An investigation of new control method for MPPT in PV array using DC/DC buck – boost converter

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Abstract: - In this paper, solar radiation simulation using clearness index k_t, hour of day ω_s and day of year n is studied. Daily distributions of solar radiation are presented for various clearness indexes k_t. Additionally, taking into the studies about solar radiation, a photovoltaic array system and a DC/DC buck – boost converter are studied. Simulation of the whole system is presented focusing on DC/DC converter's control strategy so that the system operates in maximum power point (MPP) and converter's output voltage remains constant. Incremental conductance algorithm is used for maximum power point tracker (MPPT) implementation. A simplest method for controlling duty cycle D and photovoltaic array's voltage by using a new variable $d = \frac{D}{1-D}$ is proposed. Simulation results are shown and analyzed.

Key-Words: - MPPT, Photovoltaic array, Incremental conductance algorithm, solar radiation, DC/DC Converter

1 Introduction

Recent years, due to big demand of electrical energy, extended research in electricity production from solar energy using Photovoltaics (PV) has been done. Basic advantage of these energy sources is the abundance of solar radiation in nature and environmental friendly way of electricity production. Although the high cost of PV panels and their low efficiency, big PV parks have been installed in recent years around the world. Research, also has been done in increasing PV's efficiency and consequently maximizing output power. Furthermore, many papers have been published for PV's coupling with varied loads and PV's grid connection, using Power Electronics devices such as DC/DC converters and DC/AC single or three phase inverters [1], [2], [3], [4], [5]. For PV's output power maximization many algorithms have been developed and improved [13], [14], [15], such as Incremental Conductance, Perturbation and Observation (P&O), Parasitic Capacitance and Constant Voltage and Current algorithm. The most usual of these algorithms above is the Incremental Conductance one. According to this method maximum power points are detected by comparing for each step the derivative of conductance with the instant conductance. Derivative of conductance and instant one can be calculated by sensing instant PV voltage and current values and using previous.

2 Distribution of Solar Radiation

Clearness index k_t, hour angle ω_s and air mass m constitute basic parameters for solar radiation study and simulation. Air mass, m, will not be taken into account in this paper analysis.

The clearness index probability density distribution can be constructed as a mixture [12] of two normal distributions, as shown below:

$$f(k_t) = \tau \cdot f_1(k_t) + (1-\tau)\cdot f_2(k_t) \quad (1)$$

Where $f_1(k_t)$ and $f_2(k_t)$ are density functions of normal random variables:

$$f_i(k_t) = \left(2\cdot\pi\cdot\sigma_i^2\right)^{-0.5}\cdot\exp\left(\frac{-0.5\cdot(k_t-\mu_i)^2}{\sigma_i^2}\right),\ i=1,2$$

(2)

The "mixing factor" τ is equal to:

$$\tau = \frac{\left(\overline{\mu_2} - \overline{k_t}\right)}{\left(\overline{\mu_2} - \overline{\mu_1}\right)} \quad (3)$$

Where μ_1 and μ_2 are the mean values of normal distributions f_1 and f_2 respectively and $\overline{k_t}$ is the mean value of clearness index. The range of τ values is $0<\tau<1$.

Clearness index k_t is defined as the ratio of solar radiation G to extraterrestrial radiation G_{ref} as shown in (4).

$$k_t = \frac{G}{G_{ref}} \quad (4)$$

Extraterrestrial solar radiation is given by equation (5) as shown below:

$$G_{ref} = G_{SC} \cdot \left[1 + 0.033 \cdot \cos\left(\frac{360 \cdot n}{365} \right) \right] \cdot \\ \cdot \left(\cos\phi \cdot \cos\delta \cdot \cos\omega + \sin\phi \cdot \sin\delta \right) \quad (5)$$

Where:

G_{SC} = 1367 W/m^2 is the solar constant

ω is the hour angle

φ is the latitude

n is the day of the year (1<n<365)

δ is given by (6)

$$\delta = 23.45 \cdot \sin\left(360 \cdot \frac{284 + n}{365} \right) \quad (6)$$

Taking into account specific conditions for simulation (φ=41.08^o and n=284, which refer to Xanthi, Greece and on October 11th respectively) and using Matlab/Simulink, figures 1 to 3 presents daily distribution of solar radiation for three different values of clearness index 0.4, 0.65 and 0.8 correspondingly.

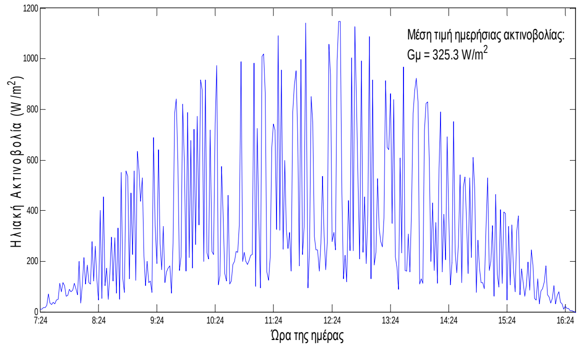

Fig.1 Daily solar radiation for k_t=0.4.

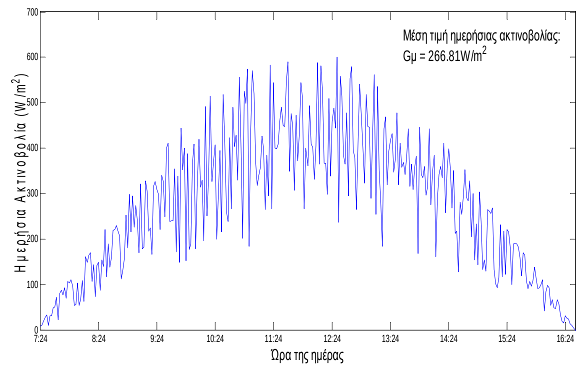

Fig.2 Daily solar radiation for k_t=0.65.

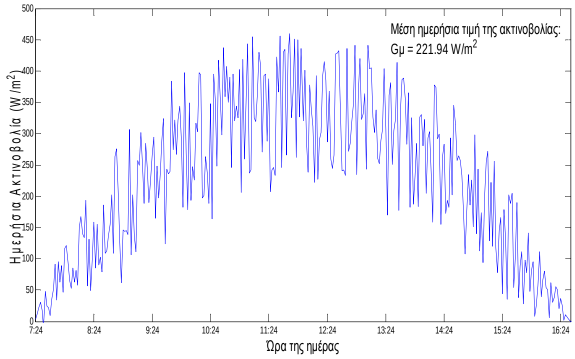

Fig.3 Daily solar radiation for k_t=0.8.

3 Mathematical Model of PV

The simplest equivalent circuit of PV cells consists of a current source in parallel with a diode as shown in Fig. 4.

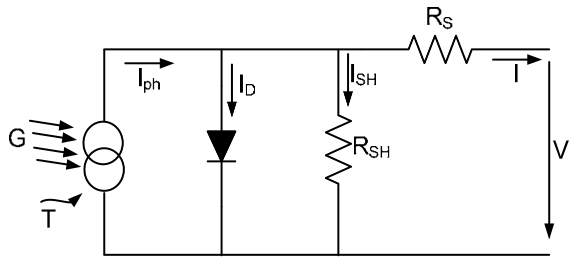

Fig. 4 Equivalent circuit of PV

Photo current I_{ph} is directly proportional to solar radiation G. Temperature T and photo current I_{ph} have a linear relationship according to equation (7), where $I_{ph(Tref)}$ is the photo current which corresponds to reference temperature T_{ref}, and is equal to (8) K_o is a constant given by (9) and T is the temperature. In equation (8) and (9) G_{ref} is the nominal radiation given by PV's constructor I_{SC} is the short circuit current.

$$I_{ph} = I_{ph(T_{ref})} \cdot \left(1 + K_o \cdot \left(T - T_{ref} \right) \right) \quad (7)$$

$$I_{ph(Tref)} = \frac{G}{G_{ref}} \cdot I_{SC(Tref)} \quad (8)$$

$$K_o = \frac{I_{SC(T)} - I_{SC(Tref)}}{T - T_{ref}} \quad (9)$$

Diode's current is given by (10), where V and I are PV's output voltage and current correspondingly, I_o is saturation current of diode, V_T thermal voltage of it and R_S is in series resistance.

$$I_D = I_o \cdot \left[\exp\left(\frac{V + I \cdot R_S}{V_T} \right) - 1 \right] \quad (10)$$

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Current I_{SH} through shunt resistance R_{SH} according to Ohm's law is equal to:

$$I_{SH} = \frac{V + I \cdot R_S}{R_{SH}} \qquad (11)$$

Taking into account equations (7) – (11) and applying Kirchhoff's current law, it results the I –V characteristic (12) for PV cell:

$$I = I_{ph} - I_o \cdot \left[\exp\left(\frac{V + I \cdot R_S}{V_T} \right) - 1 \right] - \frac{V + I \cdot R_S}{R_{SH}}$$

(12)

Analyzing (12) for s PV panels in series and p in parallel and ignoring current through shunt resistance, equation (13) gives the general I – V characteristic for PVs. Equation (14) gives the output power of PV cells.

$$I = p \cdot I_{ph} - p \cdot I_o \cdot \left[\exp\left(\frac{V + I \cdot \left(\frac{s}{p} \right) \cdot R_S}{s \cdot V_T} \right) - 1 \right]$$

(13)

$$P = V \cdot I \qquad (14)$$

4 MPPT Algorithm

Incremental Conductance algorithm is based on differentiation of PV power to its voltage and on condition of zero slope of P – V curve in maximum power point (MPP). Especially, differencing PV power and replacing power with equation (14), arises equation (15).

$$\frac{dP}{dV} = \frac{d(V \cdot I)}{dV} = I \cdot \frac{dV}{dV} + V \cdot \frac{dI}{dV} = I + V \cdot \frac{dI}{dV}$$

(15)

From equation (15) and taking into account the basic condition of zero slope of P –V curve equation (16) is deduced.

$$\frac{dP}{dV} = 0 \Rightarrow I + V \cdot \frac{dI}{dV} = 0 \Rightarrow -\frac{I}{V} = \frac{dI}{dV} \qquad (16)$$

–I/V represents the opposite of instant conductance of PV cells and dI/dV the incremental conductance. According to (16) these two quantities must be equal in MPP. Moreover, in the right of MPP is $dI/dV < -I/V$, thus a reduction in PV's voltage is essential to achieve MPP. Similarly, in the left of MPP is $dI/dV > -I/V$, thus an increase in PV's voltage is essential to achieve MPP. These changes in PV's voltage may be done by coupling a DC/DC converter to PV and controlling properly its duty cycle, D. Most common used DC/DC converters in MPPT are the buck and boost, due to easy way of duty cycle control.

In this paper is presented a tracker for MPP using a buck – boost DC/DC converter (fig. 5) which is able to operate in a wide range of output voltages and different loads demands. Equation (17) gives the basic relationship between input and output voltage of this converter.

$$V_{out} = \frac{D}{1 - D} \cdot V_{in} \qquad (17)$$

As shown of (17), duty cycle is not support directly a linear relationship between V_{out} and V_{in}. This means that a linear change in duty cycle D, will not imply for example a linear change of V_{in} for keeping V_{out} constant.

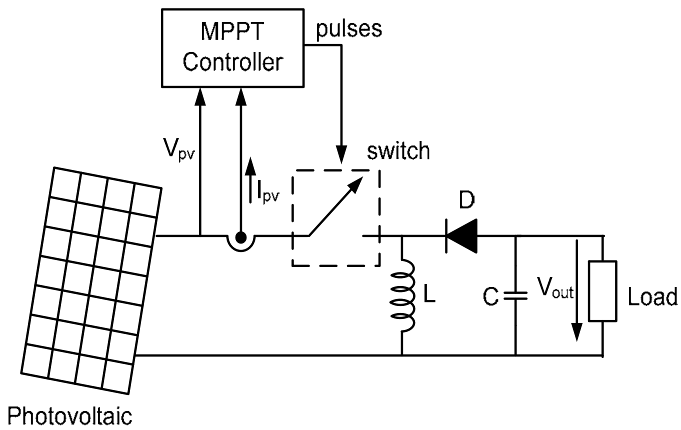

Fig. 5 Buck Boost DC/DC converter using for MPPT

Thus, in this paper is proposed an alternative way of PV's voltage control for achieving MPP. A new variable is defined as shown in (18).

$$d = \frac{D}{1 - D} \qquad (18)$$

By using this new variable, d there is a linear relationship between the two voltages. So, in algorithm implementation using Matlab/Simulink, it is essential to control and change only d and not the actual duty cycle, D.

Flow chart in fig. 6 shows the whole operation of Incremental Conductance algorithm. In each algorithm cycle, d is calculated using the instant value of duty cycle, D and after this d is changed properly. Finally, new value of D is calculated again using the new value of ratio d and switch is driven.

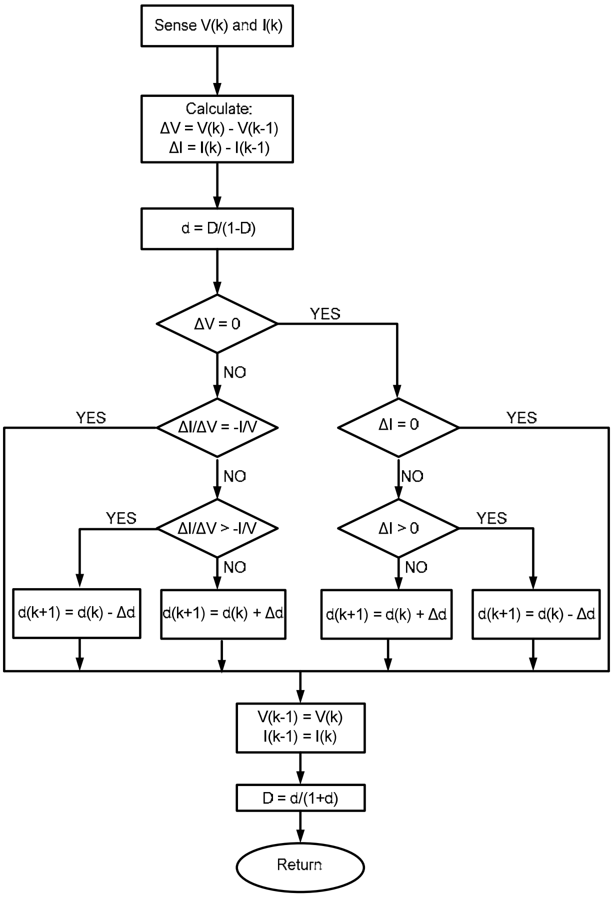

Fig. 6 Flow Chart of the MPPT algorithm

5 Simulation Results

For whole system simulation is used Matlab/Simulink and especially SimPowerSystems Toolbox.

Before system implementation it is necessary to calculate the appropriate values of inductor and capacitor, by using equations (19) and (20), on condition of non – intermittent inductor current and capacitor voltage ripple vary in particular limits.

$$\frac{\Delta V_O}{V_O} = \frac{D \cdot T}{R \cdot C} = \frac{D}{R \cdot C \cdot f} \qquad (19)$$

$$L_{min} = \frac{R}{2 \cdot f} \cdot (1 - D)^2 \qquad (20)$$

Making use of these two equations, driving the switch with a frequency of 20 KHz and taking into account a percent of tolerance, these values were calculated as follows:

L = 330μH and C = 220μF.

The whole system simulation has been done for a gradual change of solar radiation from 400 W/m^2 to 500 W/m^2, as shown in fig. 7.

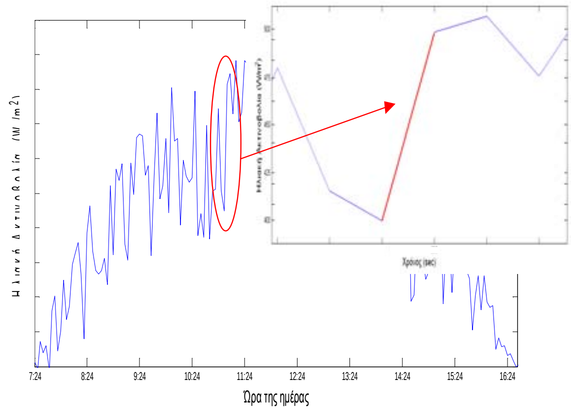

Fig. 7 Gradual change of solar radiation from 400 W/m^2 to 500 W/m^2, using for system simulation.

Taking into account three different values of d change, Δd (Δd = 0.0005, 0.001 and 0.01), and keeping the sampling time for A/D converters, which measure instant values of voltage and current, constant and equal to 0.5 ms, figures 8 to 10 presents MPPT's operation.

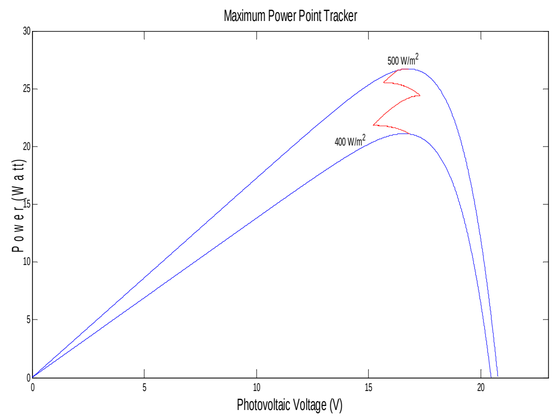

Fig. 8 MPPT's operation for Δd = 0.0005 for a gradual solar radiation change and sampling time 0.5 ms.

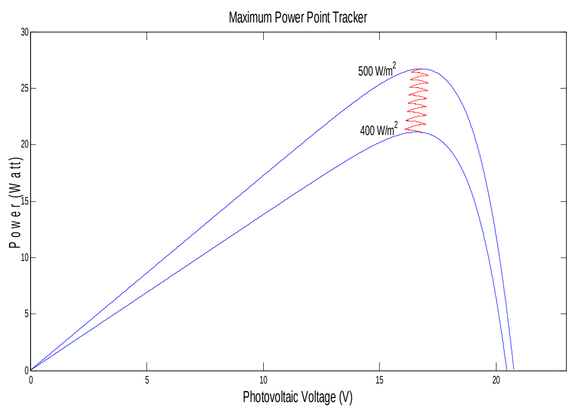

Fig. 9 MPPT's operation for Δd = 0.001 for a gradual solar radiation change and sampling time 0.5 ms.

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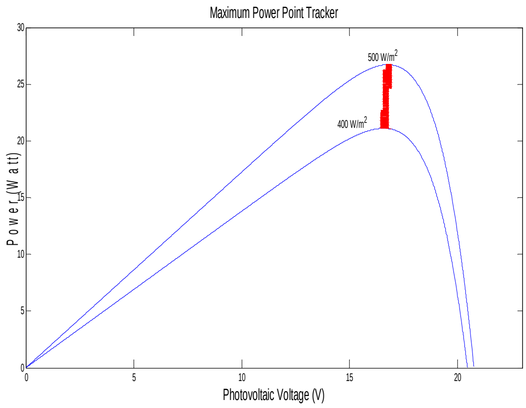

Fig. 10 MPPT's operation for Δd = 0.01 for a gradual solar radiation change and sampling time 0.5 ms.

Figure 11 shows a comparison between MPPT's operation for the three different variations, Δd.

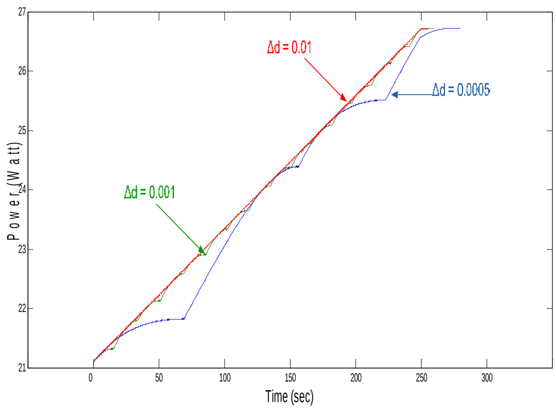

Fig.11 Comparison between tracker's operation for different Δd variations.

From fig. 11 is shown that the bigger Δd variation is used, the more linear operation of tracker occurs. Especially for very small values of Δd, such as Δd = 0.0005, extensive ripple is existed, which is undesirable.

Furthermore, simulation of the system has been done for different sampling times (T_S = 0.5ms, 1ms and 2.5ms) for A/D converters with constant variation Δd. Δd is taken equal to 0.001, due to the fact that this value of Δd variation gives a small ripple as shown with green color in fig. 11. Figures 12 and 13 present simulation results for conditions quoted above. Curve for T_S = 0.5ms and Δd = 0.001 is the same as fig. 9.

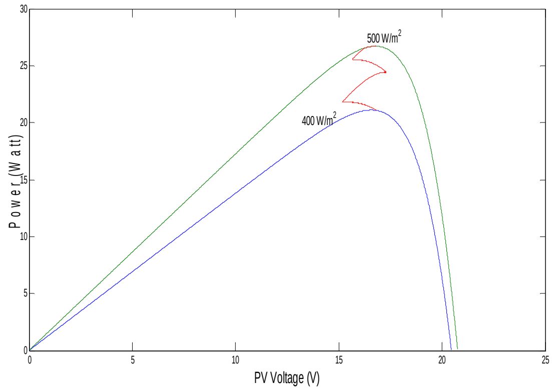

Fig. 12 MPPT's operation for T_S = 1ms for a gradual solar radiation change as shown in fig. 7 and Δd = 0.001.

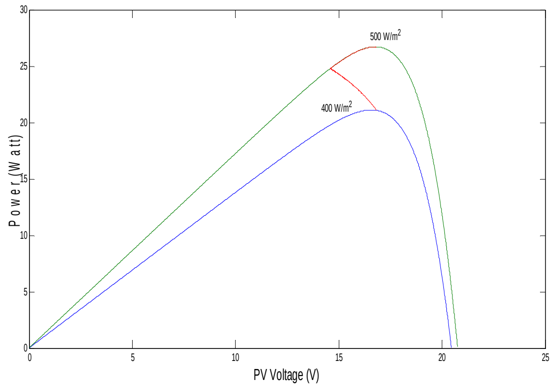

Fig. 13 MPPT's operation for T_S = 2.5ms for a gradual solar radiation change as shown in fig. 7 and Δd = 0.001.

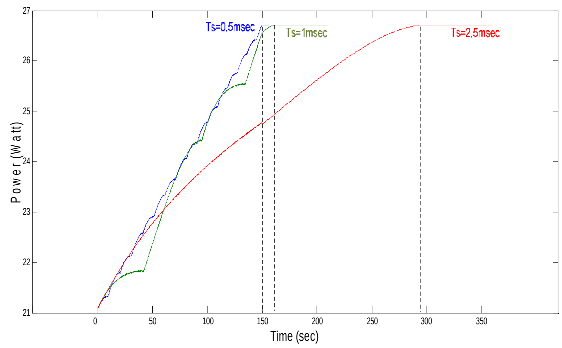

Fig.14 Comparison between tracker's operation for different sampling times T_S for A/D converters.

A comparison study between three different sampling time conditions with constant variation Δd, is resulted figure 14. In this figure is shown the big difference in time for achieving MPP. Especially, the red line represents sampling time 2.5 ms and the time for achieving MPP is far bigger than the other two cases. Operation for achieving MPP for T_S = 0.5 ms and T_S = 1 ms (blue and green lines in fig. 14) needs about the same time, but operation for T_S = 1 ms occurs some ripple.

6 Conclusion

From this paper is concluded that it is necessary to occur a linear variation Δd of d and not of D (Duty Cycle). Moreover, it is proved that according to a gradual change of solar radiation, as variation Δd is increased, the maximum power point approach is getting smoother. Moreover, a small sampling time for measuring voltage and current of PV is necessary for reducing MPP's achieving time. Generally, it is essential to make an appropriate choice for variation Δd and sampling time T_S of A/D channels. Thus, undesirable ripples during MPPT's operation will be eliminated and MPP will be achieved faster.

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