Optimising Solar Tracking Systems for Solar Cells

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Abstract: Solar cells are playing a role of increasing importance in household and other areas of electricity consumption. Applying solar tracking systems can increase the electric energy produced by the solar cells and enhance the overall efficiency of solar cell systems as well. The efficiency enhancing effect of the different solar tracking systems has to be investigated in the different regions of Hungary. This paper describes a preliminary optimising investigation of a tracking system planned to be installed for the solar cells operating at the Pollack Mihály (PM) Faculty of Engineering at the University of Pécs.

1 Introduction

A solar cell based electric energy production unit has been installed several years before onto the horizontal roof of a laboratory building of the Institute of Information Technology and Electrical Engineering of the Pollack Mihály (PM) Faculty of Engineering of the University of Pécs. The project has been financed jointly by the University and the regional electric utility company E.ON [1]. A tracking system is planned to be developed and operated for these solar cells. As a first step of the development the preliminary optimising investigation of a tracking system has been completed in a technological, i.e. non-financial field.

This kind of investigation needs a great amount of measurement results collected during a relatively long period. We have utilised results measured by Budapest Tech [2] and by students of our institute as well [3], [4]. Technical literature gives data about the basic considerations for solar trackers, e.g. a modification in the adjustment of the angle of 15° result very little difference in the produced power [5].

2 Experimental Procedure

Two different solar cells have been measured, one of them manufactured by amorphous (PV1) and the other with monochristalline technology (PV2). For the registration of the voltage and current values supplied by the solar cells a data acquisition system (DAS) and a PC software have been developed at the institute. The measurement layout is shown by Fig. 1. Sampling frequency can be set on DAS to fit it to the measurement period.

One of the measurement results can be seen on Fig. 2. Measurements have been performed during a cloudless period around noon. Sampling frequency has been adjusted to several seconds to get the results rather quickly. Fig. 2 shows the power given by the amorphous solar cell with a nominal power value of 60 W. Output power depends highly on the load. Considering the date and time - middle of June, half past noon - the maximum power should have been yielded from the solar cell but the load could be set only to a value with the obtained power values. The aim of the measurement was to find out the dependence of the power on the tilt angle of the solar cell.

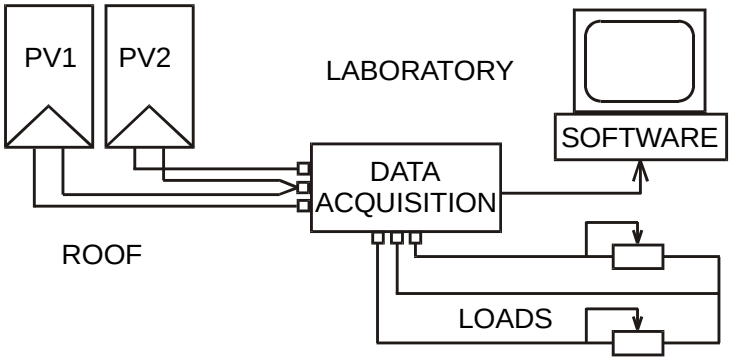

Figure 1
Measurement layout

It can be seen in Fig. 2, that the maximum power has been obtained at a tilting angle of 30° corresponding to the altitude of the sun in Southern Hungary in June. It is remarkable, that the differences of the power values are relatively small than expected by us. A reason of this phenomenon can be the use of a prismatic layer above the solar cell surface collecting peripheral radiation as well.

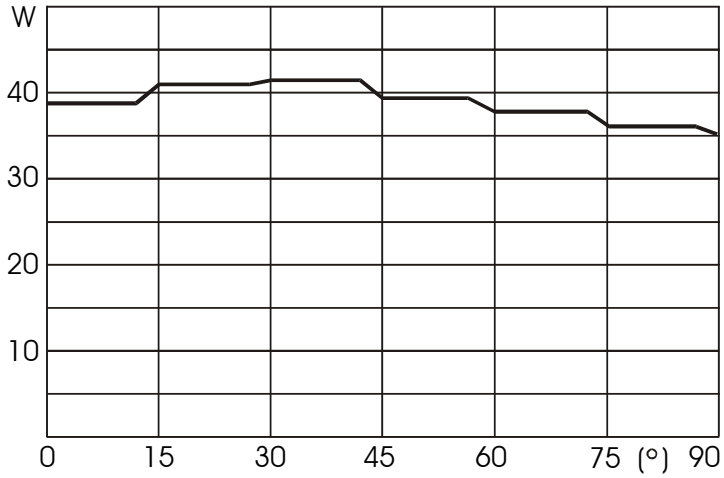

Figure 2
Power values depending on the tilt angle

These measurements comprise the basis of the optimising process of the tracking system. Other long term measurement results are necessary as well collected at Budapest Tech (BT). An example of these results can be seen in Fig. 3. The figure shows the dependence of the output power of the solar cell on the date and on the point of the compass.

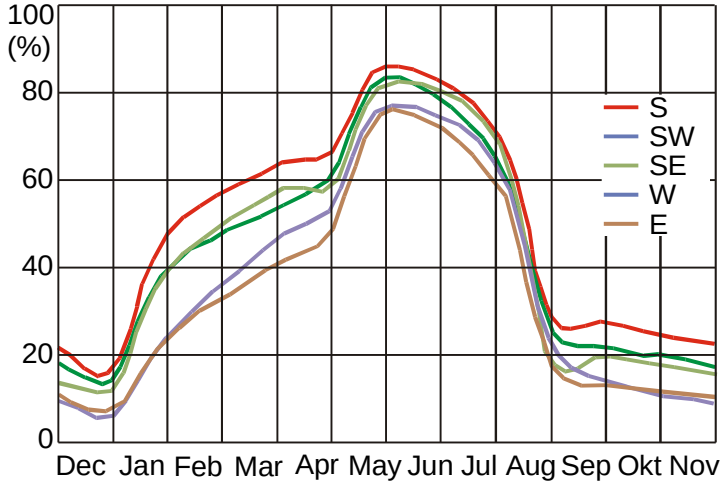

Figure 3
Power output of the solar cell depending on the season (BTC)

3 Optimising Considerations

Optimising a tracking system for solar cells is not a simple process. A great amount of considerations arise when beginning to solve this task. The considerations listed below focus on the technological layer of point of views. In the following three fields are to be find the optimum solution:

1 Mechanical structure,

2 Electric equipment,

3 Electronics / controlling programme.

During investigation the following possible basic types have been taken into account:

1 Single column structure or of parallel console type?

2 One or two moving motors?

3 Does it have light sensing device or not?

4 Does the moving structure have an autonomous energy supply of utilise an auxiliary supply?

5 Does it search for the brightest direction or move according to the calendar?

6 Continuous or step-wise movement?

7 Tracking all year or except winter?

8 Adjust only the orientation or the tilt angle as well?

3.1 Versions of the Mechanical Structure

When evaluating the versions also existing types have been taken into consideration. Versions of the mechanical structures are marked with *M* followed by the version number.

M.1 Single Column Structure

Most of the existing types belong to this group, several solar cells are moved together mounted on one single vertical column.

Advantages of this solution:

- simple mechanical structure,
- one moving unit moves higher solar cell power,
- solar cells do not shade each-other.

Disadvantages of this solution:

- wind load burdens a big solar cell surface,
- the structure is high, thus enhanced attention has to be paid to the lightning protection.

M.2 Parallel Structure - 1

The existing structure at the institute supports three solar cells and can be regarded as a parallel system. The degree of freedom of this structure equals 2, it can rotate around a vertical and a horizontal axes on the bottom. The movement around the vertical axis can be realised through a motor which can drive several similar structures with mechanical driving rods (Fig. 4).

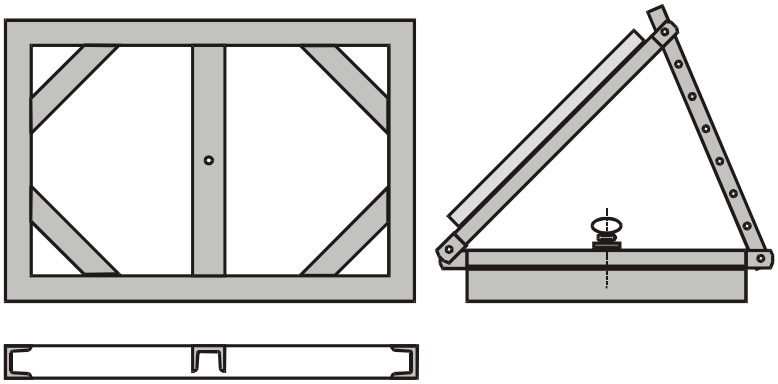

Figure 4
The existing support structure

Rotating around the horizontal axis is, due to the mechanical layout, more complicated. In case of one support rod in the middle this task could be solved more simple. The transfer of the movement is difficult to other structures. If in case of a priority of the energy production in summer this problem does not arise.

Advantages of this solution:

- more robust and stable structure, simple mechanical structure,
- not so sensible against wind load,
- not so high structure, less sensitivity against lightning.

Disadvantages of this solution:

- more complicated structure makes the rotation more complicates as well,
- in case of several structures solar cells shade each-other on mornings and evenings.

M.3 Parallel Structure - 2

A much simpler parallel structure can be realised if the solar cells have one movable joint to the support base and two motors - e.g. gate opening motors - are connected to both upper corner of the solar cells. The plane containing the solar cells can thus be moved nearly any desired direction in one space quarter (Fig. 5).

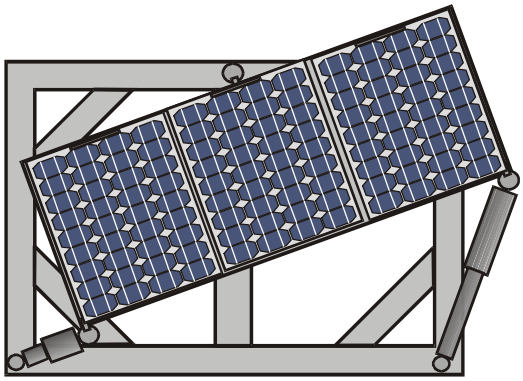

Figure 5
Simple parallel structure with two motors

Advantages of this solution:

- simple mechanical structure,
- orientation and tilt angle can be simply adjusted,
- not so sensible against wind load,
- not so high structure, less sensitivity against lightning.

Disadvantages of this solution:

- in case of several structures solar cells shade each-other on mornings and evenings,
- the structure can not be rotated directly to the directions of South and West,
- the adjustment of the plane requires relatively complicated mathematical algorithm,
- the structure is held by motors in a position, thus motors being adequate for this purpose are needed.

The reason of the third disadvantage is that the upper two points of the plane move dependently on each-other. This problem is similar to that known in case of industrial robots with parallel structure. In case of robots with series mechanical structure - most of the robots are of this kind - mathematical algorithms with

general validity are available for direct and indirect calculations. In case of robots with parallel mechanical structure similar to that of this solar tracker, a special mathematical apparatus and control programme are to be developed for nearly all different structures.

3.2 Versions of the Electric Equipment

Electric equipment having a great impact on the complexity of the control and the programme can vary as follows:

V.1 Two motors with extra light sensing.

V.2 Two motors with extra energy supply.

V.3 Single motor/solenoid without any auxiliary devices.

V.1 Two Motors with Extra Light Sensing

This is the 'full service' version if it works in winter and at night as well. This solution can be applied with all the three of the above structures.

V.1.1 Rotates to the Direction with the Highest Light Density also at Night

Preconditions of the use of this system:

- the system works autonomously - no auxiliary electricity supply available and
- the solar panels are to be dimensioned to a minimum measures (maximum efficiency) e.g. because of lack of place.

It is to be further investigated if any movement at night yields more energy than it is needed for the movement. If not then this version has no sense.

Advantages of this solution:

- maximum energy can be yielded with the PV system,
- minimum PV surface and battery capacity is needed,
- most appropriate for research purposes.

Disadvantages of this solution:

- expensive and only with the use of special devices can plus energy be achieved,
- higher maintenance requirement,
- life span of the complete system is reduced by the movements.

V.1.2 Rotates to the Direction with the Highest Light Density only Daytime

It is also a field of investigation if it pays back when the solar cells are rotated to other directions than that of the sun e.g. because of partly covered sky. The question is the same: can one gain plus energy with this measure?

Advantages of this solution:

- energy need of the movements is slightly less than in case of the previous version,
- longer life span than in case of the previous version,
- more economical,
- produces maximum energy daytime.

Disadvantages of this solution:

- expensive,
- high maintenance requirement,
- life span of the complete system is reduced by the movements.

V.1.3 Rotates to the Perfect Direction except Winter

According to long term measurements a little portion (12.5%) of the annual energy production is gained in winter [5], from the end of October till mid January. Thus if no need exists for maximum energy production in winter, it can be investigated if any movement is beneficial in this period. The period with low yield can vary according to the weather, thus an appropriate date adjustment can be investigated as well.

Advantages of this solution:

- cheaper than the previous ones,
- more simple structure,
- more economical,
- longer life span than the that of the previous ones.

Disadvantages of this solution:

- does not produce the possible maximum energy.

V.2 Two Motors with Extra Energy Supply

Subversions of this are the same as above.

V.3 Single Motor/Solenoid without any Auxiliary Devices

V.3.1 Rotates with Motor only According to the Point of Compass

Taking into consideration that in case of systems with two motors only one of the motors operates every day, the other only ones per several weeks, thus other

solutions can be used for the later purpose. Such a solution can be investigated, that the PV panels are tilted to a lower angle by the own weight of the panel in every several weeks e.g. with energising a solenoid beginning from the end of December. At the end of June in inverted process beginning e.g. by reverting a counterweight.

Advantages of this solution:

- much cheaper than the previous versions,
- much simpler structure,
- longer life span than the that of the previous ones.

Disadvantages of this solution:

- produces significantly less energy then maximum,
- requires human intervention twice a year.

V.3.2 Rotates only According to the Point of Compass

Long time investigations show, that the tilt angle has a relatively low impact on the power. Thus a version rotating only according to the point of compass can also be offered in case of which the PV panels are tilted to an angle ideal in summer - 30°.

Advantages of this solution:

- much cheaper than the previous versions,
- much simpler structure,
- longer life span than the that of the previous ones.

Disadvantages of this solution:

- produces minimum energy.

V.3.3 Rotates only According to the Point of Compass with a Counterweight

From electrical point of view the most simple layout can be achieved if the solar panels are rotated by a counterweight daytime in one direction and by the motor every evening in the other direction.

Advantages of this solution:

- the cheapest version,
- the simplest electric equipment,
- low energy need for the operation, no need for special devices,
- minimum maintenance need,
- long life span.

Disadvantages of this solution:

- produces minimum energy,
- relatively sensible mechanical equipment.

3.3 Versions of the Electronics / Controlling Programme

E.1 Light Sensing

If no light sensing is used the version is marked with *E.1.0*.

E.1 Applying Light Sensing

Advantages of this solution:

- enables the opportunity to determine the direction with highest light density,
- enables the opportunity for gaining maximum energy.

Disadvantages of this solution:

- electronics/programme have to be able to process the signal from the device,
- excess cost.

E.1.1 Phototransistors

Applying three phototransistors in three fixed directions to determine the direction with maximum light density.

Advantages of this solution:

- low dimension,
- good direction sensibility,
- optimum direction can be determined without any movement.

Disadvantages of this solution:

- auxiliary devices,
- because of its small size slight contamination can impact the result.

E.1.2 Small Solar Cell as Light Sensor

Using them the same way as the phototransistors.

Advantages of this solution:

- low dimension,
- good direction sensibility,
- optimum direction can be determined without any movement.

Disadvantages of this solution:

- auxiliary devices,
- because of its small size slight contamination can impact the result.

E.1.3 PV Module as Light Sensor

From the point of view of light sensing the least device need is posed by a version using the PV module as light sensor. However in case of certain decrease of the power the whole PV panel is to be rotated to search for the optimum direction.

Advantages of this solution:

- no extra devices needed.

Disadvantages of this solution:

- because of the dimensions of the PV panel the detection of optimum direction needs relatively high amount of energy,
- because of its textured covering layer direction sensibility of the PV module is not optimum.

E.2 Determination of Date and Time

Some of the versions mentioned above do not need any date and time measurement, however other do. Several versions have this as precondition for their operation. If no date and time measurement is applied, the version is marked with *E.2.0*.

E.2.1 DCF Receiver

DCF receivers receiving the signal from the atomic clock in Frankfurt can be purchased with relatively low cost on the market and now no licence fee is to be paid for it in Hungary.

Advantages of this solution:

- most precise solution, enables every functions mentioned above.

Disadvantages of this solution:

- extra cost,
- the program has to able to process the signal.

E.2.2 Own Time Measurement

Applying clock ICs.

Advantages of this solution:

- good solution, enables every functions mentioned above,
- lower costs than then in case of the previous version.

Disadvantages of this solution:

- extra cost,
- the program has to able to process the signal,
- lower precision in time measurement.

E.3 Movement Control

The following versions are investigated for the function of controlling the motor(s) and the possible solenoid.

E.3.1 Moving to the Direction with Maximum Light Density

For the versions V1(2) - E.1.

Advantages of this solution:

- maximum energy can be achieved,
- minimum PV surface and battery capacity.

Disadvantages of this solution:

- expensive and need for special devices,
- high maintenance need,
- shorter life span.

E.3.2 Moving According to Time Schedule

The programme shifts the PV module according to date and time.

Advantages of this solution:

- cheaper then the previous version,
- more simple,
- longer life span.

Disadvantages of this solution:

- does not produce maximum energy.

E.3.3 Rotating to Base Position Once per Day

Belongs to the version *V.2.2* operating with a counterweight.

Advantages of this solution:

- the cheapest version,
- most simple electric equipment,
- low energy need for the operation, no special devices needed,
- minimum maintenance need,
- long life span.

Disadvantages of this solution:

- produces minimum solar energy,
- sensible mechanics.

4 Choosing the Version to be Realised

Since the primary objective of the system at the institute is research work the followings constitute the basis for the choice:

- ability for the investigating most possible functions,
- ability to give most possible test data,
- easy access,
- ability for modifications.

As a result the version proposed for realisation is more than the 'full service' version as follows:

M.2 - V.1+2.1 - E.1.1-3 - E.2.1-2 - E.3.1

Mechanical version *M.2* has been chosen because this is the existing structure and every function can be realised with it. *V.1+2* means extra light detection and electric energy supply, however both extra and autonomous electricity supply will be investigated. The suffix *.1* means optimum direction all day long. Since the further investigation will focus onto the control, nearly all *E* subversions are to be tested, that is why *E.1.1-3* and *E.2.1-2* are marked. Movement control *E.3.1* is able to realise all movement functions, thus this subversion has been chosen.

Conclusions

According to the literature no solar tracking device is efficient in Northern regions like Great Britain because of the high percentage of the diffuse part of solar radiation. At least twice as much energy can be obtained with solar trackers in regions with maximum sun shine, like the Sahara. Hungary is in between, so investigations are needed to offer the optimum solar tracker version. Next step of the research will be the fabrication of the solar tracker with 'full service' and conducting measurements on it.

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