Design and Implementation of Brushless DC Motor based Solar Water Pumping System for Agriculture using Arduino UNO

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***Abstract*—This technical paper focuses about the design and implementation of brushless dc (BLDC) motor based solar water pumping system for agriculture. The abundant solar energy has been effectively tracked and utilized for powering the water in urban area agriculture where the electricity is not available or it would be a costly one. This paper presents an entire design of the solar powered water pumping system based on the requirement of water and other factors for an acre land. For extracting the maximum power generated by photovoltaic array (PV) array, Cuk converter is used as maximum power point tracker with basic perturb and observe (P&O) algorithm. The dc link voltage obtained from the Cuk converter is fed to three phase inverter to provide proper supply to BLDC motor. The BLDC motor pumping system is selected among other motor pumping systems, because it has won features like small in size, noiseless operation, long operating life, less maintenance and high output torque. The performance of the system has been validated using Arduino UNO. The given design can be used for any size of land by simply recalculating the parameters.**

Keyword- brushless dc motor, photovoltaic array, perturb and observe.

I. INTRODUCTION

Nowadays, agriculture has been drastically diminished due to the frequent power cut and reduction in underground water levels. To consider the above problem, the solar water pumping is the best choice to improve the agriculture outcome. Fig. 1 shows the block diagram of the BLDC motor based solar water pumping system. The solar energy is the widely available energy due to its abundant availability with free of cost, so it would be the most attractive solution in many fields. The main issue is the high initial cost, but it has long life span of about twenty five years hence it gives a good payback period [1]. The solar water pumping system initially uses a DC motor, because it doesn't needs an intermediate voltage conversion, but it needs a regular maintenance due to the presence of commutator and brushes [2]. The induction motor is also a best suit for solar water pumping system due to its reliability and ruggedness, however the control of an induction motor is complex by introducing the field oriented control and it also needs an intermediate voltage conversion [3]-[4]. To consider the above issues the BLDC motor is preferred among other commercially available motors, because it has certain features such as small in size, noiseless operation, long operating life, less maintenance and high output torque [5]. Cuk converter is used for the purpose of maximum power point tracking and provides necessary dc link voltage. Cuk converter has the ability to provide non-inverted buck/boost voltage at the output and its current is continuous, which eliminates the need for external filter. Hence it provides ripple free voltage at the input of BLDC motor, thus avoids an oscillation in motor torque [6]-[7]. The P&O MPPT algorithm has been used to track a maximum power, becasuse of its simple algorithm and easy implementation[8]-[9].

This paper is organized as follows; Section II deals about the designing of parameters based on the water requirement of an acre agriculture land; Section III deals about the simulation and its results with the designed data from the section II, implementation and the validation of the results using Arduino UNO.

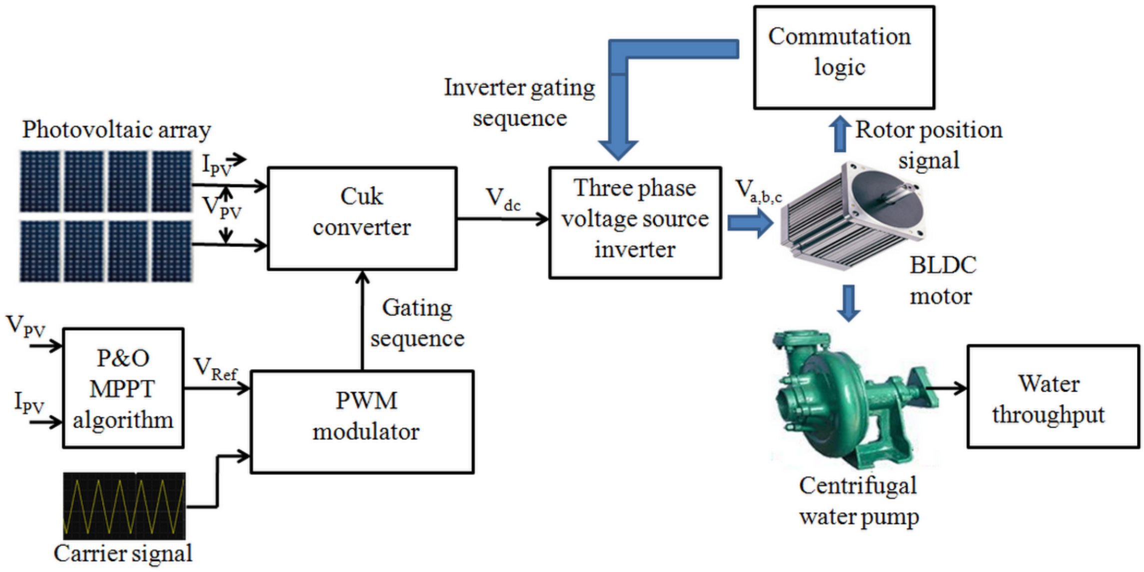

Fig. 1. Block diagram of solar water pumping system

II. Materials and Methods

A. *Designing of PV water pumping system*

The designing parameters of BLDC motor based solar water pumping system depends on the water requirement of the particular agriculture land. In this paper the parameters are chosen by considering the water requirement of an acre agriculture land and rice as corp, the water is required in depth of eight inches from the land surface [10].

Required water for agriculture land in liter = 27154 × (Area of land in acre) × (Water depth in inch) × 3.78 (1)
Required water for one acre agriculture land in liters = 27154 × 1 × 8 × 3.78
Required water for one acre agriculture land in liters = 821136.96 liters ≈ 821137 liters.

B. *Selection of centrifugal water pump*

The required water for rice corp in depth of eight inches from the land surface of an acre land is 821137 liters. The pump has been selected by considering the total water requirement, the discharge rate of the pump and the total system cost. The 2.5 HP oswal monoblock surface mounted pump is selected, it has been operated in the water head range of 12-15 metre with the water flow rate of 405-190 LPM, its cost about 10,000 INR. The selected pump is able to deliver the required water of an acre land.

C. *Selection of BLDC motor:*

To meet the torque requirement of the selected pump, the TETRA85TR 3.2 BLDC motor is selected. Its power rating is about 1.8 kW. The motor parameters are listed in appendix section.

D. *Selection of PV panel:*

The 2.5 kW PV array is designed, by consider the load and converter losses also to consider the power requirement of the PV water pumping system. The SOLKAR SPV module is selected for this application. Its technical details are listed in appendix section. An open circuit voltage and the short circuit current of SOLKAR SPV module is given as follows: Open circuit voltage of single PV panel (V_{oc}) = 21.24 V; Short circuit current of single panel (I_{scr}) = 2.55 A.

The available voltage and current of the single PV panel at full insolation is 80% of the open circuit voltage and short circuit current [11], so the available voltage and current of the single PV pannel is 16.992 V and 1.8 A.The PV water pumping system requires a maximum voltage and current of 310 V and 6.57 A, to effectively runs the BLDC motor.

$$P_{MPP} = V_{MPP} \times I_{MPP} \tag{2}$$

$$P_{MPP} = 2kW \tag{3}$$

The maximum voltage available across the PV array is (V_{MMP}) 270 V.

$$I_{MPP} = \frac{P_{MPP}}{V_{MPP}} \tag{4}$$

$$I_{MPP} = \frac{2000}{270} = 7.4A$$

The number of panels arranging in series (N_{ss}) = V_{MPP}/V_{mp} , where, V_{MPP}= Required maximum voltage from the PV array and V_{mp} = Maximum voltage obtained from the single panel.

N_{ss} = 270/16.992=16.

The number of panels arranging in parallel (N_{pp}) = I_{MPP}/I_{mp}

N_{pp} = 7.4/1.8=5.

where, I_{MPP}= Required maximum current from the PV array and I_{mp} = Maximum current obtained from the single panel.

E. Designing of Cuk converter parameters:

Fig. 2 shows the Cuk converter circuit, the required dc link voltage V_{dc}=300 V by considering the maximum operating voltage of the BLDC motor, the duty has been computed by follows [6],

$$D = \frac{V_{dc}}{V_{dc} + V_{PV}} \tag{5}$$

The switching frequency is selected for 20 kHz to keep the low inductor ripple current and also it reduces the inductor size. The inductor L_1 is calculated by follows, here I_{L1} is equal to the I_{MPP}.

$$L_1 = \frac{V_{pv}D}{f_{switch}\Delta I_{L1}} = \frac{270\times 0.52}{20000\times 7.4\times 0.06} = 15.81mH \tag{6}$$

where f_{switch} is the switching frequency and ΔI_{L1} is the inductor ripple current.

The inductor L_2 is calculated by follows, here first to calculate the inductor current $I_{L2,}$

$$I_{L2} = \frac{P_{PV}}{V_{dc}} = \frac{2kW}{300} = 6.6A \tag{7}$$

from the I_{L2} to take an inductor L_2 ripple current as 6%.

$$L_2 = \frac{V_{pv}D}{f_{switch}\Delta I_{L2}} = \frac{270\times 0.52}{20000\times 6.6\times 0.06} = 17.72mH \tag{8}$$

The intermediate energy transfer capacitor C_1 is calculated follows,

The V_{C1} is calculated as follows,

$$V_{C1} = \frac{V_{PV}}{1-D} = \frac{270}{1-0.52} = 562.5V \tag{9}$$

The 4% of capacitor ripple is selected.

$$C_1 = \frac{I_{PV}(1-D)}{f_{switch}\Delta V_{C1}} = \frac{7.4\times(1-0.52)}{20000\times 562.5\times 0.04} = 7.893\mu F \tag{10}$$

The DC link capacitor is calculated as follows,

$$C_2 = \frac{1-D}{\Delta V_o 8L_2 f_{switch}^2} = \frac{1-0.52}{0.1\times 8\times 17.72\times 10^{-3}\times 20000^2} = 846.50\mu F \tag{11}$$

Where ΔV_o is the ripple voltage.

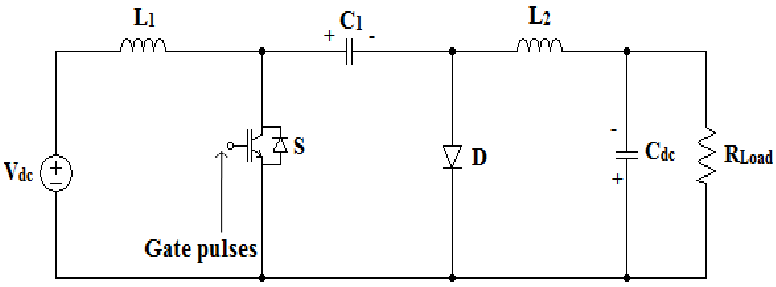

Fig. 2. Circuit diagram of cuk converter

III. Results

A. *Simulation results of PV water pumping system:*

The designed parameters in Section II and the motor parameters from an appendix section have been used for simulation. The simulation has been done by using MatLab/Simulink software. Fig. 3 shows the PV voltage versus current and PV voltage versus power curves under different solar insolation. The near 2500 W PV power has been obtained at full insolation.

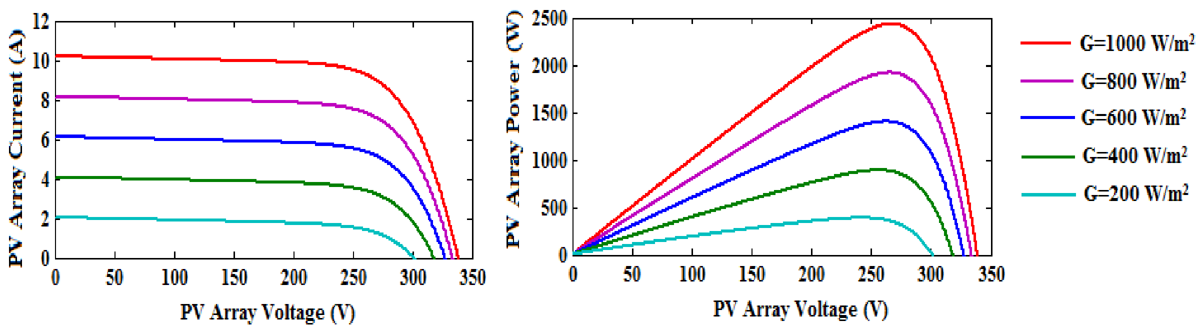

Fig. 3. Simulated P-V and I-V characteristics of PV array under different insolation

In simulation the system performance has been tested under different solar insolation shown in Fig. 4.a. The solar insolation is maintained at different levels in the total simulation time, in starting it is about full insolation i.e., 1000 W/m^2 upto the time of 2 seconds. Then it has been decremented to the level of 600W/m^2 and 400W/m^2 at the time of 2 and 4 second.

Fig. 4.b. and Fig. 4.c show the response of PV voltage and PV current, the PV voltage has been maintained in the level of 260-270 V at entire simulation time. The PV current only changed abruptly in the level of 5.2 to 9 A for the change in insolation. Obviously the PV power gets changed under change in insolation levels shown in Fig. 4.d from the level of 2500 W to 1400 W.

Fig. 4. e shows the dc link voltage or output voltage of the cuk converter, the cuk converter is fired with MPPT algorithm so the pulse width has been changed at different values irrespective of solar insolation levels. so the dc link voltage gets changed from the levels of 320 to 220 V. Fig. 4. g, Fig. 4. h and Fig. 4. i show the BLDC motor parameters like motor phase a back EMF, motor phase a current, motor speed and electromagnetic torque, for the sack of clarity the zoomed version of motor phase a back emf and current has been shown in Fig.5.

In the motor phase an emf is gets varied depends on dc link voltage or solar insolation levels, it is varied about 110 V to 80 V. The motor phase a current is obtained about 6 A. The motor speed gets varies depends on insolation levels from 2900 rpm to 2000 rpm. The motor electromagnetic torque is obtained about 3 to 4 Nm. The simulated results of the motor speed and torque is capable to drive the selected centrifugal pump.

The perturb and absorb MPPT algorithm is used to track the maximum power from the PV array under change in insolation levels. The PV voltage versus current and PV voltage versus power is shown in Fig. 6. The maximum PV power of different insolation has been obtained for a power levels of 2500 to 1400 W. Fig. 7 shows the graphical representation of the PV power under different solar insolation levels with corresponding duty cycles from the MPPT controller.

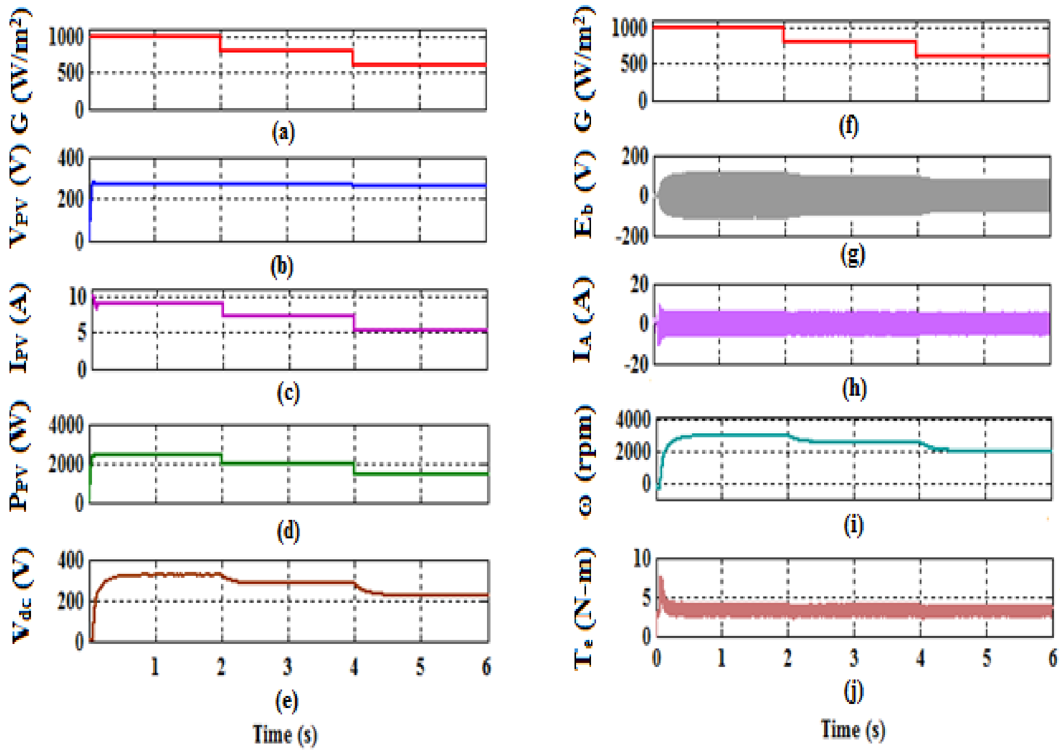

Fig. 4. Simulated results of PV water pumping system under different solar insolation

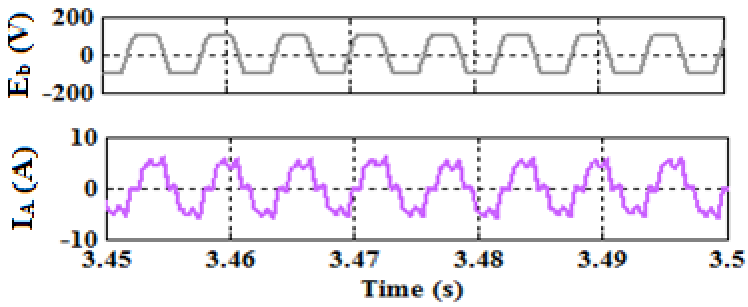

Fig. 5. Zoomed view of simulated BLDC motor back emf and current of phase A

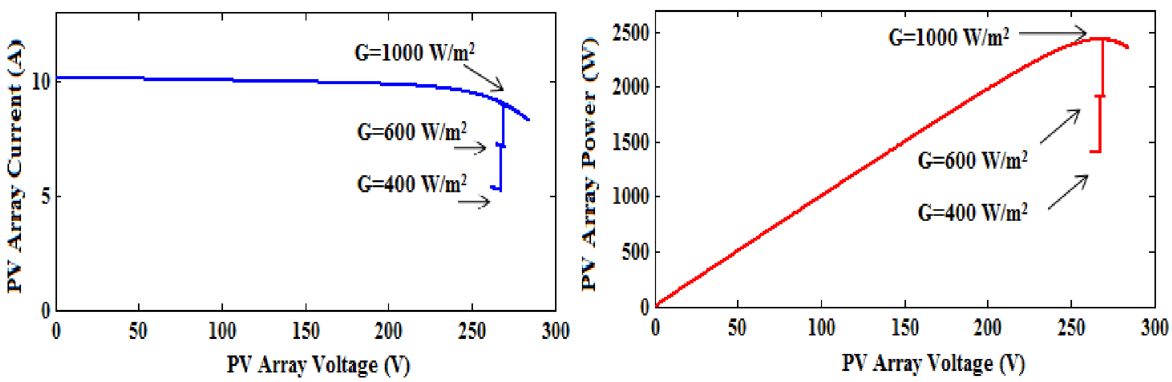

Fig. 6. Simulated MPPT results for PV voltage vs current and PV voltage vs power

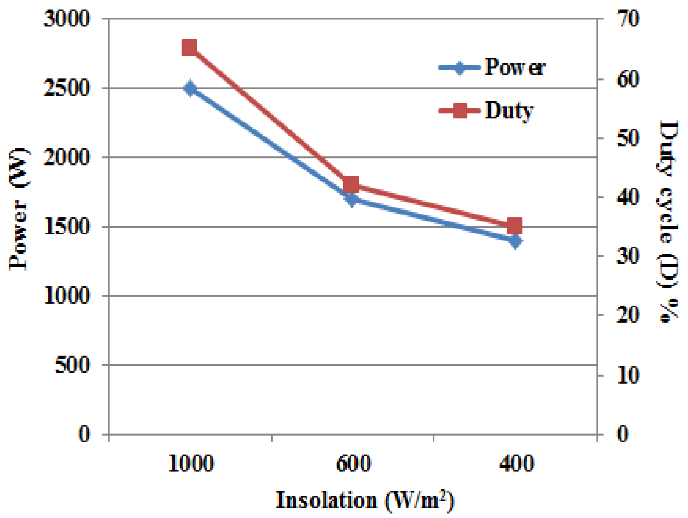

Fig. 7. Graphical representation of the PV power under different solar insolation with corresponding duty cycles

B. Hardware Realization of PV water pumping system:

Arduino UNO is used for an implementation, among other commercially available micro controllers and feild programmable gate arrays (FPGA), the arduino UNO has own features like, it has more included libraries to allow many number of hardware devices, build in analog and digital pins. It supports the pulse width modulation at I/O pins by simply adjusting the duty cycle with a single line code. It supports the USB connectivity for data communication with PC.It available in the market at low cost compared to other controllers [12].The hardware setup has been developed and tested under two different insolation levels. The schematic diagram of the developed hardware has been shown in the Fig. 8. It comprises the following circuits cuk converter (dc-dc converter), three phase voltage source inverter, power conditioning circuit, driver circuit unit and the controller board arduino. The layout diagram itself having the components rating and their part names. The arduino has been programmed to track the maximum power form the solar array and also provide the pulses for three phase inverter (120° commutation). The HCPL 3120 has been used for an isolation purpose between pulses from the controller and the gate terminals of the power switches, it provides high switching speed upto 500 ns and great temperature withstand capability in the range of -40º C to 100° C. The power switches and diodes are having the high voltage and current ratings in both inverter and dc-dc converter. In cuk converter the power MOSFET IRFZ44 is used similarly in three phase voltage source inverter the FPGA25N120 is used. The power conditioning circuits having the op-amp. circuit which converts the sensor voltage into the level of voltages that can be accesible by an arduino UNO.

The results of the PV water pumping system is shown below under two different solar insolation conditions. Fig. 9 shows the PV voltage, dc-dc converter output voltage, MPPT pulses and the inductor current of the dc-dc converter under unshaded condtion. The zoomed version of the above results are shown in Fig. 10.

The power generated from the PV source is measured through fluke meter shown in Fig. 11. Considering the BLDC motor runs at the speed of 2800 rpm. Fig. 14 shows the motor back emf of the three phases and Fig. 15 shows the motor phase a current.

Fig. 12 shows the PV voltage, dc-dc converter output voltage, MPPT pulses and the inductor current of the dc-dc converter under shaded condition. The power generated from the PV source under shaded condition is measured through fluke meter shown in Fig. 13. Considereing the BLDC motor runs at the speed of 1500 rpm. Fig. 16 shows the motor back emf of the three phases and Fig. 17 shows the motor current.

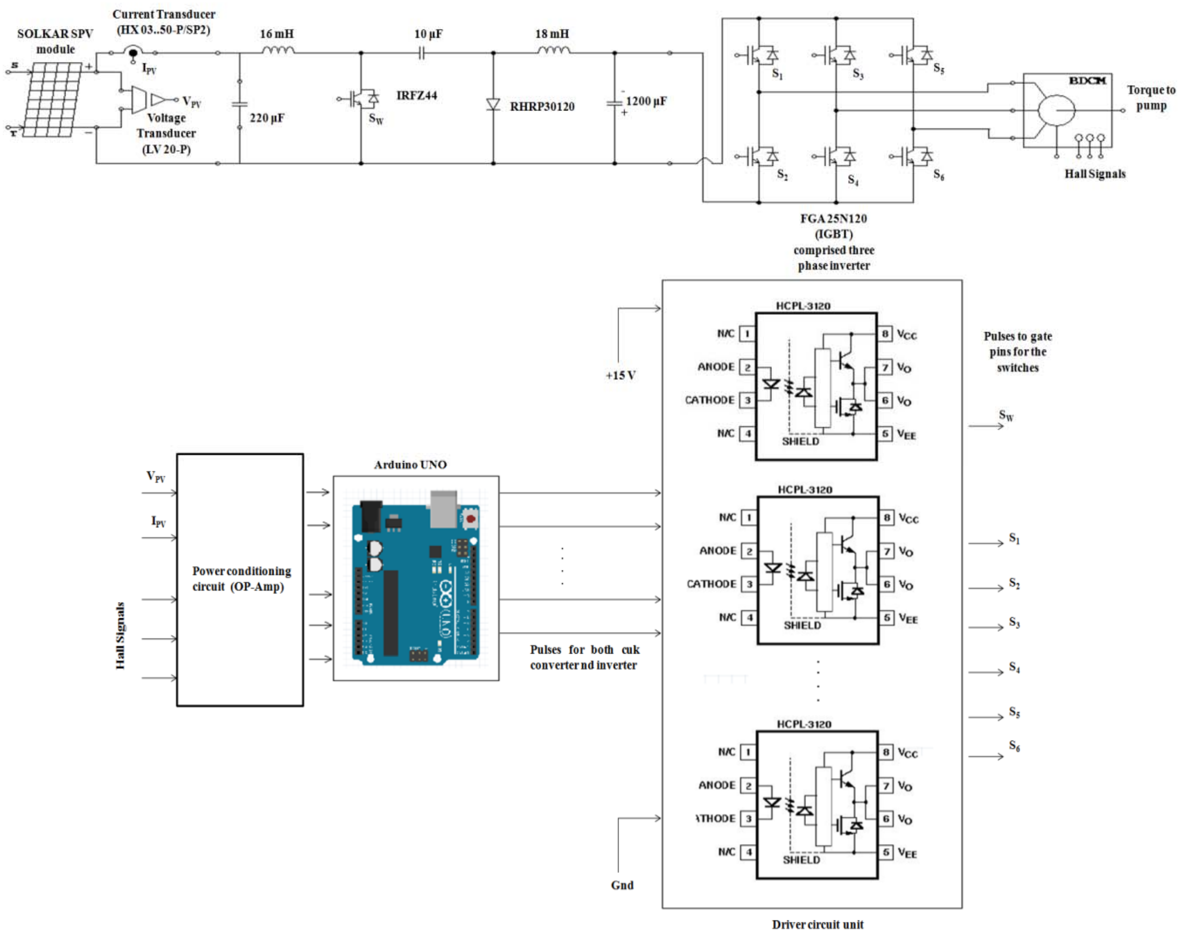

Fig. 8. Schematic diagram of PV water pumping system using Arduino UNO.

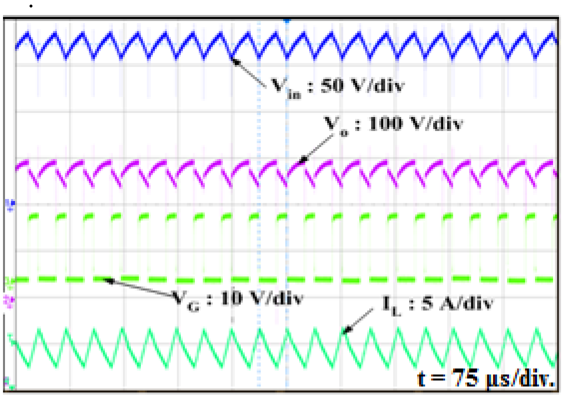

Fig. 9. PV voltage, dc link voltage of cuk converter, gate pulses of cuk converter and cuk converter inductor current under unshaded condition.

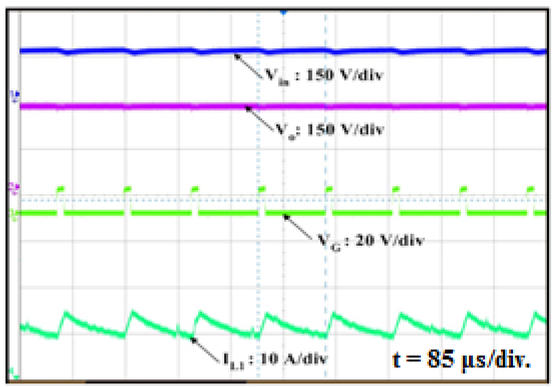

Fig. 10. Zoomed view of PV voltage, dc link voltage of cuk converter, gate pulses of cuk converter and cuk converter inductor current under unshaded condition.

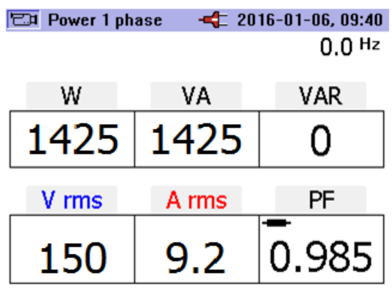

Fig. 11. Measured PV power under unshaded condition.

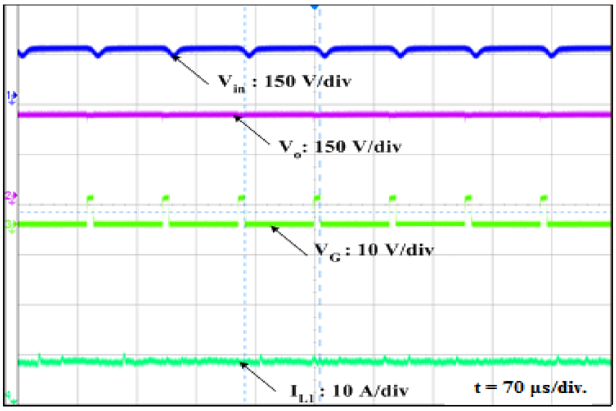

Fig. 12. PV voltage, dc link voltage of cuk converter, gate pulses of cuk converter and cuk converter inductor current under shaded condition.

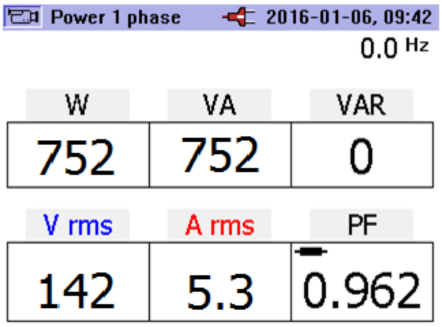

Fig. 13. Measured PV power under shaded condition

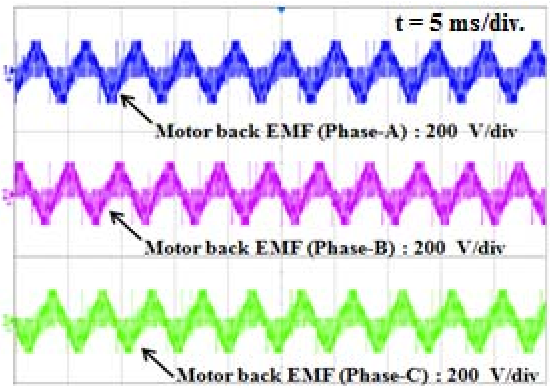

Fig. 14. Motor back emf of the three phases under unshaded condition

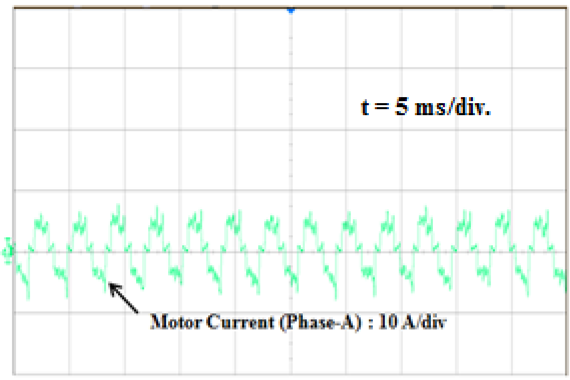

Fig. 15. Motor phase-A current under unshaded condition

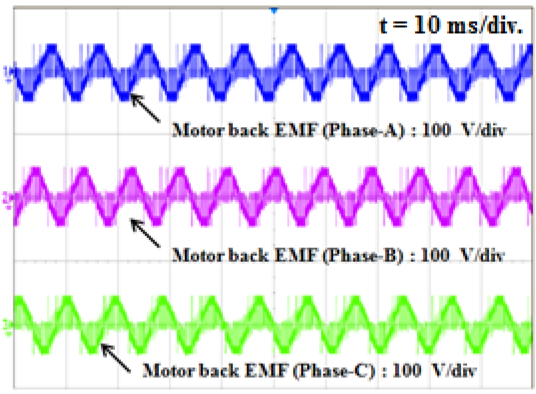

Fig. 16. Motor back emf of the three phases under shaded condition

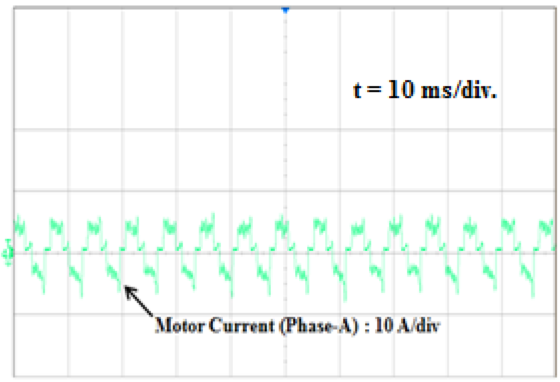

Fig. 17. Motor phase-A current shaded condition

IV. CONCLUSION

In this paper, the complete design of PV water pumping system for an agricultural land has been carried out to deliver the required water of an acre agriculture land. The simulation of PV water pumping system was done and its results were taken under different solar insolation using MatLab/Simulink software. The prototype has been implemented and the maximum power were tracked from the solar PV array using Arduino Uno with perturb and observe algorithm (P&O). The results were taken at different insolation levels and those results are validated with the simulation results. This paper provides an idea to implements the solar PV water pumping for any size of land, by simply recalculating the above work.

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