Design of Water Pumping System Using Solar Powered Brushless DC Motor

D. Santhosh Kumar, A. Nirmala, T. Umamaheswari and S. Vinuppriya

Abstract--- The project produces a cost effective solution for low power consuming using Solar Based Photovoltaic (SPV) array supplied water pumping framework using Boost converter as an interconnected DC to DC converter to get more power from solar panel. The boost converter's controlled using Incremental Conductance, Maximum Power Point Tracking (INC-MPPT). This is used to smooth running of brushless direct current machine connected to centrifugal water pump connected through shaft. Smooth running i.e. which reduces starting machine drawing the high current is reduced in windings of the BLDC machine. The parameters of the Brushless direct current motor is controlled by using Fuzzy Logic Controller algorithm through gate driver circuit of the Boost converter. The project designed such that operate under variable conditions like irradiation, voltage, power. Here the model is produced new modification approach for the improved version of the system.The proposed control is done by using MATLAB/SIMULINK and also implemented in hardware.

Keywords--- MPPT Algorithm, BLDC Motor, Microcontroller, MATLAB/SIMULINK, Boost Converter, Fuzzy Logic Controller.

D. Santhosh Kumar, Assistant Professor, Electrical and Electronics Engineering, Vivekanandha College of Engineering for Women, Tiruchengode, Namakkal, India.

A. Nirmala, Final Year, Electrical and Electronics Engineering, Vivekanandha College of Engineering for Women, Tiruchengode, Namakkal, India.

T. Umamaheswari, Final Year, Electrical and Electronics Engineering, Vivekanandha College of Engineering for Women, Tiruchengode, Namakkal, India.

S. Vinuppriya, Final Year, Electrical and Electronics Engineering, Vivekanandha College of Engineering for Women, Tiruchengode, Namakkal, India.

I. INTRODUCTION

Solar energy is remarkably exclusive form of renewable energy sources which has procurement increasing attention in modernistic year. The power generation from solar source is always clean; free from pollution furthermore a bend in nature due to that solar source is mostly used any place, where it gives maximum benefits from source. In recent year, the price of solar PV panel is going downwards which increase attention to use solar PV application in modernistic year. Renewable energy sources based application used in industries and hometown application. Among all other application based solar PV system, water pumping is most effective, crucial and cost effective application for power generation by Solar PV array. For water pumping system generally induction motor, dc motor are used in rural as well as grid connected area for induction motor. For pumping load, simple, low cost and efficient motor is generally used. Basically, for pumping section, induction motor is generally preferred it is easily available in market furthermore gives good performances for any load condition but when induction motor is preferred for solar PV based application, it suffers from overheating phenomenon of motor, if voltage of motor is going to low, due to that it require a complicated control. Under low voltage condition, efficient, reliable and cost-effective motor has to be used. So, The BLDC motor is used for such application. The brushless DC motor is ideal choice for application that requires high reliability, high efficiency and power to volume ratio. Generally, a BLDC motor is well thought-out to be a high concert motor that is proficient of providing enormous amounts of torque more than a vast speed range. For Solar PV based application, BLDC motor is undoubtedly compete with any other motor for pumping application as it gives superior performance of motor along with soft starting. BLDC motor is advancement of most of the DC motor and they have almost same torque and speed usual curve uniqueness. The key variation between two is the use of brushes. 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 best performance under rapidly changing atmospheric condition, however it shows poor performance at low irradiance level using the DC–DC converters. This paper elaborate idea for proper use of Solar PV based application and soft starting of BLDC motor. For maximum benefits from solar PV array, boost converter is Used and switch of boost converter is operated through incremental conductance MPPT algorithm. The following proposed system gives benefits of solar PV based application driven by BLDC motor for water pump. There are various ways to control speed of BLDC motor like hysteresis control and other control scheme are used. Here Fuzzy Logic Controller is used to control the speed of the BLDC Motor. But following configuration is simple, low cost, noise free and having least component of the system; make configuration is suitable for water pumping system

II. PROPOSED SYSTEM

The light energy from the Sun is absorbed by Solar PV panel which converts light energy to the electrical energy through Photovoltaic effect. The maximum solar irradiance is achieved by using MPPT algorithm. There are several types of MPPT algorithm is used. In our project, we are using Incremental-Conductance MPPT algorithm which uses tracking mechanism to get the maximum output from the solar panel.The output from the panel is stored in 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.

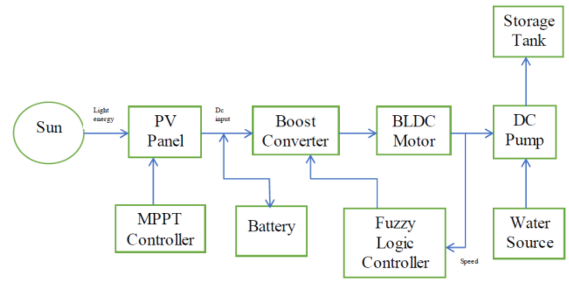

Figure 1: Block Diagram of Proposed System

III. DESIGN OF THE PROPOSED SYSTEM

A. *Design of Solar Panel*

Mathematical Model of Solar PV Cell

Let us consider,

V is the output voltage of Solar Cell

I is the output current of Solar Cell

T_{op} is Solar PV Cell operating temperature

T_{ref} is Solar PV Cell reference temperature

I_{Ph} Light Generated Photo-Current

I_D is the Diode Current of Solar PV Cell

A is an Ideality Factor =1.3 for polycrystalline silicon solar cell

k is Boltzman constant=1.3805x10-23J/K

q is Electron charge=1.6x10-19 oC

K_i is the Temperature co-efficient of short-circuit current =0.00017A/oC

I_{rs} is the cell reverse saturation current(A)

I_{rr} is Operating solar irradiance = 1000w/m2

I_{sc} is Solar Cell short-circuit current

V_{oc} is Solar Cell open-circuit voltage

N_s is number of cell connected in series

N_p is number of cell connected in parallel

R_s is series resistance of PV cell

R_{sh} is shunt resistance of PV cell

To understand the Physical behaviour of a solar cell, it is useful to create a model which is electrically equivalent, and is based on discrete electrical components whose behaviour is well known. Figure 1. Equivalent circuit of solar PV Cell A Solar PV Cell circuit includes current source Iph which represents the cell photocurrent.I_D is

Diode current, Ish is the shunt current. R_{sh} and R_s are the shunt and series resistance of the cell respectively

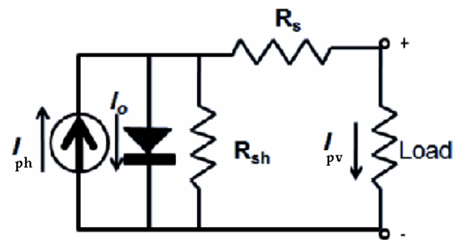

Figure 2: Equivalent Circuit of Solar PV Cell Solar Cell Photo Current

The Solar Cell Photo-current(I_{ph}) is depends linearly on solar irradiation(I_{rr}), Short-circuit current(I_{sc}) and also influenced by the temperatures according to following equation.

$$I_{ph}=[I_{sc}+K_i(T_{op}-T_{ref})]*I_{rr}/1000 \ldots\ldots\ldots\ldots\ldots(1)$$

Solar Cell Reverses Saturation Current

The Solar Cell Reverse Saturation current(I_{rs}) is depends on Short-circuit current of solar cell, Electron charge, Solar cell operating temperature. It is given by follows

$$I_{rs} = I_{sc}/[\exp((q*V_{OC})/(N_s*A*k*T_{op})) - 1] \ldots\ldots\ldots(2)$$

Diode current of solar cell Diode current of Solar Cell(I_D) is depends on Reverse saturation of solar cell, Electron charge, Solar cell operating temperature, Boltzman constant, Solar cell Ideality factor etc. It is given by as follows.

$$I_D= I_{rs}* [(\exp)] \wedge((q*(V+I*R_s)/(N_s*A*K*T_{op}))-1) \ldots..(3)$$

Shunt Current of Solar Cell

Shunt current of Solar PV cell is varies with Series resistance, shunt resistance, current and voltage across the circuit. It is given as follows.

$$I_{sh}= V+ (I*R_s)/R_p \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Output Current of Solar Cell

The Output current of Solar PV cell is given by as follows.

$$I = I_{ph}-I_D-I_{sh} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

B. Incremental Conductance MPPT Algorithm

This algorithm, shown below, compares the incremental conductance to the instantaneous conductance in a PV system. Depending on the result, it increases or decreases the voltage until the maximum power point (MPP) is reached. Unlike with the P&O algorithm, the voltage remains constant once MPP is reached.

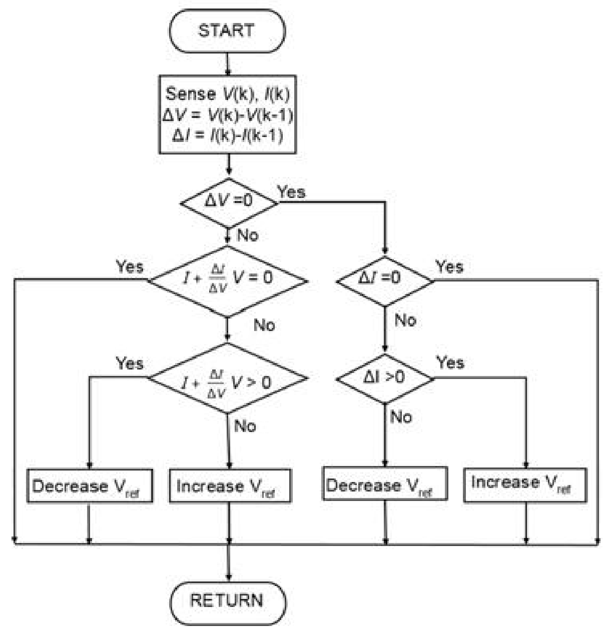

Figure 3: Flow Chart of Incremental Conductance MPPT

C. Brushless DC Motor (BLDC Motor)

Brushless DC Motors (BLDC motors) are synchronous motors that are powered by a DC electric source via an integrated switching power supply, which produces an AC electric signal to drive the motor & semiconductor devices such as MOSFET control the inverter output amplitude and waveform and frequency (i.e. rotor speed). The motor part of a brushless motor is generally a permanent magnet synchronous motor, but can also be a switched reluctance motor, or an induction motor. These motors cannot operate without its electronic controller & therefore, a brushless DC Motor is a combined machine system that joins into a single unit an ac motor, solid state semiconductor switching devices and a rotor position sensor. The solid-state semiconductor switching devices employ transistors for low-power driving arrangements and thyristors for high-power systems. This paper deals with the simulation model of a BLDC Motor and results are examined for the speed & torque control of these machines, the comparison has been done by varying the GATE signal magnitude & nature through different switching devices such as MOSFET & JFET.

Working of a BLDC Motor

Switching Devices-In any power conversion process small power loss and high efficiency are important because of two reasons that is the cost of the wasted energy and the difficulty in removing the heat generated due to the dissipated energy.

Other important considerations are reduction in size, weight and cost.

Operation: The underlying principles for the working of a BLDC Motor are same as for a brushed DC Motor i.e. Internal Shaft Position feedback. In case of a Brushed DC Motor, feedback is implemented using a mechanical commutator and brushes whereas it is achieved in a BLDC Motor via multiple feedback sensors. The most commonly used sensors are Hall Sensors and Encoders.

Note: Hall Sensors work on the hall-effect principle that when a current carrying conductor is exposed to the magnetic field, charge carriers experience a force based on the voltage developed across the two sides of the conductor.

D. Design of Boost Converter

Generally, boost converter is used to operate system at higher voltage level. Proper design of converter helps for proper utilization of the system. As due to the only switch of boost converter had extremely excellent renovation efficiency. Boost converter helps to determine maximum power from solar PV array. Voltage of SPV array at maximum point is Vpv≡ 248.5,as source of input voltage, and Vdc is dc output voltage of boost converter, the input–output relationship of boost converter as shown in equation (1).

$$D=(Vdc/(Vdc+Vpv)) = (311/(311+248.5)) = 0.55 \quad ……(1)$$

Where Vdc is DC voltage of inverter and $I_{PV}$is calculated as according to equation (2).

$$I_{dc} = P_{mpp}/V_{dc} =1500/311 =4.98 \quad ……………………..(2)$$

As summation of the two current Idc and I_{PV} flow through circuit, inductor L is estimated as according to equation (3).

$$L =((D*V_{pv})/(fsw* \Delta I_L))$$
$$=((0.55*248.5)/(10000*11*0.4) = 3Mh \quad …………(3).$$

Where fsw is switching frequency of the boost converter and ΔI_L is a ripple content in the inductor.

E. Fuzzy Logic Controller for Speed Control of BLDC Motor

Fuzzy logic controllers have been widely used for industrial processes in the resent years due to their heuristic nature associated with simplicity and effectiveness for both linear and nonlinear systems. The control objective is to track maximum power, will lead consequently to maximize the dc motor speed and the water discharge rate of the coupled centrifugal pump. At the time when output power of the PV generator is maximum at a given condition the hydraulic power PP = KT ω is maximum. Consequently, the rotational speed ω is a maximum at the maximum power point. By making use of the relation between the PV output power and the rotational speed, a fuzzy logic controller has been proposed to adjust the buck converter ratio which adapts online the PVG output power to maximize the rotational speed.

Fuzzy Controller

A fuzzy control system is a control system based on fuzzy logic, a mathematical system that analyzes analog input values in terms of logical variables that take on continuous between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively).

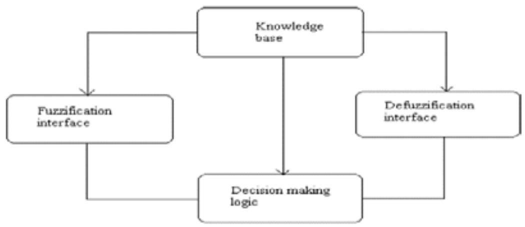

Figure 4: Fuzzy Logic Controller Block Diagram

Fuzzy logic is widely used in machine control. The term "fuzzy" refers to the fact that the logic involved can deal with concepts that cannot be expressed as "true" or "false" but rather as "partially true". Although alternative approaches such as genetic algorithms and neural networks can perform just as well as fuzzy logic in many cases, fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller. This makes it easier to mechanize tasks that are already successfully performed by humans.

Fuzzy Sets

The input variables in a fuzzy control system are in general mapped by sets of membership functions similar to this, known as "fuzzy sets". The process of converting a crisp input value to a fuzzy value is called "fuzzification". A control system may also have various types of switch, or "ON-OFF", inputs along with its analog inputs, and such switch inputs of course will always have a truth value equal to either 1 or 0, but the scheme can deal with them as simplified fuzzy functions that happen to be either one value or another. Given "mappings" of input variables into membership functions and truth values, the microcontroller then makes decisions for what action to take, based on a set of "rules", each of the form:

IF brake temperature IS warm AND speed IS not very fast

THEN brake pressure IS slightly decreased.

In this example, the two input variables are "brake temperature" and "speed" that have values defined as fuzzy sets. This rule by itself is very puzzling since it looks like it could be used without bothering with fuzzy logic, but remember that the decision is based on a set of rules:

1. All the rules that apply are invoked, using the membership functions and truth values obtained from the inputs, to determine the result of the rule.
2. This result in turn will be mapped into a membership function and truth value controlling the output variable.
3. These results are combined to give a specific ("crisp") answer, the actual brake pressure, a procedure known as "defuzzification".

This combination of fuzzy operations and rule-based "inference" describes a "fuzzy expert system". The two FLC input variables are the error E and change of error CE at sampled times k defined by:

$$E(k) = \frac{P_{ph}(k) - P_{ph}(k-1)}{V_{ph}(k) - V_{ph}(k-1)} \quad \ldots\ldots\ldots\ldots\ldots.. \qquad (1)$$

CE(K)=E(K)-E(K-1) ……………………….......... (2)

The input E(k) shows if the load operation point at the instant k is located on the left or on the right of the maximum power point on the PV characteristic, while the input CE(k) expresses the moving direction of this point. The fuzzy inference is carried out by using Mamdani’s method, (Table 6.1), and the defuzzification uses the centre of gravity to compute the output of this FLC which is the duty cycle. The control rules are indicated in Table 5.1 with E and CE as inputs.

Table 1: Rules of fuzzy

Change in Error(CE)							
Error(E)	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PB	PM	PS	Z
NM	PB	PB	PB	PM	PS	Z	NS
NS	PB	PB	PM	PS	Z	NS	NM
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NB	NB	NB
PB	Z	NS	NM	NB	NB	NB	NB

A rule base (a set of If-Then rules), which contains a fuzzy logic quantification of the expert's linguistic description of how to achieve control action. Once the rules have been established, a fuzzy logic system can be viewed as a mapping from inputs to outputs. Rules may be provided by experts or can be extracted from numerical data. The performance of the controller can be improved by adjusting the membership function and rules. Different types of inferential procedures to help us understand things or to make decisions, there are many different fuzzy logic inferential procedures. The fuzzy inference operation is implemented by using the 49 rules. Some of these rules are

1. If error (E) is NB and change in error (CE) is NB then output is PB.
2. If error (E) is NB and change in error (CE) is NM then output is PB
3. If error (E) is NB and change in error (CE) is NS then output is PB
4. If error (E) is NB and change in error (CE) is NS then output is PM

Likewise, 49 rules are defined. The same set of rules could be presented in a sliding mode format, a more compact representation given in Table 5.1.

The AND, OR, and NOT operators of boolean logic exist in fuzzy logic, usually defined as the minimum, maximum, and complement; when they are defined this way, they are called the Zade operators. So for the fuzzy variables x and y:

NOT x = (1 - truth(x))

x AND y = minimum(truth(x), truth(y))

x OR y = maximum(truth(x), truth(y))

There are also other operators, more linguistic in nature, called hedges that can be applied. These are generally adverbs such as "very", or "somewhat", which modify the meaning of a set using a mathematical formula.

F. PIC16F877A Microcontroller

The 16F877A has 368B of RAM and 14kB of program memory. It has four ports namely as porta, portb, portc and portd. Each port has eight pins. As shown in figure the pinRA belongs to porta and same as for RB, RC and RD.

These are the power supply pins. VSS is ground and VDD is the positive supply pin. The range of supply is 2V to 5.5V. The maximum supply is 5V and minimum is 3V. (above 5V the IC can damage so be care full).Since microcontroller has some kind of timing, so we connect an external clock with these pins. In normal mode this pin connects to the positive (5V) supply. Specially, this pin is used to erase the memory location. These are the bidirectional ports. That can be configured as an input and output. The number following RA0, RA1 is the bit number. These is another clock, which operate an internal timer. There are two ways for programming, the easy and DIY way. The easy way is to buy a PIC burner, which will connect to your PC and you can program it by using software. The DIY is to build your own burner and use free software to program it. In these tutorial, first we will learn the programming of PIC and will see the simulation by using Proteus. Then we will proceed to the hardware**.**

G. Water Pump

For pumping load, centrifugal pump is used as it is simple, easy to understand and used for most of the application purpose. Specialty of centrifugal Pump provides high speed performances with having least maintenance, due to that for pumping load, centrifugal pump is chosen. As it gives, the output of motor is smooth dynamic, constant along with steady output.

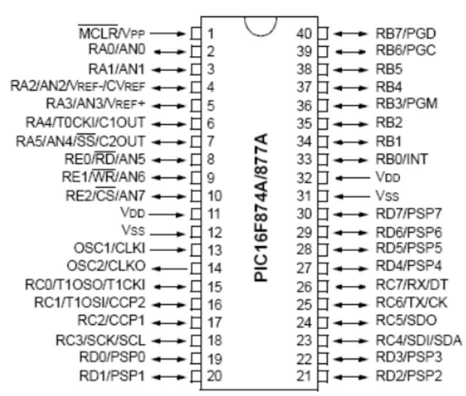

Figure 5: Pin Diagram of PIC16877A

IV. SIMULATION

Over all Simulation Model

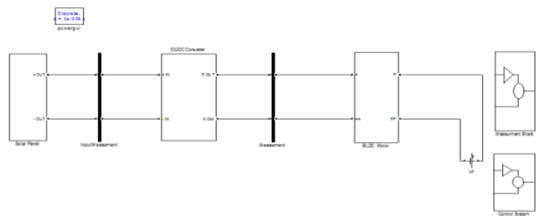

Figure 6: Simulink Diagram for Proposed System

The figure 6 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.

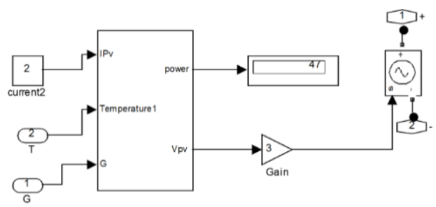

Figure 7: Simulink of Solar PV Panel

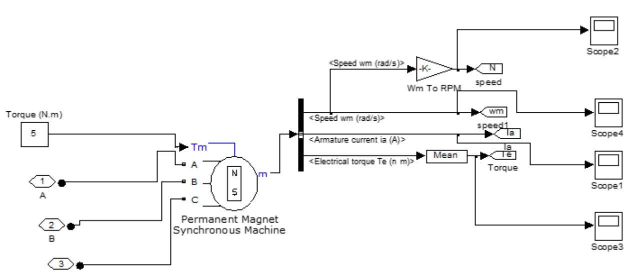

Figure 8: Simulink of BLDC Motor

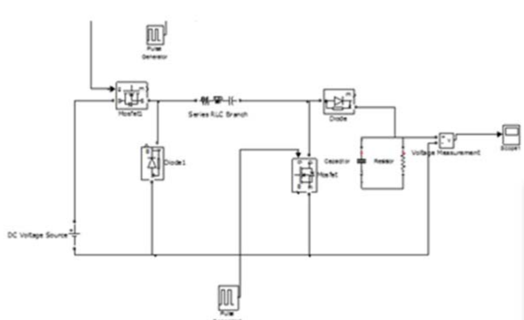

Figure 9: Simulink of DC-DC Boost Converter

V. SIMULATION RESULT

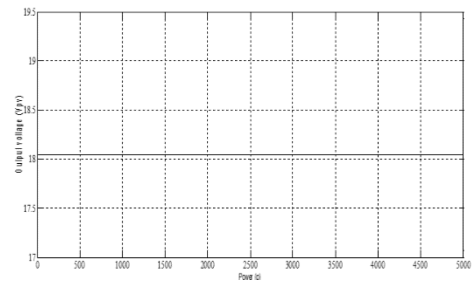

Figure 10: Simulation Output of Solar Panel

Table 2: Panel Specifications

Type ofPanel	Number of Cells	Output
12V	36	18V

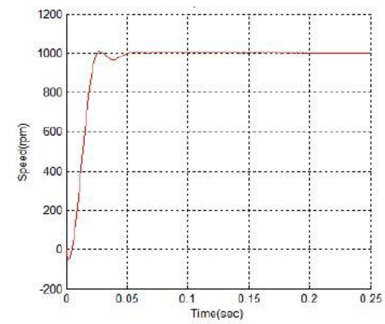

Figure 11: Speed Response of BLDC Motor

VI. HARDWARE RESULT

Hardware Model

This is hardware module of Design of Water Pumping System using Solar Powered Brushless DC Motor.

Figure 12: Hardware Module

VII. CONCLUSION

The DC-DC boost converter gives reliable trapping as well as efficient from SPV panel by using suitable incremental conductance MPPT algorithm is properly tracked. The MPPT tracking gives result along with little bit drop which fed to inverter gives exact result to inverter then inverter output fed to BLDC Motor. The proposed system gives smooth and soft starting of BLDC motor. The proposed system having centrifugal pump load gives smooth speed and power performances of BLDC Motor. By using fuzzy logic controller the rise time decreases when compared with the PID controller and it attains the settling time in a very short duration. The hardware Implementation is verified successfully and the simulation was done by using MATLAB\SIMULINK.

REFERENCES

[1] A.Trejos, C.A. Ramos-Paja and S. Serna, "Compensation of DC-Link Voltage Oscillations in Grid-Connected PV System Based on High Order DC/DC Converters", IEEE International Symposium on Alternative Energies and Energy Quality (SIFAE), Pp.1-6, 2012.

[2] A.R. Reisi, M.H. Moradi and S. Jamasb, "Classification and comparison of maximum power point tracking techniques for photovoltaic system: A review", Renewable and Sustainable Energy Reviews, Vol.19, Pp.433-443, 2013.

[3] A. Shahin, A. Payman, J.P. Martin, S. Pierfederici and F. Meibody Tabar, "Approximate Novel Loss Formulae Estimation for Optimization of Power Controller of DC/DC Converter", 36th Annual Conference on IEEE Industrial Electronics Society, Pp.373-378, 2010.

[4] B. Singh and V.Bist, "A Single Sensor Based PFC Zeta Converter Fed BLDC Motor Drive for Fan Applications", Fifth IEEE Power India Conference, Pp.1-6, 2012.

[5] D.D. Lu and Q.N. Nguyen, "A photovoltaic panel emulator using a buck-boost DC/DC converter and a low cost micro-controller", Solar Energy, Vol.86, No.5, Pp.1477-1484, 2012.

[6] M. Uno and A. Kukita, "Single-Switch Voltage Equalizer Using Multi Stacked Buck-Boost Converters for Partially-Shaded Photovoltaic Modules", IEEE Transactions on Power Electronics, 2014.

[7] R. Arulmurugan and N. Suthanthiravanitha, "Model and Design of A Fuzzy-Based Hopfield NN Tracking Controller for Standalone PV Applications", Electr. Power Syst. Res., 2014.

[8] R.F. Coelho, W.M. dos Santos and D.C. Martins, "Influence of Power Converters on PV Maximum Power Point Tracking Efficiency", 10th IEEE/IAS International Conference on Industry Applications (INDUSCON), Pp.1-8, 2012.

[9] S. Satapathy, K.M.Dash and B.C. Babu, "Variable Step Size MPPT Algorithm for Photo Voltaic Array Using Zeta Converter–A Comparative Analysis", Students Conference on Motor erring and Systems (SCES), Pp.1-6, 2013.

[10] Z. Xuesong, S. Daichun, M. Youjie and C. Deshu, "The simulation and design for MPPT of PV system based on incremental conductance method", WASE international conference on information engineering, Pp. 314-317, 2010.