Optimizing solar panel energetic efficiency using an automatic tracking microdetector

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Abstract: - Increasing energetic efficiency of solar power plants implies high technological and scientific efforts every year. A significant efficiency increase of these systems can be also obtained by optimal exposure of the panels to the sunlight, by using automatic solar trackers. For wide scale use of these control systems, it is very important to find reliable and low cost solutions. In the current paper we propose a low cost tracking procedure, based on amplitude comparison method and a special signal microdetector, made with MEMS technology. The procedure permits simple rotations of the panel based on complete tracking, by azimuth and elevation. The possible regulation angle is in the range of 30 -150°.

Key-Words: - photovoltaics, efficiency, optimisation, automatic, orientation, tracking, control, microdetector, MEMS

1. Introduction

The generation of the renewable energy was important due to oil, gas and carbon resources limitation. But in the present time, the climatic changes due to CO_2 emission makes research into renewable energy generation very actual, particularly into photoelectric (PV) energy.
The price of the PV equipment is still high: about 5$/W for solar panels (polycrystalline Si) and about 10$/W for small and medium systems with conversion DC/AC . The price is the main limitation in the wide use of this clean energy.
In the near future the rise of the classical energy prices and the critical ecological aspects like
greenhouse effect, will increase the financial governmental support for PV power plants and for home use of the solar panels, especially in EU and Japan. In some application, like water pumping in agriculture, the use of the small solar panel will be the main solution.
The Si solar cell efficiency is near the theoretical maximum. So it's possible to obtain a significant efficiency growth of the DC part of the PV systems by optimal orientation of the solar panels.
So, the simple solution of SP optimal orientation are very important.

2. Solar panels orientation - advantages and disadvantages

There are 2 type of solar panels: the fixed SP usually used in home applications and the orientable SP used in PV power plants and the other professional applications.
A comparison in efficiency for the 2 types of SP can be made by applying the first Lambert Law regarding radiation power dependence of the incident angle:
$m = I \, dS \, d\omega \cos i$
where:- dS-elementary surface of the radiant tell
- $d\omega$ – elementary angle
- i - the incident angle of the received radiation

We can consider isotropic the solar radiation over Earth atmosphere . In this case, use of the average radiation power of the Sun over the Earth atmosphere M_0 = 1370 W/m^2 allows to eliminate the dependence of solid angle in initial form of law and to consider a finite receiving surface (Fig.1):

$$M=M_0 S_0 \cos i \quad (1)$$

where S_0 =1m^2 , and M is the receiving power on the unity surface in condition of zero reflectance of the surface and zero absorbance of the atmosphere.

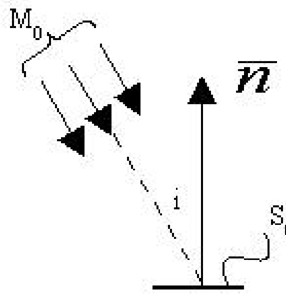

Fig.1 Radiation power with incident angle i

For the small and medium PV systems the most cost-effective option is the seasonal manual adjustement in elevation and single axis automatic tracking (E-W).

When a SP is fully orientable E-W, e.g. in the range of 0-180^0 , the solar radiation is all the time normal on the surface of the solar cells, and $M=M_0$, the maximum (ideal) value.

For the fixed SP we can consider the change of the incident angle across the average day (on the Equinox). In this case the average radiation power received on the S_0 will be:

$$M_A = \frac{1}{\pi} M_0 \int_{-\pi/2}^{\pi/2} \cos i \cdot di = \frac{2}{\pi} M_0 = 0.64\, M_0 \quad (2)$$

In the real case the losses are bigger than 36% because of the variable atmospheric absorption during the day. We can estimate this effect correcting the integral's limits. If the day at the Equinox have 12 hours we will consider zero the radiation during the first and the last hours, when the atmospheric thickness is biggest:

$$M_A = \frac{1}{\pi} M_0 \int_{-5\pi/6}^{5\pi/6} \cos i \cdot di = \frac{1.93}{\pi} M_0 = 0.61 M_0 \quad (3)$$

So we can estimate a 40% losses of the incident energy in the case of fixed SP. This is a very significant resource an it's reasonable to use it in all the applications.

The main limitation of the trackers use are:

- the price of the vertical trackers are high because of the complicate mechanical structure and of associate electronics (for heavy conditions of work).
- SP with large regulation angle must be protected against strong wind
- orientable SP need more space to avoid the reciprocal shadow

It's important to find the simple, low cost and reliable solutions for wide use of orientation systems

3. Proposed detector and orientation method

There are a 2 type of automatic trackers for small and medium SP: with electronic control and with electro-mechanical control.

In the first case, the detectors of the solar radiation are a solar cells, thermoresistors or thermistors. Two devices are connected in a differential circuit: device no.1 receive radiation from East deviation at Sun direction and device no.2 receive radiation from West deviation at Sun direction. When the SP is oriented to the Sun, the signals from detectors are equal end no error signal. In all other situations the error signal command a reversible motor to eliminate the deviation and to follow the sun movement.. The detectors are mounted in the same plan like SP and it's possible to use the mirrors to modify the light beam direction. For return to initial position (to East) of the SP can be used the clock or the separate light detector.

In the actual solar power plants the trackers are computer controlled by azimuth and by elevation.

The orientation of SP's are very precise in each moment of the day.
The electro-mechanical detectors are bimetal devices and they use the thermal effect of the radiation. The regulation have small precision and big delay. This type of devices don't work at the negative temperature of the ambient also.
We propose an electronic differential detector consisting of 5 solar cells in one package, like in the figure 2.

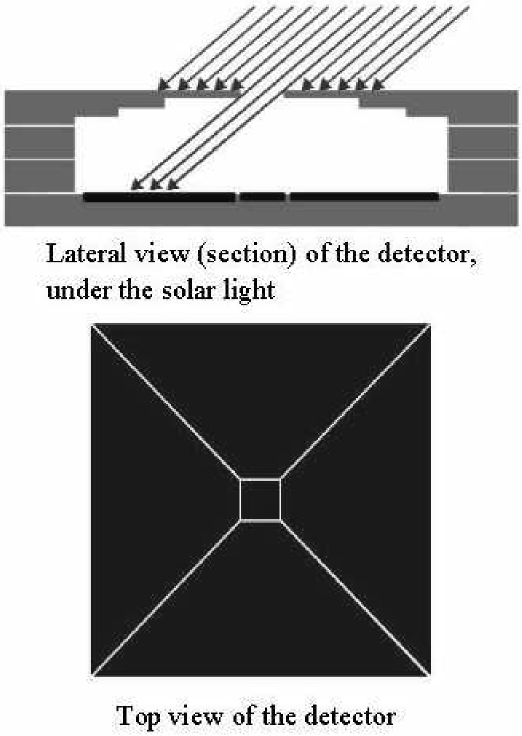

Fig.2 Structure of proposed detector

The package is made in MEMS technology, the structure is symmetrical and the cells have one common terminal (will be connected to the ground) and the second terminal is independent.
This detector allows the SP to be orientated to the angle bisector of the 90^0 angle.
We consider I_i the output signal (current) of the cell no.i. There are 4 different situations (see table no.1). In the angular sectors 1 and 4 one cell receives the Sunlight only. In the angular sectors 2 and 3 one the received by cells radiation power is different. In the direction of the angle bisector of. the 90^0 angle, the light power is identical and $I_1 – I_2 = 0$.

Table 1

	sect. 1	sect. 2	sect. 3	sect. 4	OO_1
I_0	> 0	> 0	> 0	0	> 0
$I_1 - I_2$	+	+	-	-	0
$I_3 - I_4$	+	+	-	-	0

The proposed detector structure have some main advantages:
1.The sensibility is very good in the regulation region: the variation of the cosine function of i is near it's maximum at 45° .
2. The regulation angle is 120°. For plan detectors, it's necessary to use additional optical systems (mirrors) to obtain this range of regulation.
3.The hysteresis of this detector is null for small
deviations from the regulation line O-O1 , if the cells are identical.
4. There are a very simple solution for the "return to the East" of SP, using 2 our detectors.

The drivers for DC reversible motors need a voltage input signal.
The simple differential converter in Fig.3 have the output voltage Uε positive for the East deviation of Sun direction from OO1 line; for the West deviation, Uε will be negative.
We assume that the detector in fixed with mounting base in the plan of the SP.

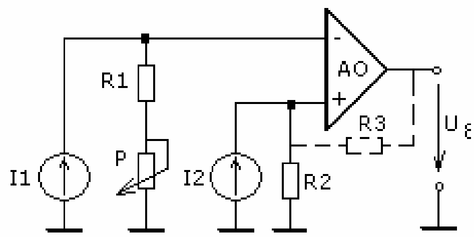

Fig.3 Converter $(I_1 – I_2)$ / Uε for a differential detector

The resistor R_3 allows the system to have a small hysteresis around regulation line if necessary; potentiometer P is for the balance of differential structure in the case the cells

are not identical.
The output voltage of the cells in 2 different detectors can have small differences. The serial resistors reduce the resulted offset.

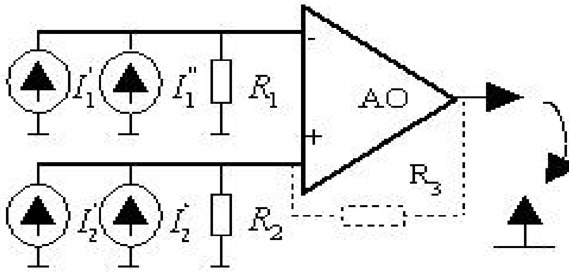

Fig.5 Converter $\Delta I / U_\varepsilon$ *for two detectors*

The value of angle β depends of maximum tracking angle of the SP. Usually, a solar cell doesn't work properly when the incident angle "i" is bigger then 75^0 (or the complementary angle is 15^0, regarding cell surface).For example, for the tracking angle of $\delta = \pm 60^0$ it is necessary to have the minimum value $\beta = 30^0$. The general formula is:

$$\beta_{min} = (\delta - 45^0) + 15^0$$

The proposed detector is useful especially for home and business applications, when the PV system are mounted on the plan roof of the building.

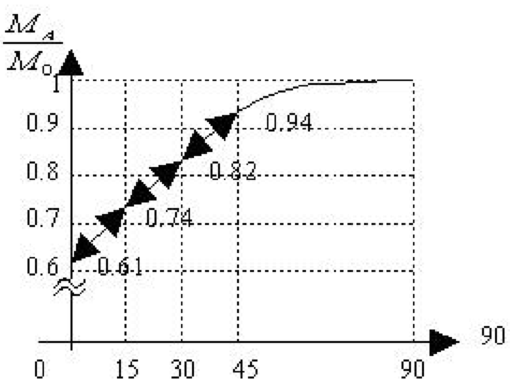

Fig.6 Mean received radiation power versus tracking angle

We can estimate the optimum tracking angle δ in the terms of efficiency-cost. The equations (1) and (3) allow for the drawing of the curve in Fig.6 for one axis tracking East-West. We can see the angle δ bigger than 45^0 is not practical because the loss in efficiency is smaller than 6% (39% maximum in the fixed SP).
The mechanical structure of tracker can be simple for $\delta_{MAX} = 45^0$ and distance between adjacent SP are reasonable.
Using the curve in Fig.6 it is very simple to compute the value of the supplementary energy generated in case of using tracking during the life cycle of the system. This value must be bigger than the tracker cost.

4. Conclusions

An original structure is proposed for a solar radiation detector used in for orienting solar panels. The complete method for solar panels tracking is proposed (including simple original solution for "comeback to the East " of SP).
As the result of the efficiency increase evaluation for one axis tracking, are indicate practical method of regulation angle establish, in home and business application of small and medium power PV systems.

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