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Solar PV fed FPGA Controlled BLDC Motor Speed Control

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Abstract— **In this paper a novel converter is designed for the applications of water pumping system driven by Brush less DC motor (BLDC). The photo voltaic (PV) system is proposed in this paper in order to replace the conventional energy sources like coal, nuclear, gas etc. BLDC motor is replaced with the commercial dc motor to achieve better performance, less maintenance and also less cost for water pumping applications. A boost converter is used to step up the available low level dc voltage form solar panel into high voltage. An LC filter design is introduced in this paper to reduce the harmonics and to smoothen the out of the boost converter. A single phase inverter is used to convert boost output dc voltage into an ac voltage. The pulses for inverter are generated with SVPWM technique and the speed of the motor is adjusted with the help of PI controller. Finally a absolute model of water pumping system with the proposed inverter is implemented in Matlab/Simulink. To obtain the optimum output this system is examined with conventional boost converter.**

Key Words— Photovoltaic (PV) system, MPPT, BLDC Motor, Three phase inverter, SVPWM, dc–dc Boost Converter, FPGA, LC filter, PI Controller

INTRODUCTION

In rural areas the availability of drinking water and electric power supply is the main problem. In such places PV system is most efficient and promising way to water pumping system. To reduce the burden on conventional energy sources the researchers looking for alternate energy sources like solar, wind, tidal etc. among all the alternate sources, solar energy attracts due to its tremendous characteristics. As the solar energy is generated from sun light, generation cost is almost free. This PV system directly converts available light energy into electrical energy without any intermediate energy conversion, therefore losses are reduced and efficiency is increased.

There are several commercial converters like dc motors and fuel cells available in the market to drive the water pump with higher efficiency, but due to the drawback of the batteries having low life time when compared with PV system and requires frequent replacement and frequent maintenance. The proposed PV energy source model is cheaper and can quickly reach the poor people who need these systems for water pumping applications. In this paper BLDC motor is replaced the commercial DC motors to avoid maintenance cost, to increase efficiency [20]. These BLDC motors are fast in advance popularity. These motors frequently used in industries, aerospace, medical and instrumentation, consumer. In this paper BLDC motor used for solar water pumping system [21]. These motors are electronically commutated. The stator of the BLDC motors having stacked steel laminations and windings are in distributed manner. The rotor is having alternate north and south poles made up of permanent magnets.

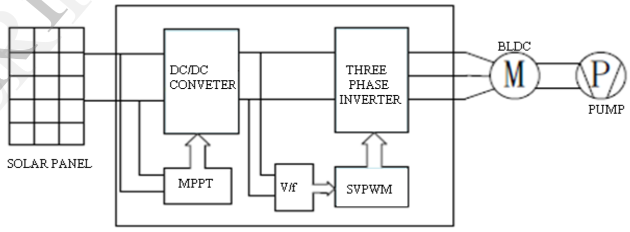

Fig.1. Block diagram of the proposed model

The block diagram shows the proposed solar fed water pumping system. This PV system directly converts solar radiation into electrical energy. The challenges have to face with solar system like, maximum energy generation under solar irradiation conditions and also improve the quantity of water pumped [1]. These necessities a novel converter with high efficiency, where the availability of electrical energy is small, less cost to use where it is most needed, robustness therefore it needed less possible maintenance and finally has high life time usually 20 years. SVPWM control strategy is proposed in this paper for new dc/dc boost converter and it is perfectly suitable for solar PV water pumping system [1]-[4].

Solar Cell Model:

Solar PV cells are made with P-type and N-type semiconductor materials. A solar cell is basically a light-emitting diode, because it activates when exposed to sun light and generates the voltage. I-V characteristics of Solar PV system is a non-linear in nature, equivalent circuit of solar cell is shown in fig.2 and fig.3. It contains a current generator shunted by a diode, one series resistor and a Shunt resistor. The shunt resistor specifies the leakage currents through the ground; generally the significance of shunt resistor is high, around 1000 ohms. Series resistor specifies the internal resistance of leads which are connected to the solar cell and the significance of series resistance is low around 0.001 ohms.

A single solar cell will generate low voltages (typically 0.5V-0.7V), as a result these cells are connected either in series or in parallel to meet our requirement. Number of solar PV modules stacked together to make a solar array. A single unit of solar PV module is enough for water pumping applications.

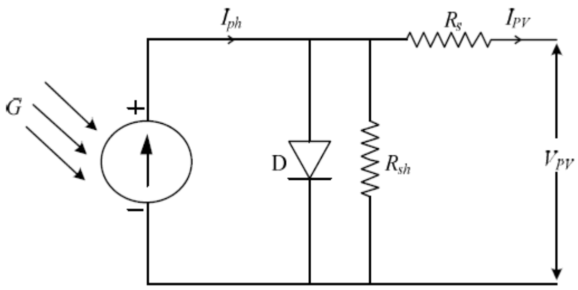

Fig.2. Practical model of solar cell

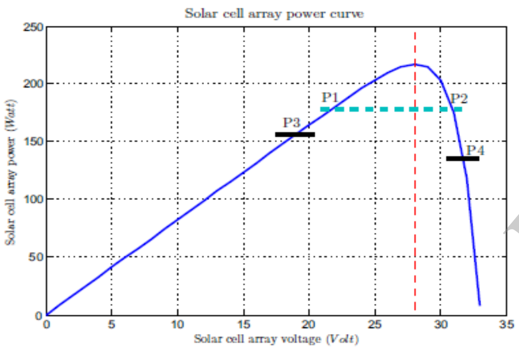

Fig.3. VI Characteristics of PV Generator

SEquations :

$$I = I_{ph} - I_d\left[\exp\left(q\left(V + IR_s\right)/kT_c A - 1\right)\right] - \left(V + IR_s\right)/R_p \qquad (1)$$

I ph=Short-circuit current due to sunlight; Id=Current shunted through the diode; R=Load resistance; I=Current through the load; V=Voltage on the load; Rs=series resistance;

Rp=Shunt resistance; q=Electron charge; K=Boltzmann's constant;

$$I_{ph} = \left[I_{sc} + \alpha\left(T_c - T_{ref}\right)\right]G \qquad (2)$$

Where $\alpha = 0.0012 * I_{sc}$

PROPOSED CONVERTER

The design of a single solar PV module is presented in this paper it can drive the motor of 1/3 hp. it is adequate to thrust the water for single family unit. The proposed PV system is generates the dc output around 0.5v – 0.6v, this low level voltage is fed to a new DC – DC Boost converter to enhance the module output. Inverter is used to convert this high DC voltage into AC voltage. SVPWM based three level inverter is presented in this paper [5]. SVPWM technique improved the output voltage of an inverter when compared with SPWM technique. All the states are used in SVPWM state vector model i.e. the states (000 and 111) are not used in SPWM technique. By using these two states this proposed SVPWM scheme is superior to SPWM technique. A boost converter is required to have a huge voltage conversion ratio. MPPT technique is used in solar PV system to track the maximum power even in cloudy condition.

In this paper current fed converter is projected over the voltage fed converter. Because of high input current ripple and large transformer turns ratio Voltage fed converters are not used in water pumping applications [19]. In case of current fed converters a large inductor is placed at the input side, thus it allows low input current ripple and reduces the input capacitor. Current fed converter is obtained from the boost converter model and has huge step-up voltage conversion ratio, this reduces the transformer turns ratio. This paper proposed a boost converter due to the advantage of small components size, high efficiency and also simple design.

MPPT Control:

By using MPPT technique the operating point of the solar PV system is fixed at the maximum power point. MPPT is the most widely used hill-climbing algorithm in PV applications, because it gives fast dynamic response and has simple implementation. MPPT algorithm Works mainly based on operating characteristics of the solar power curves of the PV panel. This solar power curves are estranged into two sides; left side and right side of the maximum power point. Variation of power and voltage is analyzed to approach to the operating point, then work out exact operating region of solar PV panel and fine-tune the reference voltage. Based on this reference voltage, PI controller will increase or reduce the speed of the motor. The expression fill factor (FF) is the amalgamation of open circuit voltage (VOC) and short circuit current (ISC) of the solar PV panel. Fill factor can also be defined as the fraction of maximum power of solar panel to the product of open circuit voltage (VOC) and short circuit current (ISC). Fill factor determines the maximum power obtained from the PV panel. There are numerous types of MPPT algorithms explicitly perturb-and-observe (P&O), incremental conductance and constant voltage etc. The first two methods are often referred to as hill climbing methods.

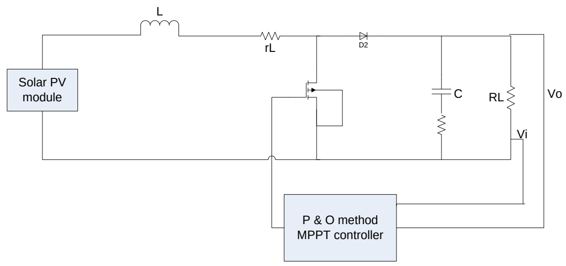

Fig.4. P&O method MPPT charge controller

DC-DC Boost Converter:

Low level DC voltage of magnitude (0.5v to 0.7v) is converted into high level DC voltage magnitude using DC-DC Boost converter. There are two conduction modes of operation is possible in Boost converter one is continuous conduction mode and discontinuous conduction mode.

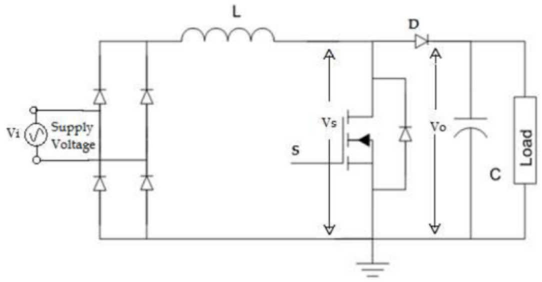

Fig.5. DC-DC Boost converter

These two modes of operations are decided by proper turn ON and turn OFF control of the proper switches. Circuit diagram of boost converter consists of an inductor in series with input voltage source, a high frequency power switch, a diode and an LC filter as shown ABOVE. The relationship between V0 and Vs is given as:

$$V_0 = \frac{V_s}{(1-D)} \qquad (3)$$

LC- filter modeling.

LC-filter is a second order filter because it has two energy storage components namely inductor and capacitor. Here LC filter modeling is proposed due to the advantage of better filtering ability when compared to other filters like L and C. The design of LC filter is easy to understand, the block diagram of proposed filter is shown below

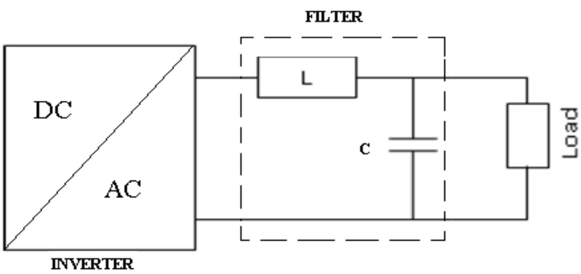

Fig.6. Basic block diagram of LC-filter

Design procedure:

(i) Find out the best filter to design.

(ii) Calculation of impedance of designed filter.

(iii) Equating the energy storage elements like inductor and capacitor values using the second step.

Impedance form can be calculated using equation (2).

$$R_d = \frac{V_{Max}}{I_{Max}} \qquad (4)$$

L and C values can be calculated as follows

$$L = \frac{R_d}{2\Pi f} \qquad (5)$$

$$C = \frac{1}{2\Pi f R_d} \qquad (6)$$

MULTI LEVEL INVERTER

Most of the Industries have been using multilevel inverters for high power applications of MW level, because most of the drives high power ac drive. When linked with medium voltage power supplies these AC high power drives having a difficulty. Multilevel inverters (MLI) have overcome this problem [15]. Three levels inverter is proposed for water pumping system and the inverter output is fed to the BLDC motor which drives the water pump efficiently [14]. MLI consists of diode switches, capacitors and voltage sources. These MLI's can be handled high power than conventional inverters. Harmonics are successfully diminished by using appropriate PWM scheme [5]-[8] to inverter; therefore efficiency is improved [15]. There is no need of any supplementary coupling transformers

Different topologies are used for multilevel inverters: (i) flying capacitors (ii) neutral-clamped and (iii) Cascaded multi cell having separate dc supply. The control strategies for inverters are: (i) SPWM technique (ii) harmonic elimination method and (iii) Space-vector modulation (SVM). SVPWM is introduced in this paper, as a controlling technique.

Space-Vector Pulse Width Modulation (SVPWM):

PWM signals are generated to the inverter using advanced SVPWM technique to increase the output [5]. SVPWM technique was introduced in 1980s. Recently this technique has become most commanding PWM technique for three-phase inverters. In this paper the performance of the pumping system is enhanced and minimizes the power losses by controlling the output of the inverter using SVPWM technique. Several PWM schemes are implemented with the Microprocessor technology, which helps to reduce the switching losses, harmonics and for precise controlling of inverter output. By using SVPWM technique the output voltage enhanced when compared to SPWM technique and also it uses all the states in state vector model i.e. SPWM technique couldn't use the states (000 and 111) [14]. Because of the two states, this proposed scheme is better than SPWM technique.

SVPWM generates less THD than SPWM. Maximum fundamental magnitude of SVPWM controlled inverter is 90.6% and Maximum voltage acquired is 15.5% [14]. Representation of Space Vector is shown in fig.7. All the peak points of vectors touching with a reference vector, in this manner a circle can be shaped inside the state model. There are mainly two regions in state model, under modulation, and over modulation. These two regions are relying on modulation index.

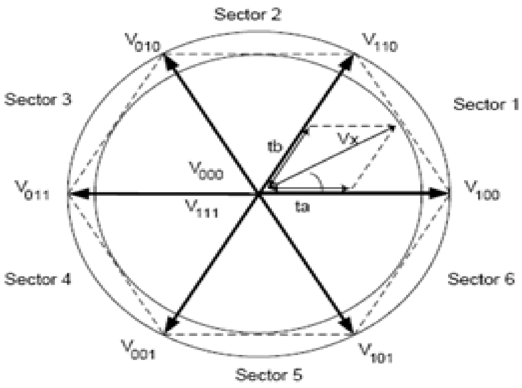

Fig.7. Space Vector Representation

FPGA based PWM Control of Inverter design:

Generating PWM signals for various Power electronic Applications is becoming very easy by using Field Programmable Gate Array (FPGA). FPGA generates signals by interconnecting various logic gates. After completion of programming it can be modified easily by changing the connections of logic gates. This Reprogramming makes suitable to design using FPGA [16]. Implementation using FPGA takes short time. Therefore this is the best way of implementing digital PWM Generators [8]. Implementation of FPGA-based digital controllers suitable for small designs hence less costly, hence in this thesis FPGA based PWM Generator technique is discussed.[5]-[8].

Fig.8 shows the PWM control of an inverter. PWM signal (VPWM) is generated by the PWM generator and is fed to S1 and S3 [5]-[8]. The switches S2 and S4 receive the inverted rectangular wave form. Therefore DC input voltage is converted into desired AC voltage by proper turn ON and OFF controlling time of power electronic switches.

These power switches are basically IGBT or MOSFET. Inverter size is compatible with these power switches. Inverter size is inversely proportional to the switching frequency of power switches therefore size of the inverter is reduced by increasing the switching frequency of power switches. Thus the selection of switching frequency by PWM Generator is optimized [5].

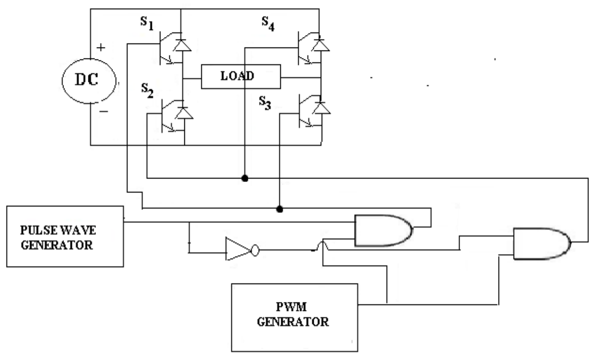

Fig.8. PWM Control of Inverter

BLDC MOTOR PRINCIPLE

Inside-out DC motors are called BLDC motors. The stator in a DC motor has no windings and has permanent magnet. The rotor windings are excited with a current. To generate a stirring electric field the rotor current is inverted through a split commutator and brushes. Conversely, in a BLDC motor has windings on the stator side and rotor acts like a permanent magnet. For this reason BLDC motors are called as inside-out DC motor. Numerous motors can be considered as brushless motors, together with stepper motor and induction motors, but the word "brushless" is specified to a set of motors acts in the same way to DC brush type motors exclusive of the boundaries of a physical commutator. To construct a brushless DC motor, rotating current coils must be replaced with permanent magnets to rotate within the case. Based on the rotor position, the current should be altered. Figure.9 shows a reversing switch is activated by a cam

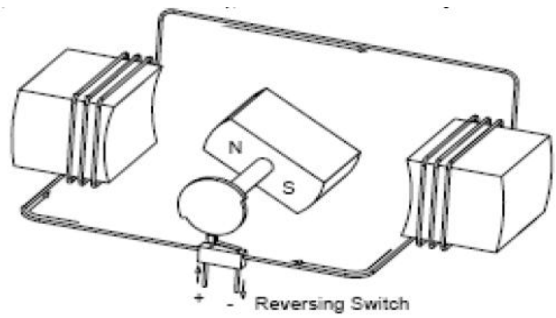

Fig.9. Shows a reversing switch is activated by a cam

SIMULATION RESULTS

To investigate the performance analysis of proposed study computational simulations have been performed on Xilinx system generator interfaced MATLAB Simulink environment. The overall system Simulink block diagram is shown in following figure.

In Matlab solar PV module is modeled with the following specifications as Shown in Table.1.

Table.1 Design specifications of Solar PV Module

ELECTRICAL CHARACTERISTICS	VALUE
Maximum power(P max)	150W
Voltage at P max(V mp)	34.5W
Current at P max(I mp)	4.35A
Open-Circuit Voltage(Voc)	43.5V
Short-Circuit C urrent(I sc)	4.75A
Temperature Cofficient of Isc	0.065±0.015%/oC
Temperature Cofficient of Vsc	-160±20mV/oC
Temperature Cofficient of Power	-0.5±0.05%/oC
NOCT	47±2oC

By using the above data, PV module is modeled in MATLAB and shown their characteristics; output voltage and current waveforms are shown in following figure.

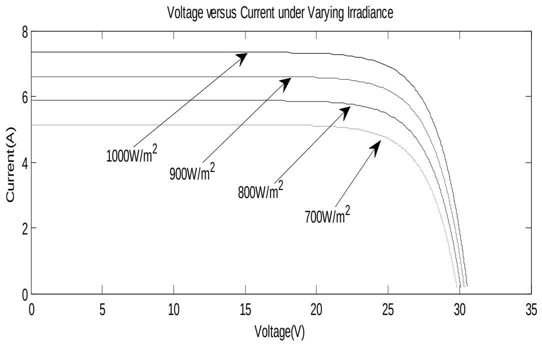

Fig.10. Voltage versus Current of Solar PV Module under varying Irradiance Conditions

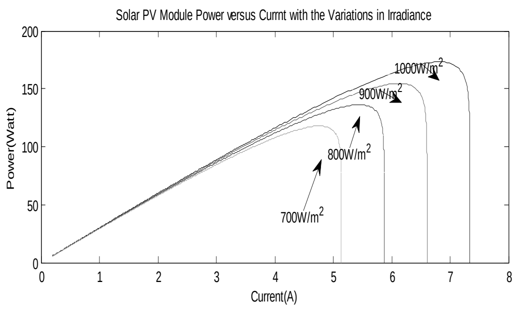

Fig.11. Power versus Current of Solar PV Module under varying Irradiance Conditions

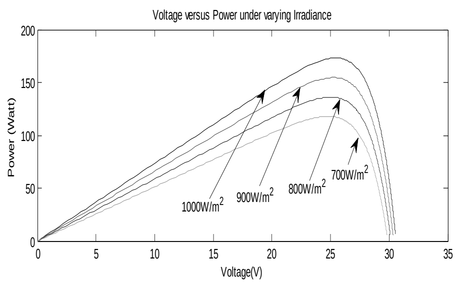

Fig.12. P vs V of Solar PV Module under varying Irradiance Conditions

After doing the modeling on Matlab simulated solar PV module under different irradiance conditions like 1000W/m2, 900W/m2, 800W/m2and 700W/m2. Based on simulations of solar PV module drawn their various characteristics and presented them in the above figures (Figure 9: solar voltage versus current, Figure 10: solar PV module Current versus Voltage and Figure 11: solar PV module Power versus Voltage). To test system under variable irradiance conditions, variable irradiance is given in the input of solar PV module and the observed the output of module output parameters (voltage and current) and presented them in following figures 12 and 13. By seeing these output voltage and current waveforms it is clearly observed that solar PV module producing variable natured DC quantities under varying atmospheric conditions as discussed in an earlier chapter. Hence the constant voltage mode MPPT is designed to make these quantities constant at the optimum operating point of solar PV module with the help of DC-DC converter.

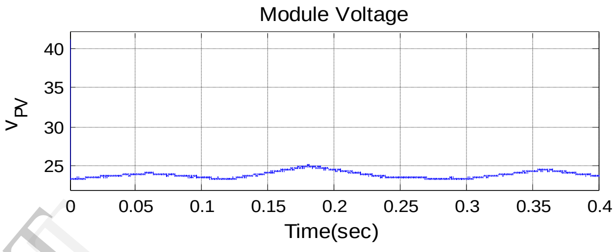

Fig.13. Solar Module output Voltage

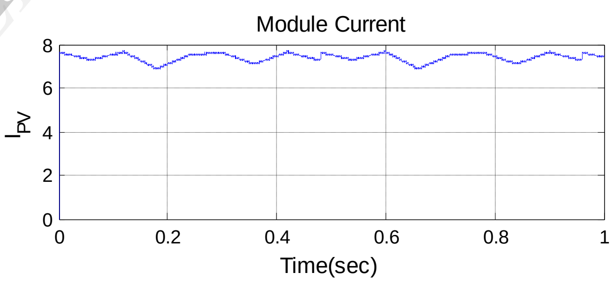

Fig.14. Solar Module output current

A.Design specifications of MPPT charge controller:

Input Voltage= 24V, Output Voltage= 60V Output Power = 165W, Switching frequency = 20 KHz

Inductor =700µH, Capacitor C= 470µF and their parasitic elements ESR of inductor = 0.019Ω, ESR of capacitor = 0.111Ω, internal on-state resistance of MOSFET= 0.18Ω and on-state voltage drop of diode = 0.8V

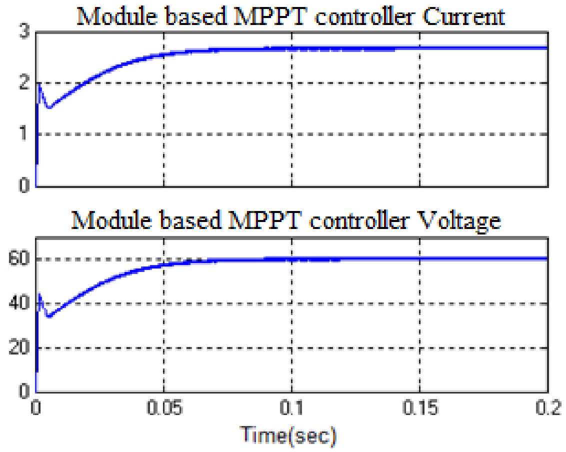

Fig.15. PV module voltage and current

MPPT based Solar PV modules of 7 numbers together in parallel mode, to form a solar PV array to meet power demand of BLDC motor. PV array output voltage and current waveforms are shown in the figures below. With the help of PV array DC bus is created at same voltage level required by BLDC motor to drive the centrifugal pump for water pumping and purification applications. The motor which is modeled in MATLAB Simulink, details have been presented in Table 3. Based the datasheet of BLDC motor, Modeled Simulink model of BLDC motor is connected with the output terminals of PV array and observed following results shown in figure 12, 13 and 14.

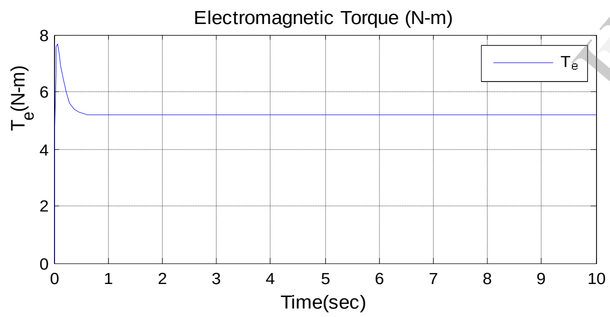

Fig.16. Electromagnetic Torque produced by BLDC Motor

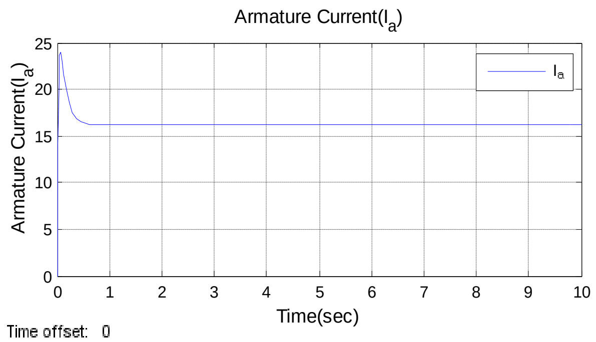

Fig.17. Armature current of BLDC motor

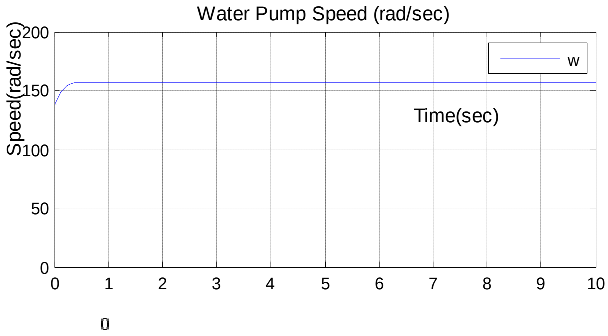

Fig.18. BLDC motor speed

CONCLUSION

Based on the Simulations model of proposed system in MATLAB Simulink platform, results have been taken to analyze the system. Firstly, design of system started with the design of BLDC motor by considering the pumps a load to it, after that design of solar PV array is completed to meet the demand of BLDC motor fed load .Designed solar PV array consists of 7 solar PV models with module based MPPT charge controllers and these boost converter based MPPT charge controllers are controlling with the help of P&O method MPPT to extract maximum power from the modules. And all the solar PV modeled based MPPT charge controllers are connected in parallel to meet the current demand of the load. After completion of design, Simulink modeling has done to judge the system design is proper or not? Based on the simulation results which have been presented in previous section it is concluded that proposed system is proper, and is running successfully the water pump load in Xilinx interfaced MATLAB Simulink platform.

REFERENCES

1. Hahn, "Technical maturity and reliability of photovoltaic pump systems," in Proc. 13th Eur. Photovoltaic Solar Energy Conf., Nice, France, pp. 1783–1786.
2. M. A. Vitorino and M. B. R. Correa, "High performance photovoltaic pumping system using induction motor," in Proc. Brazilian Power Electron. Conf., 2009, pp. 797–804.
3. D. Tschanz, H. Lovatt, A. Vezzini, and V. Perrenoud, "A multi-functional converter for a reduced cost, solar powered, water pump," in Proc. IEEE ISIE, 2010, pp. 568–572.
4. M. A. Vitorino, M. B. R. Correa, C. B. Jacobina, and A. M. N. Lima, "An effective induction motor control for photovoltaic pumping," IEEE Trans. Ind. Electron., vol. 58, no. 4, pp. 1162–1170, Apr. 2011.
5. S. R. Bowes and A. Midoun, "Suboptimal switching strategies for microprocessor controlled PWM inverter drives," Proc. Inst. Elect. Eng.—Elect. Power Appl., vol. 132, no. 3, pp. 133–148, May 1985.
6. M. Cacciato, A. Consoli, and V. Crisafulli, "A high voltage gain dc/dc converter for energy harvesting in single module photovoltaic applications," in Proc. IEEE ISIE, 2010, pp. 550–555.
7. W. Li, L. Fan, Y. Zhao, X. He, D. Xu, and B. Wu, "High step-up and high efficiency fuel cell power generation system with active clamp flybackforward converter," IEEE Trans. Ind. Electron., vol. 59, no. 1, pp. 599– 610, Jan. 2012.

8. P. M. Barbosa and I. Barbi, “A new current-fed, isolated PWM dc-dc converter,” IEEE Trans. Power Electron., vol. 11, no. 3, pp. 431–438, May 1996.
9. B. Liu, C. Liang, and S. Duan, “Design considerations and topology selection for dc-module-based building integrated photovoltaic system,” in Proc. 3rd IEEE Conf. ICIEA, Jun. 3–5, 2008, pp. 1066–1070.
10. D. Li, B. Liu, B. Yuan, X. Yang, J. Duan, and J. Zhai, “A high step-up current fed multi-resonant converter with output voltage doubler,
11. R. Faranda and S. Leva, “Energy comparison of MPPT techniques for PV systems,” WSEAS Trans. Power Syst., vol. 3, no. 6, pp. 446–455, Jun. 2008
12. M. Liserre, F. Blaabjerg, and S. Hansen, “Design and Control of an LCL-Filter-Based Three-Phase Active Rectifier,” IEEE Transactions on Industry Applications, vol. 41, no. 5, pp. 1281– 1291, Sep. 2005.
13. V. Blasko and V. Kaura, “A Novel Control to Actively Damp Resonance in Input LC Filter of a Three-Phase Voltage Source Converter,” IEEE Transactions on Industry Applications, vol. 33, no. 2, pp. 542–550, 1997.
14. M. Rajendar Reddy, T. Brahmananda Reddy, 1. Amarnath and D. Subba Rayudu “Space Vector Based Novel and Simple Unified Pulsewidth Algorithm for Induction Motor Drives" IJIEC Volume 2, No.1, pp. 9- 32,2010.
15. V. T. Somasekhar, B. Venugopal Reddy" A New Four-level Dual Inverter fed Open-end Winding Induction Motor Drive" IEEE PEDS 20ll,PP.167-170 Singapore, 5 - 8 Dec-20ll.
16. Koutroulis E., Dollas A. and Kazantzakis K., “High-frequency pulse width modulation implementation using FPGA and CPLD ICs”, Journal of Systems Architecture , Vol.52 (2006): pp. 332–344
17. Rahim N.A. and Islam Z., “Field Programmable Gate Array-Based Pulse-Width Modulation for Single Phase Active Power Filter”; American Journal of Applied Sciences, Vol.6 (2009): pp. 1742-1747
18. Dancy A.P., Amirtharajah R. and Chandrakasan A.P., “High-Efficiency Multiple-Output DC–DC Conversion for Low-Voltage Systems”, IEEE Trans. on Very Large Scale Integration (VLSI) Systems, Vol. 8, No. 3, June 2000: pp.252-2
19. Langridge D, Lawrence W, Wichert B. High-efficiency solar water pumping systems using a BDC motor. In: 12th European photovoltaic solar energy conference, Netherlands; 1994. p. 227–30.
20. J. Shao, D. Nolan, M. Teissier, D. Swanson, “A Novel Microcontroller-Based Sensorless Brushless DC (BLDC) Motor Drive for Automotive Fuel Pumps”, IEEE Trans. on Ind. Appl., vol. 39, no. 6, Nov./Dec. 2003.
21. J. Shao, “An Improved Microcontroller-Based Sensor less Brushless DC (BLDC) Motor Drive for Automotive Applications”, IEEE Trans. On Ind. Appl., vol. 42, no. 5, Sept./Oct. 2006, pp. 1216–1221.