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Solar fan with BLDC Motor

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ABSTRACT

Lately, there is a need to come up with the latest and most efficient designs for any electrical appliance. The following is a design of a brushless DC fan running based on solar power, which is expected to run using a small 12 V battery and solar pv panel. A brushless DC motor (BLDC) is a synchronous motor powered by electrical communication system than mechanical commutator and brushes. This fan is implemented via Arduino UNO that generates the pulses and has an in-built analog comparator. The BLDC motor is enabled with a hall effect sensor that senses the pulses of the inverter and controls the fan. This assembly provides an alternative to conventional fan models with minimal energy use.

Keywords: BLDC motor, Solar energy, Arduino UNO, Hall effect.

CONTENTS

I. Introduction

A solar fan runs on DC power fitted with a motor and solar panel which consists of photovoltaic (pv) cells made of Silicon or Germanium which help in absorbing solar energy and produce electrons. These electrons are responsible in running the motor.

DC motors are high performing and efficient motors that consume less power and generate lesser noise. A specific BLDC motor is one such DC motors that functions without brushes or a commutator. These are powered up by permanent magnets.

The following model of a fan equipped with an efficient BLDC motor gives performance even in hot conditions and without much noise.

The speed controller of the fan has been designed using a potentiometer for the sensored motor and speed up and down buttons for the sensorless motor.

The reason solar fans are now in more demand is their efficiency, versatility and availability. Devices that are powered by solar energy are today much preferred to older designs.

For years, ceiling fans used to come with the same hardware of induction motor which typically consumed 70-80 watts for a standard ceiling fan. But in the last few years, BLDC technology is being used to make fans consume a lesser amount of energy, compromising less on the air delivery. Most of these fans are typically given a 5- star rating which proves it performance and thus, making them superior to the standard existing fan models. They provide an average 65% savings and longer backup on inverters promising a longer lifetime and reliability supplemented with optimum noise reduction.

Table 1: General Performance Analysis

	Wattage	**Hourly Electricity consumption**	**Daily Electricity consumption**	**Yearly Electricity consumption**	**Cost per annum**
Regular Fan	75	0.075 units	1.125 units	410.625 units	Rs. 2463.75
BLDC Fan	30	0.030 units	0.45 units	164.25 units	Rs. 983.5

The BLDC fan being a rotating electric machine in which the stator is a two-phase stator and the rotor has surface-mounted permanent magnets. In this respect, the BLDC fan is equivalent to a reverse-conventional DC fan; the current polarity is altered by the electrical commutator instead of mechanical brushes. Due to the polarity reversal performed by transistors / FETs switching in synchronization with the rotor position, a Hall Effect must sensor is used to sense the actual rotor position.

The Hall effect sensor provides provide the signal to rotate the motor and drives the stator coils. The sensor indicates the switch-on positive magnetic field and switch-off negative magnetic field.

1.1 Certain Limitations

Since solar cells produce a DC source only while the domestic equipment in countries like India and neighbours need an AC source, inverter is required to produce AC source. However, in certain conditions where the sun cannot give a source to the solar panel, electricity is not produced when constant supply is required in order to get a stable source to the equipment. Battery is needed for this case to make sure the source still has energy to supply and this makes it essential to have a solar charger. Sometimes during power fluctuations at home, the need of backup power supply is also required in order to ensure the continuous of energy.

1.2 Aim of this project

The aim of this research work is to develop a solar powered standing D.C. fan that can be used for both urban and rural areas. Also, this research therefore is aimed at achieving the following objectives:

i. To minimize the problems encountered due to the lack of adequate power supply.

ii. To fully utilize our abundant energy source, that is sunlight.

iii. To perform several functions for home owners and office workers.

iv. To determine the efficiency of the design using mathematical model.

v. To reduce the over reliance on alternating current.

vi. To simulate the behaviour of solar powered standing D.C. fan design.

vii. To develop the existing solar fan and make it better by designing a simple inverter that can be used on domestic equipment

II. Problem Definition

2.1 Analytical model

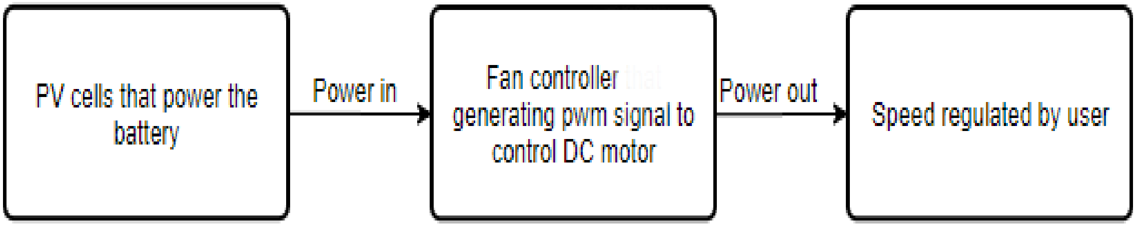

Figure 1: Basic block diagram of the analytical model

The controller block (second from right) needs to be meticulously designed in order to get desired results. We have designed the speed control of the fan using and arduino microcontroller. The arduino is responsible for generating the pulse (PWM) that is necessary to drive the fan. The pulses then produced by the microcontroller are detected by the sensored-bldc motor and thus, making the user able to control the fan.

We have achieved the final model using Proteus (software) and Arduino IDE to run the code for the specific Arduino that has been used.

A three-phase inverter is needed to convert the AC signal to DC. While our initial testing began with a single-phase inverter and a single-phase motor, the same does not suffice for a three-phase BLDC motor. Based upon the hall effect sensor values, the rotor position is known with respect to the magnetic poles. The MOSEFT bridge (inverter) is switched based on that position information and this begins the rotation of the rotor and the switching operation so as to ensure the smooth rotation. Using the PWM technique, electrical shorts are also avoided.

2.3. Components

i. Arduino UNO board
ii. Brushless DC (BLDC) motor
iii. 6 x N-type mosfet
iv. 3 x IR2101 (IR2101S) gate driver IC - used to control high side and low side mosfets of each phase. The switching between the high side and the low side is done according to the control lines IN and SD.
v. 6 x 33k ohm resistor
vi. 3 x 10k ohm resistor
vii. 6 x 10-ohm resistor
viii. 3 x IN4148 diode
ix. 3 x 10uF capacitor
x. 3 x 2.2uF capacitor

xi. 2 x push button
xii. 12V source
xiii. Breadboard
xiv. Jumper wires
xv. LM399 quad comparator

2.3. The BLDC Motor

Typical BLDC motors are high rpm, low torque motors which are used in computer applications or DVD/CD drives and lately even in fans. They are quiet and have long life with no service-related issues unlike the other AC or DC motors along with the other advantage of high efficiency. They are also frictionless motors.

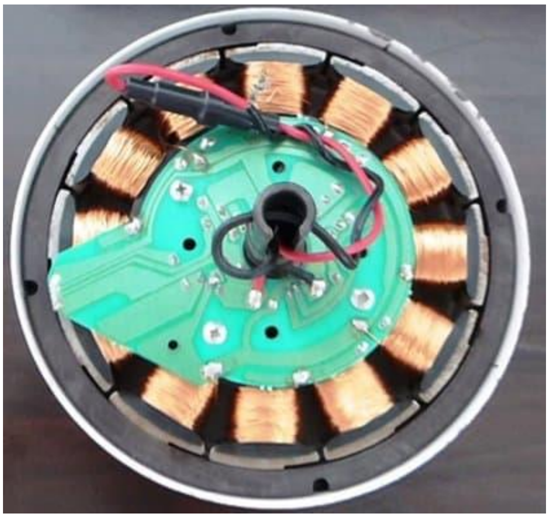

Figure 2: BLDC motor with controller

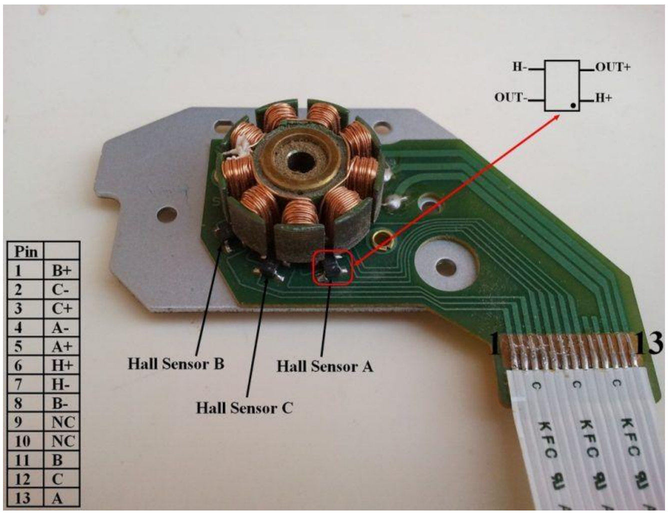

Figure 3: Hall sensor

III. Background and Related work

Today’s shortage on energy resources, especially renewable energy sources bring us to consider alternate sources. With growing needs to convert to efficient and renewable options to produce energy, our project- a solar fan that runs on a BLDC motor seems a perfectly viable option to meet fulfilments. We have tried to gather the potential components that can give better results with less consumption and develop a model that efficient, enhanced as well as eco-friendly.

3.1. Research

Based upon the data collected from various resources and references, we could analyse that some related/similar projects developed multiple designs that deliver results.

Referring to various sources, we came across one such model which uses a fly back converter, SMPS supply. This component however, increases the cost by and additional 3$ (RS. 260 approximately) and there are certain other cons attached to it-
i. High EMI since of the gap.
ii. Higher ripple current.
iii. More output and input capacitance.
iv. More losses.
v. Right half pole in compensation loop.

Rather, in our model, we used an Arduino UNO MCU that produces the required PWM signals. Although one would suggest that an Arduino is much costlier, it does not possess the above disadvantages.

Not many of the reference models made use of an OPTOCOUPLER. This component has its own many advantages-

i. Removes or reduces electrical noise from signals.
ii. Isolates low-voltage devices from high-voltage circuits.
iii. Allows you to use small digital signals to control larger AC voltages.

Another such model made use of a PI (Proportional-integral controller).

The controller’s priority is usually to keep the error between the actual output and the set point as low as possible. The actual output is the one that needs to be controlled, whereas the set point is the expected output. In terms of speed control, the error can be given by the equation: $e(t) = \omega SP(t) - \omega PV(t)$, where e(t) is the error function with respect to time, $\omega SP(t)$ is the reference speed, and $\omega PV(t)$ is the actual motor speed in function of time.

The proportional part is the error multiplied by a constant gain known as KP and the integral part is the integration of time with respect to time multiplied by a constant gain known as KI. The equation for the PI controller can be given by: u (t) = K$Pe(t)$ + $KIe(t)dt$, where u(t) is the PI output, KP is the proportional gain, KI is the integral gain, and e(t) is the error function.

Again, this model has a few shortcomings. To be specific, the PI controllers have high starting overshoot and are sensitive to controller gain. Adding on, to the sudden disturbances, the response is very slow. There is no guarantee of good performance. Coming to evaluation of the gain coefficients, they require complex calculations. Hence the system can become unstable for higher order and complex ones and thus it is not recommended.

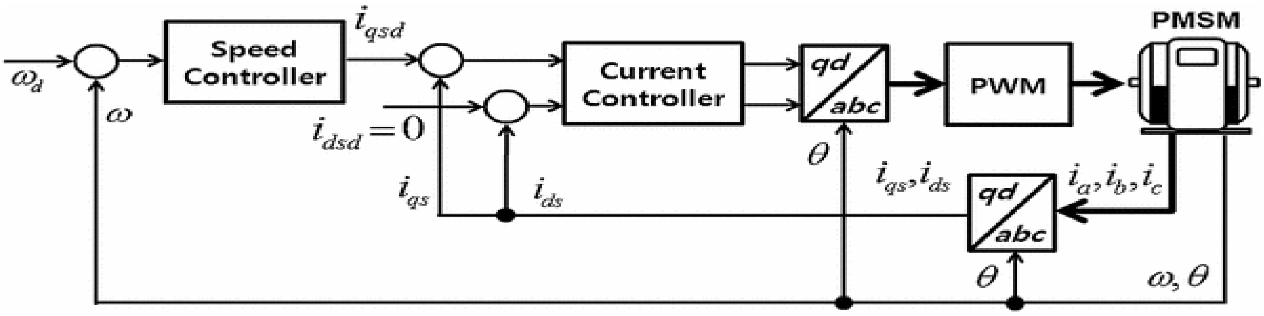

Figure 4: PI speed control design

A model using Zeta converter and fuzzy logic can work in both step-up and step-down mode. This is a brilliant idea as fuzzy logics (a superset of Boolean logic) are very flexible and rapidly customizable, providing stability as well as robustness to the system.

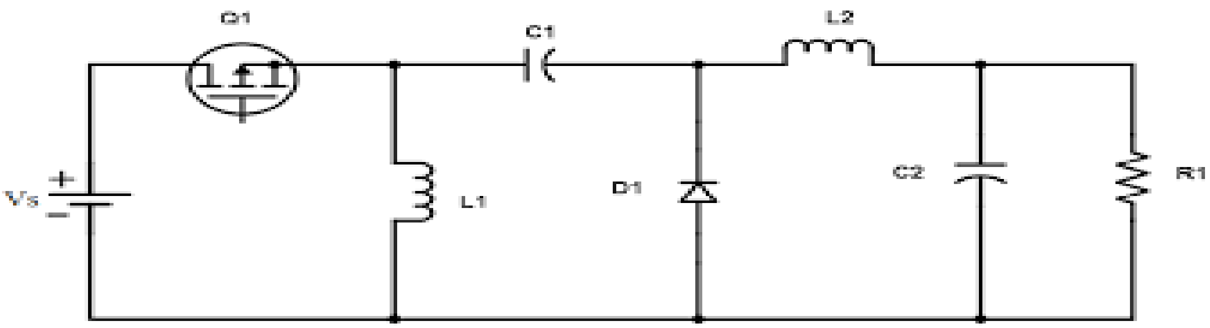

Figure 5: Zeta controller

3.2. Why this model?

Considering our research, we filtered through components and analytical models and came up with a final design. Under the guidance of Dr. Sreedhar Madichetty who suggested a microcontroller-based designed, we developed a model using the components that will be explained in detail in the coming sections.

Our inspiration came from the ideas of energy efficiency suited with environment friendly aspects to it.

IV. Implementation

4.1. Single Phase motor

We initially read on all the components that we should chose and how should we proceed in order to make the most suitable schematic. We made the schematic using two npn opt-coupler and a 74LS139 Decoder. We used 4 MOSFET devices, the output of two going to one optocoupler and the signal passed to the other MOSFET device. The output of these 2 MOSFET devices was given to the fan. The input to the circuit was 12V.

Since we are using 74LS139 Decoder, there was no need to put a PIC microcontroller which will reduce the overall circuit. We applied optocoupler for isolating power circuit and control circuit.

However, the motor that we had was a 3-phase motor, so we had to discard the above model. Taking inspiration from it we designed a 3-phase circuit.

4.2. Three phase BLDC Motor

Any three phase BLDC motor(sensored and sensoreless) have 3 windings on the stator core. Two coils are energized creating a rotating electric field. The method is easy but to prevent the magnet rotor from getting locked with the stator, the excitation must be in a specific manner. Hence, to drive this we require a 3-phase bridge involving 6 MOSFETs.

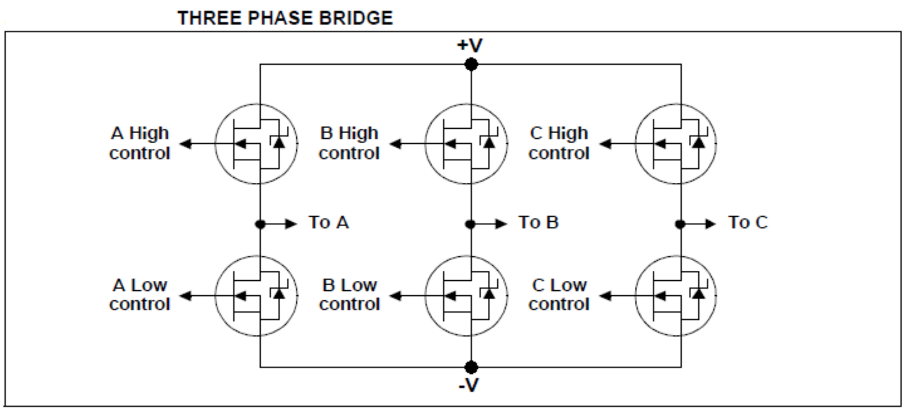

Figure 6: 3-phase bridge using 6 MOSFET devices

Each phase has 120 degrees high and 120 degrees low where it operates. Each bridge is 0 for 60 degrees after its high-low cycle.

Phase A+: 300->60 Phase A-: 120->240

Phase B+: 60->180 Phase B-: 240->360

Phase C+: 180->300 Phase C-: 0->120

Above all measurements are given in degrees.

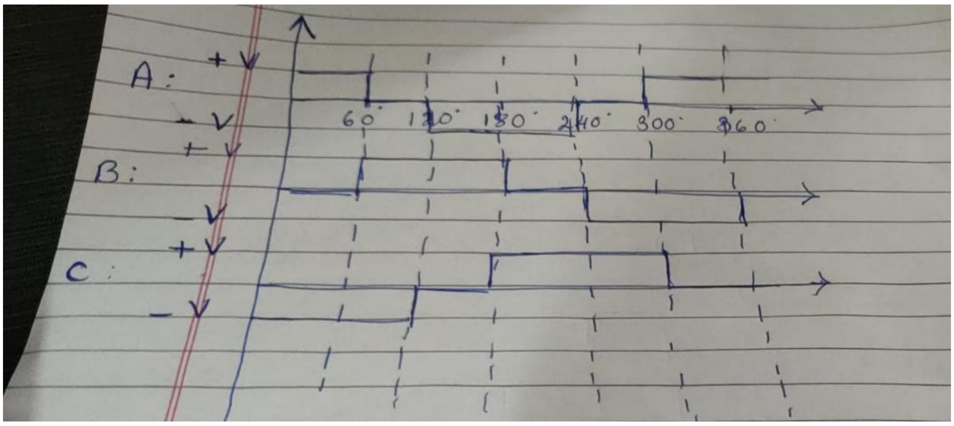

Figure 7: working of three phase bridge

4.3. Three Phase BLDC motor sensorless

Sensorless BLDC motor doesn't have any sensor to detect its rotor position. It detects rotor position based on the BEMF (Back Electromotive Force) produced in the stator windings. The advantage of a sensoreless BLDC motor is its low cost however it has a disadvantage that the motor must be moving at a minimum sufficient rate to detect BEMF.

When the BLDC motor rotates, each winding generates BEMF opposing the main voltage. The 3 generated BEMF signals are 120° out of phase which is the same as the hall effect sensor signals.

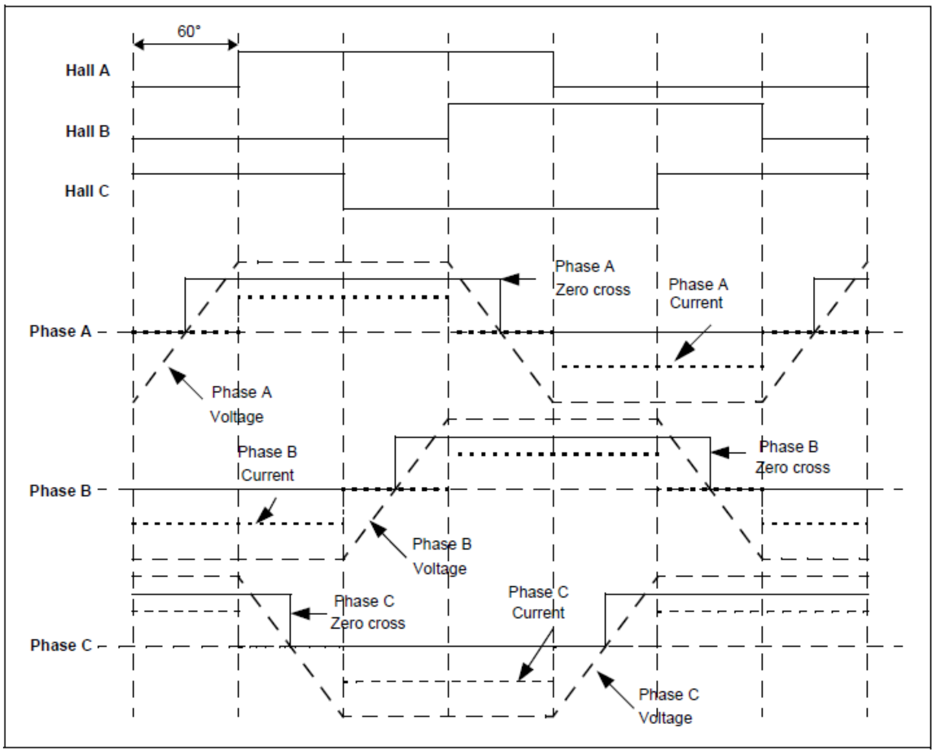

Figure 8: Relation between hall effect signal and BEMF signal

As shown in the figure the BEMF signals are not synchronous with the hall effect sensors as there is a phase shift of 30 degrees. In every energizing sequence only 2 windings are energized one with the positive, one with the negative and the other winding is left open. The winding left open is used to detect the zero crossing. There are 6 zero crossings in total, two for each phase.

The easiest way to detect the zero crossing is using comparators. Arduino UNO has in-built comparators since it is based on ATmega328P microcontroller which has one analog comparator, with each comparator having 2 input pins, one positive and the other negative and an output pin. The output logic is high if positive voltage greater than negative and low if positive voltage lower than the negative.

4.4. Three Phase BLDC motor sensored

The sensored BLDC motor has 3 hall effect sensors (A, B, C) to detect the positions of the rotor windings. Each sensor has a digital high and a digital low for 180 degrees.

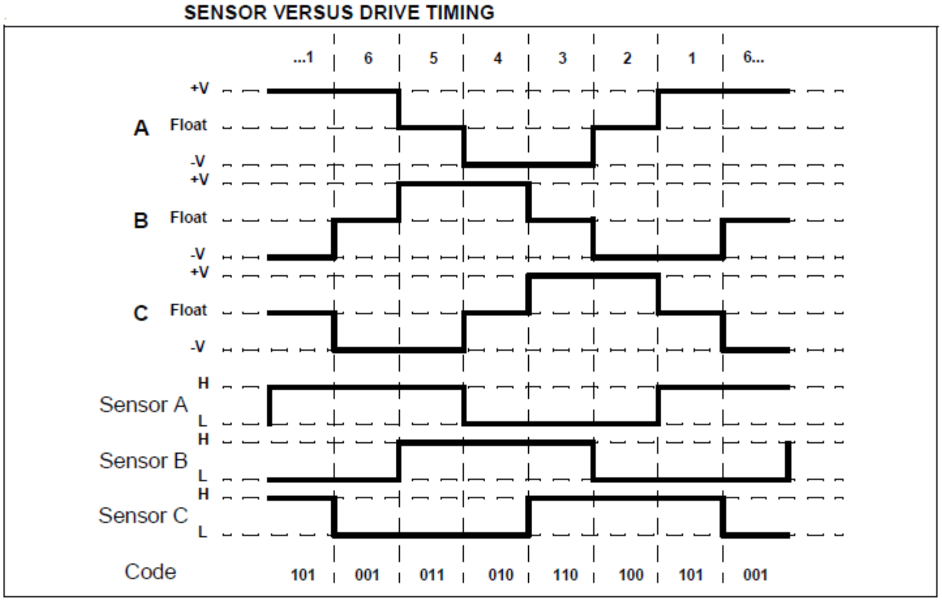

Figure 9: Relation between sensor outputs and motor driving voltage

According to the hall effect sensors, the 3-phase bridge is controlled as shown in the following table:

Table 2

Phase	Sensor C	Sensor B	Sensor A	C High Drive	C Low Drive	B High Drive	B Low Drive	A High Drive	A Low Drive
6	0	0	1	0	1	0	0	1	0
4	0	1	0	0	0	1	0	0	1
5	0	1	1	0	1	1	0	0	0
2	1	0	0	1	0	0	1	0	0
1	1	0	1	0	0	0	1	1	0
3	1	1	0	1	0	0	0	0	1

RESULT

5.1. Single phase-Motor:

We only took inspiration from this working, since this was not the desired project. Using this result we were further built on our schematic and implement the working for a three phase BLDC motor.

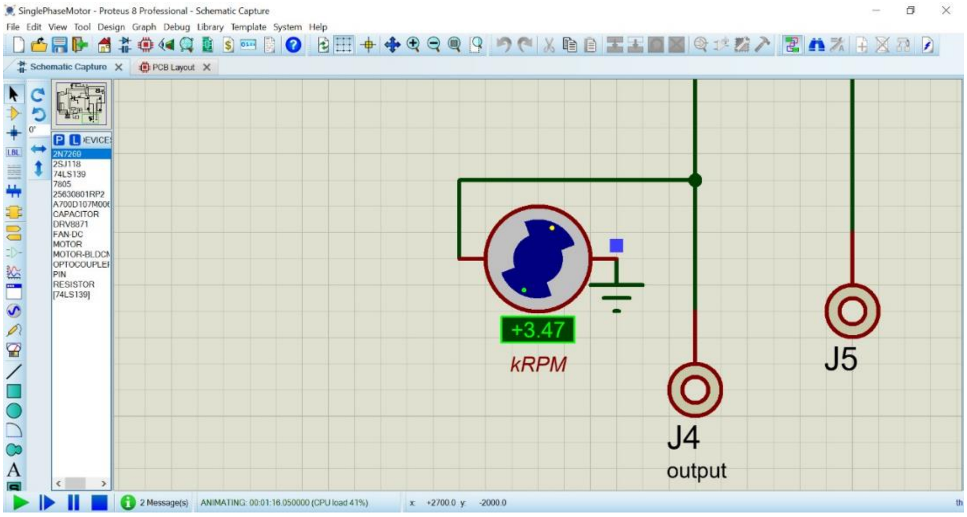

Figure 10: Working of Single-Phase Motor

5.2. Sensorless BLDC-Motor:

The BLDC Motor successfully runs. We are able to control the speed by the speed up and speed down design parameters introduced in the circuit.

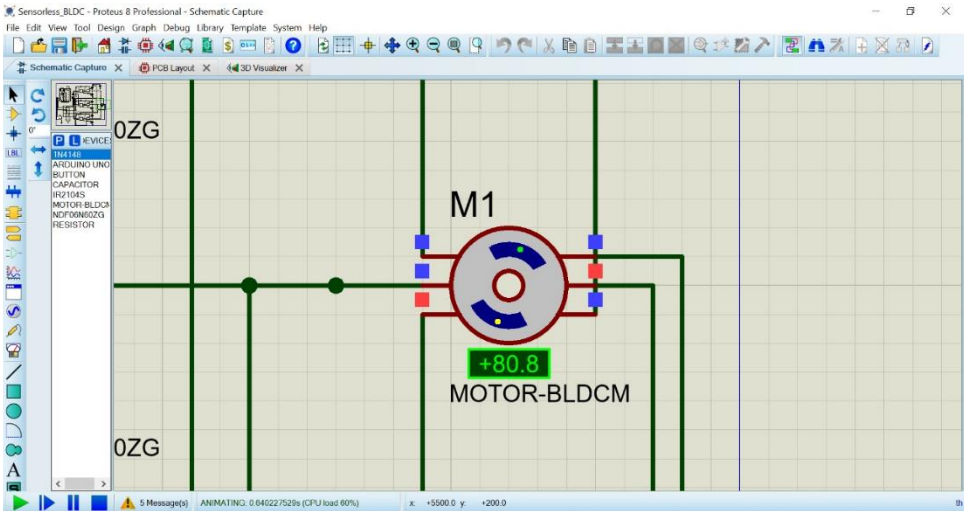

Figure 11: On clicking speed up button

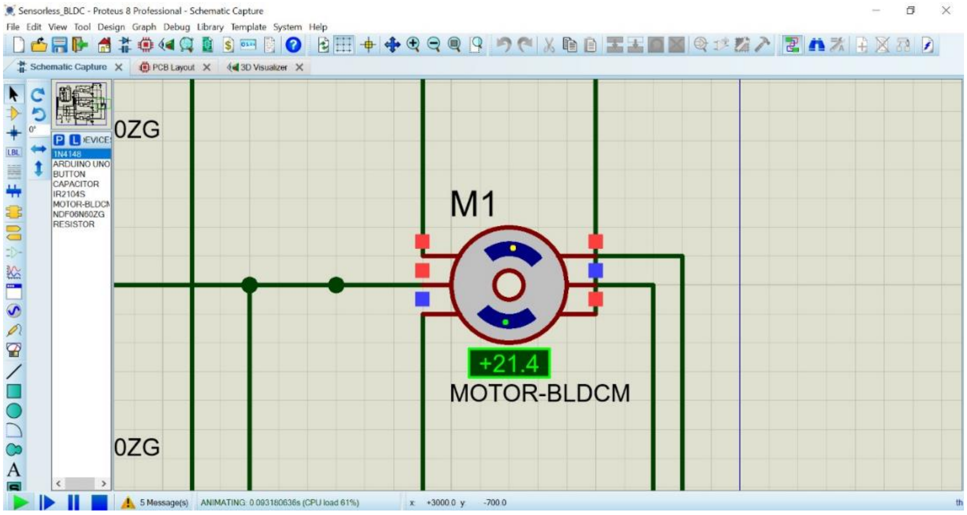

Figure 12: On clicking speed down button

Due to the current circumstances, we were not able to do the hardware implementation of our project. Our simulation is working and we created the PCB, but were unable to order the Gerber file and test the PCB.

5.3. Sensored BLDC-Motor:

We were not able to find any sensored BLDC motor component online. We required a 11 pin Hall sensor but could not find it anywhere. We would have modified our code depending on any sensor we could find, but failed to do so. However, we have made the schematic excluding for that pin.

Conclusion

We started working on a simple single-phase motor running on 12V and extended it to a 3 Phase BLDC Motor. We have shown and explained the working of both sensored and sensorless BLDC motor. We have explained in depth how hall sensors are able to detect rotor positions in a sensored motor and how we have measured back emf using analog comparators in a sensoreless motor.

The purpose of the project was chosen to create a low-cost low-power model solar BLDC fan, that would benefit the lives of poor. The implementations and advantages of solar BLDC fan have also been discussed.

Appendix A: Schematics and PCB layouts

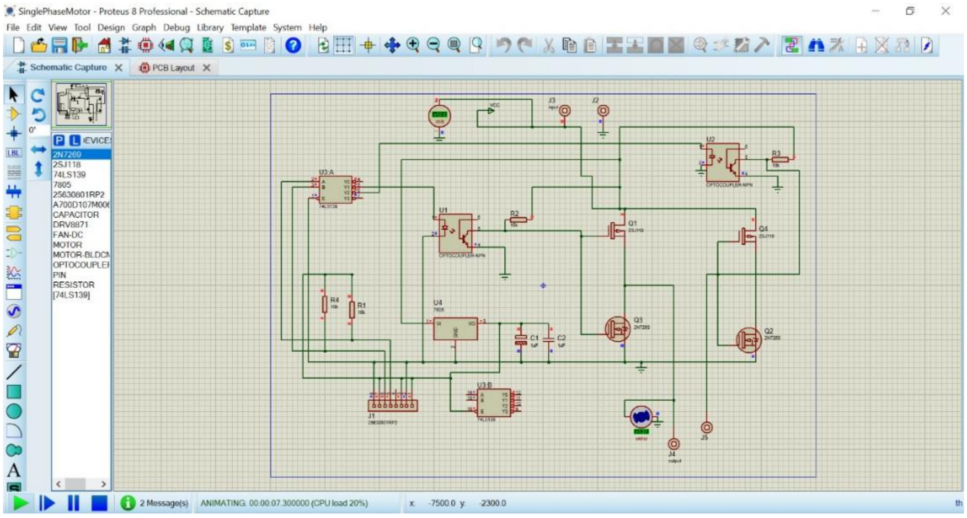

Figure 13: Schematic for Single Phase Motor

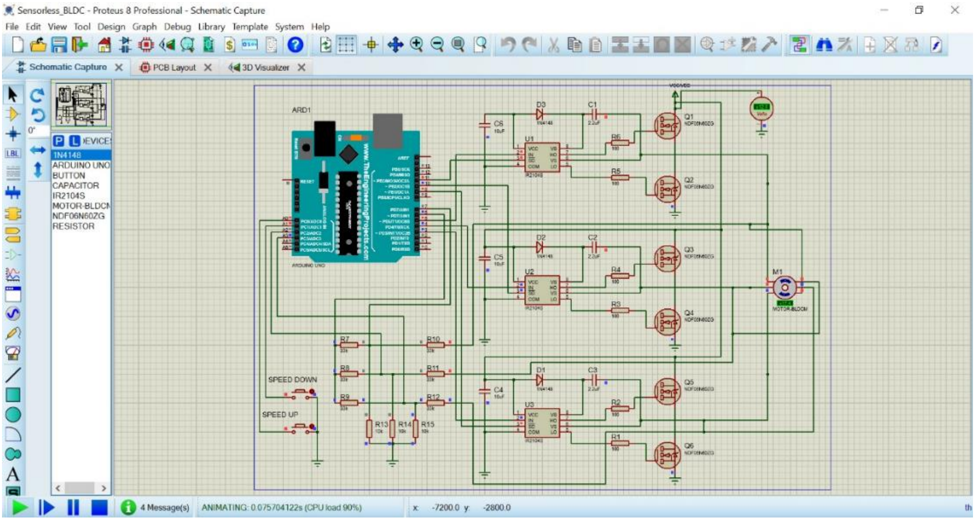

Figure 14: Schematic for sensorless BLDC Motor

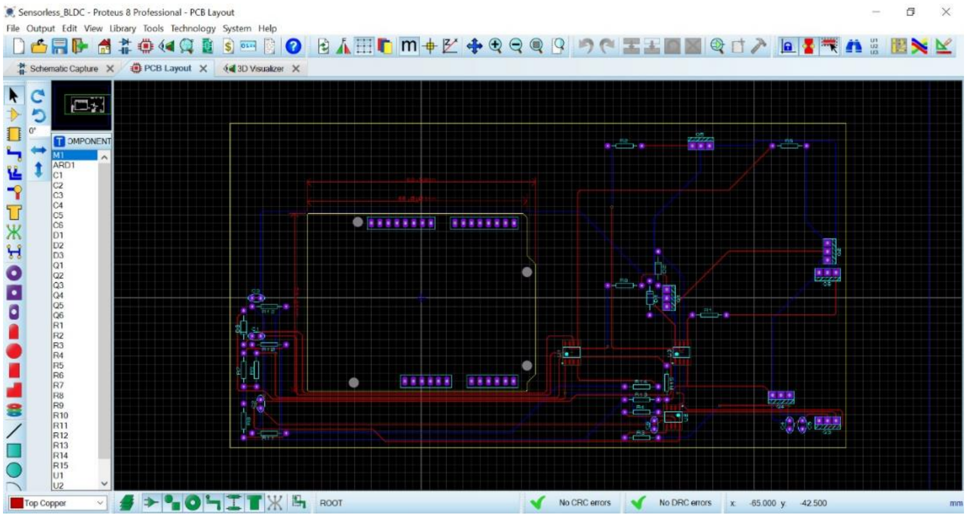

Figure 15: PCB representation for sensoreless BLDC Motor

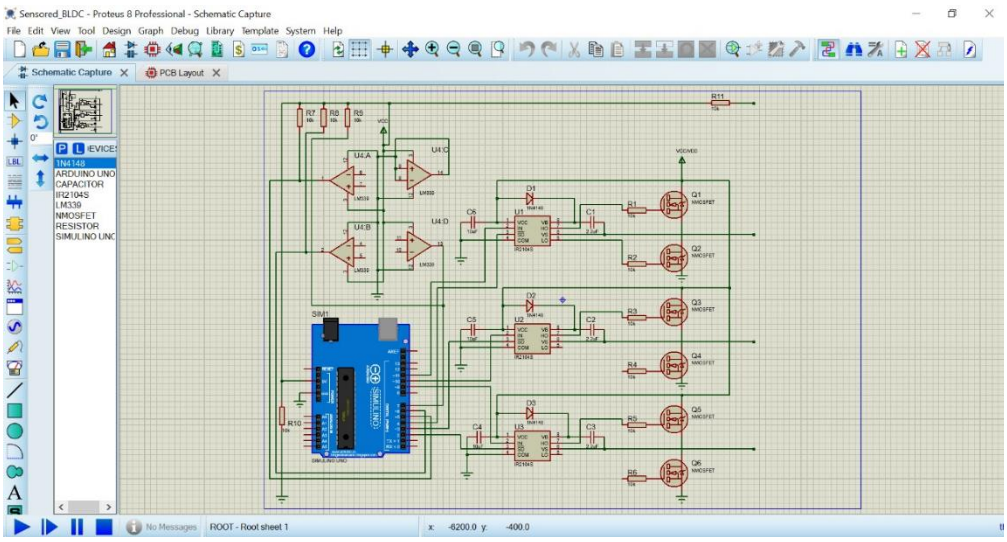

Figure 16: Schematic for sensored BLDC Motor

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