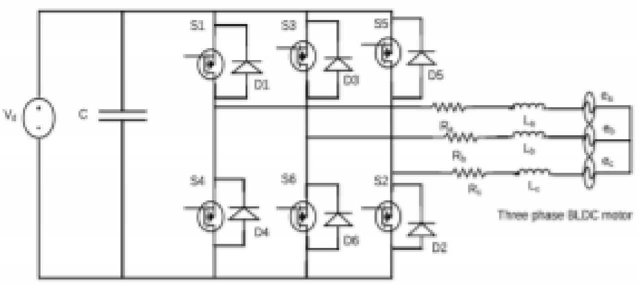

Fig. 1. Inverter based driving circuit of BLDC motor.

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PROPOSED CIRCUIT

The structure of the bidirectional converter [is illustrated . The bi-directional performance analysis is mentioned. It consists of two switches and two diodes it behaves as a buck converter when the switch T1 and D2 are operational, these operations are utilized in the drive during motoring mode and for regenerative braking T2 and D1 are operational, thus making the converter work in boost operation by boosting the dc-link voltage to charge the battery. Diodes allow the flow of current in one particular direction depending on the operation. During the buck operation the inverter side voltage is stepped down α time of the battery voltage is the time period for which switch conducts.

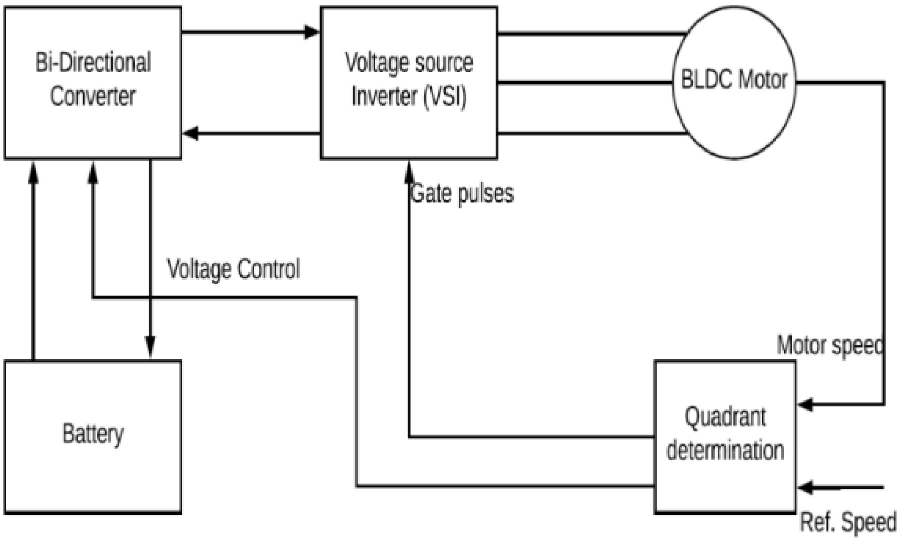

Fig.2. Block diagram representation of four quadrant operation.

The four-quadrant operation of BLDC motor is depicted clearly in Fig. 4. In the first and third quadrant, (Fig. 6) both the torque and speed are having the same sign either positive or negative. The four-quadrant operation of BLDC motor is slightly different as the direction of rotation cannot be made opposite just by reversing the voltage polarity of dc link as in case of DC motor. For reversing the direction of rotation of the motor the phase sequence of the BLDC motor has to change as the voltage across the dc link is always positive and therefore current is positive. For operating the motor in the third quadrant phase sequence of BLDC should be changed. This could be achieved by changing the switching sequence of the inverter.

Braking is obtained through the bi-directional DC-DC converter. The bi-directional converter operates in two modes buck or boost mode. Motoring mode utilizes the buck operation and braking mode utilizes the boost operation. The logic diagram of the four quadrant operation is mentioned in Fig. 7. When the regenerative braking is required the torque and speed command are detected and the gate pulses to the switches of VSI are switched off. As the diodes are connected across the antiparallel switches, the VSI behave as a rectifier and the alternating three-phase back EMF (ع (?is converted which appears across the inverter DC supply. But this can happen only when the diodes (D) of VSI are forward biased this is achieved by reducing the dc-link voltage making it less than the rectified back EMF voltage which is an ideal case in absence phase resistance is 2ε) Fig. 2), with the presence of phase resistance the equation becomes, Once the diodes are forward biased, immediately the control is transferred to switch T2 which step up the voltage (4) and charges the battery. The control logic is elaborated .The controlling of switch T2 is done through the current control. During vehicle downhill run the speed is more than the reference speed (higher potential energy) is converted to kinetic energy. To maintain the speed equal to the reference speed, the kinetic energy of the motor could be returned to the battery.

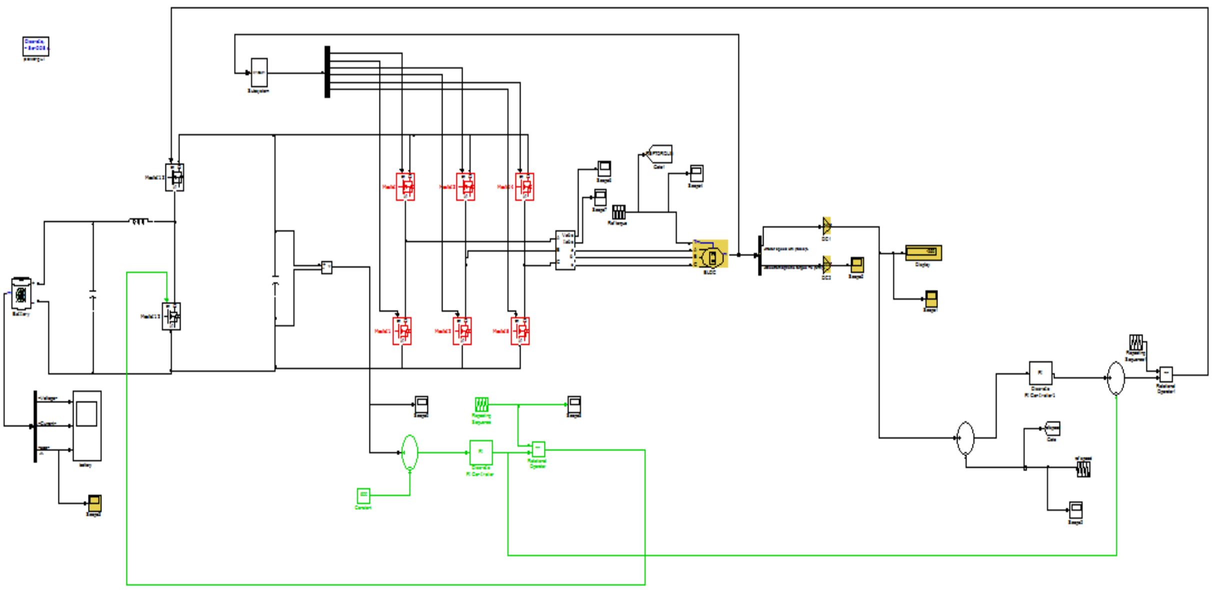

Fig 3 Existing PI based control approach

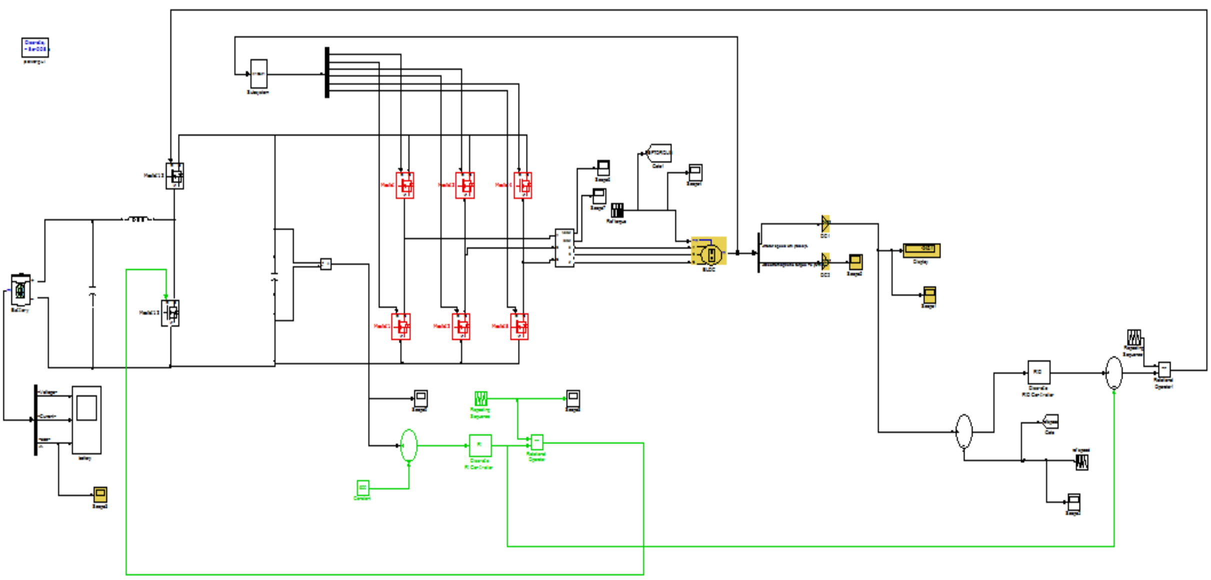

Fig 4 Proposed PID based control approach

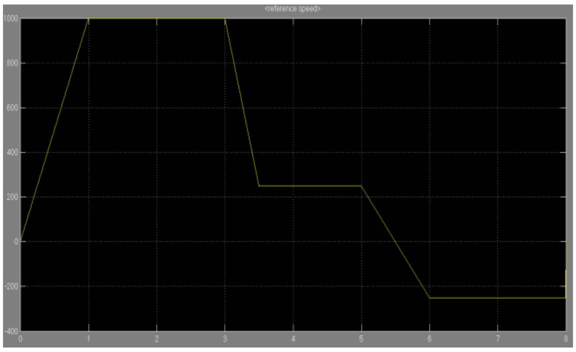

Fig 5 Reference speed vs time

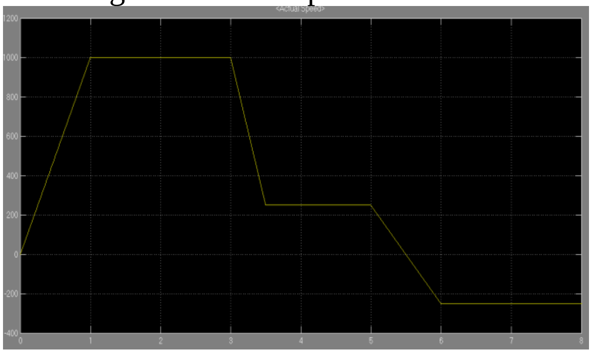

Fig 6 Actual speed vs time

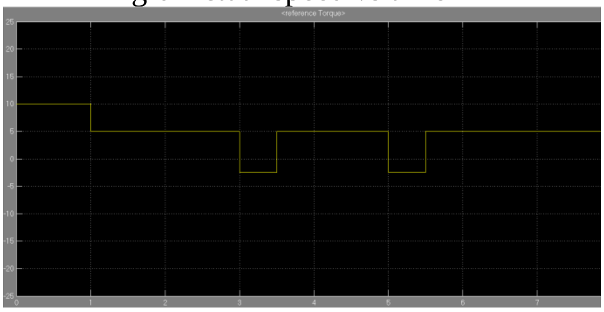

Fig 7 Reference torque vs time

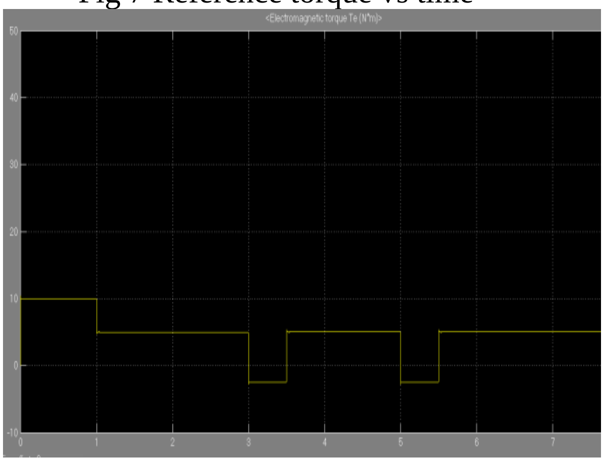

Fig 8 Electromagnetic torque

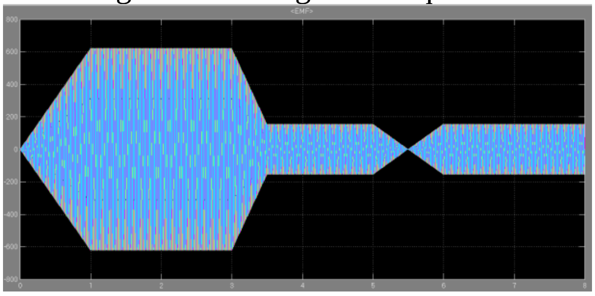

Fig 9 Back EMF vs time

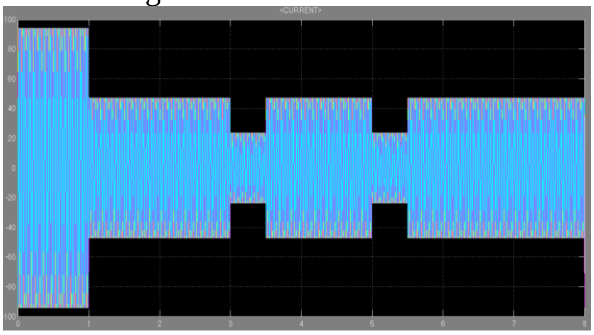

Fig 10 Current vs time

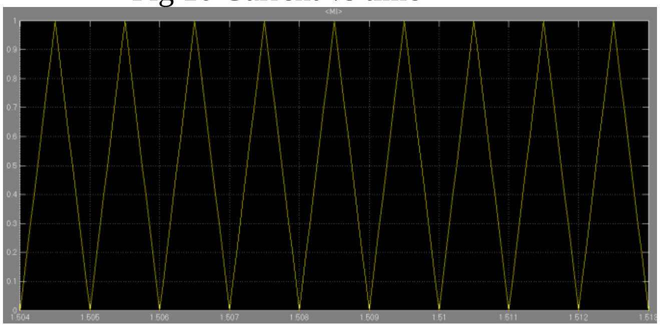

fig 11 modulation index vs time

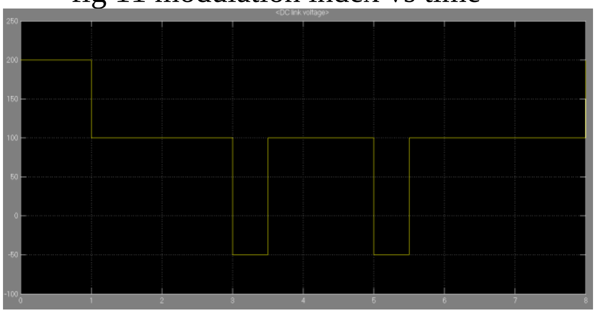

Fig 12 Dc link voltage vs time

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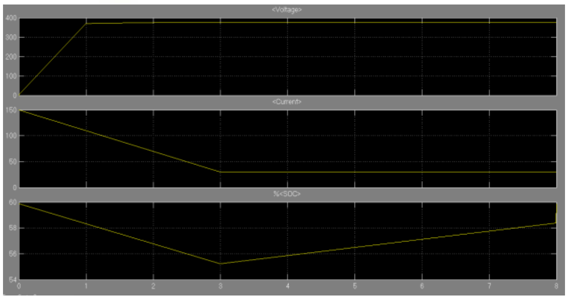

Fig 13 Battery voltage, current, SOC vs time

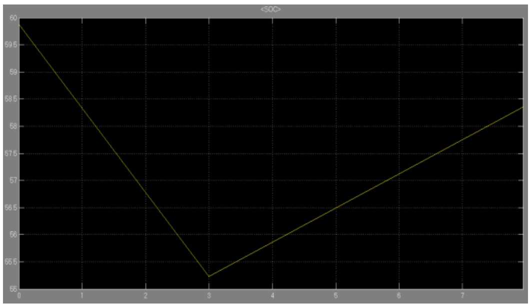

Fig 15 Higher SOC for PID based controller circuit

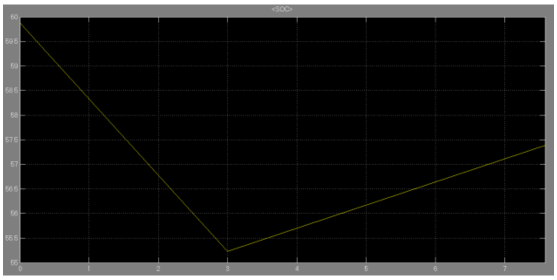

Fig 14 Lower SOC for PI based controller circuit

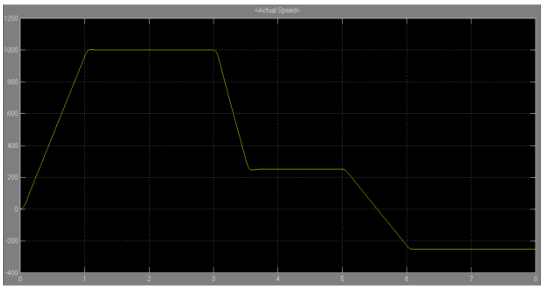

Fig 16 PI controller based Actual speed With high settling time

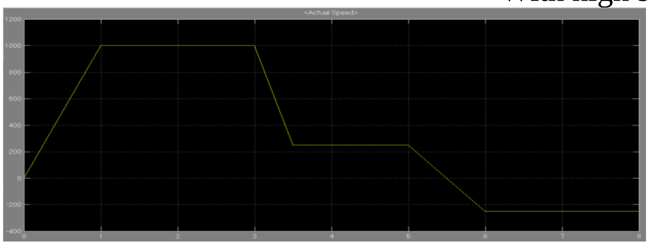

Fig 17 PID controller based Actual speed With low settling time

CONCLUSION

The four quadrant operation is simulated for the electric drive with maximum efficiency keeping in mind the fuel constraint. The battery is charged during the regenerative mode and the speed control using the closed loop control is performed. The proposed method requires the minimum hardware and the operation can be controlled in all the four quadrants. During the regenerative mode, the kinetic energy is returned via the bi-directional converter to charge the battery. The abovementioned proposal could be applied in electric vehicle downhill run by controlling the speeding in gravitational action where the speed becomes more than the reference speed. The practical implementation is under progress for the proposed method. A comparative analysis is carried out with PI and PID Controller in this work with simulation results.

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