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FPGA Based Battery Energy Storage System Using Solar Cells

P. Rachelin Sujae

M. Tech Embedded Systems,
Bharath University, Chennai, India

Abstract: This work implements a FPGA based battery energy system using solar cells under various illumination and temperature. It performs maximum power tracking based on perturbation and observation method, where it gets the desired maximum power by changing the duty cycle of the switch in the converter. The control algorithm is simple and easy to implement. The algorithm is implemented with the help of FPGA controller which controls the duty cycle by outputting PWM pulse based on the voltage and current from the solar panel. The generated power from the solar cells using the converter is stored in the lead-acid battery to supply the load.

Key words: Fly-back converter · Perturbation and Observation (P&O) · Photovoltaic · Maximum power point tracking (MPPT).

INTRODUCTION

In the last few years, the effect of over usage of non renewable energy has shown serious effect on the human life and also on the environment. With nuclear power plant, despite of the inexpensive power generation, it also results in global warming and green house effect. The nuclear waste also became one of the threats. Thus the world is forced to adopt and use green energy power generation technologies [1].

The green energy power generation technologies include wind energy, solar energy, tide energy, fuel cells, hydraulic power etc. Among these wind and solar power form the most promising technologies in our country. Generating power from wind energy requires low dense area and also the installation cost is more. Also it yields low economic output. Thus the next promising energy resources is solar power as it has the advantages of no maintenance, large scale installation is possible, no noise, no waste and abundant supply.

French scientist A. E. Becquerel pioneered the photovoltaic effect in 1839, largely via energy conversion from the semiconductor photovoltaic effect. Bell laboratory invented the solar cell in 1954 with the intension of providing electricity to remote areas. At that time, solar cell efficiency was only around 6%. When the former Soviet Union launched its first man-made satellite in 1957, solar cells profoundly impacted space flight. The landing of American astronauts on the moon in 1969 streamlined the use solar cells. After 1990, advances in semiconductor technology led to the integration of power generation from solar cells with power consumption in daily live. The retail price and conversion efficiency of solar energy module represent the major limitations in developing solar cells.

A photovoltaic (PV) array has only one maximum power point on I-V characteristic at any given instance. As the pv array I-V characteristic shifts with changing illumination and cell temperature the maximum power point moves. Therefore, to operate a PV array at or near its maximum power output, several methods of maximum power point tracking MPPT have been suggested. Here Perturbation and observation method is used.

Photovoltaic Cell: The word photovoltaic (PV) literally means conversion of sun light directly to electricity. It is clean, easy maintenance and long lifespan (>25 years) characteristics gained a lot of attention in the recent decade. The annual growth of solar energy installation nowadays is around 30% and this number is still climbing [2]. A typical photovoltaic system consists of two major parts: the solar panels that generate DC power from sunlight and the power electronics that convert DC into standard AC voltages. Most solar cells on the market can

Corresponding Author: P. Rachelin Sujae, M. Tech Embedded Systems, Bharath University, Chennai, India.

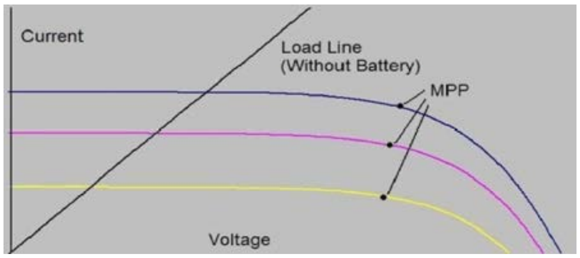

Fig. 1: Load Line and Solar Cell Characteristics.

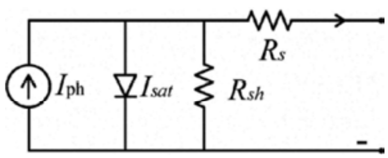

Fig. 2: Equivalent circuit of the PV array

achieve 13 ~ 15% of energy conversion and over 20% in lab environments [3]. While research goes on to improve the PV cell efficiency, it is fundamentally the power electronics that provide controllability over this renewable energy source. In particular, good control to track the maximum power that the PV cells can provide is critically important because the photovoltaic energy is subject to weather changes and the amount of electricity produced by solar panels is highly unpredictable throughout the day.

There are many issues concerning the development of a practical PV system, e.g., energy conversion, grid connection, etc. In this paper we will only focus on one particular power control technique, that is, maximum power point tracking (MPPT). Due to the mismatch between load line and operating characteristic of the solar cells, the power available from the solar cells is not always fully extracted [4]. This can be demonstrated by Fig.1.1 below. Maximum power point tracking (MPPT) is a control technique to adjust the terminal voltage of PV panels so that maximum power can be extracted.

The equivalent circuit of a PV array is shown in Fig. 2. Isat is the diode saturation current. There is some leakage current through shunt resistor Rsh. Normally, the value of shunt resistor Rsh is so big and the value of cascade resistor Rs is so small that both of them can be omitted. V and I represent the PV array output voltage and current, respectively.

Fly Back Converter: Fly back converter is used to control the charging process as it provides isolation and suitable for low power applications. Figure 3 schematically gives the diagram of the fly back converter.

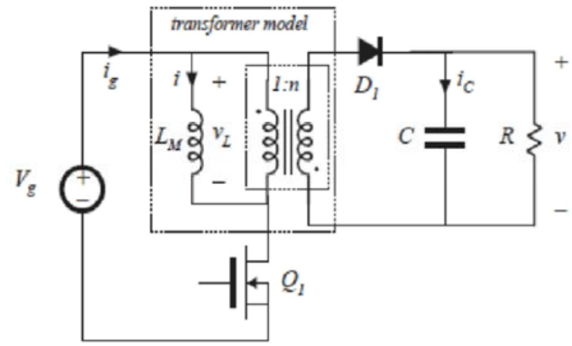

Fig. 3: Fly back Converter.

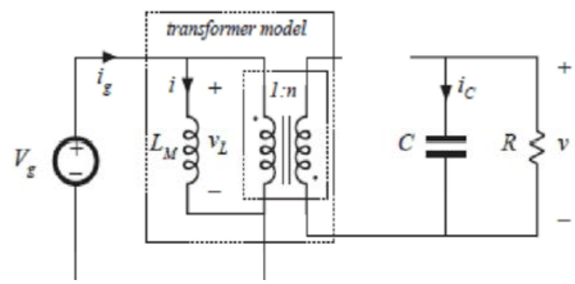

Fig. 4: Fly back operation when switch is turned ON.

Stage I: Switch Q1 is turned ON, D1 is turned OFF

When transistor Q1 conducts, energy from the dc source Vg is stored in LM. When diode D1 conducts, this stored energy is transferred to the load, with the inductor voltage and current scaled according to the 1:n turns ratio. During subinterval 1, while transistor Q1 conducts, the converter circuit model reduces to Fig. 4. The inductor voltage vL, capacitor current iC and dc source current ig, are given by

vL = Vg
iC = -
vR ig = I (1)

With the assumption that the converter operates with small inductor current ripple and small capacitor voltage ripple, the magnetizing current i and output capacitor voltage v can be approximated by their dc components, I and V, respectively. Equation (1) then becomes

vL = Vg
iC = -
V/R ig = I (2)

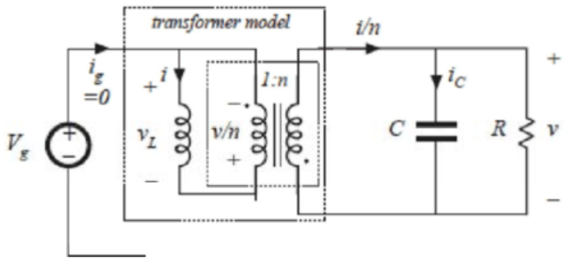

Fig. 5: Fly back operation when switch is turned OFF

The behavior of most transformer-isolated converters can be adequately understood by modeling the physical transformer with a simple equivalent circuit consisting of an ideal transformer in parallel with the magnetizing inductance. The magnetizing inductance must then follow all of the usual rules for inductors; in particular, volt-second balance must hold when the circuit operates in steady-state. This implies that the average voltage applied across every winding of the transformer must be zero.

The operation of the fly back converter can be explained in two stages.

Stage II: Switch Q1 is turned OFF, D1 is turned ON

During the second subinterval, the transistor is in the off-state and the diode conducts. The equivalent circuit of Fig. 5 is obtained. The primary- side magnetizing inductance voltage vL, the capacitor current iC and the dc source current ig, for this subinterval are,

vL= - v/n
iC =(i/n) -
(v/R) ig = 0 (3)

It is important to consistently define vL(t) on the same side of the transformer for all subintervals. Upon making the small- ripple approximation, one obtains.

vL= - V/n
iC = (I/n) - (V/R)
ig = 0 (4)

The waveforms of the related components is showed in the below figure Fig. 6. The components are operated in continuous current mode.

Application of the principle of volt-second balance to the primary-side magnetizing inductance yields.

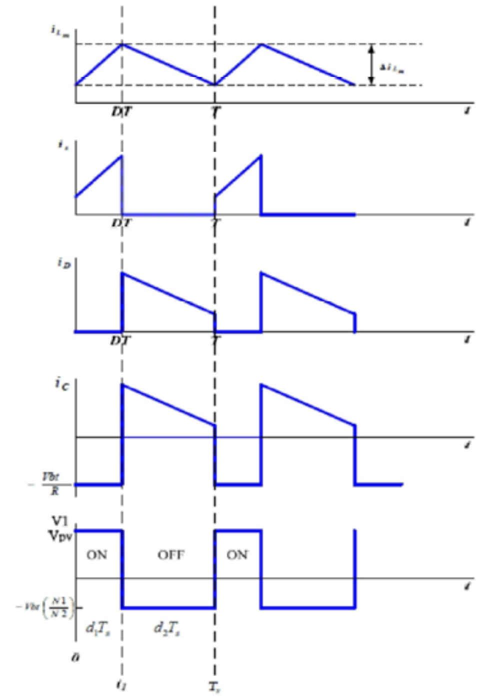

Fig. 6: Waveforms of related components in a continuous current mode

vL = D (Vg) + D' (- V/n) = 0 (5)

So the conversion ratio of the fly back converter is similar to that of the buck-boost converter, but contains an added factor of n. [8] Application of the principle of charge balance to the output capacitor C leads to

M(D) = V/Vg= n (D/D') (6)

The perturb-and-observe method, also known as perturbation method, is the most commonly used MPPT algorithm in commercial PV products (K. Chomsuwan *et al*., 1995; W. Xiao *et al*., 2004) because of its simplicity [5]. Fig. 7. illustrates the general flow chart of the P&O algorithm. The idea is to disturb the PV array system by periodically increasing or decreasing a fixed step size (ΔV) of PV array voltage (Vref). If this given disturbance gives rise to an increase (ΔPpv) of the output power to the MPP, then the following perturbation is given by the same step size in the same direction and vice versa. In order to make sure the MPPT algorithm taken effect, it is necessary that the time between two consecutive perturbation steps should be long enough to allow the output power Ppv to reach its steady state value [6].

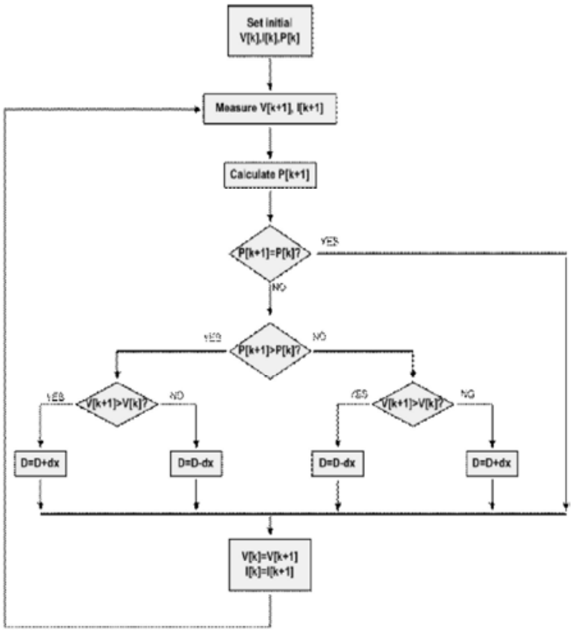

Fig. 7: Flowchart for P&O Algorithm

The choice of a proper step size (either increment or decrement) is essential. If a relatively large number is chosen, oscillations around the MPP occur and give rise to the waste of some accessible energy. By contrast, if a relatively small number is chosen, slow response to irradiance variations incurs and lessens the algorithm efficiency. It is tough to come up with a reasonable step size to level off [7].

Although the P&O algorithm is easy to implement, it has a number of problems, including 1) The PV system cannot always operate at the maximum power point due to the slow trial and error process and thus the solar energy from the PV arrays are not fully utilized; 2) The PV system may always operate in an oscillating mode even with a steady-state sunshine condition, leading to fluctuating inverter output; and 3) The operation of the PV system may fail to track the maximum power point due to the sudden changes in sunshine [9-15].

Implementation with FPGA: The block diagram of the entire developed system is shown below in Fig. 8.

As the block diagram shows, the output of the solar panel is sensed and given to the dividing circuit to reduce it to the range of FPGA kit (Spartan 3E). The reduced current and voltage is given as the input to the FPGA kit. These values are taken as the input for the ADC conversion and the converted digital output is then

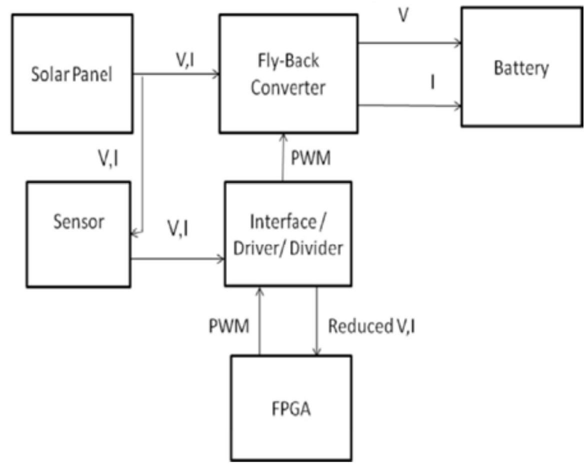

Fig. 8: Block Diagram

implemented in MPPT algorithm where the duty cycle of the switch is changed according to the calculated power. Thus the constant output is achieved from the converter. [16]]

About FPGA: Xilinx® Field Programmable Gate Arrays (FPGAs) are highly flexible, reprogrammable logic devices that leverage advanced CMOS manufacturing technologies, similar to other

Industry- leading processors and processor peripherals. Like processors and peripherals, Xilinx FPGAs are fully user programmable. For FPGAs, the program is called a configuration bit stream, which defines the FPGA's functionality. The bit stream loads into the FPGA at system power-up or upon demand by the system. The process whereby the defining data is loaded or programmed into the FPGA is called configuration. Configuration is designed to be flexible to accommodate different application needs and, wherever possible, to leverage existing system resources to minimize system costs. Similar to microprocessors, Xilinx FPGAs optionally load or boot themselves automatically from an external nonvolatile memory device. Alternatively, similar to microprocessor peripherals, Spartan-3 generation FPGAs can be downloaded or programmed by an external “smart agent”, such as a microprocessor, DSP processor, microcontroller, PC, or board tester. In either case, the configuration data path is either serial to minimize pin requirements or byte-wide for maximum performance or for easier interfaces to processors or to byte-wide Flash memory. Similar to both processors and processor peripherals, Xilinx FPGAs can be reprogrammed, in system, on demand, an unlimited number of times. After configuration, the FPGA configuration bit stream is stored in highly robust CMOS configuration latches (CCLs). Although CCLs are reprogrammable like SRAM memory, CCLs are designed primarily for data integrity, not for performance. The data stored in CCLs is written only during configuration and remains static unless changed by another configuration event [17-18].

RESULTS

The parameters of the solar cell of 100W power is listed below

Total Power	- 100W
Short Circuit Current	- 6.14A
Open Circuit Voltage	- 21.4V
Voltage at Maximum Power	- 17.4V
Current at Maximum Power	- 5.75A

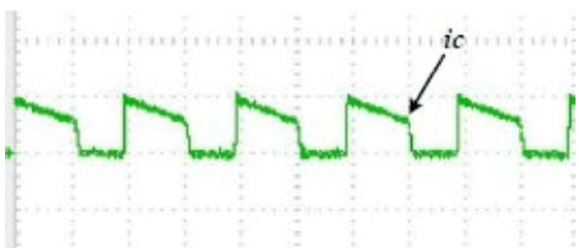

Fig. 9: Waveform of Capacitor Current

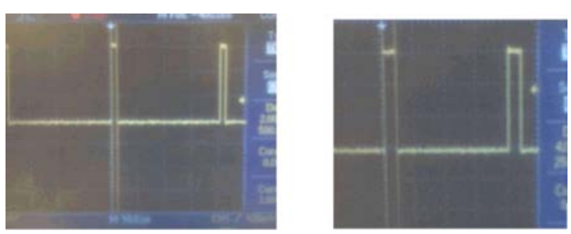

Fig. 10: Varying PWM Pulses

The waveform of the capacitor current at the G-S terminal of the MOSFET and the PWM pulse produced by FPGA are shown in figure below.

CONCLUSION

This work presents a solar energy battery energy storage system with maximum power point tracking, in which a FPGA (Spartan 3E) is used to retrieve the voltage and current in the fly back circuit for increasing or decreasing the duty of the MOSFET switch to achieve maximum power output. Additionally, this work adopts the frequently used perturbation and observation method with a simple mathematic formula in maximum power point tracking, despite the power losses incurred by perturbation around the maximum power point. However, a microchip with a less expensive and moderately difficult calculation capability can be selected to lower the costs of overall circuit, making it highly promising for industrial use [19-22].

REFERENCES

1. Ke, Yu-Lung, Ying-Chun Chuang, Yuan-Kang Wu and Bo-Tsung Jou, 2010. Implementation of a Solar Power Battery Energy Storage System with Maximum Power Point Tracking, in Industrial Annual Meeting.
2. NZPVA Info sheet #1. [Online]. Available: http://www.photovoltaics.org.nz/infosheets.html [15th April 2006].
3. NZPVA Info sheet #2. [Online]. Available: http://www.photovoltaics.org.nz/infosheets.html [15th April 2006].
4. Swiegers, W., Johan H.R. Enslin, 1998. An Integrated Maximum Power Point Tracker for Photovoltaic Panels. [Online], Available: IEEE Explore database. [20th July 2006].
5. Hussein, K.H, I. Muta, T. Hoshino and M. Osakada, 2006. Maximum Photovoltaic Power Tracking: an algorithm for rapidly changing atmospheric conditions. [Online], IEE Proceeding of Generation, Transmission and Distribution, pp: 142.
6. EL-Shibinu, M.A. and H.H.Rakha, Maximum Power Point Tracking Technique, in the 1989 Electro technical Conference, pp: 21-24.
7. Jahn, U. and W. Nasse, 2003. Performance Analysis and Reliability of Grid connected PV system in IEA countries in the 3rd World Conference on Pv Energy Conversion.
8. Kimber, Detrick, A and L. Mitchell, 2005. Performance Evaluation Standards for Photovoltaic Modules & system, in the 31st IEEE Photovoltaic Specialist Conference.
9. Liu, C., B. Wu and R. Cheung, 2004. Advanced Algorithm for MPPT Control of Photovoltaic Systems in the Canadian Solar Buildings Conference, Montreal, pp: 20-24.
10. Faranda, Roberto and Sonia Leva, 2008. Energy comparison of MPPT techniques for PV Systems, in Wseas Transactions on Power Systems, 6: 3.

11. Cheng, C.D., 2001. Introduction to Power Electronics, Chuan Hwa Book Co,
12. Wang, S.C., 1998. Power Electronics, Tung Hua Book Co.
13. Koutroulis, E., A. Dollas and K. Kalaitzakis, 2006. High-frequency pulse width modulation implementation using FPGA and CPLD ICs, Journal of Systems Architecture, 52: 332-344.
14. Salhi, M. and R. El-Bachtiri, 2010. A Maximum Power Point Control photovoltaic System, in Proc. The 18th Mediterranean Conf. Control and Automation. Marrakech Morocco, January, pp: 61 (abstract).
15. Enrique, J.M., J.M Andú jar and M.A. Bohórquez, 2009. A reliable, fast and low cost maximum power point tracker for photovoltaic applications, Solar Energy, 84: 79-89.
16. Leyva, R., C. Alonso, I. Queinnec, A. Cid-Pastor, A. Lagrange and D. Martinez-Salamero, 2006. MPPT of photovoltaic systems using extremum- seeking control," IEEE Trans. Aerospace and Electronic Systems, 42: 249-258.
17. Tafticht, T., K. Agbossou, M.L. Doumbia and A. Ché riti, 2007. An improved Maximum power point tracking method for photovoltaic systems, Renewable Energy, 33: 1508-1516.
18. Hohm, P. and M.E. Ropp, 2003. Comparative Study of Maximum Power Point Tracking Algorithms, progress in photovoltaics: Research and Applications, 11: 47-62.
19. Shafaq Sherazi and Habib Ahmad, 2014. Volatility of Stock Market and Capital Flow Middle-East Journal of Scientific Research, 19(5): 688-692.
20. Kishwar Sultana, Najm ul Hassan Khan and Khadija Shahid, 2013. Efficient Solvent Free Synthesis and X Ray Crystal Structure of Some Cyclic Moieties Containing N-Aryl Imide and Amide,Middle-East Journal of Scientific Research, 18(4): 438-443.
21. Pattanayak, Monalisa. and P.L. Nayak, 2013. Green Synthesis of Gold Nanoparticles Using Elettaria cardamomum (ELAICHI) Aqueous Extract World Journal of Nano Science & Technology, 2(1): 01-05.
22. Chahataray, Rajashree. and P.L. Nayak, 2013. Synthesis and Characterization of Conducting Polymers Multi Walled Carbon Nanotube-Chitosan Composites Coupled with Poly (P-Aminophenol) World Journal of Nano Science & Technology, 2(1): 18-25.