A MODEL BASED MAXIMUM POWER POINT TRACKER FOR PHOTO VOLTAIC GENERATOR

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ABSTRACT

In this paper a method that forces a Photo Voltaic Generator (PVG) to operate on its maximum power point under variable load and insolation contidions is introduced. The method based on the closed loop current control, in which the reference current is determined from the fitted function of I_{mpp} versus P_{max} points of a particular PVG. In the paper, a simplified computer model of the PVG is given, computer simulations for demonstrating the effectiveness of the proposed algorithm are presented. Method has been also practically realized by using a PC with IO interface card in the laboratory environment. From the results of the simulations and experimental studies, it was concluded that proposed approach can be used as a robust and fast acting maximum power point tracker.

I. INTRODUCTION

Among other alternative energy sources for electricity production, wind and solar energy systems become more attractive in recent years. For the areas where electricity is not available, stand alone wind and solar systems have been increasingly used. Since in some provinces wind is not adequate to produce required amount of electrical energy, either wind-solar or pure solar systems are the only and environmental friendly way of electric generation. A PVG consists of number of solar cells connected as series and parallel units depending on the required Power, Voltage and Current ratings. Although their prices are decreasing, the PVG systems still require expensive investments. Therefore it is very important to extract as much as possible energy from a PVG system . A PVG can only be used efficiently when it operates on its optimum operating point. Since the operating point of a PVG - load system depends on the load, irradiance and temperature, it is almost impossible to utilize the available solar energy in varying load and atmospheric conditions trough an uncontrolled system. It is a crucial problem to force PVG system to operate on its optimum operating point, therefore various solutions presented in the literature. The simplest maximum power tracking algoritm is to operate the PVG under constant voltage reference [1]-[2] and to use a step up or down type dc to dc converter which keeps PVG voltage constant. This algoritm is based on the assumption of that the operating voltage at the maximum power points is independent of the insolation and the temperature. Although it is simple and requires only voltage measurement, some loss of available power is unavoidable in such systems.

Perturbation and observation method is another algorithm which is used in maximum power tracking. It is based on periodically changing the operating point and observing the resultant change in power. This algorithm may cause continuous oscillations around the optimum point and may cause instabilities and power loss. It is a slow acting algoritm and may not response properly for instance rapid load and irradiation changes [5].

Another algoritm is based on the searching of operating point which makes $dP/dV = 0$. Since the sign of dP/dV gives the direction of the search it is possible to determine maximum operating by continuously detecting PVG power and voltage [5]-[7].

Presented system uses a step down type DC-DC converter to control the operating point of PVG. The voltage and current of the PVG is continuously monitored and the average power is calculated. Calculated power is used as the argument of the pre-determined $I_{mpp}=f(P_{max})$ function and a current reference is obtained. A PI type controller adjusts the duty cycle of the DC-DC converter . The zero error is reached when the current and power of the PVG are equal to the pre-determined values of I_{mpp} and P_{max} . Any change on the insolation and load results a disturbance on the tuned system and PI controller again brings the system to its optimum operating point. Since system is not based a search algorithm there is no risk of instability or hanging on a local maximum points.

II. MODELING AND SIMULATION OF THE SYSTEM

The external characteristic of a solar cell gives current dependent voltage variation. This characteristics is given as [1]-[5],

$$V = -R_s I + \frac{1}{\Lambda}\ln\left(1+\frac{(I_p - I)}{I_o}\right). \qquad (1)$$

Where V is the cell voltage, I is the load current, R_s is the resistance in series, Λ is the cell constant, I_p is the photocurrent and I_o is the reverse saturation current. The characteristic of an array which consists of a number of series and parallel connected cells is also given in the form of (1) with different numerical values. The typical V-I characteristics of a PVG is given in Fig. 1.

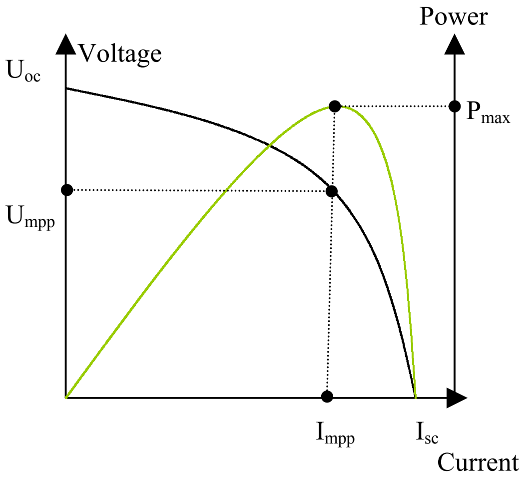

Fig. 1. Typical V-I and P-I characteristics of a PVG.

For a particular load and PVG, which is modeled at certain irradiance and temperature conditions, three distinct operating points can be encountered. In Fig.2. these three points are shown. The optimum load line which is labeled as L_{opt} results in a point of Q_{opt}, enables the operation of the panel at its maximum power. Lines L_1 and L_2 are two arbitrary load lines that result in operating points Q_1 and Q_2. On the points other than Q_{opt}, the power which is extracted from PVG may be significantly lower. Inspecting points Q_1 and Q_2, it can be said that, the slope of the load line L_2 is very small and draws too much current to drop voltage very low level (close to short circuit), whilst the load L_1 doesn't draw sufficient current to load the PVG (close to open circuit). Beside the variations on load, the variations on the irradiance level result in different operating points. In Fig. 3. the situation, in which the same load line results in different operating points due to change in insolation is shown. Although the load is optimal for a irradiance level, decrease of the irradiance level results a new operating point which is deviated from the new maximum power point. In Fig. 3. the typical loci of the local maximum power points are also shown. The aim of a maximum power point tracking system is to ensure the PVG to operate on points which are located on these curved trace.

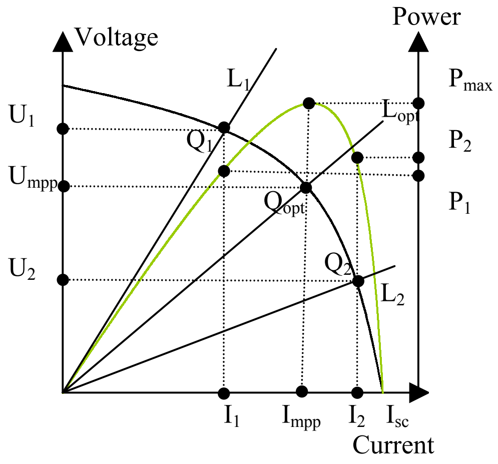

Fig. 2. Three possible load lines and corresponding operating points.

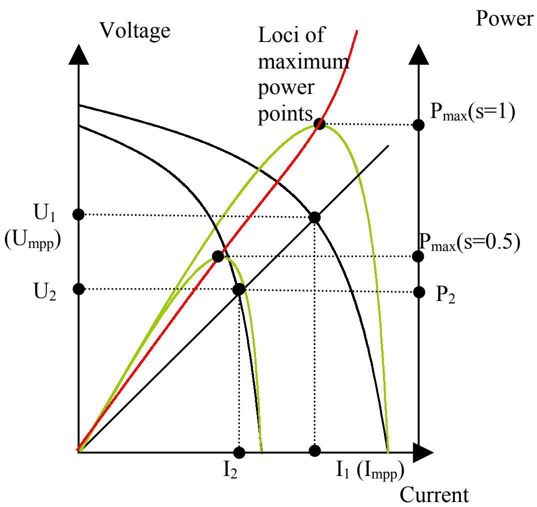

Fig. 3. The effect of irradiance variation on the operating points.

As it is explained above the operating point of a PVG should be continuously adjusted in order to compensate the variations on load, temperature and irradiance level. In order to adjust the operating point of a PVG a DC-DC converter is used. If the role of a DC-DC converter is to match the PVG to the load in any possible case, then a converter, which is able to operate in both step up or step down mode, is required. However, it is difficult to design a dc-dc converter, which operates efficiently in either boost or buck mode. In general the system is so planned that, even under the extreme case, the load line should intersect the PVG external characteristic close to short circuit current, then a simple and efficient step down type converter can match the PVG to load under all possible circumstances. For an ideal DC-DC buck converter, averaged input and output currents and voltages are related as ,

$V_{out}= V_{in}\,\lambda$ (2)
$I_{out} = I_{in} / \lambda.$ (3)
$R_y= V_{out}/I_{out}$ (4)
$R_y'=V_{in}/I_{in}$ (5)
$R_y'=R_y/ \lambda.^2$

Where
R_y : Load resistance,
R_y' : PVG side referred load resistance,
λ : duty cycle of the switch.

According to eq. (5) Any load can be referred to the PVG side as the optimal load line by changing the duty cycle of the DC-DC buck type converter. In the modeling and simulation of the system, the external characteristics of the PVG is modeled by a linearly interpolated three point look up table, instead of exponential equations. The approximate three point linearly interpolated characteristic is shown in Fig.5. The overall model of the proposed MPPT system is shown in Fig.6. In order to adjust the duty cycle of the switch, the average power of the panel should be continuously monitored. Note that, due to the fact that the current and voltage are both fluctuate, the average power should be calculated by the averaging of the product of instantaneous voltage and current values of the PVG.

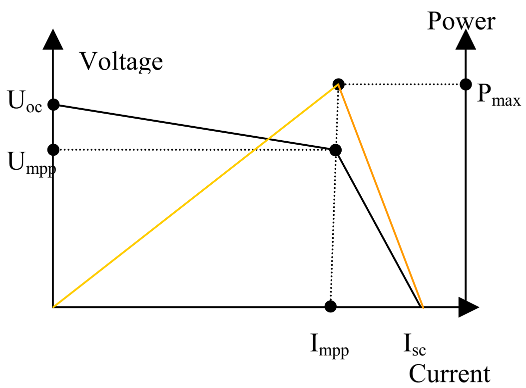

Fig.5. Approximated three point linearly interpolated external characteristic of a PVG

The power, which is obtained by this calculation, is used as the argument of a functional of $I_{mpp}=f(P_{max})$ in order to obtain the reference current for the PVG. The reference current is compared with the actual average current and the error is processed by a PI controller. For a specific radiance level, the zero steady state current error is reached only if the operating point is optimum. Since this process is independent of the load and irradiance variations, the optimum point is reached on different duty cycles as the load and the radiance change.A large buffer capacitor is required in order to limit the voltage fluctuations due to switching. Beside this, if no capacitance is used, the instantaneous load current never increases over the short circuit current value of the PVG and therefore average current can not be brought to optimal level.

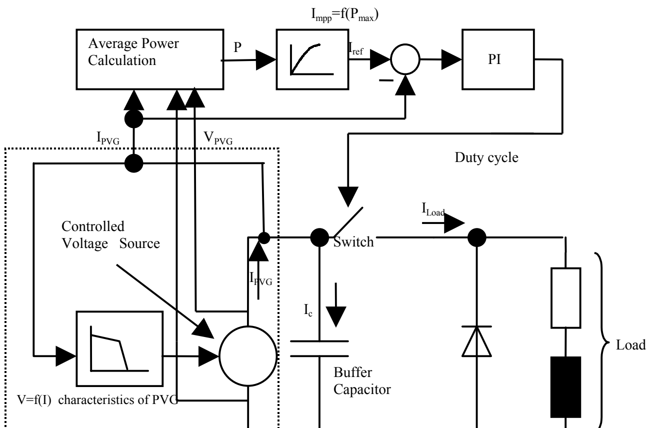

Fig.6. Model for the computer simulation of the proposed system.

In Fig.7. how the system reaches the optimum point is graphically explained.

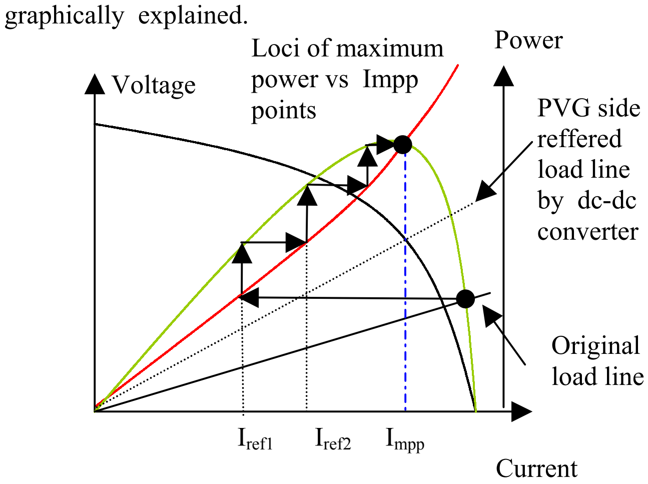

Fig.7. Reaching the optimum operating point by reference current adjustment.

The most important step of the design is either experimental or analytical determination of the maximum power and Impp values of a particular PVG for a series values of irradiance levels. For this study this estimation is based on the approximation of constant fill factor and insolation dependent per cent efficiency reduction of a typical solar cell [1],[2]. The name plate data of the 129 W SCHUCO PV panel are used.

$$P_{tip}(s)= P_{tip}(s=stc)\ \Delta\eta(s)\ s. \qquad (6)$$

Where ;

s : Relative insolation (percent of 1000 W/m^2),

$\Delta\eta(s)$: Relative efficiency of solar cell (relative to 1000W/m^2),

$P_{tip}(s=stc)$: Name plate tip power of a solar cell at "Standart Test Conditions " 25°C and 1000 W/m^2.

Then by using constant fill factor which is defined as,

$$FF= (U_{mpp}I_{mpp})/(U_{oc}I_{sc}), \qquad (7)$$
$$P_{max}(s) = P_{tip}(s)\ FF, \qquad (8)$$
$$U_{mpp}(s) = P_{max}(s) / I_{mpp}(s), \qquad (9)$$
$$U_{oc}= P_{tip}(s)/I_{sc}(s), \qquad (10)$$

are obtained

The estimated V-I curves and the trace of maximum power versus current points are shown in Fig.8. By using curve fitting technique, the mathematical relation between maximum power points and currents can be expressed as a second order polynomial which is given as,

$$I_{mpp} = (-3.93\ 10^{-6}P_{max}^{2}+0.05095\ P_{max}+0.287) \quad (11)$$

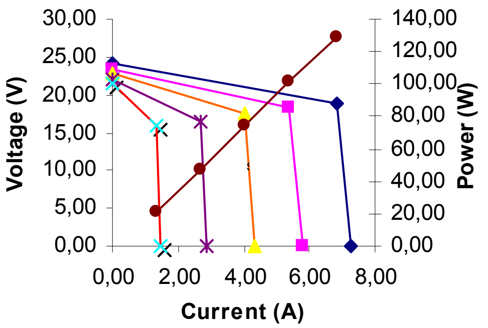

Fig.8 Estimated irradiance (200 W/m^2-1000 W/m^2) dependent external characteristics of the particular PVG and loci of P_{max} points.

In order to demonstrate the effectiveness of the proposed algorithm, some simulations are made. In the first simulation study, the effect of rapid irradiance variation is simulated. At the beginning the PVG is modeled at 1000 W/m^2, then insolation rapidly reduced to 500 W/m^2. The load is the series connected 1Ω resistive load and 1 mH inductor. 3 kHz switching frequency and 1000uF buffer capacitor values are used. . The duty cycle is set to "0" and overall system is started from natural initial conditions.

The first transient, which is shown in Fig.9 a) is the result of inrush charging current of buffer capacitor, which creates a momentary short circuit condition for the PVG. After the capacitor voltage is increased up to the open circuit voltage of the PVG, current reference algorithm starts to tune of the PVG operating point. The PI controller brings the system into the optimal point after a couple oscillations and the steady state is then reached. In the steady state it is shown that the average current of the PVG is very close to its optimal value of 6.8 A. At time 0.048 s, insolation level decreased to 500 W/m^2, it is shown that after a short transient panel current is adjusted to the new optimal value, which is 3.4 A for this insolation level.

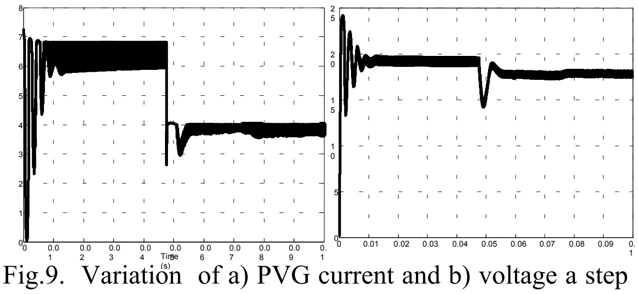

Fig.9. Variation of a) PVG current and b) voltage a step change of insolation.

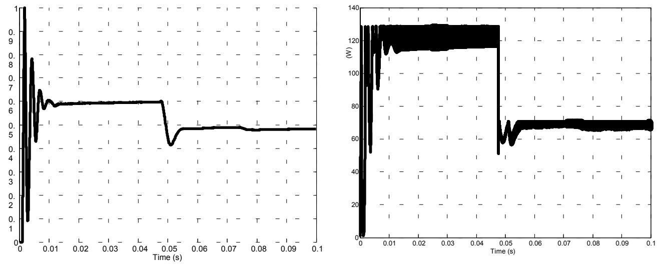

Fig.10. Variation of a)duty cycle and b)power for a step change on insolation.

The variation of PVG voltage is shown in Fig. 9 b). Similar to the current, the voltage also varies during the tuning of PI controller. The steady state average values are close to optimal voltage values which are 18.9 V for 1000 w/m^2 and 17.5 V for 500 W/m^2 respectively. Another variation, which demonstrates the efficient maximum power tracking ability of the method, is shown in Fig.10 a). The duty cycle of the switch rapidly changes as the insolation changes. Second simulation study is made to demonstrate the response of the proposed method to rapid load changes. For this purpose, the load, which is initially 0.67 Ohm, is switched to 1 Ohm at 0.05 s. Figures 11. and 12 are given in the same order of the previous simulation. Since variation of load should not change the operating point of the PVG, the results are as expected. After a short transient PVG current, voltage and power variations remain unchanged. The change on the duty cycle of the switch is demonstrates that method is able to keep PVG operating point independent of the load variations.

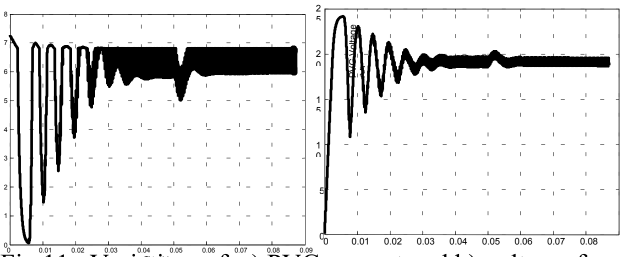

Fig.11. Variation of a) PVG current and b) voltage for a step change of load.

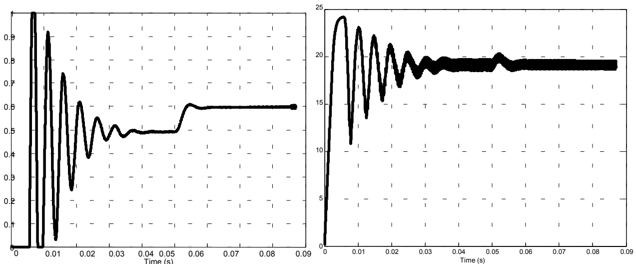

Fig.12 Variation of a) duty cycle and b) power for a step change on load.

3. Experimental Study

Beside the simulations given above, an experimental study has been made in order to see the practical validity of the method. Experimental set up is shown in Fig. 13. In the experimental system a 100 Mhz Pentium PC with a Bytronic IO interface card for data acquisition was used. The IO card has 8 channel 8 or 12 Bit ADC and programmable timers which were used to measure current and voltage and to control the PWM of the power switch. The power switch was a IRF 2807 type MOSFET. PVG voltage was sensed by a simple voltage divider and the current was sensed by hall effect type LA 55P (manufactured by LEM) current sensor. As a filter 1 mH inductor was added to the load which consists of a variable number of auto lamps. 4700 uF 40 V electrolytic capacitor was used as a buffer. 5 kHz switching frequency is selected.

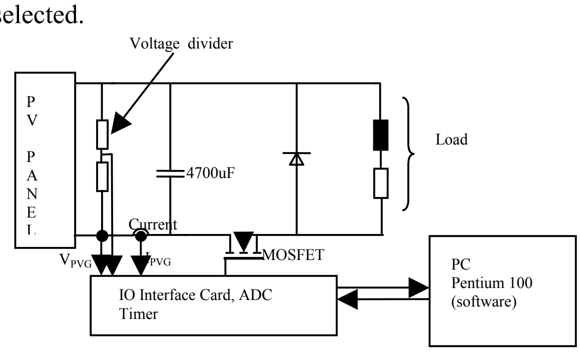

Fig. 13. Experimental setup.

The operational performance of the system is good enough to demonstrate the validity of the proposed algorithm. It was determined that the load type has no practical effect upon the implementation of the algorithm provided that the uncontrolled operating point results a current higher than I_{mpp} under all conditions. The only practical problem was the difference of the theoretical and measured values of the open circuit voltage of the PVG It was mainly because of the excessive PVG temperature during the experiments which increased about 45-50 ^oC. The maximum open circuit voltage for this temperature was about 22 V, which was 10% lower than the rated value (24.2 V) given in name plate for 25 ^oC. Consequently, the maximum power which was 129 W for 25^oC, has dropped down to 110 Watts. Since the current - power curve was estimated from the nameplate data of the PVG, a re-tuning during the experiments was required. This tuning has been made by multiplying I=f(P) function by a correction term such as 1.1-1.15 in order to get the maximum power due to voltage drop.

The experimental study has been repeated over the hours, both in cloudy and clear sunny days and it is demonstrated that the operation points are always very close to points which are determined by duty cycle scanning from 1 to 0. It must be noted that small deviations due to temperature changes is unavoidably occurred during the early in the morning and late in the afternoon times.

4. Results and Discussion

A MPPT algorithm proposed and tested by simulations and experimental setup. It is concluded that the method is able to track rapidly irradiance changes and it is robust against the load changes. Since the algorithm is based on neither a type of search nor perturbation & observation methods, it is very fast and causes no oscillation around the operating point. Temperature compensation of the method will be the subject of the future works.

5.References

[1] Akbaba, M., Qamber, I., Kamal, A., 1998. Matching of separately excited DC motors to photovoltaic generators for maximum power output. Solar Energy 63, 375–385.

[2] Akbaba, M., 2003. Matching three-phase AC loads to PVG for maximum power transfer using an enchanced version of the Akbaba model and double step up converter. Solar Energy 75, 15-25

[3] Alghuwainem, S.M., 1992. Steady-state performance of DC motors supplied from photovoltaic generators with a step up converter. IEEE Trans. Energy Convers. EC-7, 267–272.

[4] Appelbaum, J., 1986. Starting and steady-state characteristics of DC motors powered by solar cell generators. IEEE Trans. Energy Convers. EC-1, 17–25.

[5] Hiyama, T., Kouzuma, S., Iimakudo, T., 1995. Evaluation of neural network based real time maximum power tracking controller for PV system. IEEE Trans. Energy Convers. EC-10, 543–548.

[6] Hua, C., Lin, J., Shen, C., 1998. Implementation of a DSP-controlled photovoltaic system with peak power tracking. IEEE Trans. Ind. Electron. IE-45, 99–107.

[7] Hua, C., Lin, J. 2003. An on-line MPPT algorithm for rapidly changing illuminations of solar arrays. Renewable Energy 28,1129-1142.