The International Journal Of Engineering And Science (IJES)
|| Volume || 3 || Issue || 3 || Pages || 41-46 || 2014 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Design of solar PV water pumping system using BLDC drive using sensorless method

B.Kavitha, Assistant Professor
Department of Electrical and Electronics Engineering, Sri Krishna College Of Technology.
S.Karthikeyan, UG Student
Department of Electrical and Electronics Engineering, Sri Krishna College Of Technology.
B.Iswarya, UG Student
Department of Electrical and Electronics Engineering, Sri Krishna College Of Technology.

ABSTRACT

This paper deals with the development of low cost PV pumping system using a PMBLDC (permanent magnet brushless dc motor) drive coupled to a pump load. The controller has been designed and developed without current and position sensors therefore reducing to a large extent the overall cost of the drive system. DC-DC converters are used to maintain the required output in case of low solar insolation during the winter and also in case of reduced solar output due to increase in cell temperature. A simple filter circuit is introduced before inverter to reduce ripples which increases the efficiency of the system. The inverter drives PMBLDC to pump the water to the tank. The input from the water level sensors attached to the tank indicates the water level to the controller and thereby automates the pumping system.

Date of Submission: 14 March 2014 Date of Publication: 30 March 2014

I. INTRODUCTION

The global energy crisis that is being experienced today has lead to the need for more energy efficient systems. Solar energy is an ideal form of energy with the features of being environment friendly and substitute of dwindling energy resources. It is clean, non-exhaustible and available all over the world with varying intensity. Silicon - the main material used in manufacturing of solar cells - is the second-most plentiful element available on the earth. Thus, there is no problem of resource availability.

The main advantages of the ECM (electronically commutated motor) over the brushed motors are less maintenance requirements, reduced environmental effects and less electromagnetic radiation I-2]. Within the last three decades, several improved magnetic materials are developed for high-performance PM motors. The features of high operating efficiency, brushless construction, maintenance-free operation and increasing awareness about energy conservation have given a scope to the demand of the PMBLDC motor in water pumping application operated by PV-array, particularly, in remote villages where electric supply is not available.

Specially designed low-inertia motors fed by the MOSFET-based current-controlled voltage-source inverter (CC-VSI), provide desirable features such as high power-to weight ratio, high torque-to-current ratio, fast response and above all high operating efficiency.

Automation plays a vital role when these systems are installed in rural unattended zones and areas where scarcity of water prevails in summer. Water resource available can be utilized effectively without wastage and this improves efficiency of the system. Simple probe sensors are used to determine the water level which is also of low cost.

II. ANALYSIS OF THE SYSTEM

The figure (1) shows the block diagram of the proposed water pumping system.

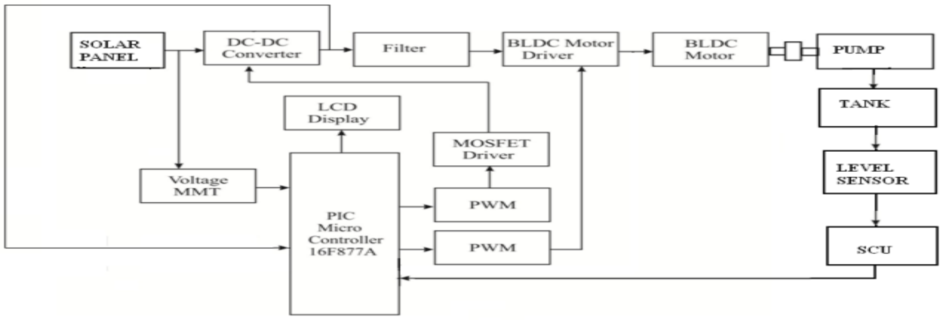

Figure.1.Block diagram of the overall system

2.1 PV-array

The solar cells are connected in series and parallel combinations in order to get the desired level of voltage and current. The equivalent circuit of PV array is shown in Figure.2.

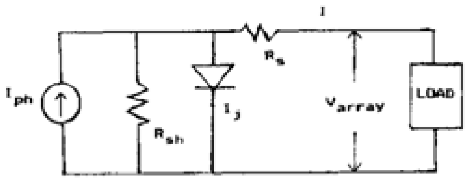

Figure.2. Equivalent circuit of PV array

The *I-V* equations of a solar cell is given by

$$V = -IR_s + (1/D)\ln(1 + (I_{ph} - I)/I_o) \qquad (1)$$

where I_{ph} is the photon current proportional to the insolation, R_s the series resistance of the cell, I_o the cell reverse saturation current, D the *q/AK T*, *q* the electric charge of an electron, K the Boltzmann constant, T the absolute temperature, and A the compilation factor [1].

2.2 DC-DC CONVERTER

The DC/DC converter used in this work is a boost converter, which is chosen based on the ratings of the PV array and the inverter voltage. Boost converter configuration (shown in figure.3) steps up the PV output voltage to the voltage required by the inverter. Irrespective of the variations in the PV output voltage, the boost converter output voltage is kept constant by a control circuit which incorporates a PIC controller. A switching frequency of 1 kHz is chosen for the design and a MOSFET of appropriate rating IRF250 is selected as the switch.

$$L \geq V_i * D * T / (2 * \Delta I) \qquad (2)$$

$$C = D * Io * TS / \Delta Vo \qquad (3)$$

Here Ts and D are the switching time period and duty cycle of the switch S used in the converter. V_i is the output voltage of the PV array and Vo is the inverter input voltage. A value of 12MH of inductor and 10 MFD capacitor was designed for this work based on (2) and (3).

2.2.1 PWM BASED MOSFET DRIVER CIRCUIT

PWM signals are given from PIC microcontroller .MOSFET drive circuit consists of two transistors BC547 and BC557 which are *npn* and *pnp* transistor respectively. When BC547 is given a low input it is in off state and so BC557 base input is high making it to be in off state .during this condition the MOSFET receives low input and remains in off state. When the input to the BC 547 is high it moves to on state and the 12v supply is grounded. This gives a low input to BC 557 which turns it on .during this period the MOSFET receives a high signal and switches to on state. The boost converter circuit along with MOSFET gate drive is as in figure (3)

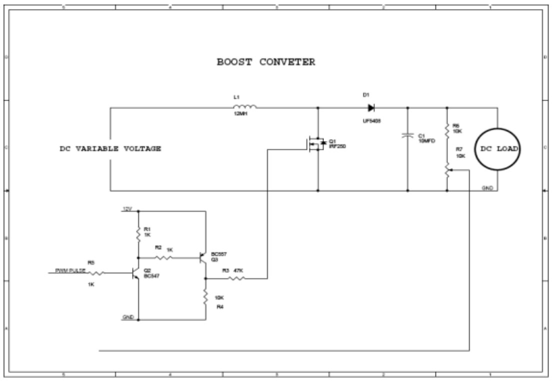

Figure.3.DC-DC boost converter circuit with MOSFET gate driver

2.3 INVERTER AND BLDC

In a conventional DC motor, current polarity is altered by commutator and brushes. In the brushless DC motor, polarity reversal is performed by power transistor switching in synchronization with the rotor position. To accomplish this, the input of PMBLDC motor is connected to inverter. Inverter is designed in such a way that, its output frequency is a function of instantaneous rotor speed and its phase control will correspond to actual rotor position.

Typically a BLDC motor is driven by 3 phase inverter with six step commutation as shown in Figure.5 [8]. Here the conducting interval of each phase is 120° electrical angle. In order to produce maximum torque, inverter should be commutated every 60°, so that current is in phase with the back EMF. Commutation timing is determined by back EMF method and the sequence of commutation is retained in the proper order so that the inverter performs the function of brush and commutator in the conventional DC motor to generate a rotational stator flux. At one time instant, only 2 out of 3 phases are conducting current, and one winding is floating. The circuit connection of inverter and BLDC is as in Figure.(4)

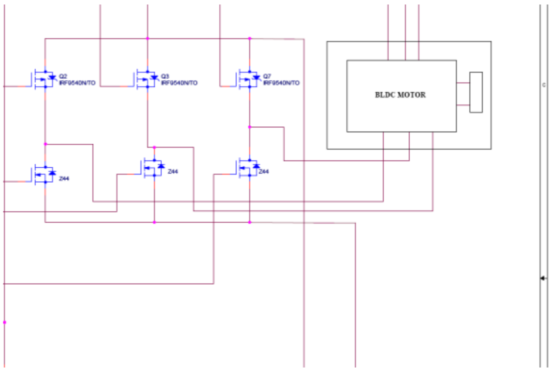

Figure.4.Inverter and BLDC circuit

2.4 PUMP

Two types of pumps are commonly used for water pumping applications: positive displacement and centrifugal. Positive displacement types are used in low-volume pumps and cost-effective. Centrifugal pumps have relatively high efficiency and are capable of pumping a high volume of water. It is found that PV energy utilized by centrifugal pump is much higher than volumetric pump [6].

The pump used is of centrifugal type which can be described by an aerodynamic load and is characterized by the following equation:

$$T = A.\ \omega 2 \qquad (4)$$

where A is the pump constant

Pump output or hydraulic horse power (HP) is the liquid horsepower delivered by the pump and is calculated by (4)

$$\text{Hydraulic horse power} = (Q*TDH*\rho*g)/1000 \qquad (5)$$

In (5) Q is the flow rate in m^3/s, TDH is the total dynamic head in m, ρ is the density of water in kg/m^3, and g is the acceleration in m/s^2.

2.5 AUTOMATION

Probe sensors are used to indicate the water level. When the lowest level is reached the PWM signals are given to the BLDC driver which starts the BLDC motor thereby initiating the pumping process. When the medium level is reached the duty cycle is reduced to run the drive at a relatively low speed. When the highest level is reached i.e. when the tank is full the controller provides the brake signal to the BLDC motor thereby stopping the pumping operation.

2.6 PIC CONTROLLER

PIC microcontroller is the RISC based microcontroller fabricated in CMOS (complementary metal oxide semiconductor) that uses separate bus for instruction and data allowing simultaneous access of program and data memory. The main advantage of CMOS and RISC combination is low power consumption resulting in a very small chip size with a small pin count. The main advantage of CMOS is that it has immunity to noise than other fabrication techniques.

PIC microcontroller performs the following three prime functions:

- It receives solar panel output voltage and boost converter output voltage as input and based on these inputs it generates PWM signals to MOSFET (in boost converter).
- It generates PWM signals for the MOSFET switches in the inverter.
- It receives input from the water level sensor based on which it automates the drive operation.

III. BACK EMF METHOD

Consider the interval when phases A and C are conducting and phase B is open as indicated by the shaded region. Phase A winding is connected to the positive terminal of the dc supply, phase C to the negative terminal of the dc supply and phase B is open. Therefore, $i_a = -ic$ and $i_b = 0$. It can be seen from Figure. 5 (shaded region) that the back EMF in phases A and C are equal and opposite. The difference of line voltages waveform is, thus, an inverted representation of the back EMF waveform. It is again evident from Figure. 4 that during this interval (shaded portion) the back EMF e_{bn} transits from one polarity to another crossing zero. Therefore, the operation $V_{ab} - V_{bc}$ (V_{abbc}) enables detection of the zero crossing of the phase B EMF. Therefore, the zero-crossing instants of the back EMF waveforms may be estimated indirectly from measurements of only the three terminal voltages of the motor. From the ZCD of all the back EMF in a similar manner we obtain the switching sequence. Commutation instances are determined 30° from ZCD [2].

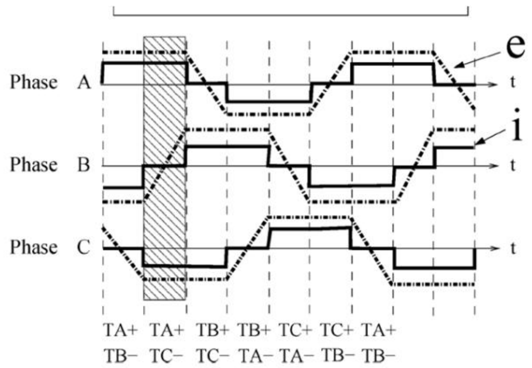

Figure.5. Graph depicting line voltage and trapezoidal back-EMF of BLDC.

IV. DESIGN DETAILS

4.1. Water Requirement

The first step in designing a solar-powered water pump system is to determine the capacity of the tank.
Amount of water to be pumped = 50 m^3/day.

4.2 Centrifugal Pump selection

Pump output or hydraulic horse power (HP) is the liquid horsepower delivered by the pump and is calculated by (5)

TABLE I : DATA USED FOR PUMP SELECTION

Sl.no	**Parameters**	**Values**
1	Q	5.78 * 10-4
2	TDH	40
3	ρ	1000
4	g	9.8
5	Hydraulic power	0.23 hp = 169W

So the rating of the pump is selected as 0.25HP

4.3 Rating of BLDC motor and inverter

Pump shaft power (P_s) is the actual horse power delivered to the pump shaft and can be calculated as follows:

Pump shaft power (P_s) = (hydraulic power) / pump efficiency…..(6)

Considering pump efficiency as 69%, the pump output power is 245 W from (6). This much power has to be supplied by the BLDC motor. So the rating of the motor selected for this application is 250 W. Considering the efficiency of the motor as 89%, the inverter selected has a power rating of 300W.

4.4 PV panel sizing

PV panel sizing depends on the total system load, which means determination of total wattage of the load. Considering the efficiency of the inverter as 90% and boost converter as 90%, the PV panel should supply,

PV Array size = 300/ (0.9*0.9) = 370 W

Considering the PV panel operating factor of 0.75 and mismatch factor of 0.85,

PV Array size =370/ (0.75*0.85) = 590 W.

Four 200Wp, 24V solar panels need to be used for this application.

TABLE II: SPECIFICATIONS OF 200WP, PV PANEL (STC)

Sl. No.	**Parameters**	**Values**
1	Short circuit current	7.65A
2	Open circuit Voltage	36.5V
3	Maximum Power	200W
4	Maximum Power Voltage	28.8V
5	Maximum Power Current	6.98A

V. DEMO DETAILS:

BLDC motor

Rated voltage=12V, Rated current =2A,Power rating =24W.

BOOST CONVERTER

Switching frequency=1Khz, L=12MH, C=10MFD.

MOSFET rating=200V, 30A, r_{ds} = 0.085Ω.

INVERTER

MOSFET rating=100V, 23A, r_{ds} = 0.117Ω

Circuit diagram of the demo is depicted in the figure (6)

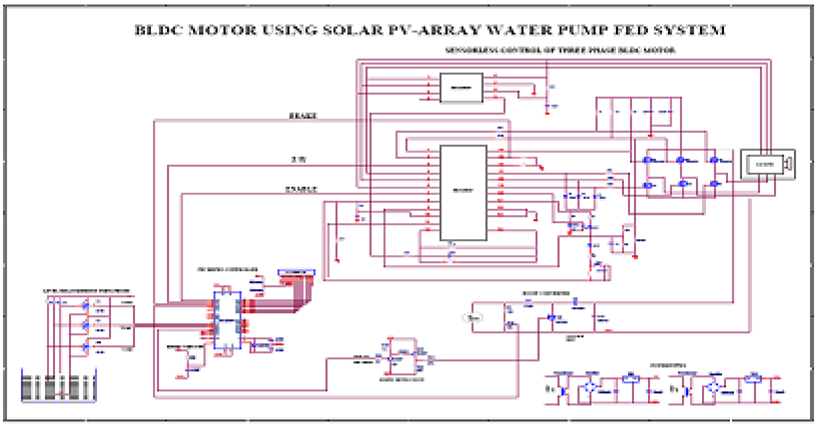

Figure.6.circuit diagram of the project demostration

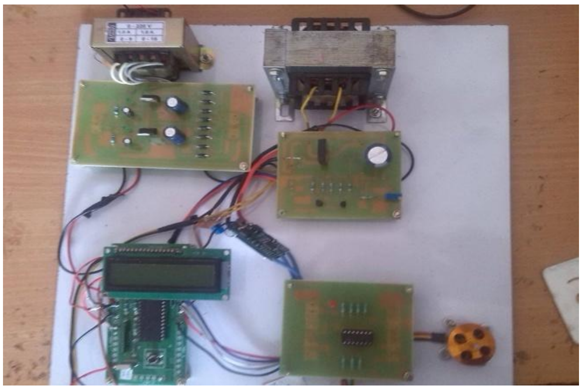

Figure.7.photo of project demonstration hardware

VI. CONCLUSION

The proposed system has been found working effectively. The elimination of sensors has reduced the cost to great extent. The position detection using back EMF method is easier to implement and works efficiently. Due to the presence of DC-DC converter the system is found suitable to work efficiently even in conditions of low power due to poor solar insolation. The automation of the water pumping system has improved the system performance and also enhanced proper utilization of the water. Owing to its improved performance, less maintenance requirement, low power requirement, efficient working at all conditions and effective use of water resource this system is ideal for water pumping especially in isolated areas.

REFERENCES

[1.] Bhim Singh*, C.L. PuttaSwamy, B.P. Singh, Analysis and development of a low-cost permanent magnet brushless DC motor drive for array fed water pumping system , Elsevier Science B.V.

[2.] P. Damodharan and Krishna Vasudevan, *Member, IEEE,* Sensorless Brushless DC Motor Drive Based on the Zero-Crossing Detection of Back Electromotive Force (EMF) From the Line Voltage Difference, IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 25, NO. 3, SEPTEMBER 2010.

[3.] Jianwen Shao, *Member, IEEE,*, Dennis Nolan, Maxime Teissier, and David Swanson , A Novel Microcontroller-Based Sensorless Brushless DC (BLDC) Motor Drive for Automotive Fuel Pumps, IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 39, NO. 6, NOVEMBER/DECEMBER 2003.

[4.] Mohanlal Kolhe , J. C. Joshi, and D. P. Kothari, *Senior Member, IEEE,* Performance Analysis of a Directly Coupled Photovoltaic Water-Pumping System, IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 19, NO. 3, SEPTEMBER 2004.

[5.] **T. D. Short, R. Oldach,** Solar Powered Water Pumps:The Past, the Present—and the Future?, Transactions of the ASME**,**Vol. 125, FEBRUARY 2003.

[6.] Sreedevi S Nair , Mini Rajeev , Design and Simulation of PV Powered PMBLDC Motor for Water Pumping, Proceedings *of Third Biennial National Conference, NCNTE- 2012, Feb 24-25* .