MPPT Simulation with DC Submersible Solar Pump using Output Sensing Direct Control Method and Cuk Converter

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Abstract- In this paper, the MPPT (Maximum Power Point Tracking) with DC submersible solar pump is implemented in MATLAB with output sensing direct control method using Cuk converter. The simulated system consists of the BP SX 150S photovoltaic (PV) module, the ideal Cuk converter, the MPPT control, and the dc submersible solar pump. The selection of the purturb & observe (P&O) algorithm permits the use of output sensing direct control method which eliminates the input voltage and current sensors. The direct control method adjusts of duty cycle within the MPP tracking algorithm. The way to adjust the duty cycle is totally based on the theory of load matching. When the value of Rload (Load of DC submersible pump) matches with that of Ropt, the maximum power transfer from PV to the load will occur. These two are, however, independent and rarely matches in practice. The goal of the MPPT is to match the impedance of load to the optimal impedance of PV.

Keywords- P&O algorithm, MPPT, Cuk converter, PV module, direct control method, DC submersible solar pump

1. Introduction

Energy generated from clean, efficient, and environmentally friends has become one of the major challenges for engineers and scientists [1], [2]. Among all renewable energy sources, photovoltaic power systems attract more attention while greenhouse emissions are reduced [1]-[4]. Regarding the endless aspect of solar energy, it is worth saying that solar energy is a unique solution for energy crisis. However, despite all the aforementioned advantages of solar power systems, they do not present desirable efficiency [5], [6].

The environmental effects such as temperature, irradiation, special characteristics of sunlight, dirt, shadow, and so on affect the performance of the photovoltaic (PV) system [7], [8]. Changes in insolation on panels due to fast climate changes such as cloudy weather and increase in ambient temperature can reduce the PV cell output power [9], [10].

The PV system has poor efficiency so it operates at the maximum power point tracking (MPPT). There are a large number of algorithms that are able to track MPPs. Here Purturb and Observe (P&O) algorithm [11-24] is recommended because of their simplicity and ease of implementation.

2. DC Submersible Pump

The DC submersible pump chosen here for its size and cost is the Kyocera SD 12-30 submersible solar pump. It is a diaphragm-type positive displacement pump equipped with a brushed permanent magnet DC motor and designed for use in standalone water delivery systems, especially for water delivery in remote locations. Flow rates up to 17.0L/min

(4.5GPM) and heads up to 30.0m (100ft.) [39]. The typical daily output is between 2700L and 5000L. The rated maximum power consumption is 150W. It operates with a low voltage (12-30V DC), and its power requirement is as little as 35W [39]. The flow rate of water in positive displacement pumps is directly proportional to the speed of the pump motor, which is governed by the available driving voltage. DC submersible solar pump is connected with a single PV module with MPPT is shown in the Fig. 6. The armature resistance of pump is 0.2Ω.

3. Perturb & Observe (P&O)-MPPT Algorithm

In the P&O algorithm [25]-[27] the operating voltage of the PV array is perturbed by a small increment, and the resulting change in power, ΔP, is measured. If ΔP is positive, then the perturbation of the operating voltage moved the PV array's operating point closer to the MPP. Thus, further voltage perturbations in the same direction (that is, with the same algebraic sign) should move the operating point toward the MPP. If ΔP is negative, the system operating point has moved away from the MPP, and the algebraic sign of the perturbation should be reverse to move back toward the MPP [21]. The advantages of P&O algorithm are simplicity and ease of implementation. The P&O MPPT algorithm which is shown in fig.1 has been implemented in MALAB to track maximum power from the solar PV module.

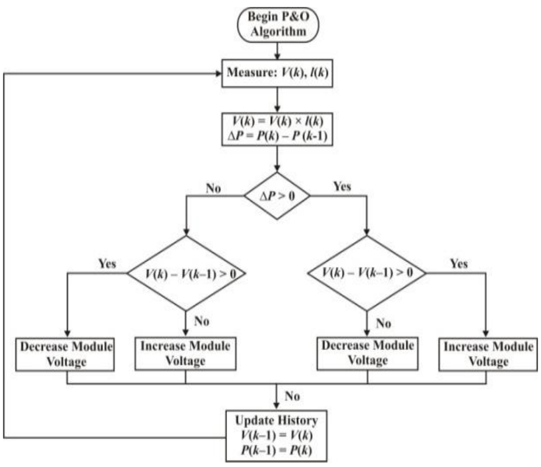


Fig. 1. Flowchart of the P&O algorithm

4. PV Module and MPPT

The PV cell converts energy in the photons of sunlight into electricity by means of the photoelectric phenomenon found in certain types of semiconductor materials such as silicon and selenium [1].

PV module characteristics are comprehensively discussed in [1], [4], [8] [18], [36], [37], which indicate an exponential and nonlinear relation between the output current and voltage of PV module. The main equation for the output current Io of a module is [8], [38]

$$I = I_{sc} - I_o(e^{q(V+I\times Rs)/nkT} - 1) - \frac{(V + I \times Rs)}{Rp}, \qquad (5)$$

where: I_{sc} is the short-circuit current that is equal to the photon generated current, I_o is the reverse saturation current of diode (A); q is the electron charge (1.602×10^{-19}C); V is the voltage across the PV cell (V); k is the Boltzmann's constant (1.38×10^{-23} J/K); T is the junction temperature in Kelvin (K). n is known as the idelity factor and takes the value between 1 and 2. R_s and R_p are series and parallel resistance respectively.

Since a single PV cell produces an output voltage of less than 1 volt, it is necessary to string together a number of PV cell in series and parallel to achieve a desired output voltage. Generally, 36 cells in series will provide a large enough voltage to charge a 12 volt battery, and 72 cells would be suitable for a 24 volt battery. For simulation the BP SX 150S PV module, which contains 72 cells, was chosen in this paper. The electrical parameters are tabulated in table 1, and the resultant curves [38] are shown in Fig. 2 and 3. It shows the effect of varying weather conditions on MPP (shown by * on various irradiances) location at *I-V* and *P-V* curves.

Table 1. Parameters of BP SX 150S Solar Module (G_O = 1KW/M^2, 25^{O}C)

Electrical Characteristics	BP SX 150S
Maximum Power (P_{max})	150W
Voltage at P_{max} (V_{mp})	34.5V
Current at P_{max} (I_{mp})	4.35A
Warrented minimum P_{max}	140W
Short-circuit Current (I_{sc})	4.75A
Open- Circuit Voltage (V_{oc})	43.5V
Temperature coefficient of I_{sc}	$0.065 \pm 0.015\%/^0$C
Temperature coefficient of V_{oc}	− 160 +20 mV/^{0}C
Temperature coefficient of Power	− 0.5 ± 0.05%/^{0}C
NOCT	47 ± 2 ^{0}C
Max. System Voltage	600V

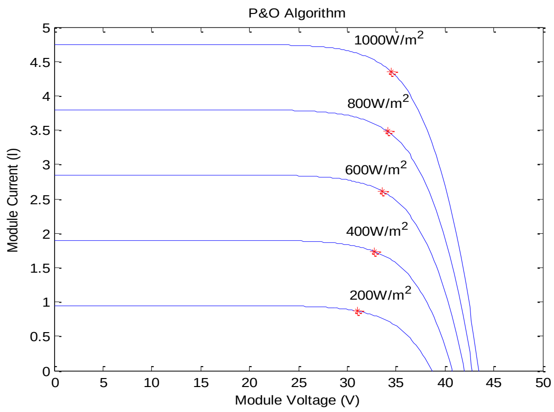


Fig. 2. I-V curves for P&O algorithm at various irradiances

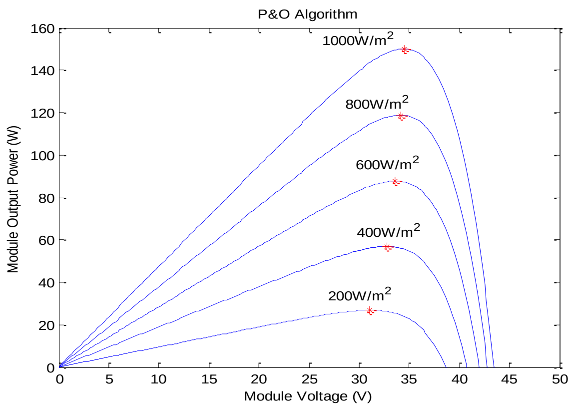


Fig. 3. P-V curves for P&O algorithm at various irradiances

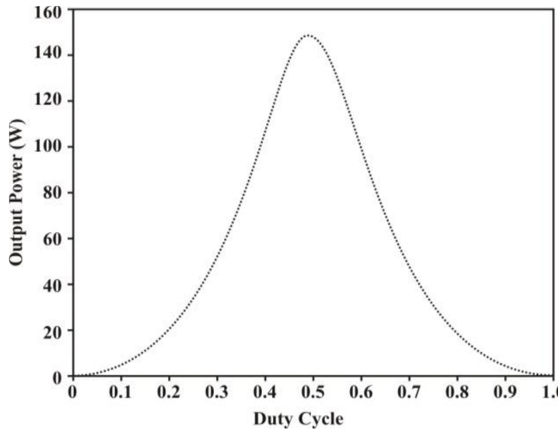


Fig. 4. Output power of Cuk converter vs. Its duty cycle (1KW/m^2, 25^{o}C)

5. Direct Control Method

Cuk converter topology is the most suitable switch-mode dc to dc power converter, called a maximum power tracker, used to maintain the PV module's operating point at the MPP [25], [28]-[30]. Cuk converter has low input current ripple, suitable to implement a system capable of measuring the I-V curve of PV module (from open-circuit-voltage to short-circuit current).

The output sensing method measures the power change of PV at the output side of converter and uses the duty cycle as a control variable [1]. The MATLAB simulation illustrates the relationship between the output power of converter and its duty cycle. In the simulation, BP SX 150S PV module [31] is coupled with the ideal (loss-less) Cuk converter with a DC submersible solar pump. The duty cycle of converter is swept from 0 to one with 1% step [3], and the output power of converter is plotted in fig. 4 [32]. As shown in the fig. 4, there is a peak of output power when the duty cycle of converter is varied. This control method employs the P&O algorithm to locate the MPP [25]-[27]. Fig. 5 shows the flowchart of P&O algorithm for the output sensing direct control method. In order to accommodate duty cycle as a control variable, the P&O algorithm used here is a slightly modified version from that previously introduced [32] but the idea how it works is the same. The algorithm perturbs the duty cycle and measure the output power of converter. If the power is increased, the duty cycle is further perturbed in the same direction; otherwise the direction will be reversed. When the output power of converter is reached at the peak, a PV module or array is supposed to be operating at the MPP [25-30], [32]. This control method only works with the P&O algorithm and its variation, and does not work with incCond algorithm.

The direct control method which shown in fig. 6 is simpler and uses only one control loop, it performs the adjustment of duty cycle within the MPP tracking algorithm. The way to adjust the duty cycle is totally based on the theory of load matching.

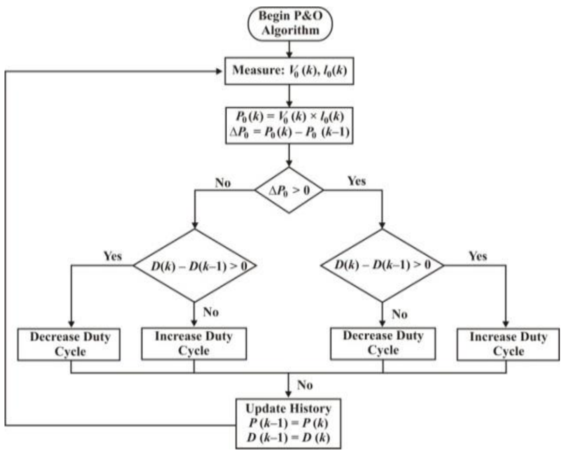


Fig. 5. Flowchart of P&O algorithm for the output sensing direct control method

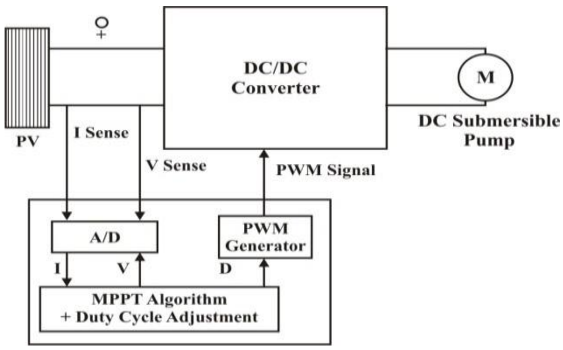


Fig. 6. Block diagram of MPPT with direct control

6. Cuk Converter

When proposing an MPPT, the major job is to chose and design a highly efficient converter, which is proposed to operate as the main part of the MPPT. The efficiency of switch-mode dc-dc converter is widely discussed in [2]. The Cuk converter has low switching losses and the highest efficiency among nonisolated dc-dc converters. It can also provide a better output-current characteristic due to the inductor on the output stage, thus, the Cuk configuration is a proper converter to be employed in designing the MPPT [1], [2], [32].

The Cuk converter and its operating modes [1], which is used as the power stage interface between the PV module and the load. The Cuk converter has two modes of operation. The first mode of operation is when the switch is closed (ON), and it is conducting as a short circuit. In this mode, the capacitor releases energy to the output. On the second operating mode when the switch is open (OFF), the diode is forward-biased and conducting energy to the output. Capacitor C1 is charging from the input [1].

The relation between output and input currents and voltages are given in the following [1], [32], [33]:

$$V_s = -\frac{1-D}{D}.V_o \tag{1}$$

$$I_o = -\frac{1-D}{D}.I_s \tag{2}$$

Where V_s and V_o are the input and output voltages of the Cuk converter respectively, I_s and I_o are the input and output currents of the Cuk converter respectively, D is the duty cycle (0 < D < 1). Some analysis of Cuk converter specifications are provided in [34], and comparative study on different schemes of switching converters is presented in the literature [35]. The duty cycle (D) for the Cuk converter used in simulation was selected as 0.1 < D > 0.6.

7. Mechanism of Load Matching

PV is directly coupled with a DC submersible solar pump; the operating point of PV is dictated by the load. The impedance of the pump is described as below

$$R_{load} = \frac{V_o}{I_o} \tag{3}$$

Where: V_o is the output voltage, and I_0 is the output current.

The optimal load for PV is described as:

$$R_{opt} = \frac{V_{MPP}}{I_{MPP}} \tag{4}$$

Where: V_{MPP} and I_{MPP} are the voltage and current at the MPP respectively. When the value of R_{load} matches with that of R_{opt}, the maximum power transfer from PV to the load will occur. These two are, however, independent and rarely matches in practice. The goal of the MPPT is to match the impedance of load to the optimal impedance of PV. From the equation (1) and (2), the input impedance of the converter is:

$$R_{in} = \frac{V_s}{I_s} = \frac{(1-D)^2}{D^2}.\frac{V_o}{I_0} = \frac{(1-D)^2}{D^2}.R_{load} \tag{5}$$

As shown in fig. 7, the impedance seem by PV is the input impedance of the converter (R_{in}). By changing the duty cycle (D), the value of R_{in} can be matched with that of R_{opt}. Therefore, the impedance of the load can be anything as long as the duty cycle is adjusted accordingly.

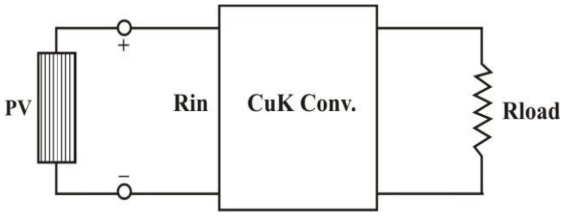
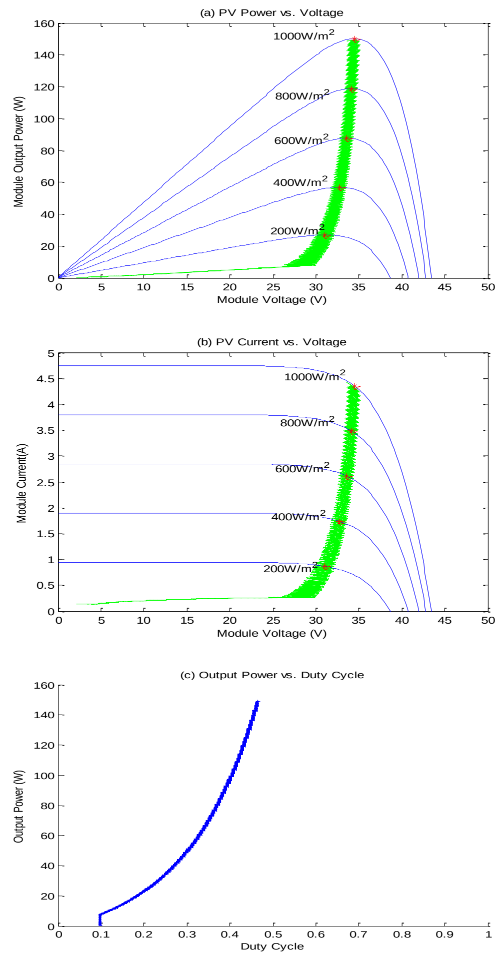


Fig. 7. The impedance seen by PV is R_{in} that is adjustable by duty cycle (D)

8. Simulation Results

The direct control method is implemented with P&O algorithm using Cuk converter and the simulation is performed under the linearly increasing irradiance varying from 200W/m^2 to 1000W/m^2. Fig. 10(a) and (b) of the *P-V* and *I-V* curves which shows that the trace of operating point is staying close to the MPPs during the simulation. Fig. 10(c) shows the relationship between the output power of converter and its duty cycle, the maximum output power is 150W at duty cycle (D) = 4.5. Fig. 8(d) shows the current and voltage relationship of converter output. Since the load is DC submersible pump, the current and voltage increase linearly with the slope of *1/R_{load}* on the *I-V* plane. It shows that maximum output current is 5A at 30V. The curve of flow rate of submersible pump vs time is shown in Fig. 8(e) which shows that in the starting the flow rate increases with time and then constant at 12L/hr.



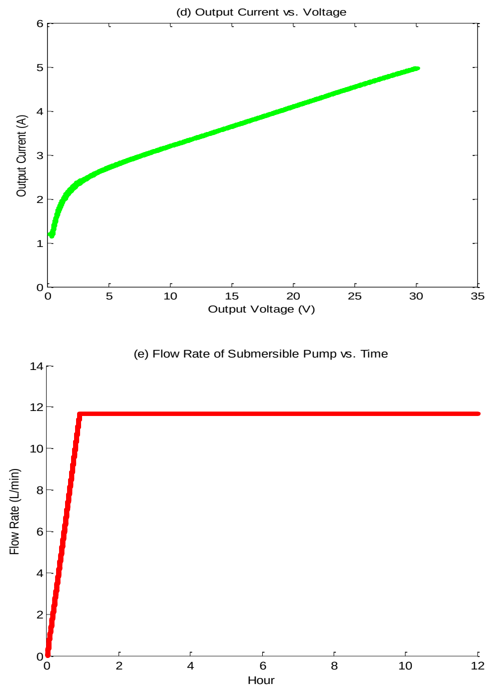


Fig. 8. MPPT Simulation of DC submersible pump with direct control method (P&O algorithm)

9. Conclusion

In recent years it is very important to concentrate on renewable energy resources. In renewable energy resources solar energy is most reliable and cheap in cost. In power system, it is important to get optimum power from the system.

The DC submersible pump is very useful for pumping ground water for irrigation in the rural areas where lack of electricity.

In this paper the authors concentrate the method which is helpful to get MPP. In recent years the P&O (MPPT) algorithm plays vital role to achieve MPP. Hence in this paper direct control method (P&O algorithm with duty cycle adjustment) is implemented.

Simulation results of DC submersible solar pump are obtained using MATLAB simulation for different values of irradiance by adjusting duty cycle of the dc-dc converter (Cuk converter). It is observed that the curves obtained by direct control method are better than simple P&O algorithm for PV module.

References

[1] Azadeh Safari and Saad Mekhilef, “Simulation and hardware implementation of incremental conductance MPPT with direct control method using Cuk converter,” IEEE Trans. on Ind. Electron., vol. 58, no. 4, pp. 1154-1161, April 2011.

[2] R.-J. Wai, W.-H. Wang, and C.-Y. Lin, “High-performance stand-alone photovoltaic generation system,” IEEE Trans. Ind. Electron., vol. 55, no. 1, pp. 240-250, Jan. 2008.

[3] W. Xiao, W. G. Dunford, P. R. Palmer, and A. Capel, “Regulation of photovoltaic voltage, ” IEEE Trans. Ind. Electron., vol. 54, no. 3, pp. 1365-1374, Jan. 2007.

[4] N. Mutoh and T. Inoue, “A control method to charge series-connected ultra electric double-layer capacitors suitable for photovoltaic generation systems combining MPPT control method,” IEEE Trans. Ind. Electron., vol. 54, no. 1, pp. 374-383, Feb. 2007.

[5] R. Faranda, S. Leva, and V. Maugeri, MPPT Techniques for PV System: Energetic and Cost Comparison. Milano, Italy: Elect. Eng. Dept.Poliecnico di Milano,2008, pp.1-6.

[6] Z. Yan, L. Fei, Y. Jinjun, and D. Shanxu, “Study on realizing MPPT by improved incremental conductance method with variable step-size,” in proc. IEEE ICIEA, Jun. 2008, pp. 547-550.

[7] M. Buresh, Photovoltaic Energy System: Design and Installation. New York: McGraw-Hill. PP. 335, 1983.

[8] Jing Jun Soon and Kay-Soon Low, “Photovoltaic model identification using particle swarn optimization with inverse barrier constraint,” IEEE Trans. on Power Electrn., vol. 27, no. 9, Sept. 2012.

[9] F. Liu, S. Duan, F. Liu, B. Liu, and Y. Kang, “A variable step size INC MPTT method for PV system,” IEEE Trans. Ind. Electron., vol. 55, no. 7, pp. 2622-2628, Jul. 2008.

[10] F. M. Gonzalez-Longatt, “Model of photovoltaic module in Matlab,” in 2do congreso iberoamericano de estudiantes de ingenieriacute; a electrica, electronic y computacion, ii cibelec, 2005, pp. 1-5.

[11] A. K. Abdelsalam, A. M. Massoud, S. Ahmed, and P. N. Enjeti, “High performance adaptive perturb and observe MPPT technique for photovoltaic-based microgrods,” IEEE Trans. Power Electron., vol. 26, no. 4, pp. 1010-1021, Apr. 2011.

[12] Y. H. Ji, D. Y. Jung, J. G. Kim, J. H. Kim, T. W. Lee, and C. Y. Won, “A real maximum power tracking method for mismatching compensation in PV array under partially shaded conditions,” IEEE Trans. Power Electron., vol. 26, no. 4, pp. 1001-1009, Apr. 2011.

[13] L. Zhang, W. G. Hurley, and W. H. Wolfle, “A new approach to acieve maximum power point tracking for PV system with a variable inductor,” IEEE Trans. Power Electron. Vol. 26, no. 4, pp. 1031-1037, Apr. 2011.

[14] L. Zhou, Y. Chen, and F. Jia, “New approach for MPPT control of photovoltaic system with mutative-scale dual-carrier chaotic search,” IEEE Trans. Power Electron., vol. 26, no. 4, pp. 1038-1048, apr. 2011.

[15] S. Chun and A. Kwasinski, “Analysis of classical root-finding methods applied to digital maximum power point tracking for sustainable photovoltaic energy generation,” IEEE Trans. Power Electron., vol. 26. No. 12, pp. 3730-3743, Dec. 2011.

[16] T. L. Nguyen and K. S. Low, "A global maximum power point tracking scheme employing DIRECT search algorithm for photovoltaic system," IEEE Trans. Ind. Electron., vol. 57, no. 10, pp. 3456-3467. Oct. 2010.

[17] S. L. Brunton, C. W. Rowley, S. R. Kulkarni, and C. Clarkson, "Maximum power point tracking for photovoltaic optimization using ripple-based extremum seeking control," IEEE Trans. Power Electron., vol. 24, no. 10. Pp. 2531-2540, oct. 2010.

[18] C. Hua, J. Lin, and C. Shen, "Implementation of a DSP controlled photovoltaic system with peak power tracking," IEEE Trans. Ind. Electron., vol. 45, no. 1, pp. 99-107, Feb. 1998.

[19] T. Noguchi, S. Togashi, and R. Nakamoto, "Short-current pulse-based maximum-power-point tracking method for multiple photovoltaic-and-converter module system," IEEE Trans. Ind. Electron., vol. 49, no. 1, pp. 217-223, Feb. 2002.

[20] N. Mutoh, M. Ohno, and T. Inoue, "A method for MPPT control while searching for parameters corresponding to weather conditions for PV generation systems," IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1055-1065, Jun. 2006.

[21] N. Femia, G. Petrone, G. Spagnuolo, andM. Vitelli, "Optimization of perturb and observe maximum power point tracking method," IEEE Trans. Power Electron., vol. 20, no. 4, pp. 963-973, Jul. 2005.

[22] N. Femia, D. Granozio, G. Petrone, G. Spagnuolo, andM. Vitelli, "Predictive & adaptive MPPT perturb and observe method," IEEE Trans. Aerosp. Electron. Syst., vol. 43, no. 3, pp. 934-950, Jul. 2007.

[23] E. Koutroulis, K. Kalaitzakis, and N. C. Voulgaris, "Development of a microcontroller-based, photovoltaic maximum power point tracking control system," IEEE Trans. Power Electron., vol. 16, no. 1, pp. 46-54, Jan. 2001.

[24] A. Pandey, N. Dasgupta, and A. K. Mukerjee, "Design issues in implementing MPPT for improved tracking and dynamic performance," in Proc. 32nd IECON, Nov. 2006, pp. 4387-4391.

[25] M. Vaigundamoorthi and R. Ramesh, "ZVS-PWM active-clamping modified Cuk converter based MPPT for solar PV modules," European Journal of Scientific Research, vol. 58, no. 3, pp. 305-315, 2011.

[26] Joe-Air Jiang, Tsong-Liang Huang, Ying-Tung Hsiao and Chia-Hong Chen, "Maximum Power Tracking for Photovoltaic Power Systems" Tamkang Journal of Science and Engineering, Vol. 8, No 2, pp. 147-153, 2005.

[27] Trishan Esram, Patrick L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques" IEEE Trans. on energy conversion, vol. 22, no. 2, pp.439-449, June 2007

[28] Durán,E J., Galán, M., Sidrach-de-Cardona, Andújar J.M, "Measuring the I-V Curve of Photovoltaic generators-analyzing different dc -dc converter topologies" IEEE ind. Eelectron. magazine, pp.4-14, Sept. 2009

[29] Tse,K.K., Ho,M.T., Henry S.-H., Chung., Ron Hui,S.Y, "A Novel Maximum Power Point Tracker for PV Panels Using Switching Frequency Modulation" IEEE Trans. on power Electron., vol. 17, no. 6, pp .980-989, Nov. 2002.

[30] Henry Shu-Hung Chung., Tse,K.K., Ron Hui,S.Y., Mok,C.M.,Ho,M.T, "A Novel Maximum Power Point Tracking Technique for Solar Panels Using a SEPIC or Cuk Converter" IEEE Trans. on power electron., vol. 18, no. 3, pp.717-724. May 2003.

[31] BP Solar BP SX150S - 150W Multi-crystalline Photovoltaic Module Datasheet, 2001.

[32] Akihiro Oi, "Design and simulation of photovoltaic water pumping system," Sept. 2005.

[33] Taufik, EE410 Power Electronics I - Lecture Note Cal Poly State University, San Luis Obispo, 2004

[34] D. Maksimovic and S. Cuk, "A unified analysis of PWM converters in discontinuous modes," IEEE Trans. Power Electron., vol. 6, no. 3, pp. 476- 490, Jul. 1991.

[35] K. K. Tse, B. M. T. Ho, H. S.-H. Chung, and S. Y. R. Hui, "A comparative study of maximum-power-point trackers for photovoltaic panels using switching-frequency modulation scheme," IEEE Trans. Ind. Electron., vol. 51, no. 2, pp. 410-418, Apr. 2004.

[36] I.-S. Kim, M.-B. Kim, and M.-J. Youn, "New maximum power point tracker using sliding-mode observer for estimation of solar array current in the grid-connected photovoltaic system," IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1027-1035, Jun. 2006.

[37] W. Xiao,M. G. J. Lind,W. G. Dunford, and A. Capel, "Real-time identification of optimal operating points in photovoltaic power systems," IEEE Trans. Ind. Electron., vol. 53, no. 4, pp. 1017-1026, Jun. 2006.

[38] M. K. Gupta, Rohit Jain, "Design and simulation of photovoltaic system using advance MPPT", International Journal of Advance Technology & Engg. Research, Vol. 2, pp. 73-76, July 2012

[39] Kyocera Solar Inc. Solar Water Pump Applications Guide 2001