

Balázs PLESZ¹, Péter SÁGI¹ and Veronika TIMÁR-HORVÁTH¹

ENHANCEMENT OF SOLAR PANELS' POWER GENERATION BY THE USAGE OF SOLAR TRACKING

WZROST GENEROWANEJ MOCY MODUŁÓW NADAŻAJĄCYCH ZA SŁOŃCEM

Abstract: Solar energy will have a continuously rising importance in energy harvesting in the future. Despite all its potential and importance photovoltaic energy still has to be improved in some fields to become competitive with the conventional energy sources of today in large scale applications. One possibility to raise the energy produced by solar modules and panels is solar tracking. Solar tracking allows us to direct solar panels continuously in optimal position to the sun, thus improving the overall efficiency of a photovoltaic system. We calculated the theoretical possible excess energy that can be gained by application of solar tracking. Based on these preliminary calculations we designed and built a complex system using two-axis positioning and electronically realized maximum power point tracking at the same time. Thanks to the built-in radio-wave communication infrastructure it is possible to monitor, control and synchronize different trackers remotely. The extension and scalability of the system enables building solar farms consisting of dozens of individual units.

Keywords: solar tracking, two axis tracking, energy enhancement

Nowadays the importance of alternative energy sources and especially solar energy has been steadily increasing. Solar cells give the opportunity to convert the sunlight directly into electrical energy. However, the energy delivered by the solar cells depends on various factors, eg the construction and efficiency of the solar cell, the temperature and of course the intensity of the irradiated light. Even under clear weather conditions (steady amount of solar radiation) the position of the sun changes during the day, which in case of fix installed solar panels leads to changes in the effective surface of the solar panels towards the sun and a decreased output power. The optimal position is, when the solar panels are perpendicular to the light; in this case the effective surface equals to the surface of the solar panel. This optimal position can be maintained with solar tracking. Despite the fact that solar tracking enhances the generated power the cost effectiveness and pay-back time is still frequently disputed.

Types of solar tracking

Solar tracking can be performed using different solutions and types of control systems. Depending on the movement's degree of freedom two different types of tracking can be distinguished:

- one axis tracking,
- two axis tracking.

The first one has the advantage of a simpler mechanics and the necessity of a tilting mechanism for only one axis, but the rotated panels cannot follow the seasonal changes in the sun's ecliptic, unlike in case of the two axis tracking.

¹ Department of Electron Devices, Budapest University of Technology and Economics, H-1521. Budapest, Hungary, email: plesz@eet.bme.hu, peter.sagi@gmail.com, timarne@eet.bme.hu

Solar trackers can also be categorised by the type of tracking control, where they can be divided into two groups:

- passive tracking,
- active tracking.

Normally the passive trackers do not incorporate sensors or actuators, but use any physical phenomenon to position the solar panels, eg thermal expansion of gases [1]. Active trackers are systems whose motion is performed by actuators controlled by signals of a sensor. The most common types of active control are the *time* and the *intensity controlled* tracking. The first one calculates the sun position from the given geographical location and the local time; the latter one tracks the brightest spot on the sky.

Theoretical gain of solar tracking

Based on data collected in our previous long-term outdoor measurements [2] we calculated the possible excess power that could be gained by two axis solar tracking. Figure 1 shows the comparison of the electric powers delivered by fixed (45 degree inclination, faced south) and tracking installations. These calculations showed that using tracking the harvested amount of energy could be increased by more than 30% (37% for the particular day in Figure 1) and this corresponds to the energy gains experienced by some manufacturers of solar trackers [3, 4]. The tracking does not increase the peak power, but the excess energy is mainly produced in the time period, where the position of the fixed system is not optimal, eg the morning and the evening hours.

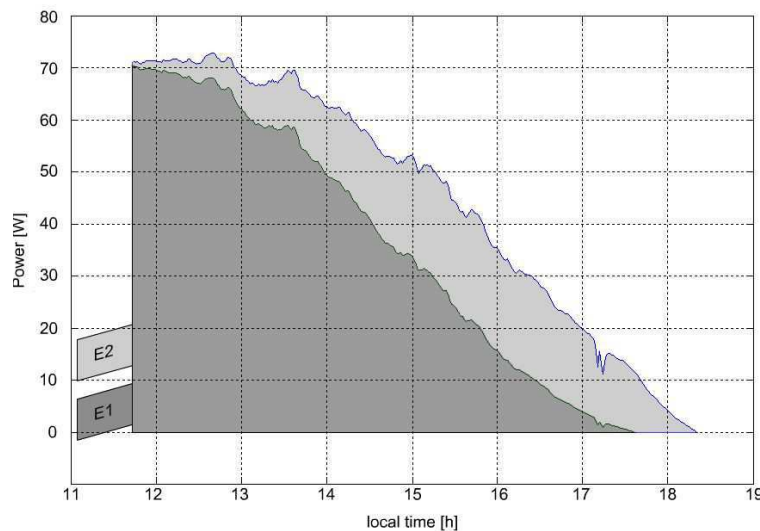


Fig. 1. Calculated energy gain during one day, $E1$ is the energy in case of a fixed module, $E2$ in case of rotated module (calculation for an 80 W monocrystalline Si module, based on data from Oct. 6th, 2006)

We also performed calculations for the yearly exploitable excess energy based on data gathered in Hungary in the year 2000 [5]. The results of the calculations are shown in

Figure 2 in monthly distribution. The calculation shows that on the average an excess power of about 33% can be gained by tracking.

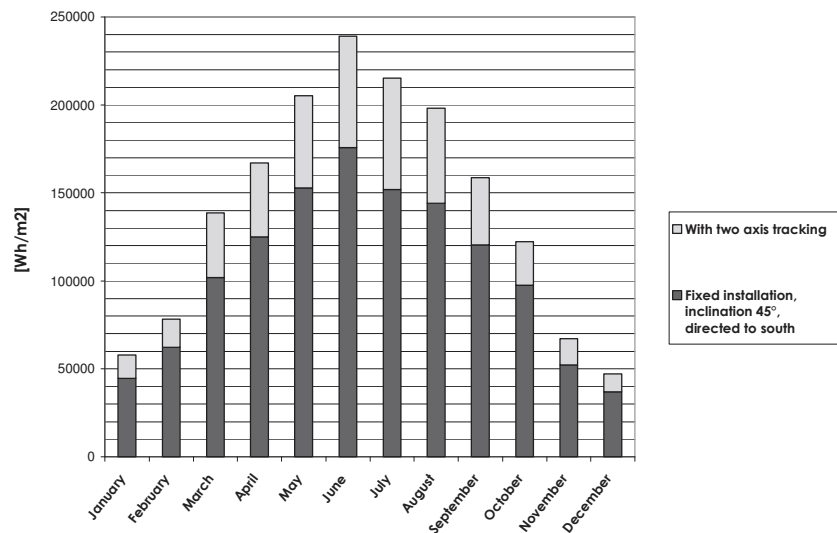


Fig. 2. Calculated yearly energy gain in monthly distribution (incoming energy/m² on the surface of fixed and rotated solar panels)

Concept of the Heliotrex solar tracking system

During the design of our system we kept two purposes in mind. The first was to build a solar tracker to perform long-term investigations, and to receive reliable data about the efficiency of tracking with photovoltaic solar panels. In addition our goal was to create a system that could be applicable in large scale energy harvesting applications like solar farms, for photovoltaics as well as for photo-thermal applications.

Thinking about future industrial applications we chose to build a fully automated system with remote controlling and monitoring possibilities. Because its attractive results in energy gain [3, 6] we decided to use two-axis tracking. Another requirement was the scalability of the system, which means trackers of different sizes and power ratings can be built with minimal changes to the design. Finally low power consumption and low manufacturing costs were also our requirements.

To achieve low power consumption DC motors with high torque gear transmissions were chosen to perform the rotation.

Electronics

Because of the mixed calculation and control tasks the electronics are based on microcontrollers. A modular structure was chosen to ensure the scalability with minimum changes to the electronics. The electronics consist of three main modules such as: the Tracking Control, the Maximum Power-Point Tracking (MPPT) module and the

Communication Module. The block diagram is shown in Figure 3. To perform the tracking only the tracking control unit is needed, the other two units are optional.

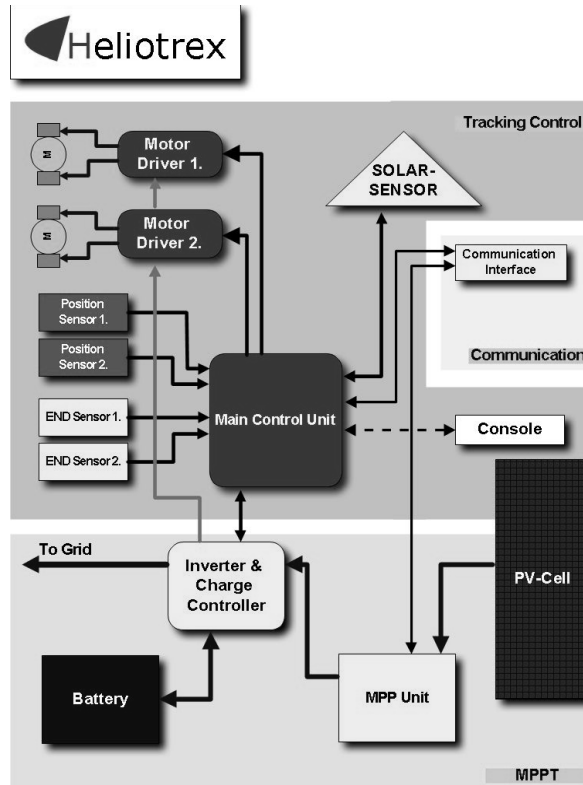


Fig. 3. Electronics scheme of the Heliotrex solar tracking system

The MPPT unit's function is to set the optimal electrical load electronically, thus reaching the maximal power-point. The maximum power-point is determined from the measured voltage and current with the "perturb and observe" (P&O) method [7]. The MPPT contains a Charge Controller circuit to control the appropriate charging of batteries and to prevent incidental overcharging or deep discharging. If applied, the MPPT unit is used as a power supply for all electronics too.

Measured values can be transmitted via the Communication Module to serve monitoring purposes. For RF transmission the 433 MHz ISM band is used. The software on the monitoring PC may transmit control commands to each of the electronic units.

The different units are connected to the Communication Module over an 8-bit parallel bus and are addressed; this allows the connection of more than one Tracking Control Unit and additional MPPT modules if needed. With the further planned TDMA communication several Communication Modules can transmit the data of different trackers, so the monitoring and control of a solar farm could be managed from a single monitoring centre (Fig. 4).

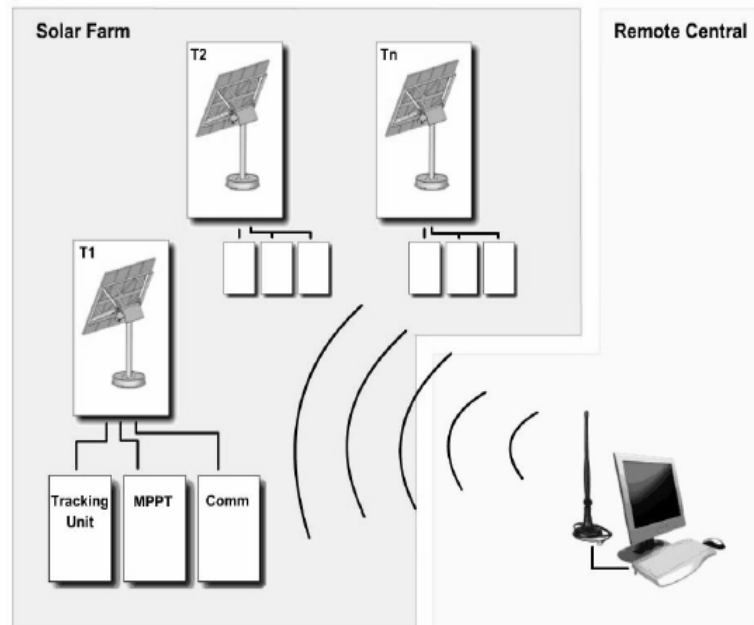


Fig. 4. Structure of a Heliotrex system solar farm

The tracking algorithm

The tracker applies both intensity- and time-controlled tracking modes. For the intensity-controlled tracking and for the detection of the weather conditions a self-developed solar sensor is used. For the time-controlled tracking a real-time clock chip is used.

The selection of the control mode can be made manually or is decided upon the weather conditions by the tracker in automatic selection mode.

The algorithm checks the intensity and the current position every 30 seconds. In automatic selection mode, if the intensity is below a certain (adjustable) level, the tracker switches to time-controlled mode, above this level the intensity-controlled mode gets activated.

In time-controlled mode the tracker performs every 8 minutes a movement of 2 degrees around the vertical axis. The rotation around the horizontal axis is performed once every hour. In intensity-controlled mode the hysteresis of the algorithm is 2 degrees.

The mechanical construction

The current version of the tracker is suitable to carry and rotate four 50 W crystalline silicon photovoltaic modules. The total weight of the rotated modules can be up to 30 kg.

The mechanical work consisted of the design of the framework and the drives for two different kinds of movement. Because the drive gears have to provide enough braking force even in the case of strong wind (100÷150 km/h) a self-locking worm-gear drive had been chosen. The structure of the tracker is shown in Figure 5.

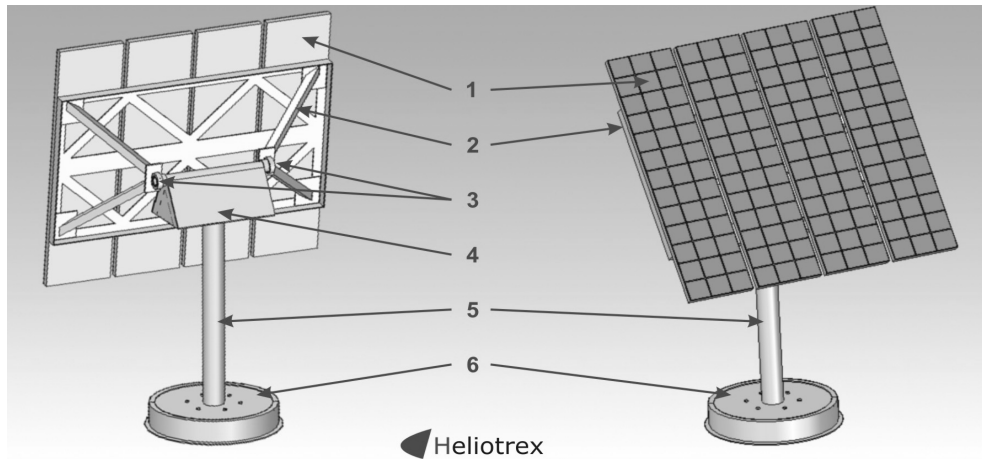


Fig. 5. Structure of the tracker: 1 - solar modules, 2 - framework with bracing, 3 - bearings, 4 - housing for the electronics and the tilting drive gear, 5 - shaft, 6 - housing for the rotating drive gear

The domains of the two axes' displacement are the followings:

- 1) rotation around the vertical axis: 270° ,
- 2) tilting of the framework: 70° .

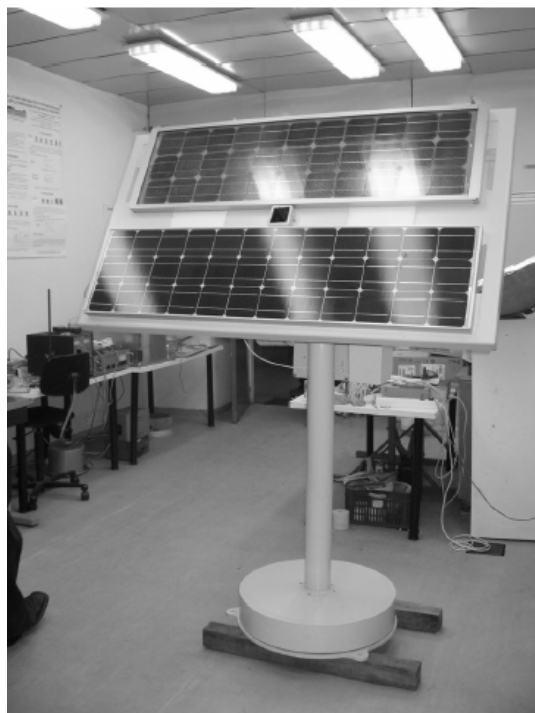


Fig. 6. The Heliotrex system with two mounted solar modules during first tests in the laboratory

The speed of rotation is not critical: 1 deg/s. The same type of motor is used for both axes with drive gears of similar structure but different gear ratio. The structural elements of the tracker are made from steel, the system is designed to be stable at wind velocities up to 150 km/h.

Costs

The theoretical calculations of the possible energy gain achievable by solar tracking were given above. In the case of an electric powered system this has to be reduced by the power consumed for operation. Based on the power consumption measured during the tests of the system, we calculated the ratio of the energy consumed for operating the system and the excess energy (Fig. 7). The calculation resulted that over a year in average only 4.6% of the excess energy is consumed for system's operation. In total this results in a calculated gain of 32.3% in comparison with the investigated fixed system.

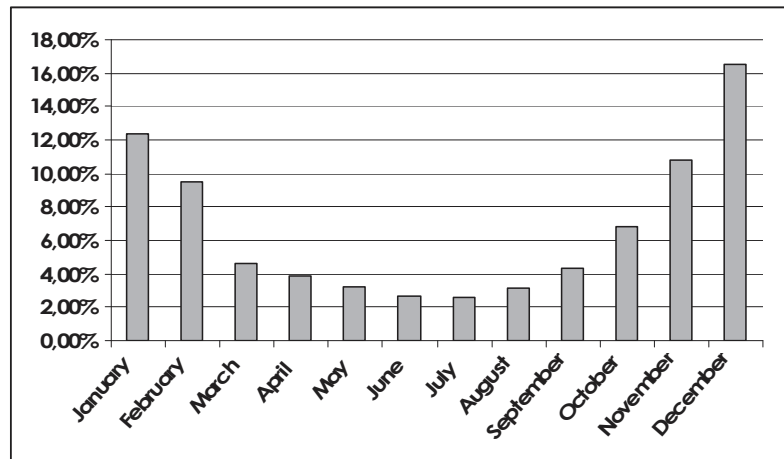


Fig. 7. Energy consumed for the operation of the tracking system in percentage of the excess energy

Like other photovoltaic systems solar tracking enhanced photovoltaics can not compete nowadays with the prices of the electrical energy produced from conventional energy sources. On the other hand our preliminary calculations showed that a tracker with mounted panels of 1 kW_p power can replace fixed installations in the size of 1.3 kW_p. Calculated with the nowadays common total installation cost of approx. 4 Euro/W_p, we found that the usage of a tracking system for 1 kW_p amounts to 80% of the cost of installation of the additional 0.3 kW_p fixed panels. Thus everywhere, where the conditions for photovoltaics are given (stand-alone systems, appropriate subventions, etc) solar tracking is a considerable option.

Conclusions

The possible energy gain of solar tracking and a micro-controller based fully automated solar tracking system was shown that can operate both in intensity and time

control mode. The system is equipped with a maximum power point tracking module for the energy enhancement and an RF communication subsystem for monitoring and remote control purposes.

Based on the power consumption of the system the total excess energy gained by tracking was calculated and resulted in 32.3%, which makes solar tracking to a considerable option in photovoltaic installations.

The next step is to perform long-term outdoor measurements, to confirm the preliminary calculations, and to determine the optimal tracking algorithm. All data of the long-term operation will be stored in a database and used for monitoring and statistical purposes.

The main aspect of the further developments to the tracking system is the ability to come to the market. With the planned TDMA communication numerous trackers can be installed and easily managed in one solar power plant.

Acknowledgments

The authors wish to express their appreciations to electrical engineering students László Jablonkai and István Rácz for the design of the MPPT and Communication subsystems and to mechanical engineering students Dávid Fekete and Krisztián Gyurák for the design and construction of the mechanical structure, as well as to Gábor Buza for participating in the calculations of excess energy gain.

This work was supported by the GVOP-3.1.1-2004-05-0282/3.0 project of the Ministry of Economy in Hungary.

References

- [1] Roth P. et al: Energy Convers. Manage., 2005, **46**, 1179-1192.
- [2] Plesz B., Pánczél S., Timár-Horváth V. and Mizsei J.: 3rd International Workshop on Teaching in Photovoltaics, Proceedings 2006, Prague, 97-101.
- [3] Homepage: <http://www.degerenergie.de>
- [4] Homepage: <http://www.solar-trackers.com>
- [5] Imre L., Bitai A. and Hecker G.: Megújuló energiaforrások. Budapest 2000.
- [6] Mazen M. Abu-Khadera, Omar O. Badran and Salah Abdallah: Renew. Sustain. Ener. Reviews, 2008, **12**(3), 864-873.
- [7] Femia N.: *Optimization of perturb and observe maximum power point tracking method*. IEEE Transact. Power Electron., 2005, **20**(4), 963-973.

WZROST GENEROWANEJ MOCY MODUŁÓW NADAŻAJĄCYCH ZA SŁOŃCEM

Abstrakt: Energia słoneczna w przyszłości będzie miała coraz większe znaczenie. Przed jej powszechnym wykorzystaniem muszą jednak zostać usunięte pewne bariery, co spowoduje, że będzie ona konkurencyjna w porównaniu z konwencjonalnymi źródłami energii. Jednym ze sposobów zwiększenia sprawności modułów jest ich nadążanie za Słońcem. Sprawia ono, że moduły przez cały dzień pracy pozostają w optymalnym położeniu względem Słońca i generują znacznie więcej energii elektrycznej niż ta zużyta przez system napędowy. W pracy omówiono budowę i działanie elektronicznie sterowanego, dwuosowego systemu nadążającego. Dzięki komunikacji radiowej jest możliwe monitorowanie, kontrolowanie i zdalna synchronizacja różnych systemów nadążających. Skalowalność i możliwość rozszerzenia systemu umożliwia jego zastosowania w wielu modułach elektrowni fotowoltaicznej.

Słowa kluczowe: nadążanie za Słońcem, dwuosowy system nadążający, przyrost generowanej energii