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Design of fuzzy logic controller using solar-powered BLDC motor for water pumping system

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ABSTRACT

This paper is mainly based on the water pumping system by using solar PV panels for the effective cost and the brushless dc motors are used here mainly because of the easy maintenance when compare with BDC it has more advantages like high efficiency, reduced noise, longer lifetime and easy construction. The main problem which created while using the brushless dc motors is to control the system parameters. Hence, to overcome from that we introduced one main control called Fuzzy Logic Controller. It is defined as a control system based on a fuzzy logic-a mathematical system that analyses analogue input values in terms of logic variables that take on continuous values between 1 or 0 which used to control the BLDC parameters thorough gate driver circuit of the boost converter. The boost converters are used here to consume more power from solar panel its nothing but the DC-DC converters. The boost converters are controlled by using maximum power point tracking (MPPT). Brushless dc motor is connected with the centrifugal pump through the shaft. The main operation of the project is operating by using the variable constructions called voltage, power and irradiation .it is the improved version of the water pumping systems and control is done by MATLAB/SIMULINK and the hardware also been implemented.

Keywords— *MPPT algorithm, BLDC motor, Microcontroller, MATLAB/SIMULINK, Boost converter, Fuzzy logic controller*

1. INTRODUCTION

The solar panels are used to convert the sun's light into useable solar energy using N-type and p-type semiconductor material. Solar energy is used today in a number of ways because of the effective cost and it is one of the renewable energy source known as an unlimited power source. As we know that solar energy has enormous potential by which the total earth is about 2,000,00 times Electric-generating received Only by earth's solar energy. Solar radiation can be converted either into thermal energy (heat) or into electrical energy, though the former is easier to accomplish. Here we are using BLDC motors to suck more power from the solar panels. A Brushless DC motor BLDC is a synchronous motor which has a permanent magnet which has the source of DC electricity and it describes an electronically controlled commutation system in case of the mechanical system. It is also known as Trapezoidal Permanent Magnet Motors. The efficiency of BLDC motors is typically 85 to 90 percent when compared with BDC motors. BLDC motors are superior to brushed DC motors in many ways, such as the ability to operate at high speeds, high efficiency, and better heat dissipation. They are an indispensable part of modern drive technology, most commonly employed for actuating drives, machine tools, electric propulsion, robotics, computer peripherals and also for electrical power generation. With the development of sensorless technology besides digital control, these motors become so effective in terms of total system cost, size and reliability. But the system parameters are some more difficult to control. So the fuzzy logic controller is used here to control that BLDC parameter. It is defined as a control system based on a fuzzy logic-a mathematical system that analyses analogue input values in terms of logic variables that take on continuous values between 1 or 0. Fuzzy logic is a branch of logic designed specifically for representing knowledge and human reasoning in such a way that it is amenable to processing by the computer as all know fuzzy logic is also applied as an expert to knowledge engineering and AI. The Values which has traditional propositional and it's logic's do not allow any degree of imprecision which is defined by words by fairly. It's much better by using multi-valued logic instead of truth table It has

the values like true, not very true, more or less true, not very false, very false, not false, and false. Alternatively, an interval such as [0,1] can be introduced and the degree of truth can be represented by some real number in this range. Predicates are then functions that map not into {true, false} but into these more general domains. BLDC motor for pumping system technique along with solar PV source, both combination increases its utilization and reliability. Maximum benefits from solar PV is obtained by using maximum power point tracking (MPPT) algorithm. For MPPT tracking, generally P &O, incremental conductance algorithm is used. Among that incremental conductance gives the best performance under rapidly changing atmospheric condition, however, it shows poor performance at low irradiance level using the DC-DC converters. The dc-dc converter is nothing but the boost coveters basically its used to operate the system in higher voltage level and its used to determine more power from the solar panel array. These are all the main components which are used in our project because of the low cost and high performance.

2. PROPOSED SYSTEM

Brushless DC motors are widely used for many industrial applications because of their high efficiency, high torque and low volume. This paper proposed an improved fuzzy logic controller to control the speed of a brushless DC motor. The system parameter like torque, speed, the position of brushless DC motors is difficult to control. The control on this parameter has been demonstrated in various papers using various controllers. In this paper, an attempt has been made in designing an alternative controller to minimize steady state error and obtain the better result for the control of the speed parameter of BLDC motor by using Fuzzy Logic Controller. Fuzzy logic provides a way of dealing with imprecision and nonlinearity in complex control situations. The benefit of the Fuzzy Logic Controller becomes transparent to the user of consumer devices since the Fuzzy Module or function is embedded within the product.

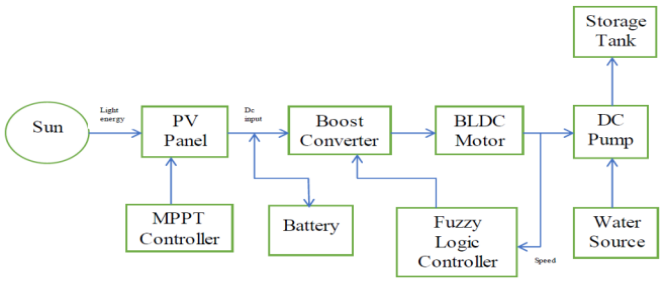

Fig. 1: Block diagram of the water pumping system

Another advantage of this paper is using solar pv panels for power consumption. The light energy from the Sun is absorbed by the Solar PV panel which converts light energy to the electrical energy through Photovoltaic effect. The maximum solar irradiance is achieved by using the MPPT algorithm. There are several types of MPPT algorithm is used. In our project, we are using Incremental-Conductance MPPT algorithm which uses a tracking mechanism to get the maximum output from the solar panel. The output from the panel is stored in a battery for the backup and then it is given to the boost converter and it is boosted up and it is given to the motor under the control of FLC.

3. DESIGN OF THE WATER PUMP SYSTEM

3.1 Design of solar panel

As shown in figure 1, the single diode model of PV panel can be presented by a photocurrent source and a diode connected with series and shunt resistances. The mathematical model of the PV panel can be presented by the following equations:

$$I = I_{ph} - I_s\left(\exp q\left(\frac{V + R_s I}{aKTNs}\right) - 1\right) - (V + IR_s)/R_{sh} \quad (1)$$

$$I_{ph} = \left(I_{sc} + K_i(T - 298.15)\right)G/1000 \quad (2)$$

$$I_s = \frac{\left(I_{sc} + K_i(T - 298.15)\right)}{\exp(q((V_{oc} + K_v(T - 298.15)/akTNs)) - 1} \quad (3)$$

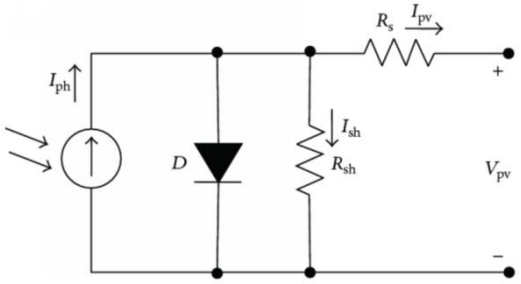

Fig. 2: PV panel equivalent circuit

Hence, the physical behaviour of the PV panel depends on the shunt and series resistance, solar irradiation, and temperature. Therefore, in this work, the impact of these parameters on the output of the PV panel is investigated.

Nomenclature

a: Diode's ideality factor
I: Output current of the panel (A)
Is: Diode saturation current (A)
I_{ph}: Panel photocurrent (A)
G: Solar irradiation (W/m^2)
K: Boltzmann constant (J.K^-1)
q: Electron charge (C)
R: The load (ohm)
R_{eq}: The resistance seen by the panel (ohm)
R_s: Series resistance (ohm)
R_{sh}: Shunt resistance (ohm)
T: Junction temperature (K)
V: Output voltage of the panel (V)

3.2 Incremental conductance MPPT Algorithm

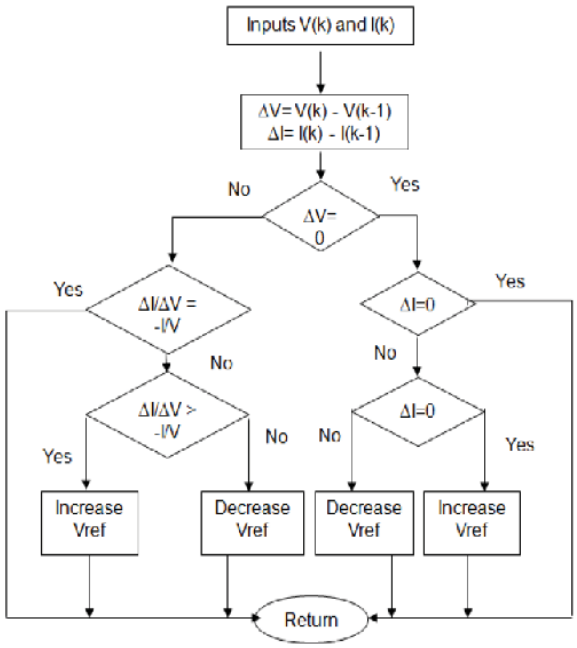

Fig. 3: Flow chart of Incremental Conductance MPPT

A Maximum Power-Point Tracking (MPPT) Method with a simple Algorithm for Photo Voltaic (PV) power generation system. This method is based on the use of Incremental Conductance of Photovoltaic to determine an operating current for Maximum output power. This Technique has an advantage in that it can reach and maintain the (MPP) without losing some efficiency by having to oscillate around this point. Under rapidly changing conditions that this Algorithm tracks more accurately than the P&O method.

4. BRUSHLESS DC MOTOR (BLDC MOTOR)

Brushless DC motor is also known as Electronically Commutated Motor or a permanent magnet synchronous electric motor which is driven directly by DC current source Electricity and it accomplishes Electronically Controlled Commutation system. Instead of a mechanical commutation system. BLDC Motor is also referred to as Trapezoidal permanent magnet motor. The armature coils are switched electronically by transistor or SCR at the correct rotor position in such a way that armature field is in space quadrature with the rotor field poles. Hence the force acting in the rotor causes it to rotate. In this paper we were going deal with the model in simulation for BLDC motor and its results was examined for the speed and torque control of the machines.

4.1 Working of a BLDC Motor

BLDC motor works on the principle similar to that of a conventional DC motor. Before explaining the principle of working of BLDC motor we should understand that it is the same as Brushed DC motor. Thus in a brushed DC motor, its feedback implementation is done by mechanical commutator and brushes. But in BLDC motor it is achieved by using sensors as the multiple feedbacks. In BLDC motors we most commonly use HALL- EFFECT sensors, whenever rotor magnetic poles pass near the Hall sensor, they generate a HIGH or LOW-level signal, which can be used to determine the position of the shaft. If the direction of the Magnetic field is reversed, the voltage developed will reverse too.

5. DESIGN OF BOOST CONVERTER

The boost converter is one of the types of Dc-Dc converter with an Output voltage greater than the source voltage. Generally, the boost converter is also called a step-up converter. Since it is step-up the source voltage, we get Maximum efficiency. One of the prominent reasons for using Boost converter is that we get proper and excellent restoration of efficiency in our device. Another usage of this boost converter helps to get maximum power source from solar Photovoltaic (PV) panel.

$$D = \left(\frac{V_{dc}}{V_{dc} + V_{pv}}\right) = \left(\frac{311}{311 + 248.5}\right) = 0.55 \qquad (4)$$

Where V_{dc} is DC voltage of the inverter and I_{pv} is calculated as according to equation (5).

$$I_{dc} = \frac{P_{mpp}}{V_{dc}} = \frac{1500}{311} = 4.98 \qquad (5)$$

As the summation of the two current I_{dc} and I_{pv} flow through the circuit, inductor L is estimated as according to equation (6).

$$L = \left(\frac{(D * V_{pv})}{f_{sw} * \Delta I_l}\right) \qquad (6)$$

$$L = \left(\frac{(0.55 * 248.5)}{10000 * 11 * 0.4}\right) = 3Mh \qquad (7)$$

Where f_{sw} is switching frequency of the boost converter and ΔI_L is a ripple content in the inductor

6. FUZZY LOGIC CONTROLLER FOR SPEED CONTROL OF BLDC MOTOR

Nowadays the fuzzy logic controllers are widely used in trends because of the effectiveness for both linear and nonlinear systems. The fuzzy logic controller was applied to the speed loop by replacing the classical polarization index (PI) controller. The input variable is speed error (E), and change in speed error (CE) is calculated by the controller with E .The output variable is the torque component of the reference (i_{ref}) where i_{ref} is obtained at the output of the controller by using the change in the reference current. The controller observes the pattern of the speed loop error signal and correspondingly updates the output DU and so that the actual speed ω_m matches the command speed ω_{ref}.

6.1 Fuzzy controller

Fuzzy logic is a complex mathematical method that allows solving difficult simulated problems with many inputs and output variables. Fuzzy logic is able to give results in the form of recommendation for a specific interval of the output state, so it is essential that this mathematical method is strictly distinguished from the more familiar logic, such as Boolean algebra. This paper contains a basic overview of the fuzzy logic controller.

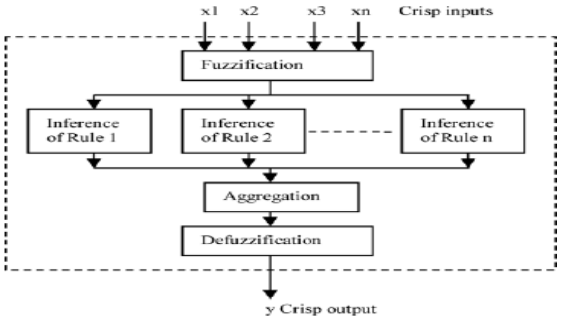

Fig. 4: Fuzzy control

Fuzzy logic works on the concept of deciding the output on the basis of assumptions. It works on the basis of sets. Each set represents some linguistic variable defining the possible state of the output. Each possible state of the input and the degrees of change of the state are a part of the set, depending upon which the output is predicted. It basically works on the principle of If-else-the, i.e. If A AND B Then Z.

6.2 Fuzzy sets

A fuzzy set is a set of ordered pairs with each containing an element and the degree of membership for that element. A higher membership value indicates that an element more closely matches the characteristic feature of the set. Zadeh proposed the concept of a fuzzy set. Fuzzy sets are functions that map a value that might be a member of the set to a number between zero and one indicating its actual degree of membership. A degree of zero means that the value is not in the set and a degree of one means that the value is completely representative of the set. This produces a curve across the members of the set. The basis of the technology is a fuzzy set that is an extension of the classical set. In traditional set theory, membership of an object belonging to a set can only be one of the two values: 0 or 1. An object either completely belongs to a set or does not at all. No partial membership is allowed.

A fuzzy set is an extension of a crisp set. Crisp sets allow only full membership or no membership at all, whereas fuzzy sets

allow partial membership. A membership function is essentially a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1.

Fuzzy set operations are analogous to crisp set operations. The important thing in defining fuzzy set logical operators is that if we keep fuzzy values to the extremes 1 (True) or 0 (False), the standard logical operations should hold. In order to define fuzzy set logical operators, let us first consider crisp set operators. The most elementary crisp set operations are union, intersection, and complement, which essentially correspond to OR, AND, and NOT operators, respectively. In FL, the truth of any statement is a matter of degree. In order to define FL operators, we have to find the corresponding operators that preserve the results of using AND, OR, and NOT operators. The answer is min, max, and complements operations. Most applications use min for the fuzzy intersection, max for the fuzzy union, and complement for complementation. We have to remember that operators used in FL, such as union, intersection, and complement, reduce to their crisp logic counterparts when the membership functions are restricted to 0 or 1.

$\dot{e} \backslash e$	NL	NM	NS	ZO	PS	PM	PL
NL	PL	PL	PM	PM	PS	ZO	ZO
NM	PL	PL	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NL
PL	ZO	ZO	NM	NM	NM	NL	NL

Fig. 5: Fuzzy Rules

7. PIC16F877A MICROCONTROLLER

It is one of the most renowned Microcontrollers which is convenient to use, coding or programming of this controller is also easy. It has 368B of RAM and 14 KB of program memory.one of the main advantage is that it can be Write-Erase as many times as possible because it uses flash memory technology.

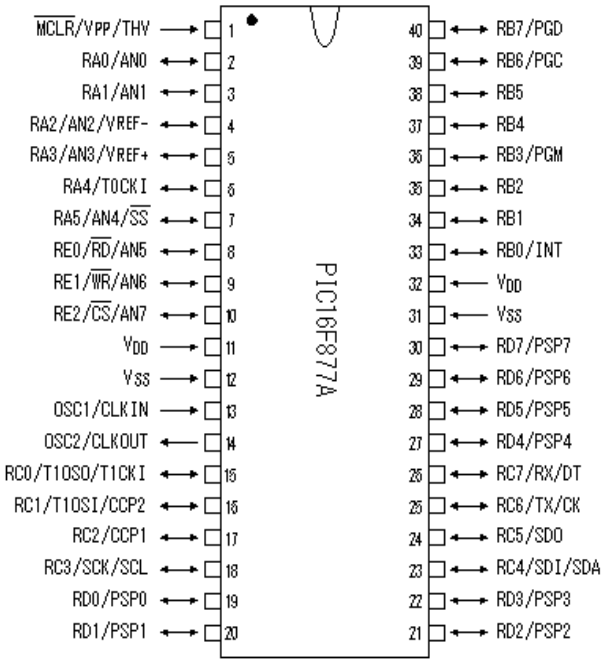

Fig. 6: Pin diagram

It range of power supply takes 2V to minimum and 5V to the maximum. It has 40 pins in total and there are 33 pins for Input and Output. It consists of Two 8 bit and one 16-bit Timer. It has 5 input and output ports, they are Port A, Port B, Port C, Port D, Port E which can be digital as well as Analog. Port A has 6 pins (Pin#2-pin#7) RA0 to RA5. Port B has 8 pins (pin#33-pin#40) RB0 to RB7. Port C has 8 pins (Pin#15-18, pin#23-26). Port D has 8 pins (pin#19-22, pin#27-30). Port E has three pins (pin#8-pin#10). Two pins for Vss Ground (pin#28, pin#31). V_{DD} for positive power supply for +5V. The pin diagram for the Plc. 16F877A Microcontroller was given below and it's we will see the simulation.

8. WATER PUMP

In this project for water pumping, centrifugal pumps were used. It is widely used because it is fairly simple in nature. The main advantages of using this centrifugal pump are that it does not require any valves, or many moving parts so space saving. Its output is very much steady and consistent. Most of all, they are very small compared to other types of pumps that Create the same output with capital cost.

9. SIMULATION

9.1 Overall simulation model

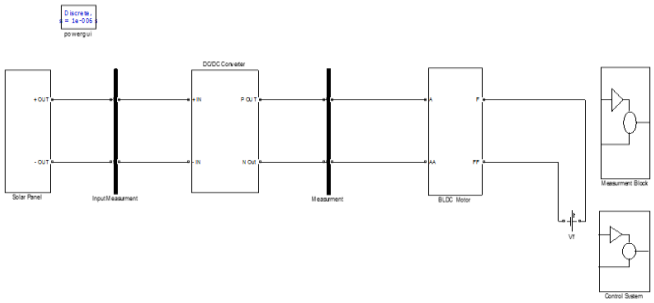

Fig. 7: Simulink diagram for the proposed system

Figure 7 shows the overall simulation model. The simulation diagram includes the Solar PV Panel, Fuzzy Logic Controller, DC-DC Boost Converter. It's used to denote the Voltage and Current of Solar PV Panel and Speed characteristics of BLDC motor.

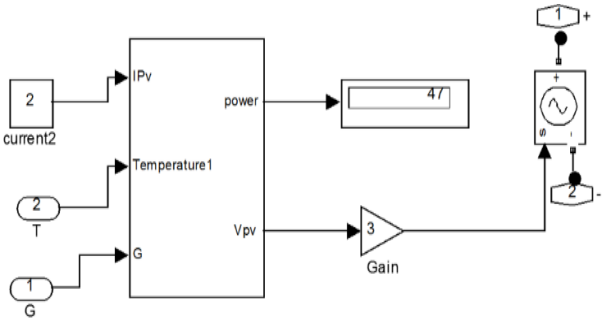

Fig. 8: Simulink of Solar PV Panel

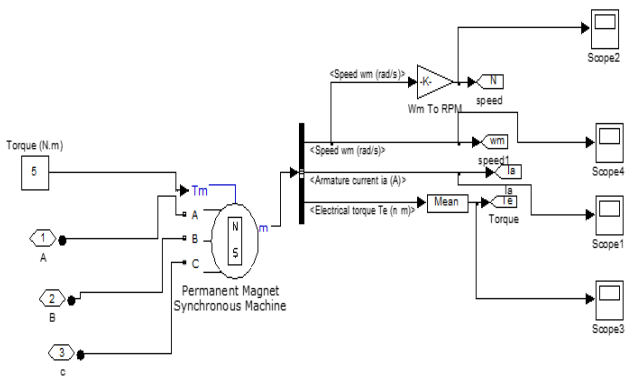

Fig. 9: Simulink of BLDC Motor

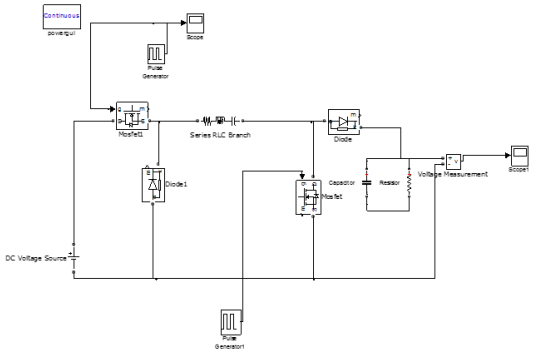

Fig. 10: Simulink of DC-DC Boost Converter

10. SIMULATION RESULT

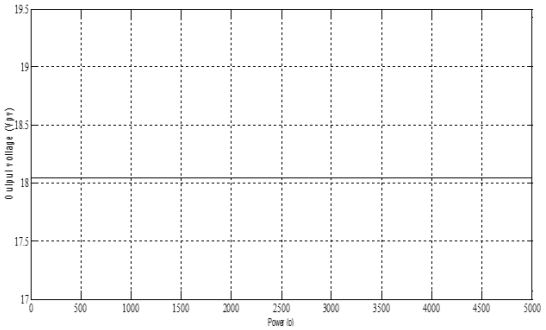

Fig. 11: Simulation output of the solar panel

Table 2: Panel Specifications

Type of panel	Number of cells	Output
12V	36	18V

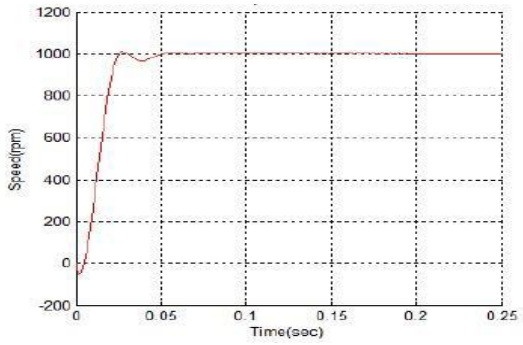

Fig. 12: Speed response of BLDC Motor

11. HARDWARE RESULT

11.1 Hardware model

This is a hardware module of Design of a fuzzy logic controller using solar-powered brushless dc motor for water pumping system.

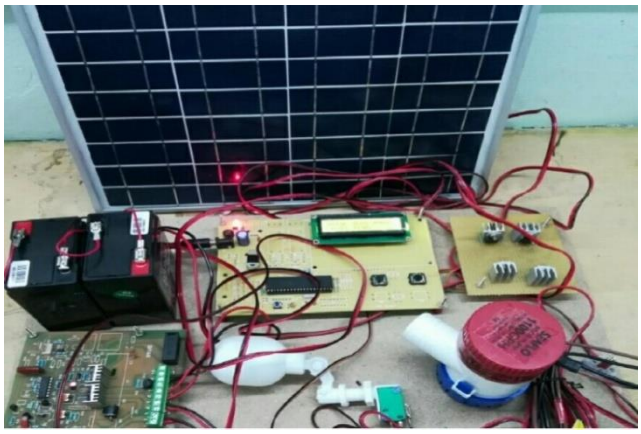

Fig. 13: Hardware module

12. CONCLUSION

The proposed system is more reliable and low cost when compared with other existing systems. We are given more attention to the control system here because it plays a major role in our project. By using the fuzzy logic controller the rise time is decreased and it easily attains the settling time in a short time of period when compared with compensation and PID controllers. Maximum power point tracking is an algorithm it is implemented here in photovoltaic inverters to continuously adjust the impedance seen by the solar array.it mainly used to maximize the power generated by the PV systems. The proposed system makes the BLDC motor very smooth and soft whiles the starting. The hardware implementation is also verified

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