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Design of Electronic Speed Controller for Solar Powered Low Power Brushless DC (BLDC) Motor

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Abstract
BLDC motor also known as electronically commutated motor is widely used for many industrial and commercial, low power motor drive applications. A simple BLDC motor is energized by DC electricity through an inverter or switching power supply, which produces an AC current to generate magnetic field in order to drive the motor. With the growing energy need and increasing environmental concern, alternatives to the list of non-renewable fuels have to be investigated. One such alternative is the solar energy. The use of solar energy to drive BLDC motors requires the need to develop the controller for the same to reduce the running cost of the motor. The main contribution of the paper is towards designing of a simple , low cost ,efficient ,solar energy based control mechanism for low power sensor less BLDC motor with effective control strategy using general purpose ATmega328P ,pulse width modulation(PWM) circuitry and power output stage .

Keywords
BLDC Motor, Gate Driver, PWM, ATmega328P (Microcontroller)

Introduction

The rapid growth of industrialization and commercial use of the electrical appliances has led to the requirement of high efficiency motor with longer life. Varieties of motors are available in the market. The BLDC motor has various advantages, which include a high power to weight ratio, high efficiency, low frictional losses and long life as compared to other motors. A Brushless DC motor has only two basic parts: rotor and the stator. The rotor is the rotating part and has permanent magnets whereas the stator is the stationary part and consists of poles and armature windings. The configuration of rotor is outside and the stator is inside then the motor is out runner and if it is opposite then it is inner runner.

It consists of 3-phase A, B and C as shown in figure 1 and the connection of all the three phase together makes a star bridge. The motor has a multiple of three number of poles. The poles are equidistantly distributed in 360°.

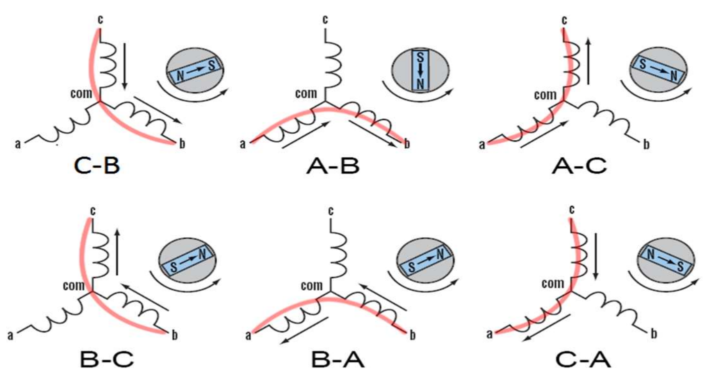

Figure 1: Driving of the BLDC

For driving the BLDC motor, a synchronous alternating current must be provided to the coils of the motor. Considering figure 1, the current enters from coil C and leaves from the coil B. Thus, it generates two different electromagnetic poles in which one pole attracts and the other repels the pole of the permanent magnet of the rotor. In the next state the current enters from the coil A, leaves from the coil B, and generates poles simultaneously and this process continues. Thus, brushless DC three-phase is operated by utilizing the attraction and repulsion of magnetic poles. Changes in stator magnetic field cause the rotor to move to follow the constant stator.

Literature Review

Daejeong et. al. (1999) [1] introduces a new waveform-reshaping circuit that is conceived as an alternative to the conventional Schmitt trigger. This circuit employs ratio less inverters, which requires no standby current and is adequate for high-speed operations. Two different logic threshold voltages of CMOS inverters in the circuit determine the hysteresis characteristics.

Amir et. al. (2011) [2] have developed a low–voltage, CMOS– compatible, voltage-mode structure for multiple-valued logic circuits. The design is based on a simple and straightforward mechanism and is operating in the voltage mode, and the proposed structure is suitable for low power applications. Design of both a quaternary inverter and a latch circuit based on the proposed structure is also presented.

Xionghui et. al. (2010) [3] have introduced a method of detecting the phase terminal voltages without current to realize Back-EMF zero crossing. It discusses the theory of Back-EMF and the method of using S12X MCU to control Brushless DC motor.

Jianwen et. al. (2003) [4] presents a improved back EMF detection circuit for high voltage sensorless BLDC motor drives. It also represents a complementary pulse width modulation (PWM) (synchronous rectification) to reduce the power dissipation for low voltage in power devices applications. In order to further extend the sensorless BLDC system to lower speed, a pre-conditioning circuit is proposed to amplify the back EMFs at a very low speed. As a result, the brushless dc motor can run at a lower speed with the improved back EMF sensing scheme.

Soib et. al. (2008) [5] have proposed a scheme for sensorless control of a BLDC motor with back-EMF zero-crossing sensing detection method using dsPIC30F3010.Here the back EMF of the motor is detected directly from the terminal voltage by properly choosing the PWM and sensing strategy. The solution provides a good S/N ratio and the resulting feedback signal is not attenuated. As a result the proposed sensorless BLDC motor drive provides a much wider speed range upto 4000 rpm, from start-up to full speed.

Young et. al. (2014) [6] published the patent for the design of a controller for sensor less BLDC motor system which includes a comparator, motor controller, three-phase inverter and a mode selector. The mode selector selects a driving mode of the BLDC motor by adjusting the specific time.

Faith et. al. (2005) [7] have directed their efforts towards development of a sample-and-hold (S/H) circuit for low-voltage and low-power CMOS analog design . The proposed circuit is based on the conventional CMOS inverter operating as a transconductor. The circuit does not require linear capacitors and employs switches that operate at fixed channel voltage.

Pharm et. al. (2014) [8] have proposed an Adaptive fuzzy logic PID controller for speed control of Brushless Direct current Motor drives is proposed. From the simulation results presented, it can be verified that Adaptive Fuzzy PID controller gives better control performance when compared to fuzzy PID controller.

Peter et al (2008) [9] have published a patent which includes the design of a variable speed sensorless BLDC motor drive circuit. The circuitry consist of a high-side and low-side controlled switched for commutating a BLDC motor. The speed control loop uses a pulse circuit receiving the drive signals from controller for controlling the high side switches and for providing a pulse signal related to desired motor speed. The gate driver is designed using IGBT.

Yannis L et. al.(2019)[10] have presented the analysis and practical implementation of hardware and software aspects during the development of a microcontroller based speed controller for motors up to 500 W. The study also presents hardware and software particulars through calculations, figures, flowcharts and code, thereby indicating the practical issues that may arise in such a low cost prototype.

Through the literature survey, it can be concluded that sensorless BLDC motor controller development, is either carried out by use of simulation or in experimental form. These approaches are useful to prove the conceptual design, and in some studies solutions using DSP processors, expensive industrial controllers etc. are presented which are not very cost effective .There are some applications where the need for fully parameterized prototype to be built is felt. In the above context, this paper presents a straightforward practical implementation approach for a solar based sensorless BLDC motor controller system for better monitoring with simplicity and low cost as a priority.

Methodology

A. Electronic Speed Controller Design

The objective of this work is to design a low power and low cost BLDC motor controller so as to provide flexibility to drive the BLDC motor from solar power which can be primarily used for water pumps thus saving considerable energy and limiting human intervention too. Reliable and varied measurement of variables is important for better monitoring and avoiding electrical failures. Programmable speed control with specified options which allow setting of low voltage cut-off limits, insufficient power check, soft start, over load and dry run conditions are included in the design. The proposed circuit is designed and tested for 60W BLDC motor.

B. Architecture of BLDC Motor Controller

The BLDC motor controller design includes three distinct circuit functions achieved through a low cost microcontroller ATmega328P as shown in figure 2 that runs the motor control algorithm, PWM circuitry that provides the switching signals and power output stage that drives the motor. The gate driver is used to provide sufficient voltage to the MOSFET to drive a large amount of output current to the motor. The Quad op-amp IC LM339 has been used to sense the back EMF of each phase in an order to detect zero crossing point which is important to switch the state. The current sensor ACS712 is used to continuously monitor the current and voltage. To drive the BLDC motor, a 3-phase inverter bridge circuit consisting of six MOSFETs is being used as shown in the figure 3. The semiconductor switching elements selection is of primary importance in order to maximize the overall efficiency. The power MOSFETs provide higher commutation speed and greater efficiency during operation at low voltages. The MOSFETs switch continuously and therefore to drive the motor high side MOSFET of phase A is ON and low side MOSFET of phase B is ON. The current enter from winding of phase A and leave from winding of phase B, thus generating opposite poles and the rotor rotates.

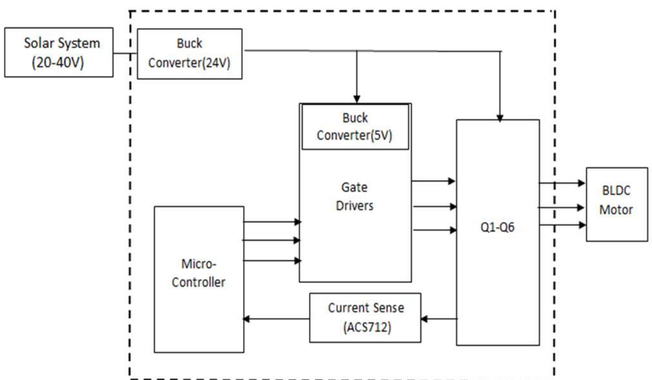

Figure 2: Block Diagram of BLDC Controller

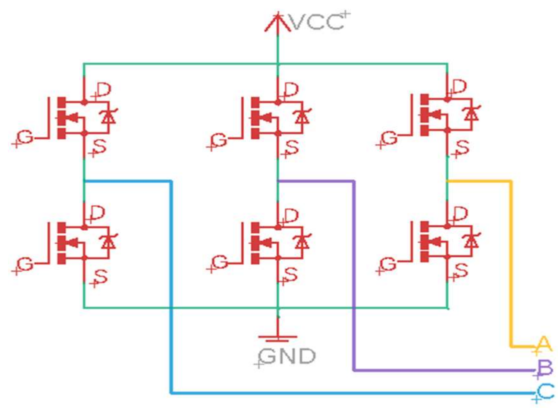

Figure 3: Three-Phase Inverter Bridge

Then in the next state the high side MOSFET of phase C is ON and low side of B is ON. The current enters from winding of phase C and leaves from winding of phase B so as to generate opposite poles and the rotor thus rotates and the sequence continues on as shown in the table 1.

High side MOSFETS	A	C	C	B	B	A	A
Low side MOSFETs	B	B	A	A	C	C	B

Table 1: Six-Switching States of MOSFETs

The poles need to be switched in order to generate the waveform which is used to drive the motor. To drive the dual MOSFETs Bridge i.e. high side and low side MOSFETs of a single phase inverter circuit, the Gate Driver is used. The connection of the gate driver IC IR2110 is shown in the figure 4,

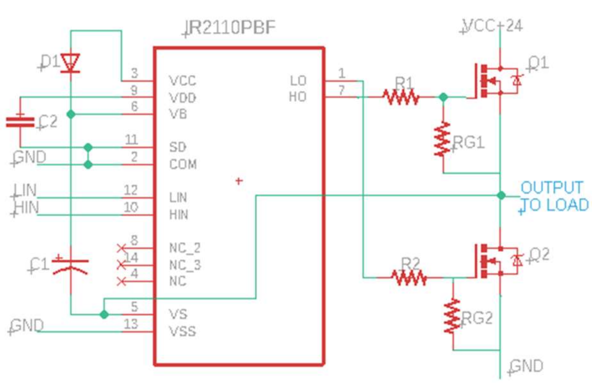

Figure 4: Gate Driver Circuit

V_{cc} is the low side supply and should be between 10-20V whereas V_{DD} is the logic supply to the gate driver IC. The capacitor between the V_B and V_s is the Bootstrap capacitor and the output of the HO and LO should be connected to the MOSFETS as shown in the figure 4. The value of the Bleeder Resistor is so chosen such that it does not affect the switching frequency of the MOSFETs. Three such gate driver circuits are required to generate the PWM pulse to be provided to the motor. The signal pin of the gate driver is connected to the PWM pin of the microcontroller. The three gate driver circuit makes a HEX-MOSFETs 3-Phase Inverter Circuit. The output of the 3-phase inverter has been provided to the 3-coils of the BLDC motor. A potentiometer has been connected to the A0 pin of the microcontroller and based on the value of the potentiometer, the duty cycle of the PWM pulses can be varied thereby varying the speed of the BLDC motor. The state switching takes place at zero crossing point based on the back-EMF detection technique using a Quad op-amp IC (LM339).

The circuit consist of a current sensor ACS712 which is continuously monitoring the voltage and the current supply from the solar power source. The standard value of the current and voltage has been provided to the microcontroller. These parameters are monitored continuously and if the value exceeds from the standard value which is mentioned to drive the motor, the microcontroller stops the rotation of motor i.e. it shuts down the motor. Thus the circuit checks whether or not the motor is rotating and then terminates forced drive interval in order to obtain efficient motor drive.

Results and Discussion

A. BLDC Controller Performance

The BLDC motor controller is designed and simulated in Proteus environment. The 120^0 degree computational waveform (figure 5) is obtained and the prototype is developed and tested as shown in figure 6 and figure 7.

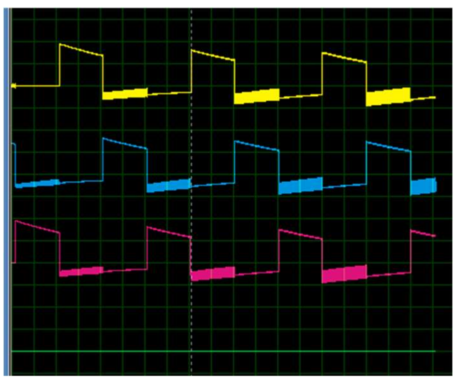

Figure 5: 120^0 Computation Waveform

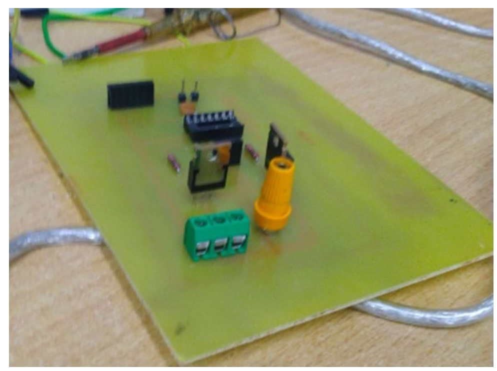

Figure 6: Single Phase Inverter

Figure 7: Single Phase Waveform.

The experiment to plot speed torque characteristics is carried out and is as shown in the figure 8. The load torque is continuously varying and the variation in the speed is observed.

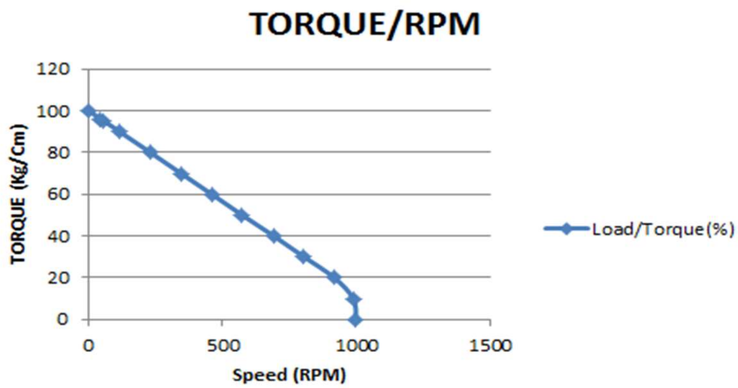

Figure 8: Torque Verses Speed (RPM) Curve

The speed is essentially controlled by the voltage, and is varied by varying the supply voltage. The motor then draws just enough current to drive the torque at this speed. It has been found that as the load torque is increased, the speed drops and the speed of the motor depends on switching speed of the MOSFETs or the PWM pulses generated by the microcontroller. It can be also adjusted by changing the duty cycle of the PWM pulses.

Conclusion

In this work, the BLDC motor is controlled by utilizing the microcontroller. The MOSFETs are used in the form of three phase bridge inverter for converting DC to three phase AC. The speed of the BLDC motor can be varied by changing the duty cycle of the PWM pulses. Thus the simulation and prototype design of the low cost electronic speed controller has been successfully carried out for solar powered BLDC motor. Sufficient checks have been incorporated to avoid electrical failures. The sensorless method employed is based on the zero crossing point detection of the back-EMF differences. A bootstrap circuit is implemented as the main driving hardware. Results obtained by experiments validate the presented hardware/software architecture of the controller. The proposed system has been designed and modelled to achieve the desired objectives and validated to examine various performances for the water pumping application. Future work could be directed to develop a graphical interface to display information regarding different parameters including motor speed, phase currents and line voltages etc.

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