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Design of Arduino based Sensorless BLDC Motor Drive for Hybrid E-Cycle

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***Abstract*—This paper presents the design analysis of digital pulse width modulation(PWM) control scheme for speed/torque control of electronically commuted trapezoidal Brushless dc (BLDC) motor using Arduino uno. This paper includes discussion on the implementation of sensorless control of BLDC motors in electric bicycles. The PWM control stategy is implemented using Arduino uno hardware prototype designed and built and effectiveness of the methods are analyzed.**

The microcontroller in the arduino performs the necessary logic operations in response to the throttle input given by the user and generates required PWM signal with proper duty for obtaining the optimum voltage for the set speed commanded by the user. In our study we use a 3 phase 4 pole BLDC motor with rated speed of 4600 rpm, 310V, 4.6A motor having rated torque of about 2.2Nm.

I. INTRODUCTION

Electric vehicles are gaining so much attention these days due to various factors like environmental polluton from internal combustion engines, need for alternate transport facility, energy crisis due to depletion of fossil fuels ,advancements in powerelectronics,advancements in electric motor technology etc. This paper tries to explore the appliction of electric drives in common bicycles.[1],[4].The BLDC motor is used as the drive,it can be driven by using position feedback or in sensorless mode [3].The speed control is achieved by PWM control of input voltage[2].The set speed is tracked with the help of PI controller. The conventional speed control technique is by using a variable DC link there by controlling the input voltage of the motor. This method involves the use of additional converter section in the input end, this imposes losses in the drive topology. By using PWM technique with proper logic operations the input voltage can be varied directly without any additional converter circuits. The speed control is acheived by using an Arduino uno board.The PWM generation process for trigerring power switches is carried out by processing data from the Hall sensor output from the motor.

II SYSTEM DESCRIPTION

The hybrid e-cycle drive mentioned here must be capable of handling the load requirements by properly modulating the power delivered to the electric machine here we use brushless dc motor for generating the drive force.the main features of the BLDC machine are it has no mechanical commutator and its power to weight ratio is better compared to other machins. The most common topology for driving a 3 phase BLDC motor is by using a 3 phase bridge with power mosfets . this bridge is fed with a dc voltage and power switches are controlled/modulated according to the commands from the rotor position circuitary and from the users speed /torque commands. The general block diagram of the e-cycle drive is shown in fig 1.The BLDC motor is directly coupled to the rear wheel of the e-cycle.

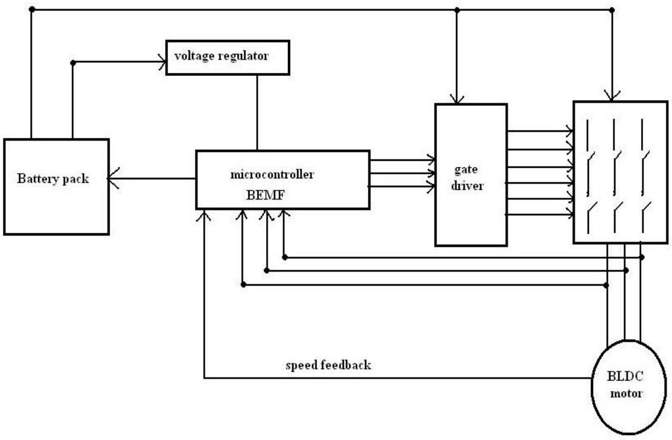

fig 1 Basic drive scheme

The BLDC motor commutation sequence is given in table 1.High represents high side power switches and low represents low side power switches.in practical circuitry some intermediate switching are needed for satisfactory drive performsnce. This additional states enable us tolimit the current in the windings to a safer value.

Table 1 commutation table

State	Conducting phase	Switches
1	AB	A high, B low
2	AC	A high, C low
3	BC	B high, C low
4	BA	B high, A low
5	CA	C high, A low
6	CB	C high, B low

The above six state completes one revolution of the rotor.the next question we have to address is the how to determine state transistion that is when to switch from AB-AC-BC-BA-CA-CB.The current flow through each windings during transistions is shown in the figure 2.

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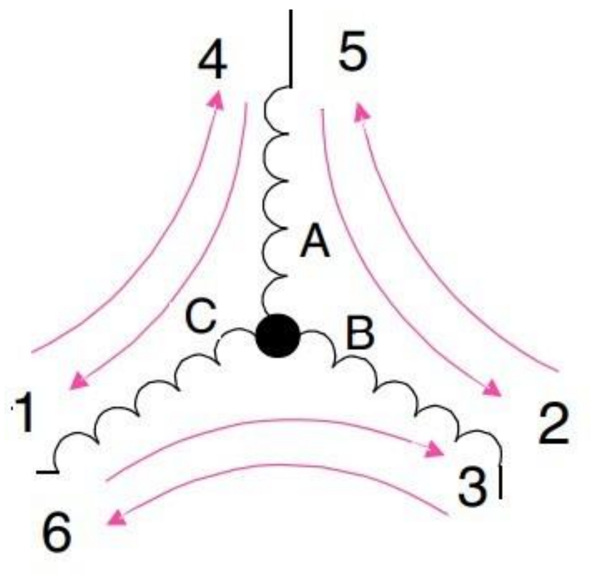

Fig 2 current direction in six states

There are many methods for acheiving this transistion instant the most popular one is the HALL sensor based rotor position feedback the sencond most popular one is the BEMF (back emf) based rotor position estimation which has no seperate sensing elements . The HALL sensor based approach has three sensor elements either 120 degree apart or 60 degree apart when the permenant magnet rotor rotates the flux cuts the sensor elements induces a voltage in the sensor and this can be used to identify the rotor position the hall signal for a three phases using three HALL elements 120 degree apart .The back emf method uses the vrtual ground to identify zero crossings of the back emf.The back emf is generated in the floating winding as in each state only two windings are excited.The zero crossings enable us to identify the next state The virtual neutral is shown in fig 3.The back emf for each state is shown in fig 4

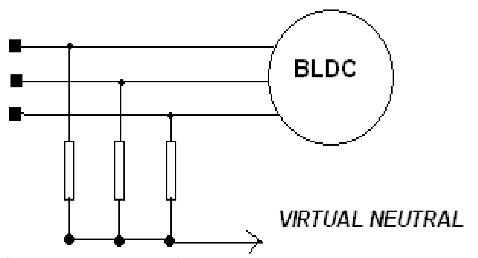

fig 3 virtual neutral for BEMF zero crossing detection

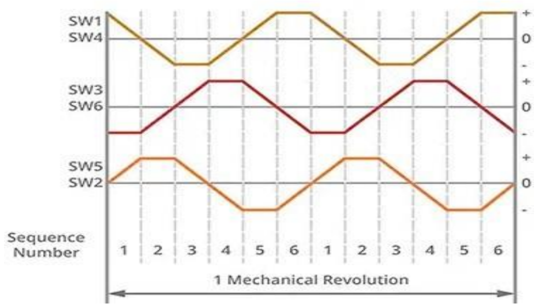

Fig 4 BEMF

The control Strategy involves mainly three steps that is processing the user input command [reference speed],determining state transition instances from monitoring BEMF zero crossings,and generate triggering pulses for the power switches in the three phase bridge.

III DRIVE SCENARIO AND DESIGN

The drive performance must meet the load requirements for the satisfactory vehicle performance.the load torque demands of bicycle is highly terrain dependent as the vehicle encounters wide range of terrrain variations during its commute.

For an electrive drive the user input must match the load the matching is done by the power moduator by suitable control strtegy .the user input is very randomn and needs to get approximated for effectively tracking the desired drive performance .The general set of drive behaviours are,aceleration,deceleration braking,& free run.the fig 5 gives an idea about the drive requirements .

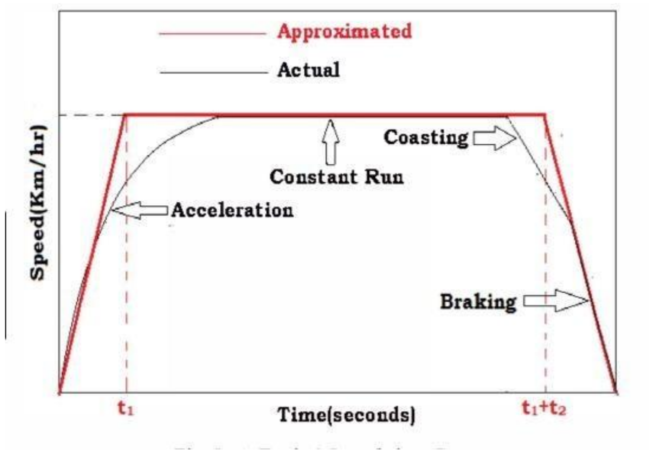

Fig 5 drive requirements

The curve on fig 5 is approximate drive requirement, and the time interval t1,t1+t2 may vary from small in the order of miili seconds to some times in minutes or hours depending on the terrain .

The electric drive requirements can be derived from the mechanical counterpart. The speed of the vehicle is assumed to be 30 km/h.the various forces acting on the vehicle are shown in fig 6.Fa is the required driving force to overcome friction drag 'Fr' and the normal reaction 'Fg ' due to gravity.

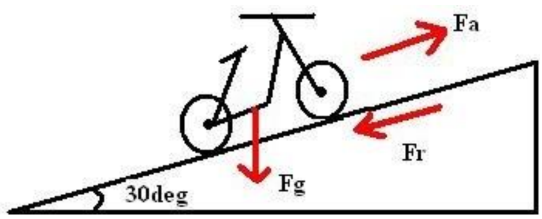

Fig 6 forces acting

Force calculation:
Diameter of Cycle Rim - 0.5 m Radius of Cycle Rim - 0.25 m e-cycle Weight - 40 kg
Rider Weight - 50 kg Total Weight - 90kg force =mass *acceleration
=90*.01=9kg/m2

Torque Requirement
torque =force*radius
=9*.25=2.25 Nm
torque required=**2.2 Nm**

Power calculation
with 30 Kmph and torque of 2.2Nm the power required =(2*Pi*NT)/60
Power of Motor,P
=Weight*Gravity*Speed*Gradient
=90* 9.8* 30*0.04
=1053 W
from the drive requirements the motor is selected with rating 310V DC ,4A, 2.2Nm of rated torque & rated power of about 1.24 kW
The simulation is done with the specifications as mentioned in table2 .the PMSM machine is selected the machine parameters are matched to the specifications mentioned in the table 2.the back emf is made trapezoidal.

Table 2 simulation specification

Sl no	Specification	Rating
1	Rated voltage	310 V
2	Rated torque	2.2 N m
3	Rated speed	4600 rpm
4	Carrier frequency	10 KHz

The power mosfet is connected in three phase obtained.This pulses along with the pulses obtained from BEMF comparison is logically ANDed to get the required

pulses .The pulses after logical operation is fed to the gates of the power MOSFETs. The results and discussion are elobrated in the next section

IV SIMULATION AND RESULTS & ANALYSIS

The PMSM motor with trapezoidal backemf is configured as a BLDC motor . The simulation diagram is shown in the the simulation is done with the following specification mentioned in the table 2.The machine performance is analyzed in no load ,full load and intermittent loads.preformance curves are obtained for the above mentioned loading patterns,.the curves are shown in fig 7 ,fig 8,fig 9 .The PI controller is tuned by trial and error method .the values of Kp & Ki are 0.5 & 0.13 respectively.The drive performance is observed to be satisfactory.The oscillations and torque peaks in practical aplications would not affect the system performance as they die out fast .

V HARDWARE DESIGN AND ANALYSIS

From the design perspective the component selection is done on the basis of peak voltage & current applied to the power switches .The range of speed control determines the switching frequency and pulse width.from the design specifications the bridge fashion.The BEMF zero crossing are deected with compare to zero block and the set speed is compared with actual speed and PI controller is usedto process the error signal and the processed signal is compared with a high frequency carrier and the triggering pulses is final drive must handle am minimum power of 1.05 kW and the BLDC machine is rated for 310V and a peak current of 4.5A the with a peak torque of about 2.2Nm.The component selection is done on the basis of above factors.the ARDUINO based scheme is depicted in fig 10

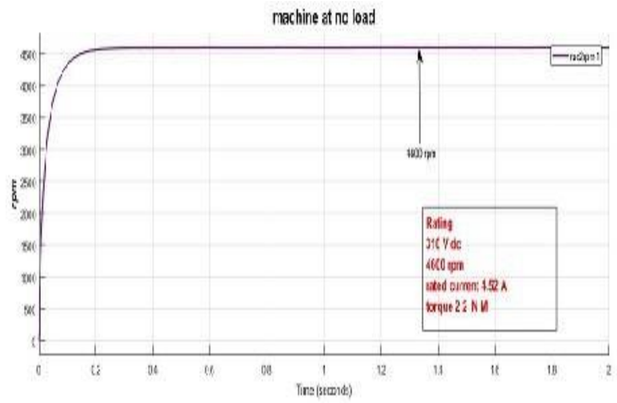

fig 7 Machine at no load

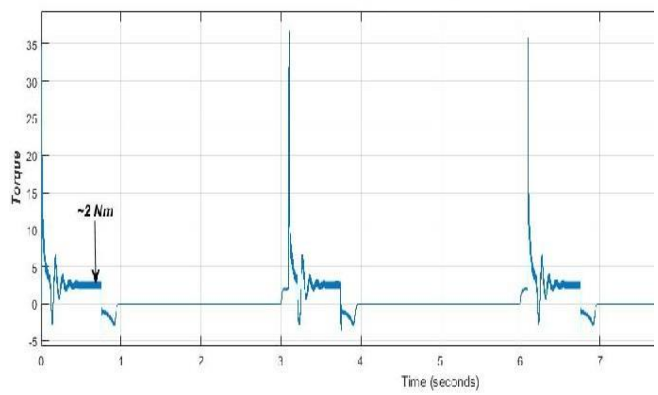

Fig 8 Torque curve for 90% loading

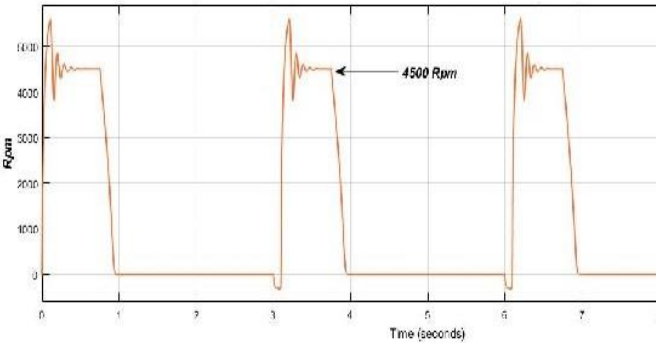

fig 9 100% speed in periodic command

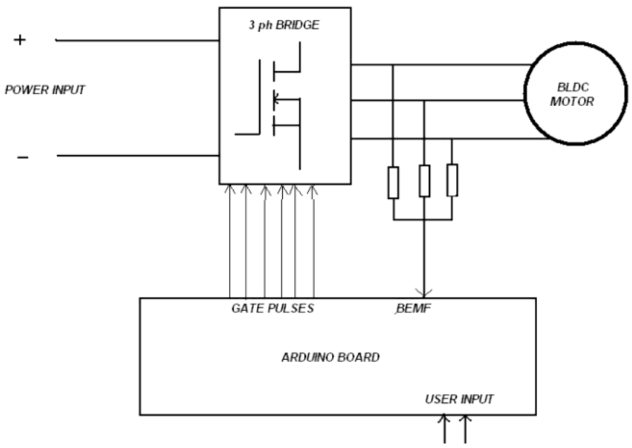

fig 10 ARDUINO based drive

The arduino base drive incorporates complete set of control for the drive operation .It process the BEMF data to estimate the switching states .it controlls the pulse width in response to the user input ant controls the peak currents and torque.

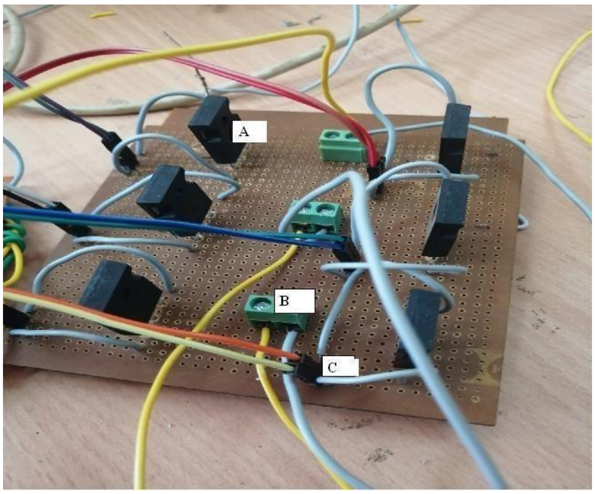

fig11Three phase bridge

From the rated values the power modulator bridge is built with IRFP460 power mosfets.It is shown in fig 11.'A' represents the power mosfet.'B' represents the load port 'c' represents the gate terminal.The gate drive is TLP250 opto coupler ic and is driving the six power mosfets .The gate voltage is set to 15V and apeak charging current of about 0.5A.the driver schematic is shown in fig 12

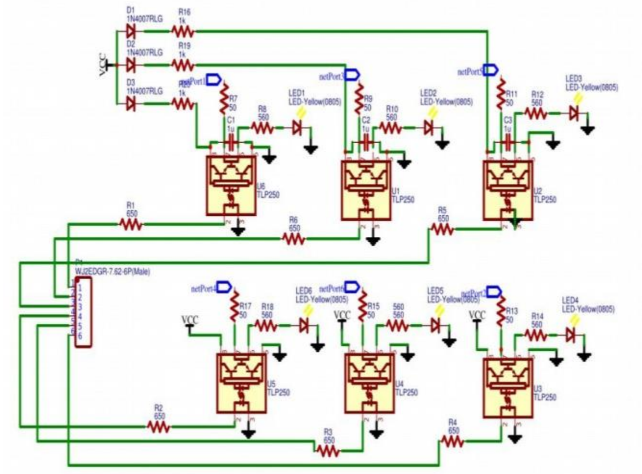

fig 12 driver schematic

The driver is designed in bootstrap mode to eliminate multiple sources.the overall bldc drive schematic is shown in fig 13.LM293 is used for

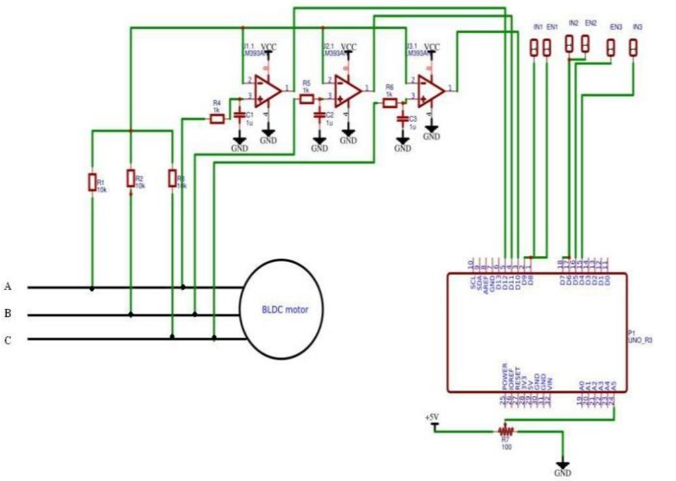

fig 13 ARDUINO integrated drive

detecting the BEMF zero crossings and the data is send to the arduino ports for determining the switching instants. The potentiometer connected to the analog port provides user control for seting the speed .The overall hardware setup is shown in fig 14.The test been done with supplying a DC voltage and with a10% load

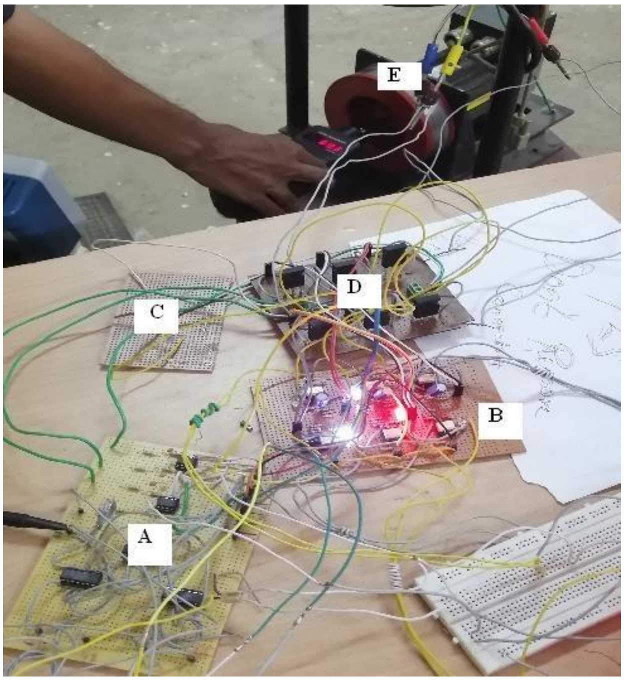

fig 14 overall drive arrangement

In fig 14 'A' represents the control logic circuit.'B' rrepresents the driver circuit.'C' represents the virtual neutral 'D' represents th power bridge circuit 'E' is the BLDC motor.The output parameter are tabulated in table 3.

Table 3 output data

slno	parameter	value
1	Input voltage	31v
2	Noload current	0.4A
3	10% load	1A

VI CONCLUSION

The performance of BLDC motor is studied using MATLAB and the behaviour of the motor under various loading conditions are obtained.Observations are made on the torque ripples and current over shoot during starting.The oscillation in speed is observed ,as it would get dampend quickly in practical conditions.The torque peaks during starting can be eliminated by current chopping methods.The prototype performed satisfactory .A max speed of 636rpm is obtained.

VI1 REFERENCES

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