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Application of one-axis sun tracking system

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ABSTRACT

This paper introduces design and application of a novel one-axis sun tracking system which follows the position of the sun and allows investigating effects of one-axis tracking system on the solar energy in Turkey. The tracking system includes a serial communication interface based on RS 485 to monitor whole processes on a computer screen and to plot data as graphic. In addition, system parameters such as the current, the voltage and the panel position have been observed by means of a microcontroller. The energy collected is measured and compared with a fixed solar system for the same solar panel. The results show that the solar energy collected on the tracking system is considerably much efficient than the fixed system. The tracking system developed in this study provides easy installation, simple mechanism and less maintenance.

1. Introduction

Electric energy is essential to maintain daily life and industrial activities. Turkey uses mainly fossil fuels to produce electricity. Generation of electricity from fossil fuels is the primary source of air pollution and greenhouse gas emissions. Alternatives to fossil fuels should be considered at the same time as potential greenhouse gas emissions targets. Nowadays, the alternatives on the market that provide examples of successful implementation are the wind the farms, the solar cells, the nuclear, the biomass, the hydropower and the geothermal energy. The objective of this paper is to evaluate one of the alternative technologies currently available in the daily life to generate electricity from the solar cells.

The solar cells convert sunlight directly into electricity and are typically combined into modules that hold about 40–70 cells. A number of these modules are mounted in PV (photovoltaic) arrays that can measure up to several meters on a side. Several connected PV arrays can provide enough power for a household and for large electric utility or industrial applications. Hundreds of arrays can be interconnected to form a single and large PV system. An inverter converts DC power to AC and sends the solar power into the grid. A typical block diagram of the grid connected solar system is given in Fig. 1 that includes photovoltaic modules, an inverter, a converter, batteries, a battery charger and DC–AC loads.

These PV arrays can be mounted on a fixed angle facing south, or they can be mounted on a tracking system that follows the sun allowing the PV arrays to capture more sunlight throughout a day. The efficiency of a solar cell is calculated in terms of its efficiency at converting sunlight into electricity. The costs of electricity production of solar PV systems are more expensive than conventional power generation. This makes the dissemination of solar PV system very complicated. The tracking PV system is one of the methods to reduce the power generation cost. There are a number of works proposed by many researchers to track the sun. Kalogirou and Alata et al. suggested [1,2] a tracking system which can be used with single-axis solar concentrating systems, Roth et al. and Bakos [3,4] constructed and tested two axis tracking system. Different types of one-axis tracking systems have been applied in the literature [5–7]. Tomson [5] described mainly the performance of PV modules with daily two-position in the morning and in the afternoon. Results indicated that the seasonal energy yield was increased by 10–20% over the yield from a fixed south-facing collector tilted at an optimal angle. Huang and Sun [6] has designed the solar tracking system called "one axis three position sun tracking PV module" with low concentration ratio reflector. The one-axis tracking mechanism adjusted the PV position only at three fixed angles. These are the morning, the noon and the afternoon. An experiment performed in the present study indicated that economic analysis showed that the price reduction was between 20% and 30% for the various market prices of flat plate PV modules. Abu-Khadera et al. [8] investigated the effects of multi-axes sun-tracking systems on the electrical generation of a flat photovoltaic system (FPVS) which was carried out to evaluate its performance under Jordanian climate. Multi-axes (N–S, E–W, vertical) electromechanical sun-tracking system was designed and constructed. The measured variables were compared with that at fixed axis. It was found that there was an overall increase of about 30–45% in the output power for the north–south axes (N–S)-tracking system compared to the fixed PV system. Also, it was found that the N–S axes sun tracking was the optimum. Bakos [4] performed to investigate the effect of using a continuous operation

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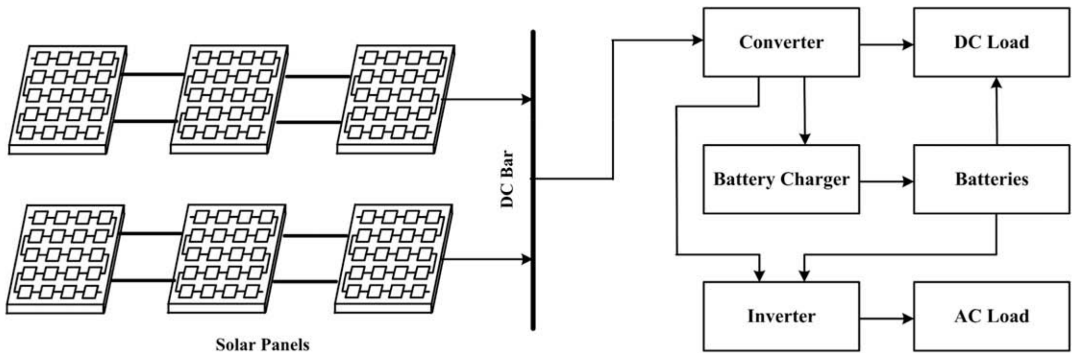


Fig. 1. A typical block diagram of the grid connected solar system.

two-axes tracking on the solar energy collected. The collected energy was measured and compared with that on a fixed surface tilted at 41° towards the south. The results showed that the measured collected solar energy on the moving surface was considerably larger (up to 46.46%) compared with the fixed surface. Abdallah [9] implemented four electromechanical sun-tracking systems, two axes, one axis vertical, one axis east–west and one axis north–south, were designed and constructed for the purpose of investigating the effect of tracking on the current, the voltage and the power, according to the different loads. The results indicated that increases of electrical power gains up to 43.87% for the two axes, 37.53% for the east–west, 34.43% for the vertical and 15.69% for the north–south tracking, as compared with the fixed surface inclined 32° to the south in Amman. There are also many different controllers such as PC, PLC, PLA, microcontroller and electro-optically to implement the control techniques [10–15]. In addition to this Georgiev et al. [16] expressed that modern measuring and registering system for actual data more easily than conventional systems [16].

When the literatures are analyzed, the parameters such as the installation, the mechanism, the cost, the efficiency, the design and the maintenance have been given as important features depend on tracking methods as given in Table 1. It is clearly shown that the fixed system was described fairly simple and low-cost electromechanical set-up with low maintenance requirements and easy installation and operation except the efficiency. When one axis and two axes systems are compared to fixed system mentioned in the literature, they are found as more efficient than fixed system. In addition to these, a commercial data acquisition card was used for collecting data. Therefore the use of a commercial data acquisition card increases the cost and size, decreases flexibility and usability of the system [13,15].

When the system developed in this study is compared to others mentioned in the literature, it provides easy installation, low cost, simple mechanism and good performance, more flexible and easy programming.

Furthermore, this paper explains a PC based one-axis sun tracking system for production of clean energy. The new solutions for one-axis sun tracking system have been achieved with the help of the PC and a microcontroller. New approach and distinctions proposed are explained below:

- Peripheral interface controller system has been used instead of data acquisition card for data acquisition in the proposed system.
- Electro mechanic system, which has 2500 W total power and 3500 kg total weight, has been designed and implemented as a solar system to obtain electrical energy from sun and to connect it in parallel with the grid.
- The solar panels fixed on mechanical body have been tilted at 32° towards the south in Turkey-Ankara, so the energy collected has maximum efficiency during both winter and summer for one-axis tracking system due to changes in altitude of sun.
- The system has been applied to one axis because of control difficulties of two axes control with huge mechanical body.

The system designed is successfully implemented and tested on a 2.5 kW solar panels, and encouraging results have been obtained.

2. Design of the sun-tracking system developed

This study introduces a sun-tracking solar system used for collecting data as illustrated in Fig. 2. The block diagram of the developed grid connected solar system includes the electro-mechanical parts, the sensors, data acquisition and control unit, connection and control unit, photovoltaic modules, an inverter, a converter, batteries, a battery charger, an AC load and a PC. The data collected by the microcontroller based data acquisition (DAQ) and control unit are transmitted to a PC using an RS 485 serial connection in where the data are stored for displaying on the PC. Furthermore, the C# based software developed displays the panel positions of the solar module, the currents and the voltages of the solar systems on the computer without any human interaction.

The solar panel is set on the sun-tracking system that is controlled by a DC motor to follow the sun during day time. The solar panels are made of photovoltaic cells and produces electrical energy transmitted to DC bar. The DC energy obtained from the panels are stored in the batteries and then used for the loads whenever

Table 1
Comparisons of solar systems.

Parameters	Fixed	One-axis	Two axes	Developed system
Installation	Easy	Easy	Difficult	Easy
Mechanism	No mechanism	Simple	Complicated	Simple
Cost	Cheap	Moderate	Expensive	Moderate
Efficiency	Reference efficiency	10–35% > fixed system	25–45% > fixed system	10–45% > fixed system
Design	Simple	Moderate	Complicated	Simple
Maintenance	Less	Moderate	More	Less

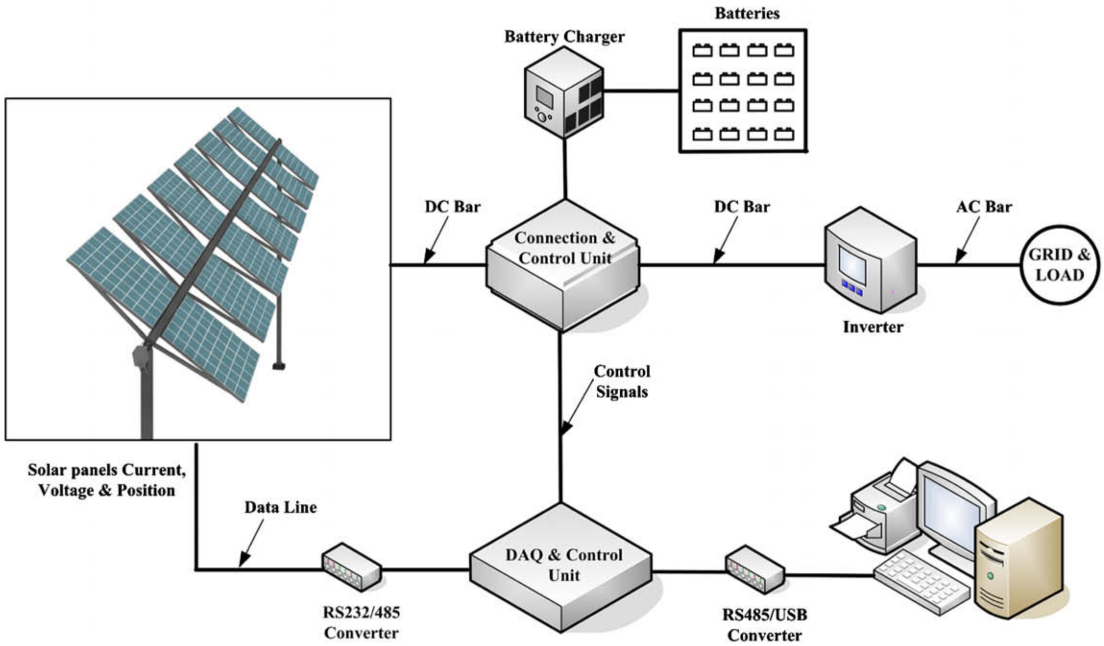


Fig. 2. A block diagram of developed system.

they are required by means of the connection and control unit and the battery charger. When the batteries are fully charged, the energy produced is either transferred directly to the load or to the power grid via the inverter. If the batteries are fully discharged, the required energy by the load is provided from the power grid. This enables the power to flow in both directions between the power station and the grid. The main parts of the system such as electro-mechanical parts, the sensors, the signal processing unit and the system software are explained in Subsections 2.1, 2.2 and 2.3 in detail.

2.1. Electro mechanic systems

The electro mechanic system for solar panels has been designed and implemented to obtain maximum electrical energy from sun and to run in parallel with the grid. The electro mechanic system used in the present study consists of 14 solar panel with 185 W and total power is 2500 W. Total weight of electro mechanic system with solar panels is 3500 kg. The photograph of mechanical system is depicted in Fig. 3.

The system has been applied as one axis because of exposing control difficulties of two axes control with huge mechanical body. A DC motor with 24 V, 50 W was used for movement of the solar panel in east or west directions. The mechanical power obtained is firstly connected to a redactor with ratio of 1/200 and then to second redactor with ratio of 1/80. There is an angle of 90° between two redactors. The movement of the tracking system is limited using end-point switches. The photograph of mechanical system is illustrated in Fig. 4.

2.2. Design of a processing unit for sensor signals

The electro mechanical mechanism is designed for the movement of the solar panels in east and west directions. All movement procedures are controlled using two photo resistors. The photo resistors are connected in serial with each other and a connection

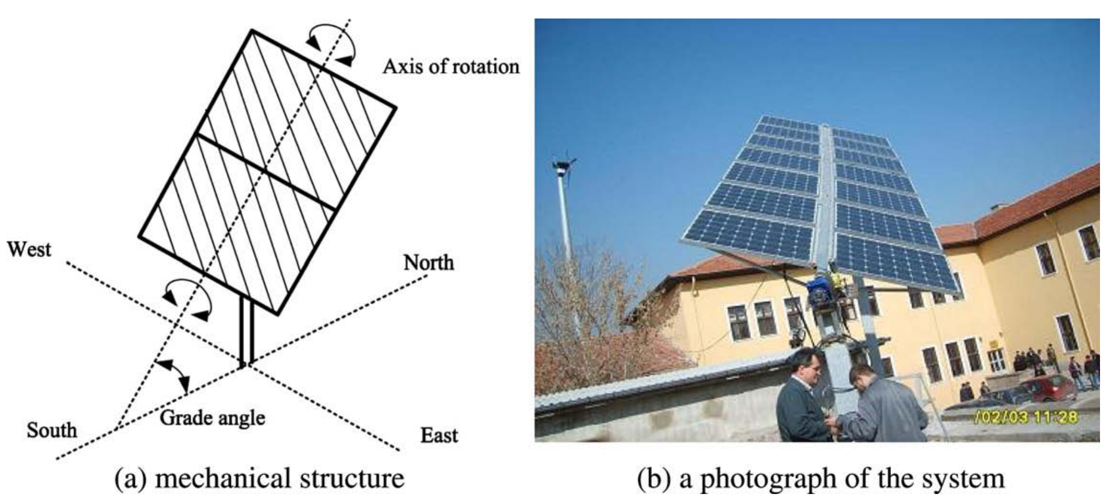


Fig. 3. Sun-tracking system: (a) mechanical structure and (b) a photograph of the system.

Fig. 4. Connection of a gear box and a DC motor to the mechanical system.

point is taken out from the middle of two resistors. The photo resistors are used as sensor and located on opposite side of pyramid structure as given in Fig. 5.

When the photo resistors are facing the sun equally, the voltages on the photo resistors are equal and the panel location is detected at exact position. Otherwise, the system continuous its movement until the same value of resistance is achieved in both photo resistors. Resistor values achieved are compared using an H-bridge driver circuit of the DC motor as illustrated in Fig. 6. The great ability of an H-bridge circuit is that the motor can be driven forward or backward at any speed. The DC motor used in the study is 50 W and 24 V. In Fig. 5, *Q*7 and *Q*8 transistors do not allow the current to flow and the DC motor does not start. If LDR1 voltage more than LDR2 voltage, *Q*7 transistor drives the *Q*5 transistor and then *Q*1 and *Q*4 are driven by means of *Q*5 transistors. Thus, the motor runs forward direction until the voltages on the photo resistors are equal. In either situation, If LDR2 voltage is more than LDR1 voltage, *Q*8 transistor drives the *Q*6 transistor and then *Q*2 and *Q*3 are driven by means of *Q*6 transistors. Thus, the motor runs backward direction until the voltages on the photo resistors are equal. *Q*1–*Q*5 and *Q*6–*Q*3 are connected as Darlington pairs so that the current flowing on the main switch is amplified. The overall current gain in Darlington connection is equal to two individual gains of transistors multiplied together.

2.3. Measurement strategy for solar tracking system

In this study, a new measurement strategy for solar systems has been introduced based on PC. In this new strategy, the fixed and the tracking solar systems collected data at the same day with same mechanism. Thus efficiency analysis of the systems was done sensitively for the solar tracking system. Moreover, the voltage, the current, the angle of the solar system and the problems occurred in the system were monitored and warning messages were shown on the computer screen by means of measurement strategy developed. The approach presented in this work provides flexibility, accuracy and reliability for smooth measuring with the help of the PC. Furthermore, the measurement system can easily be applied to different systems after doing small modifications in the software developed.

The flow diagram of the measurement strategy is given in Fig. 7. First, the program waits for waiting time of the tracking system to be entered and then the tracking system starts. After that, the position of solar system is checked. If the panel position is not true, the true panel position is found by means of the tracking system. The program is not passed following step during that time. After passing following step, the voltage, the current and the panel position are measured and recorded in a database and then the system waits during "waiting time" in first step of the program. After finishing the time determined in tracking mode, the system is directed automatically 90° for measuring the fixed system data and then data are saved in a database. In case of a necessity, operator can stop the system. Otherwise, this working strategy continues throughout the day.

For tracking measurement method, detection of possible changes is also perceived about the solar location through the related sensors. The mechanism is directed to this angle and then data are saved for determining time interval. This time must be

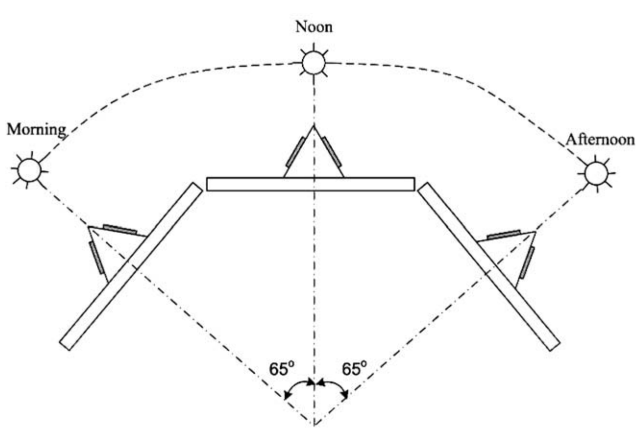


Fig. 5. Position of photo resistors on pyramid structure.

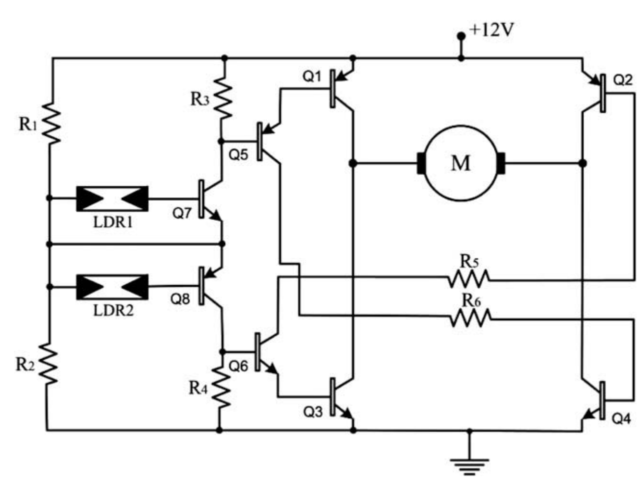


Fig. 6. Electrical connection of photo resistors and motor.

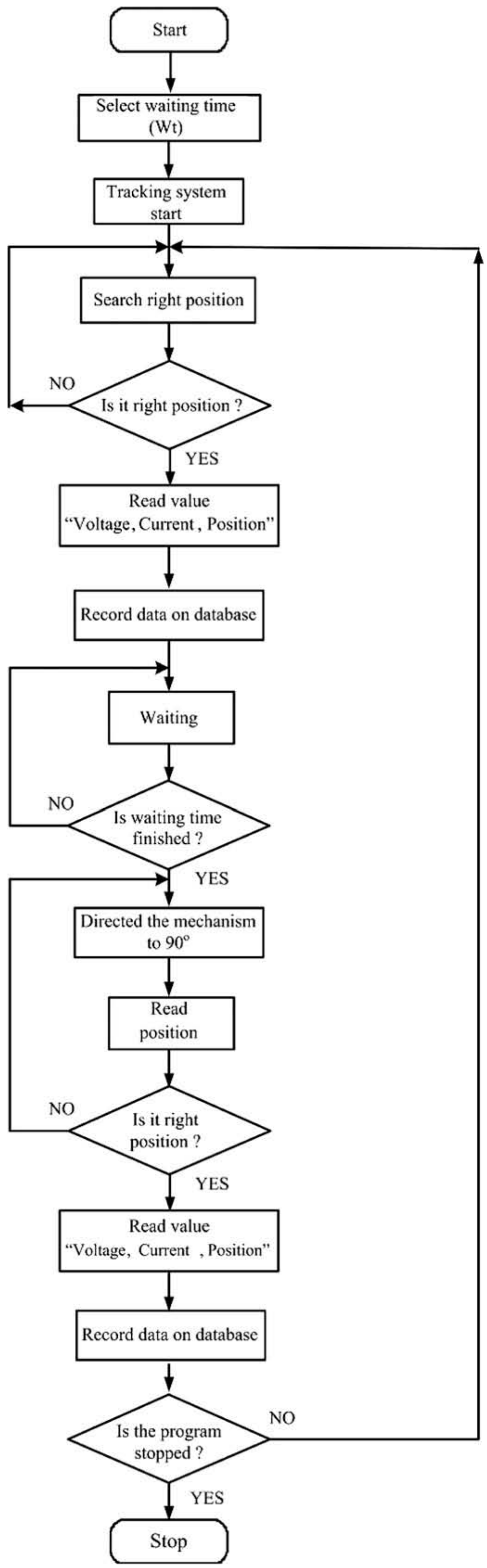
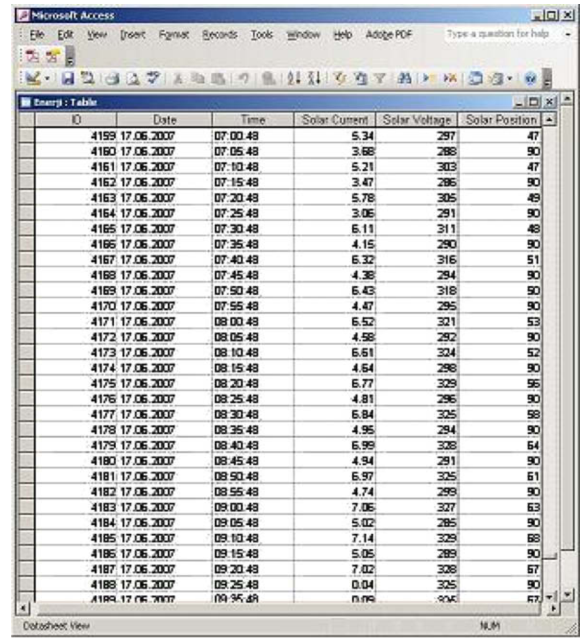


Fig. 7. Flow diagram of measurement strategy.

between 5 min and 30 min. After finishing time determined in the tracking mode, the system is directed 90° automatically for measuring the fixed system data and then data are saved in a database. After receiving data in the fixed mode, the mechanism is directed



Microsoft Access

Energi : Table

ID	Date	Time	Solar Current	Solar Voltage	Solar Position
4159	17.06.2007	07:00:48	5.34	297	47
4160	17.06.2007	07:05:48	3.68	288	90
4161	17.06.2007	07:10:48	5.21	303	47
4162	17.06.2007	07:15:48	3.47	286	90
4163	17.06.2007	07:20:48	5.78	305	49
4164	17.06.2007	07:25:48	3.06	291	90
4165	17.06.2007	07:30:48	6.11	311	48
4166	17.06.2007	07:35:48	4.15	290	90
4167	17.06.2007	07:40:48	6.32	316	51
4168	17.06.2007	07:45:48	4.38	294	90
4169	17.06.2007	07:50:48	6.43	318	50
4170	17.06.2007	07:55:48	4.47	295	90
4171	17.06.2007	08:00:48	6.52	321	53
4172	17.06.2007	08:05:48	4.58	292	90
4173	17.06.2007	08:10:48	6.61	324	52
4174	17.06.2007	08:15:48	4.64	298	90
4175	17.06.2007	08:20:48	6.77	329	56
4176	17.06.2007	08:25:48	4.81	296	90
4177	17.06.2007	08:30:48	6.84	325	58
4178	17.06.2007	08:35:48	4.95	294	90
4179	17.06.2007	08:40:48	6.99	328	64
4180	17.06.2007	08:45:48	4.94	291	90
4181	17.06.2007	08:50:48	6.97	325	61
4182	17.06.2007	08:55:48	4.74	299	90
4183	17.06.2007	09:00:48	7.06	327	63
4184	17.06.2007	09:05:48	5.02	285	90
4185	17.06.2007	09:10:48	7.14	329	68
4186	17.06.2007	09:15:48	5.05	289	90
4187	17.06.2007	09:20:48	7.02	328	67
4188	17.06.2007	09:25:48	0.04	325	90
4189	17.06.2007	09:35:48	0.09	305	67

Datasheet View NUM

Fig. 8. View of reporting file.

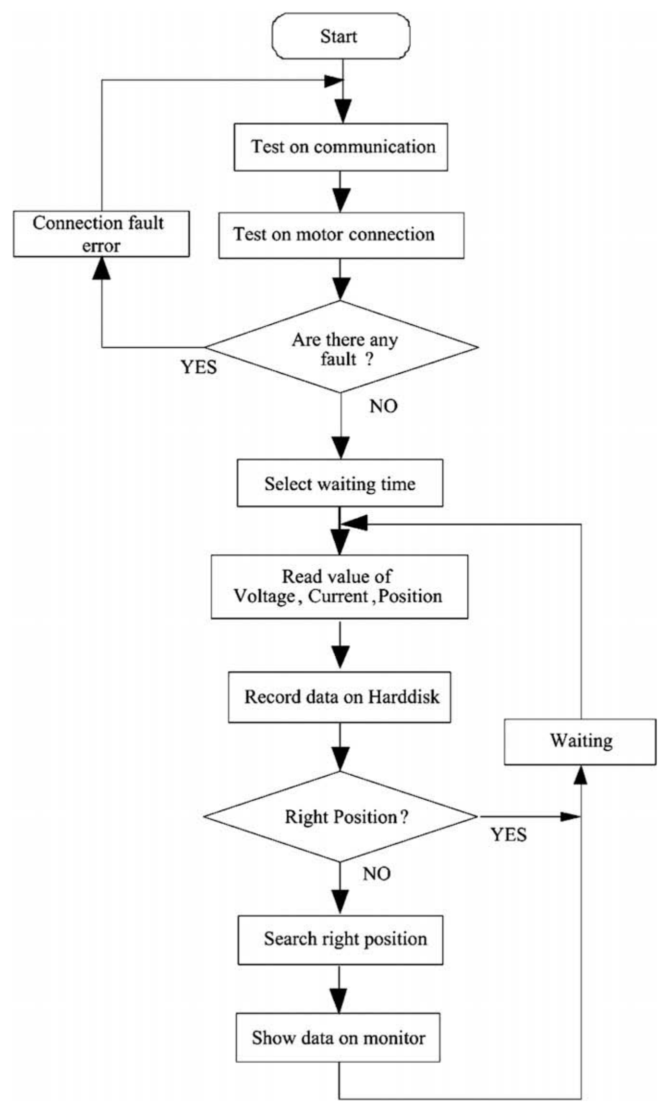


Fig. 9. Flow diagram of PC control.

to tracking mode position by means of database. This working strategy continues throughout the day. The measurement given on the screen is realized at every 5 min as the program is running continuously.

Fig. 8 shows a view of screen in where the data recorded are given in detail. The values saved on a database are demonstrated as reporting format with date and time. Values are saved on a database at determined time intervals. If required, report is prepared as hourly, daily and monthly basis. The reports taken can be saved in excel format or printed out. Owing to the reporting system, user will be able to examine energy values produced by means of reporting file.

3. The system software

The software has been prepared in VISUAL C# programming language in order to provide computer control. In addition, communication circuits has been designed and implemented to record data in electronic environment. The PC tracking system includes a serial communication interface based on RS 485 to monitor the whole processes such as the current, the voltage and the panel position as angle on a computer screen and to plot data as graphical. This monitoring and tracking system is explained in Subsection 3.1 in detail.

3.1. PC based tracking system

The flow diagram of PC monitoring system is given in Fig. 9. When the program is started, the communication is controlled firstly, and then the motor connection is tested in following steps. If any faults are occurred in communications, the program goes back to the beginning. If faults are not occurred, the program tries to choose control mode. The software has two control modes.

PC controlled software directly displays the voltage, the current and the panel position on computer without any human interaction. Waiting time of the system are first entered as second. After having all these data, they are recorded in database. Then panel position is controlled. If the panel position is true, the panel is at exact position. If the panel position is false, the panel is redirected to exact position by means of software. The program continues to run up until the system is stopped. If it is needed to restart the system, the program goes back to the beginning.

When the shortcut icon formed to run interface on the computer is clicked on, data communication traffic is tested firstly between the computer, the data collection and the control system. System can be tested by pressing on the "Test" button, and if there is an error, all processors and EPROM are reset by pressing on the "Reset" button. Screen image concerning the test of computer connection with communication unit is shown in Fig. 10. This process is called as "communication test".

After completing the communication test, the menu of energy control and database application is opened automatically as illustrated in Fig. 11. The menu of software can be examined in two sub menus, which are "the sun panel menu" and "the panel location control menu". The sub menu of program called as "sun panel" is given in Fig. 10 consisting of six buttons as Take Value, Save, View Chart, EPROM Reset, System Reset, System Test. The software then directly displays the current, the voltage, the panel position, the power and the panel angle and are saved in database and then displayed by means of sun panel menu without any human interaction.

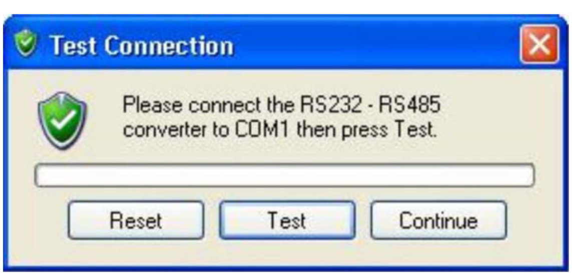


Fig. 10. Connection control menu of PC between communication units.

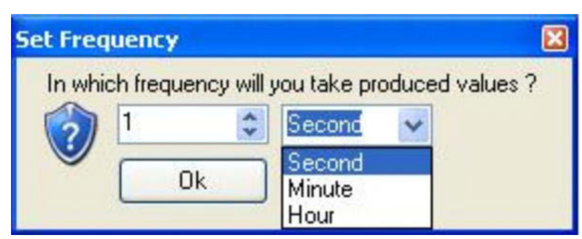


Fig. 12. Menu image given for recording frequency.

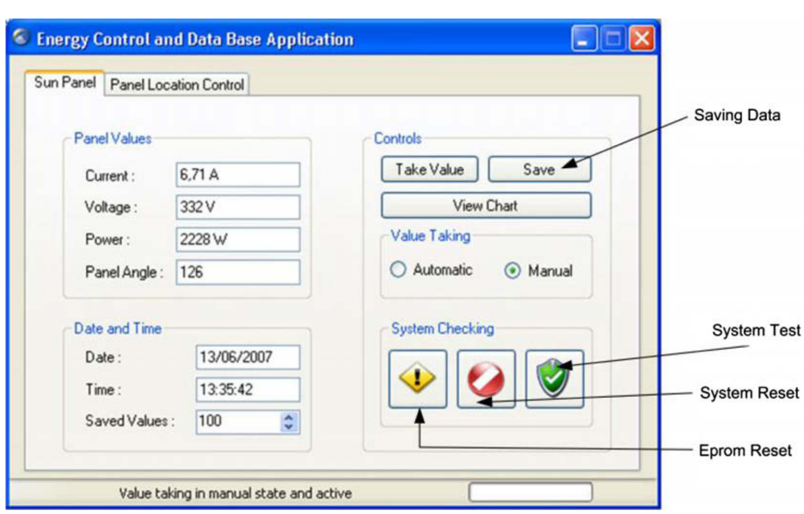


Fig. 11. Computer program menu for sun panel.

If the button on value taking part of the program prepared is at manual position, then information is received and recorded in EPROM at each time when "take value button" is pressed on. When the button is switched to "Automatic" position, a second warning window appears on the screen. Some regulations related to the frequency of time intervals to receive information take place in this

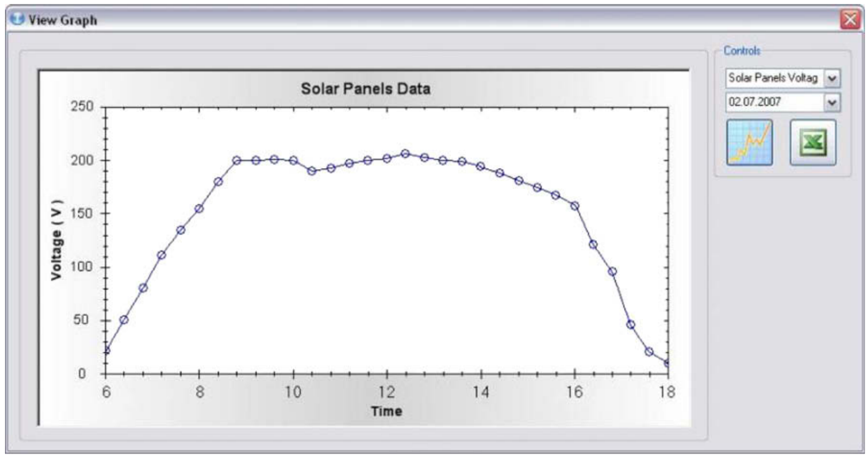


Fig. 13. Graphical illustration of the energy obtained from the sun panel.

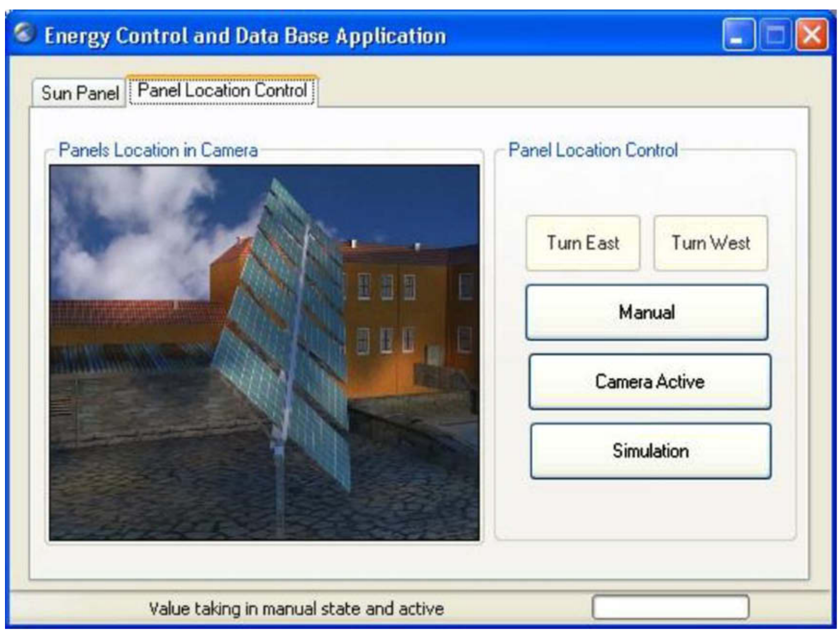


Fig. 14. Computer program menu for panel position control.

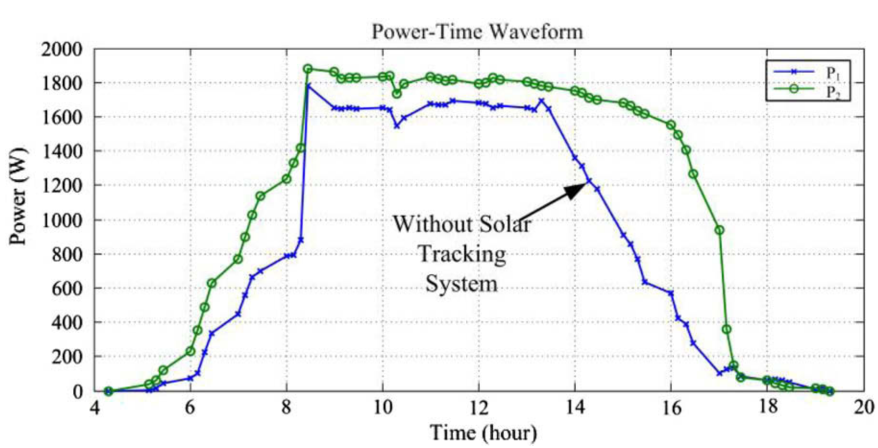


Fig. 15. Relationship between the tracking system and the fixed system.

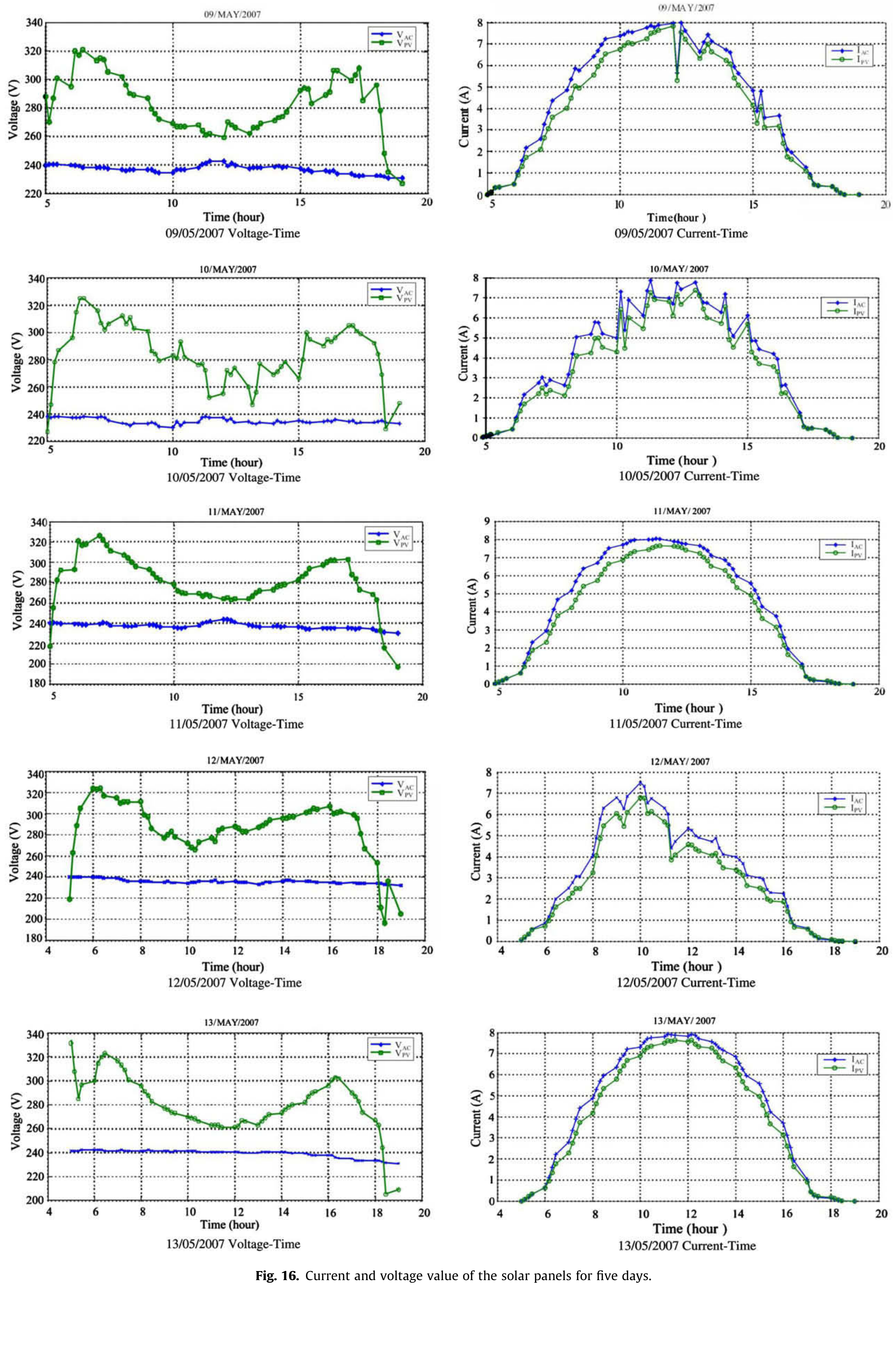


Fig. 16. Current and voltage value of the solar panels for five days.

window. The window image of frequency value record is given in Fig. 12.

After the system is set, data are collected automatically at set intervals and recorded in the memory of computer. All the records are gathered in a Microsoft Office Access application file and afterwards, information can be accessed from this file. Recorded files are viewed graphically by means of the same program on a daily basis. A graphical example for the solar panel voltage obtained for 1 day is shown in Fig. 13.

In the second menu of the designed interface, there is setting buttons related to panel position control. In this menu, the sun-tracking system can be directed manually to the east or the west upon demand. Moreover, manual position of the system can be switched off and its operation can be controlled automatically. Two separate applications are realized in order to show the position of the tracking system during its motion. In the first application, a simulation can be animated on the screen during its motion and this simulation moves simultaneously with the model after obtaining the evaluation of data of panel position. Simulation image may be enlarged to full screen upon demand. In the second application, the real image of the system can be transmitted to the user by means of a camera connected to the computer by pressing the "Camera Active" button in the menu of panel position control. Picture of the menu of panel position control is seen in Fig. 14. The menus are given below in detail.

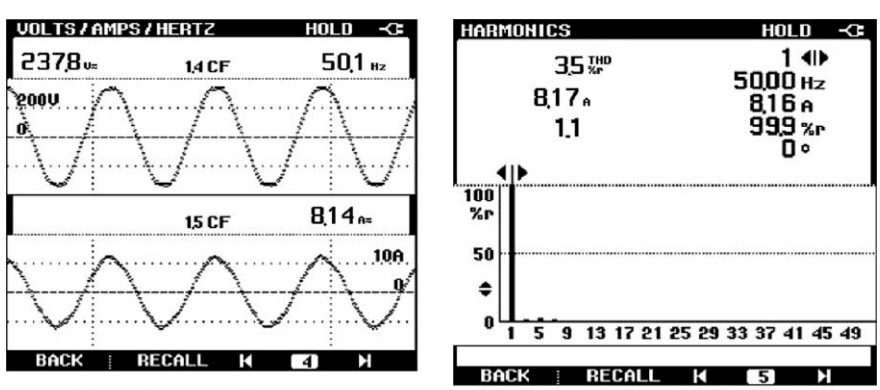
- *Manual* is used for running the system as manual. When the manual icon is clicked on, turn east and turn west menu is activated on the screen. User can be interfered to panel position required by means of the software in the second part of the designed interface. In this menu, the sun-tracking system can be directed manually to the east or the west upon demand. Moreover, manual position of the system can be switched off and its operation can be controlled automatically. Two separate applications are realized in order to show the position of the tracking system during its motion.
- *Camera active* is used for observing the system with a camera. The real image of the system is transmitted to the user by means of a camera connected to the computer by pressing the "Camera Active" button in the menu of panel position control. Picture of the menu of panel position control is shown in Fig. 14.
- *Simulation* is used for observing the system. The position of solar panel can directly be read by a position sensor and the location control of solar panel is showed as simulation on PC by means of the software. In the first application, a simulation is animated on the screen during its motion and this simulation moves simultaneously with the model after obtaining the position data. Simulation image may be enlarged to full screen upon demand.

4. Experimental study

The system with 2500 W total power and 3500 kg total weight has been designed and implemented as a solar system to obtain electrical energy from sun and to connect the system in parallel with the grid. The system has been worked continuously with and without tracking system for 15 min periods during 1 day. This measurement period can be adjusted when it is required. Daily energy production of the system with tracking is about 17.248 kW h, without tracking is about 11.862 kW h. In addition, annual energy production of system with tracking has also realized as 3.45 MW h. It is seen that the system with tracking produces much energy than without tracking, when two working modes have been compared as given in Fig. 15. These measurements show that the tracking system produces 45% much energy and better performance then the fixed system.

Waveforms of the panel voltage, the line voltage, the panel current and the inverter output are depicted in Fig. 16 for five days. In these days the solar tracking was taken in operation. The system was implemented only with MPPT. When performances of the systems were compared with each other, the best results for the experiments were achieved from the solar panel with tracking system. While the solar tracking was running, the daily energy production was 17 kW h. When the solar tracking was not running, the system produced 14 kW h energy. When the solar tracking system was compared to the MPPT control technique according to experimental results, it could be said that the solar panel with tracking system produced much energy and provides high efficiency. In addition, as seen from these figures, the signals are decreased at some points in the graphics when the weather was cloudy or the panel was not changed the position according to the solar position.

The voltage and the current waveforms and their harmonics for the inverter output were all recorded and THDs were measured. The measurements were done by means of Fluke 43B power quality analyzers. These measurements are illustrated in Fig. 17. The Fig. 17a shows that, when the inverter output was measured, there were no sparks on the voltage and the current waveforms. In steady state operation, there were few harmonics in the current waveform. Harmonics of the current can also be seen in Fig. 17b as bar plots, which belong to inverter output.



(a) voltage and current (b) harmonics

Fig. 17. Inverter output.

5. Conclusions

This paper describes design and implementation of one-axis sun tracking system based on a PC control. The PC tracking system includes a serial communication interface based on RS 485 to monitor the whole process on a computer screen. The system is successfully designed and tested by implementing on a 2500 W solar panels. Parameters of the solar sources such as the current, the voltage, the solar panel position and the operation conditions can be controlled and illustrated on a PC. The A/D converter interfaced to a microcontroller-based unit records a set of sensors signals. The data collected by the microcontroller are transmitted to a PC with an RS 485 serial connection, where they are stored for different processing. In addition, C# based software developed processes and displays the collected data on the PC.

In the literature, authors have proposed commercial data collecting systems; therefore data acquisition systems used in the literature card increases the cost and size, decreases flexibility and usability of the system. When the system developed in this study is compared to others mentioned in the literature, the new approach developed has easy installation, low cost, high efficiency, simple mechanism and good performance, easy programming and simple PV tracking system. The electro mechanic system, which has 2500 W total power and 3500 kg total weight, has been designed and implemented on a solar system. The mechanical body with fixed solar panels has been tilted at 32° towards the south in Ankara, Turkey. The energy collected has maximum efficiency during both the winter and the summer for one-axis tracking system due to changes in altitude of the sun. The system has been applied as one axis because of facing control difficulties of two axes control with huge mechanical body.

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