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Solar PV based BLDC Motor Protection using Arduino Microcontroller

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Abstract: *The Photovoltaic generation is rapidly popular by the use of solar radiations as it is renewable and pollution free source. This generation system is connected to the load by DC-DC converter and inverter system. In this power generation system, MPPT controller are used to extract the maximum power from PV panels. There are many methods of MPPT technique is available, but in this paper we have used incremental conductance method. BLDC motor which is also known as permanent magnet motors is being get used as a load, driven by commutated DC voltage. BLDC motor gaining popularity due to absence of brushes in motor and also increasingly used in every sector of market. Every system requires a protection system. So, for this we have used Arduino Microcontroller, which protects the BLDC motor from various fault conditions like overvoltage, overcurrent etc.*

Keywords: *MPPT, Incremental conductance method, BLDC motor, Arduino microcontroller.*

I. Introduction

There are two major classifications of PV solar power systems - stand alone and grid connected. Lack of electricity is one of the main hurdles in the development of rural India. India's grid system is considerably under developed, with major sections of its populace still surviving off grid. Hence, in the Indian scenario stand-alone solar systems are gaining an increasing interest and they are becoming a very competitive solution, particularly because solar energy are available in plenty throughout the year. Moreover, environmental issues such as population and global warming effects are driving researchers towards the development of renewable energy sources like solar energy.

The development of electric vehicle is now growing rapidly. A BLDC motor drive is a potential option for an electric vehicle since it has a high reliability, simple design, and ability to work at high rotation per minute (RPM). Brushless dc motor is a type of permanent magnet synchronous motor, which has permanent magnets on its rotor with trapezoidal back EMF. With the help of power devices BLDC motors energizes its stator phase windings. The phase current of BLDC motor is synchronized with the back EMF to produce constant torque at a constant speed. In BLDC, mechanical commutator of the brush dc motor is replaced by electronic switches. The brushless BLDC motor is better substitute of the DC motor and an induction motor for PV fed water pumping application, e-rickshaw etc. This motor is compact, rugged and efficient in comparison to an AC motor [8]. Moreover, a BLDC motor has many advantages like reliability, least maintenance requirement, a wide range of speed, easy-to-drive and simple control [9-

12]. In this project we have used sensor less BLDC motor, in which not used any sensors to detect its rotor position

Its commutation is based on Back Electromotive Force (BEMF). All reported solutions to PV-BLDC motor driven water pumping and other applications like e-rickshaw as of now, are associated with the position sensor based BLDC motor drive. The main objectives of this paper is to detect and analyze electrical faults in BLDC Motor by using Microcontroller and to match the specification of Motor with input supply due to which BLDC Motor run efficiently.

In this system, we have used Arduino microcontroller for fault detection and protection purpose. Arduino UNO is 8-bit microcontroller with 14 digital pin, 6 analog pin and 6 PWM pin. Its use 16MHz clock for processing. It is mainly use because it's very user friendly. In this, we will detect the fault and protect over like overvoltage, overcurrent etc.

The arrangement consist of the solar panel, battery, boost converter, three phase inverter, BLDC Motor and Arduino Microcontroller. In Three Phase Inverter IGBT switch is used, for triggering the switch pulses are produced. These pulses are produced using Arduino microcontroller.

The system under study is first designed by selecting a BLDC motor and a PV array such that it successfully operates under all the possible variations in weather conditions, and then demonstrated through its steady state, starting and dynamic functionalities, using MATLAB based simulation and an experimental system.

II. System Structure

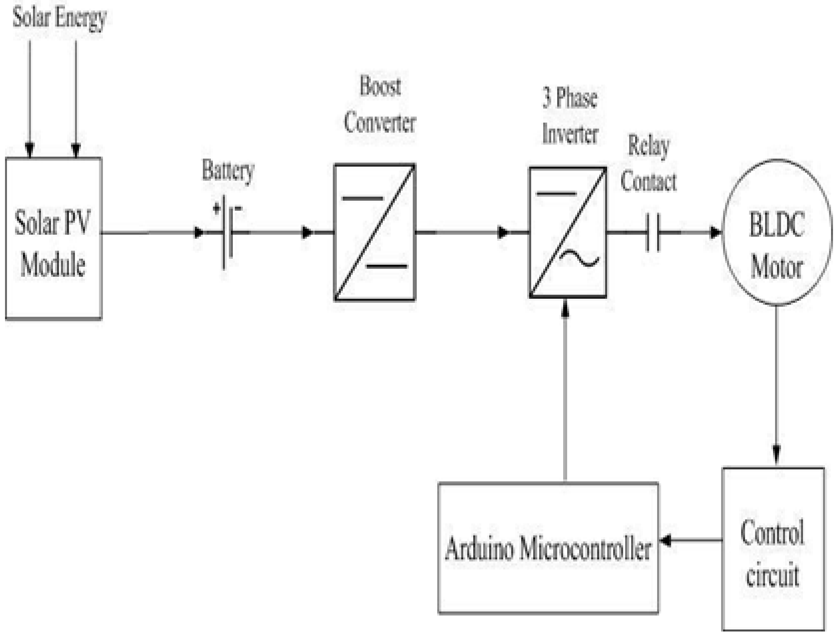

Fig. (1) Block diagram of Solar PV based BLDC Motor using Arduino microcontroller.

The configuration of proposed system solar PV fed BLDC motor using Arduino microcontroller as illustrated in fig. (1). It possesses a PV array, a DC-DC boost converter, a three phase VSI and the BLDC motor with Arduino microcontroller. The MPPT of PV array is realized by means of a boost converter. An incremental conductance (INC) based technique, which needs a feed-back of PV array voltage and current, is used to accomplish the MPPT. The solar panel will absorb the radiation from sun and convert into electricity. This electrical energy stored in battery and the voltage of the battery will be increased by boost converter. This increased voltage given to inverter as an input and it will convert the DC Voltage into AC Voltage and fed to the BLDC Motor. By using Arduino microcontroller, occurrence of electrical fault in motor will get detected through control circuit. When fault will occur, the relay contact will open automatically.

Solar panel:

A photovoltaic (PV) module is a packaged, connect assembly of typically 6x10 photovoltaic solar cell. Photovoltaic modules constitute the photovoltaic array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions (STC).

Battery:

The battery will used to store the energy obtained from solar panel and use it in cloudy days and night time, because output obtained from solar panel is not constant, if input will vary then the output also vary. There are many different batteries available on the market, but for solar systems battery cycle life is critical. A battery's life cycle is the number of times it can be charged and discharged. In solar systems a battery able to survive 10 or so cycles only is unsuitable.

Boost converter:

Energy stored in battery is not enough to run the motor. So it is required to boost the voltage of the battery with the help of boost converter which increases the input voltage being fed to the inverter and hence required electrical input is given to the motor. Hence it maximizes the power generated by Solar PV module.

Three Phase Inverter:

An inverter converts the DC electricity from sources such as solar panel, batteries or fuel cells to AC electricity .A basic three phase inverter consists of three single phase inverters switches each connected to one of the three load terminals. Any semiconductor switch like IGBT, MOSFET or BJT can be used. An inverter can produce a square wave, modified sine wave, pulsed sine wave, pulse width modulated wave (PWM) or sine wave depending on circuit design.

Arduino Microcontroller:

In this system, the micro-controller plays a vital role. Micro-controllers were originally used as components in complicated process-control systems, because of their small size and low price. Here, microcontroller is used to generate different firing pulses applied to inverter as well as to detect fault in motor. If fault occurs, it will display on LCD and relay will trip the circuit.

III. System Design

An appropriate design and specifications of BLDC motor and solar PV array play a significant role in the operation of this project. A 6-pole, 3000 rpm, 3.45 kW BLDC motor is chosen to drive the applications like e-rickshaw. The detailed specifications of BLDC motor are shown in Table I. The PV array, DC link capacitor and BLDC motor are selected such that functioning of the system is not deteriorated even by sudden disturbances in the atmospheric conditions.

TABLE I

BLDC Motor specification

Power, Pm	3.45 kW
Speed, N	3000 rpm
No. of poles, P	6
Resistance, Rs	0.92 Ω
Inductance, Ls	2.8 mH
Motor torque constant, Kt	0.74 Nm/A
Motor voltage constant, Ke	78 V/krpm
Moment of inertia, J	20.8 kg.cm^2

TABLE II

Solar PV Array Design

Specifications of PV Module	
Open circuit voltage, Vo	19.8 V
Short circuit current, Io	4.8 A
MPP voltage, Vm	15.44 V
MPP current, Im	4.3 A
Design of PV Array	
Power at MPP, Pmpp	4 kW
MPP voltage, Vmpp	310 V
MPP current, Impp	12.9 A
Numbers of series connected modules, Ns	20
Numbers of parallel connected modules, Np	3

Short circuit current, Isc	14.4 A
Open circuit voltage, Voc	396 V

Estimation of Parameters of Solar Photovoltaic Array:

A PV array with a maximum power capacity 4 kW at standard atmospheric condition (1000 W/m^2; 25°C) is designed as per the ratings of a selected BLDC motor. The operating power capacity of selected PV array is sufficient to run the motor, and also to compensate the power losses associated with the VSI and motor. A PV module with 36 cells connected in series is considered to make a PV array of the relevant size. Since a solar cell has an open circuit voltage in the range of 0.5 V-0.6 V at standard atmospheric condition [27], it is assumed that a module generates 36 0.55

= 19.8 V as its open circuit voltage. The voltage of a module at MPP is around 71%-78% of the open circuit voltage [28]. Therefore, it is estimated as, 19.8 0.78 = 15.44 V.

IV. Control Approach

The proposed system has its control parts; control of solar PV array operating point through an MPPT technique, BLDC motor electronic commutation, switching pulse generation for VSI , controlling the speed of BLDC motor and Arduino microcontroller .

A. Maximum Power Point Tracking

An INC-MPPT approach [17, 19-20, 28] is adopted to track the optimum operating point of solar PV array. The flow diagram of this algorithm is shown in Fig. 2. V pv and
ipv are the present samples whereas vpv0 and ipv0 are the previous samples of PV voltage and current, respectively.
The dvpv and dipv denote the incremental PV voltage and current corresponding to the two consecutive sampling instants. The INC-MPPT technique states that the power slope of the PV array characteristics is null at MPP (dppv/dvpv

= 0), negative at right of MPP and positive at left of MPP [17]. It utilizes the following equation,

$$\frac{\partial Ppv}{\partial Vpv} = \frac{\partial (IpvVpv)}{\partial Ppv} = Ipv + Vpv\frac{\partial Ipv}{\partial Vpv} = Ipv + Vpv\frac{\Delta Ipv}{\Delta Vpv} \quad \ldots (1)$$

$$\frac{\Delta Ipv}{\Delta Vpv} = -\frac{Ipv}{Vpv} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (2)$$

$$\frac{\Delta Ipv}{\Delta Vpv} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{at the MPP} \quad \ldots\ldots\ldots\ldots\ldots.\; (3)$$

$$\frac{\Delta Ipv}{\Delta Vpv} > 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{at the left side of MPP} \quad \ldots..(4)$$

$$\frac{\Delta Ipv}{\Delta Vpv} < 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad \text{at the right side of MPP} \ldots.\; (5)$$

The algorithm continuously tracks the PV output and adjusts the duty cycle (D) of the converter by increasing or decreasing the perturbation (ΔD) based on eq.1, eq.2 and eq.3.

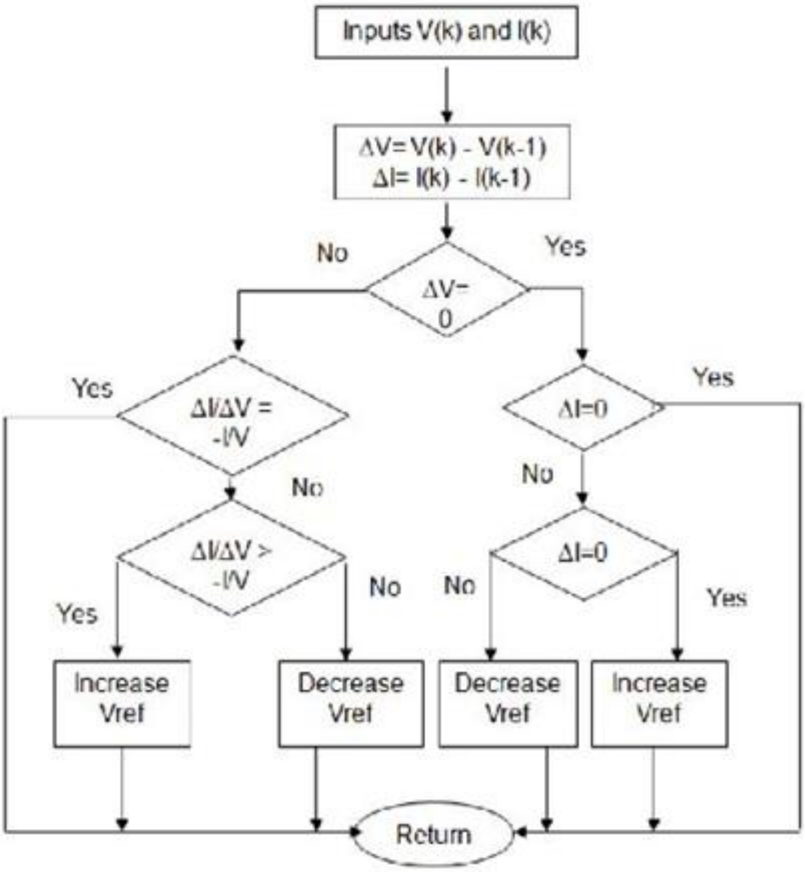

Fig. (2) Flowchart of InC MPPT Algorithm

B. ***Speed Control of Brushless DC Motor***

The speed is governed by an available maximum power from the solar PV array. Any variation in the atmospheric conditions, which causes a variation in the power output from PV array and hence in the speed of BLDC motor. Duty ratio for the VSI, regulates input voltage to the motor. Ultimately, the motor input voltage regulates the operating speed. As the duty ratio is varied by the MPPT algorithm, following the atmospheric condition, the speed of the motor is adjusted accordingly.

C. ***Protection using Arduino microcontroller***

Generally, when a DC motor is associated with any microcontroller based system, it is often connected using a Motor Driver IC. A Motor Driver IC provides the necessary current for the motor to run. It can also control the direction of the rotation. It is a Microcontroller Based prototyping board. The microcontroller used on the Arduino Uno board is ATmega328p. Arduino is responsible for controlling the speed and direction of the motor with the help of other components.

Fig. (3) Arduino microcontroller

V. Simulink Model

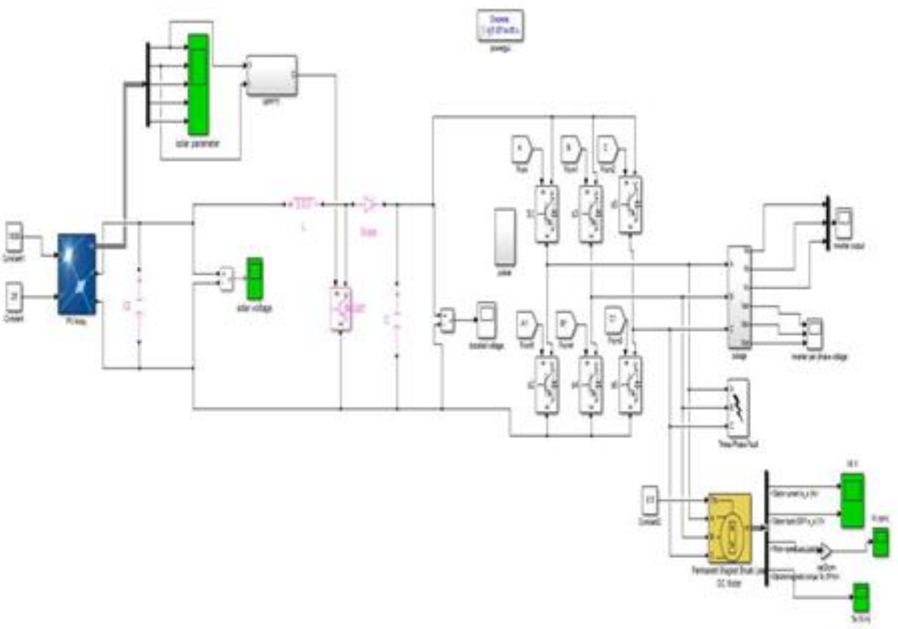

Fig. (4) Simulink model of BLDC motor

Simulation model description:

With the help of the designed circuit parameters, the MATLAB simulation is done and results are presented here. Speeds are set at 3000 rpm. The speed regulations are obtained at set speed and the simulation results are shown in fig.8. The wave form of the back emf are shown in fig. it can be seen the phasor voltages are displaced by 120 deg. The stator current waveforms are shown in fig. They are quasi sinusoidal in shape and displaced by 120 deg.

VI. Simulation Results

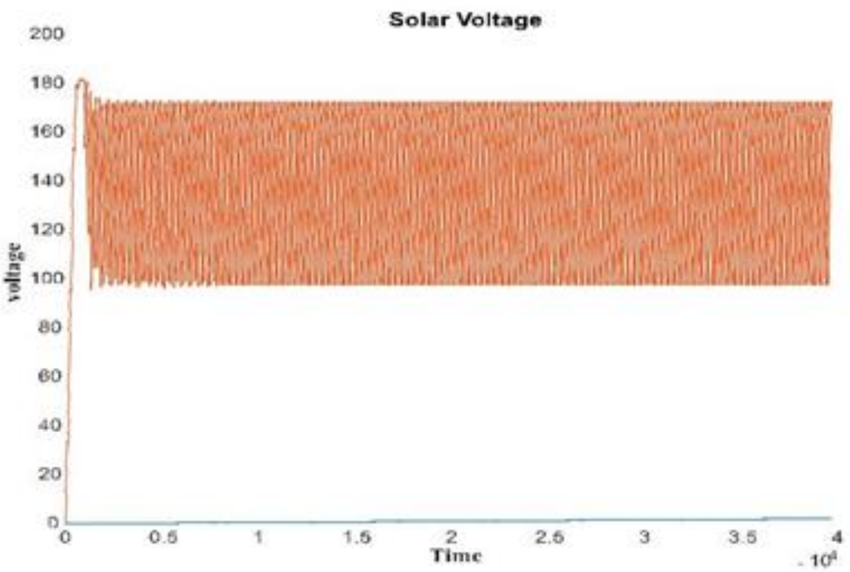

Fig. (5) Solar voltage graph

The above fig. (5) Shows the solar voltage waveform in which we have seen the 170 voltage as output of the solar PV panel. This is fed to the boost converter to increase the voltage as per specification of motor.

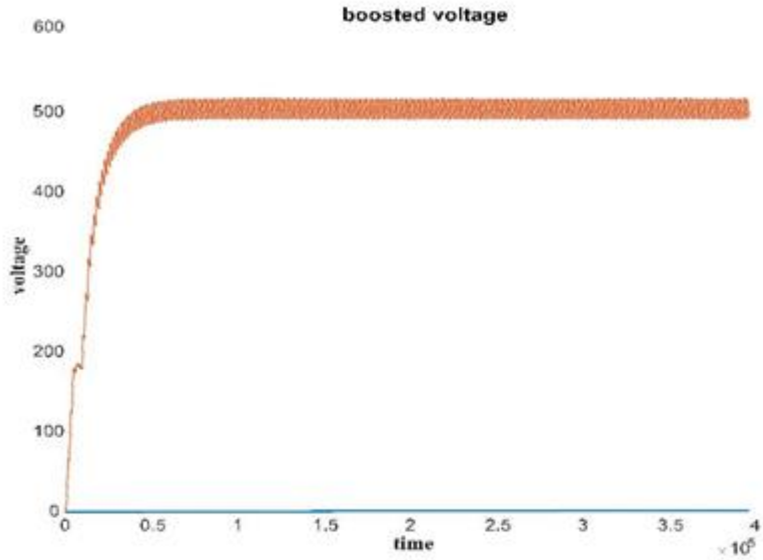

Fig. (6) Boosted voltage graph

Fig. (6) Shows the waveform of solar boosted voltage which is boost by the boost converter. As we have seen the boosted voltage is 500V.This voltage is sufficient to drive motor. This boosted voltage is fed to the inverter to convert it into AC.

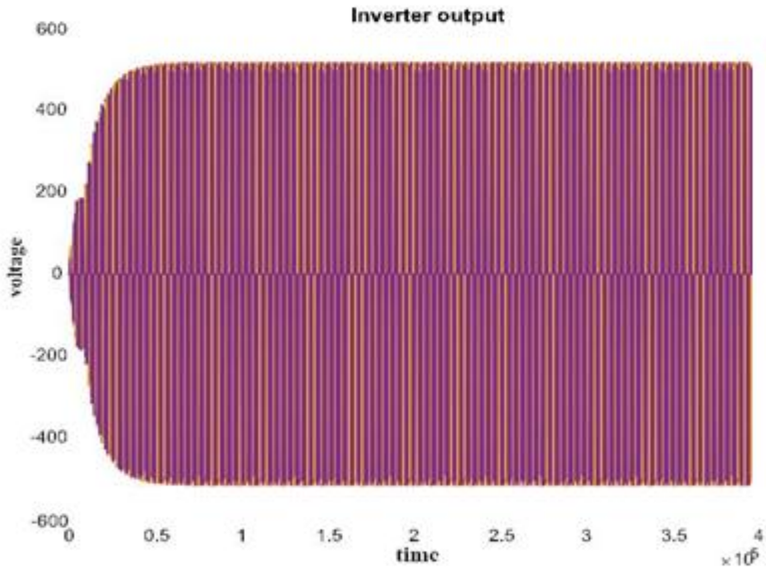

Fig. (7) Inverter output graph

Above graph shows the waveform of inverter output Boosted voltage is as input of inverter and it converts into 500 V AC as shown in fig. (7)

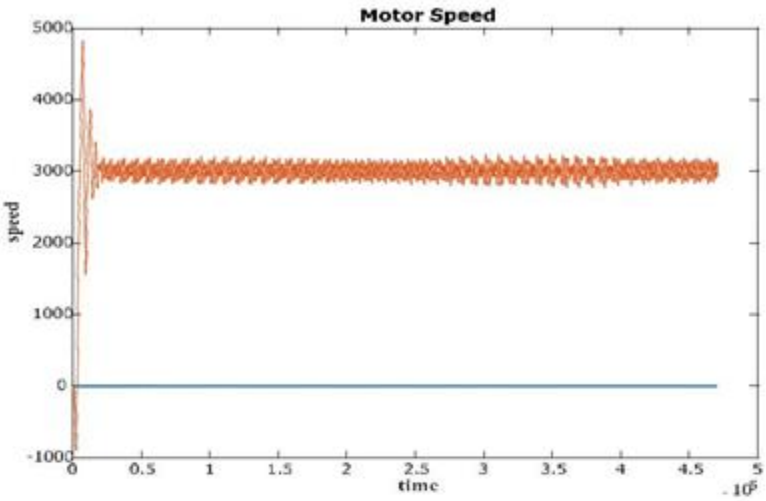

Fig. (8) Motor speed graph

Motor speed graph is shown in fig. (8). as we have set 3000 rpm speed which is achieved which shown in above figure. Motor takes input supply from the inverter output and by this input motor will start to run speed of 3000rpm.

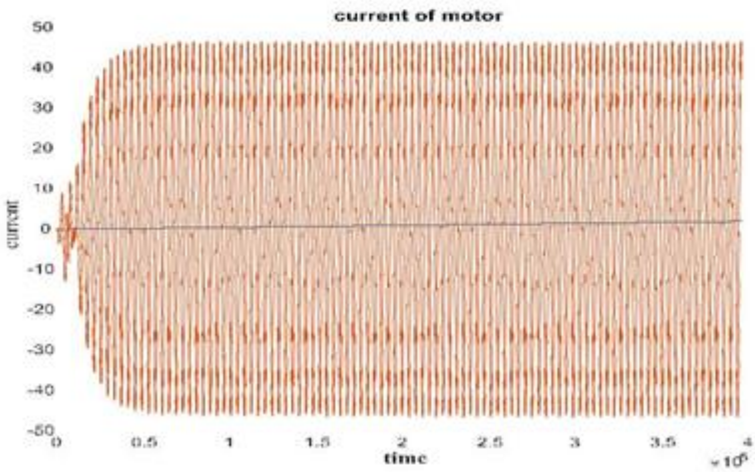

Fig. (9) Current of motor graph

Current waveform of motor is shown in fig. (9) .This is shown in the shape of quasi sinusoidal which current has 45A as a output current of motor and displaced by 120 deg.

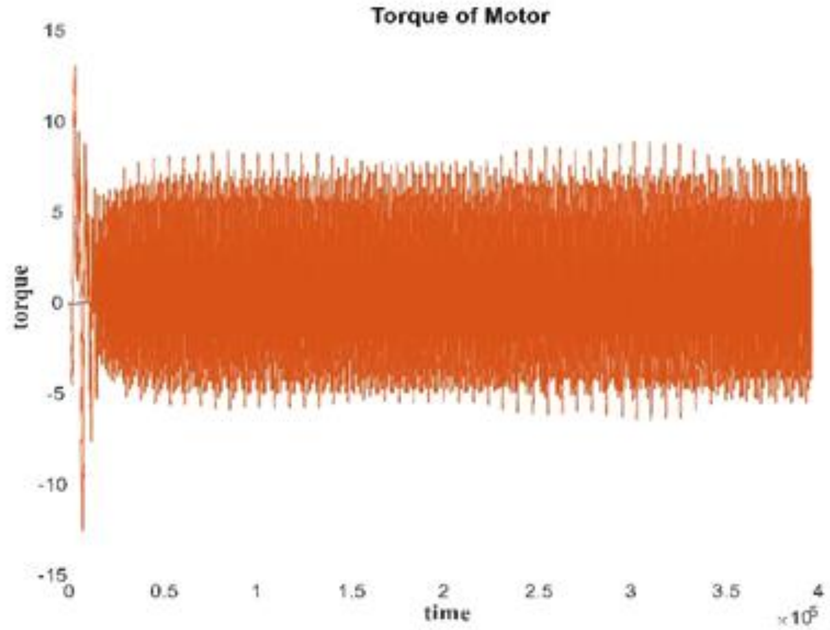

Fig. (10) Torque graph

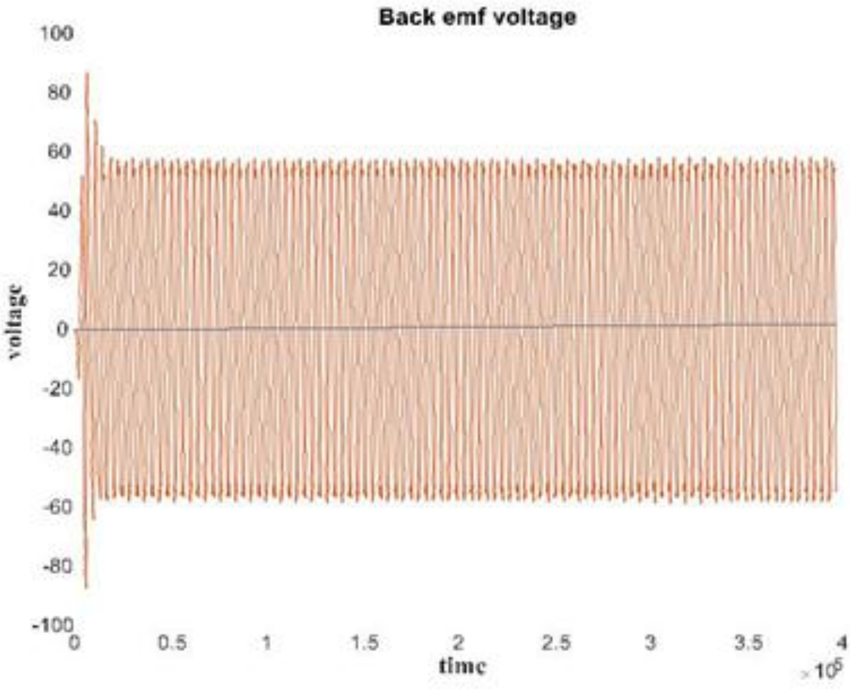

Fig. (11) Back emf voltage graph

Torque of motor and back emf voltage of motor as shown in fig. (10) and fig. (11). It can be seen the phasor voltages are displaced by 120 deg.which shows back emf voltage is 60 V.

TABLE III

Output results of simulation

Solar voltage	170 V
Boosted voltage	500 V
Inverter output	500 V
Motor speed	3000 rpm
Current of Motor	45 A
Torque of Motor	7 N-m
Back emf voltage	50 V

VII. Conclusion

A low-cost position sensorless brushless DC motor drive has been proposed and demonstrated through the software implementation. If, low cost is primary concern, then sensorless technique is best choice. This drive eliminated the motor phase current sensors and speed is simply adjusted by the available maximum power from the PV array. No closed loop has been used to control the speed. These additional features have made the sensorless BLDC motor further simple, compact and cost effective.

VIII. Future Scope

In future, this model can be integrated with small wind turbine apart from solar panels and thus making overall system a hybrid model so that more number of applications can be used by designing this model.

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