Original scientific papers
UDK 620.91:621.311.243
DOI 10.7251/COMEN1902145P

COMPARATIVE INVESTIGATION OF FIXED AND TRACKING PV SOLAR POWER PLANTS ENERGY EFFICIENCY

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Abstract: The paper provides basic information on fixed (stationary), one-axis tracking and dual-axis tracking PV solar power plants. In this regard, a schematic overview of the PV solar power plant and basic information on its components (solar modules, inverters, monitoring system, etc.) are given. The following is a description of the fixed, one-tracking and dual-tracking PV solar power plant and their energy efficiency. Finally, measured results of power and temperature of fixed and dual-axis tracking solar modules of 50 W are presented.

Keywords: solar energy, PV solar power plant, one-axis tracking PV solar power plant, dual-axis tracking PV solar power plant.

1. INTRODUCTION

Solar modules are the basics of the photovoltaic system and contain certain number of serial or parallel connected solar cells, whereby serial connected solar cells increase the output voltage and parallel connected solar cells increase the output current.

Solar modules are usually fabricated from monocrystalline, polycrystalline and amorphous silicon. On the market solar modules of different powers can be found, most frequently those power of 50 W, 100 W, 150 W and 200 W.

Solar cells can be used for: the lighting, functioning of the audiovisual and refrigeration equipment, signaling devices on roads, tunnels, airports and lighthouses, operation of telecommunications equipment and systems, operation of solar power plants, with PV systems, for electricity supply to facilities, ships, aircrafts, cosmic stations and satellites, etc.

The photovoltaic solar system means the system by which solar radiation is converted into electrical energy and consumers are supplied by DC and/or AC power. Photovoltaic solar system can operate independently of the power grid or can be attached to it. Depending on the components of which it is composed, photovoltaic solar system that is not connected to the power grid can supply consumers with DC or AC power.

Grid connected photovoltaic solar systems consist of solar modules, inverters, power meter and connecting lines for the connection of the solar system to power utility grid. In these systems, the entire amount of generated electricity is transmitted to the power utility grid. These systems include high power PV solar power plants and PV solar power plants of small power installed on private homes, residential areas, and other facilities [1–6].

2. PV SOLAR POWER PLANT

PV solar power plant denotes a plant using solar cells to convert solar irradiation into the electrical energy. PV solar power plant consists of solar modules, inverter converting DC into AC and transformer giving the generated electrical energy into the grid net. PV solar power plant is fully automatized and monitored by the applicable software. PV solar power plants mostly use solar modules made of monocrystalline and polycrystalline silicon and rarely modules made of thin film materials such as amorphous silicon, CdTe and CIS (Copper-Indium-Diselenide, $CuInSe_2$). Efficiency of the monocrystalline silicon solar cells is 17%, of polycrystalline silicon is around 15%, of amorphous silicon is around 5%, CdTe is 16% and CIS is

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around 9%. Monocrystalline and polycrystalline silicon solar modules are more suitable for the areas with predominantly direct sun radiation, while solar modules of thin film are more suitable for the areas with predominantly diffuse sun radiation.

Inverter is a device which converts DC generated by PV solar power plants of 12 V or 24 V into three phase AC of 220 V. Depending on the design inverter efficiency is up to 97%. When choosing inverter it is to bear in mind the output voltage of the solar modules array, power of the solar modules array, grid net parameters, managing type of the PV solar power plant, etc. PV solar power plants can use larger number of the inverters of smaller power or one or two invertors of greater power.

Schematic view of the PV solar power plant is shown in Figure 1 [1].

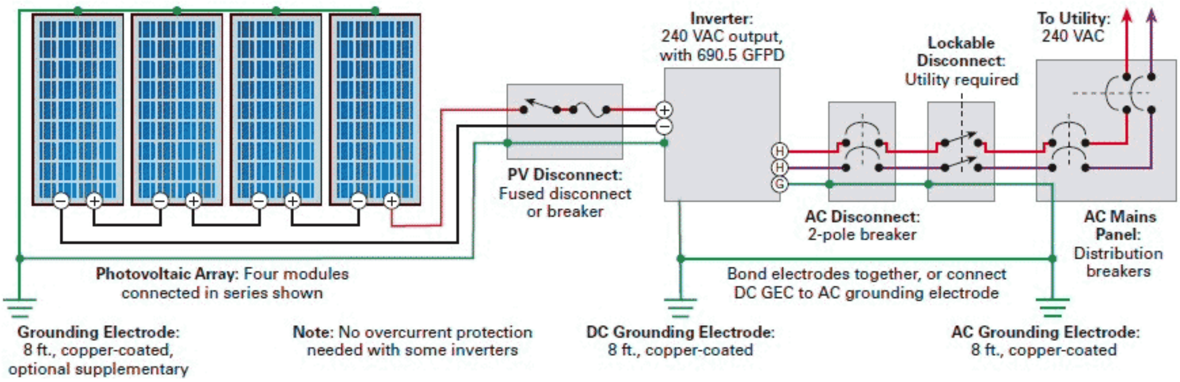

Figure 1. Schematic view of the PV solar power plant [7]

PV solar power plant monitoring system comprises central measuring – control unit for the surveillance of the working regime. Monitoring system uses sensors and softwares to obtain the following data: daily, monthly and yearly production of the electricity, reduction of CO_2, detailed change of the system parameters, recording of the events after the failure, monitoring of the meteorological parameters, etc.

PV solar power plants in accordance with the power distribution systems legal regulations use transformers by means of which solar energy generated by PV solar power plant is given to the power grid.

Practice shows that the energy efficiency of PV solar power plant annually decreases from 0.5–1%. Lifetime of PV modules depends on the solar cell technology used as well. For monocrystalline and polycrystalline silicon solar cells most manufacturers give a warranty of 10/90 and 25/80 which means: a 10-year warranty that the module will operate at above 90% of nominal power and up to 25 years above 80%. The practical lifetime of the silicon-made PV modules is expected to be at least 30 years.

PV solar power plants represent environmentally clean source of energy. PV solar power plant components (solar modules, inverters, monitoring system, conductors, etc) are manufactured by cutting edge, environmentally friendly technologies. PV solar power plants operate noiseless, do not emit harmful substances and do not emit harmful electromagnet radiation into the environment. PV solar power plant recycling is also environmentally friendly. For 1 kWh of PV solar power plant generated electrical energy emission of 0.568 kg CO_2 into the atmosphere is reduced.

Depending on climate conditions of given location fixed PV solar power plants, one-axis and dual–axis tracking PV solar power plants are being installed worldwide. Fixed PV solar power plants are used in regions with continental climate and tracking PV solar power plants are used in tropical regions [1].

3. FIXED PV SOLAR POWER PLANTS

Fixed PV solar power plant (Fig. 2) denotes plant with solar modules mounted on fixed metal supporters under optimal angle in relation to the horizontal surface and all are oriented towards south. To install fixed PV solar power plant of 1 MW it is necessary to provide around 20 000 m^2.

Figure 2. Fixed PV solar power plant [8]

Maintenance costs of the fixed PV solar power plants are much lesser than the maintenance costs of the tracking PV solar power plants. Its drawback is in that solar modules do not follow sun radiation so that on the yearly level one does not gain optimal amount of the electricity [1].

4. ONE-AXIS TRACKING PV SOLAR POWER PLANT

One-axis tracking PV solar power plant (Fig. 3) denotes a plant where solar modules installed under the optimal angle are adapted towards the Sun by revolving around the vertical axis during the day from the east towards the west, following the Sun's azimuth angle from sunrise to sunset. For solar modules revolving electromotors are used using electrical energy from the batteries of the power grid. For the rotor revolving monitoring a centralized software system is used. In case software system fails solar modules can be directed towards the sun manually. It is also possible to manually set the tilt of the solar modules in relation to the horizontal surface in steps from 5° from 0–45°. One-axis tracking PV solar power plant gives the shadow effect of solar modules situated on neighboring rotors so that for its installation it is necessary to provide around 60 000 m^2. Available literature reports the efficiency of one-axis tracking PV solar power plant is 20–25% larger than the efficiency of the fixed PV solar power plant.

Installation and maintenance costs of the one-axis tracking PV solar power plants are higher than the costs of the fixed PV solar power plants. Drawback of one-axis tracking PV solar power plant is in that year round there is no automatic adapting of the solar module tilt towards the Sun.

Figure 3. One-axis tracking PV solar power plant [9]

The diurnal and seasonal movement of earth affects the radiation intensity on the solar systems. Sun-trackers move the solar systems to compensate for these motions, keeping the best orientation relative to the Sun. Although using sun-tracker is not essential, its use can boost the collected energy 10–100% in different periods of time and geographical conditions. However, it is not recommended to use tracking system for small solar panels because of high energy losses in the driving systems. It is found that the power consumption by tracking device is 2–3% of the increased energy.

Practice showed that the yearly optimal tilt-angle of a vertical-axis tracked solar panel for maximizing the annual energy collection was almost linearly proportional to the site latitude, and the corresponding maximum annual collectible radiation on such tracked panel was about 96% of solar radiation, annually collected by a dual-axis tracked panel. Compared with a traditional fixed south-facing solar panel inclined at the optimal tilt-angle, the annual collectible radiation due to the use of the vertical-axis sun-tracking was increased by 28% in the areas with abundant solar resources, and was increased by 16% in the areas with poor solar resources [1].

5. DUAL-AXIS TRACKING PV SOLAR POWER PLANT

Dual-axis tracking PV solar power plant (Fig. 4) denotes a plant where the position of solar modules is adapted towards the Sun by revolving around the vertical and horizontal axis. These PV solar power plants follow the Sun's azimuth angle from sunrise to sunset but, they also adjust the tilt angle to follow the minute-by-minute and seasonal changes in the Sun's altitude angle. Solar modules are oriented towards the Sun by means of the appropriate electromotors. Photo sensors mounted on the array send signals to a controller that activates the motors, causing the array angles to change as the Sun's altitude and azimuth angles change during the day. Efficiency of the dual-axis tracking PV solar power plant is 25–30% bigger than the efficiency of the fixed PV solar power plant.

Figure 4. Dual-axis tracking PV solar power plant [10]

For the installation and function of dual-axis tracking PV solar power plant a substantially bigger surface is necessary than for the fixed PV solar power plant.

Installation and maintenance costs of the dual-axis tracking PV solar power plants are higher than the costs of the one-axis tracking and fixed PV solar power plants.

When designing a large PV solar power plant it is very important to optimize energy yield and occupation of land. It has been found that the energy gains associated to one north–south axis tracking referenced to static surfaces, ranges from 18% to 25%, and from 37% to 45% for the dual-axis tracker for reasonable ground cover ratios [1, 1–14].

6. EXPERIMENT

Experiment was done in October 2019 in Solar Energy Laboratory at the Academy of Sciences and Arts of the Republic of Srpska (ASARS) with the following devices:

– *Davis Vantage PRO* (*Davis*, USA) meteorological station for measuring the intensity of solar radiation, wind speed, temperature, pressure and humidity, UV index, etc;

– *KLA and Mini KLA* (*Ingenieubüro Mencke & Tegtmeyer*, Germany) for measuring the electrical characteristics of solar modules;

– *SolarUsbSW* (*Metering Solution*, Republic of Srpska) for simultaneous measurement of electrical characteristics of 5 solar modules;

– *KIPP ZONEN CMP22* pyranometer (*Kipp Zonen*, Holland) for measuring the solar radiation intensity;

– *HW SW* device (*Metering Solutions*, Banja Luka) for consecutive recording of physical characteristics of solar modules every 15 minutes;

– Digital temperature sensors *DS18B20*, used to measure the temperature of the solar module;

– *The TempLogger* measuring device (Fig. 5) was used for continuous monitoring and acquisition of solar module temperature during the day. This device transmits measured temperature values to a computer or other microcomputer system compatible with the RS232 digital communication standard.

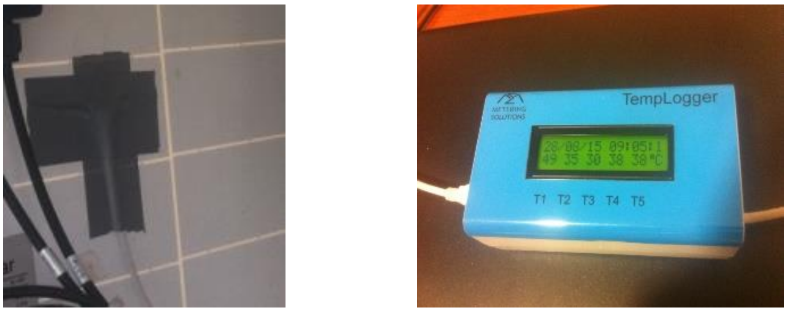

Figure 5. Sensor for temperature measurement of solar modules One Wire Digital Temperature Sensors DS18B20 (left) and TempLogger measuring device for continuous monitoring and acquisition of solar module temperature (right)

Solar Box

In order to determine the energy efficiency of solar modules, depending on the geographical orientation, angle of inclination and their temperature in the *ASARS Solar Energy Laboratory* in 2014 a Solar System was developed – *SolarBox* which is shown on Figure 6. Solar Box consists of photovoltaic solar modules made of polycrystalline silicon each of 50 W.

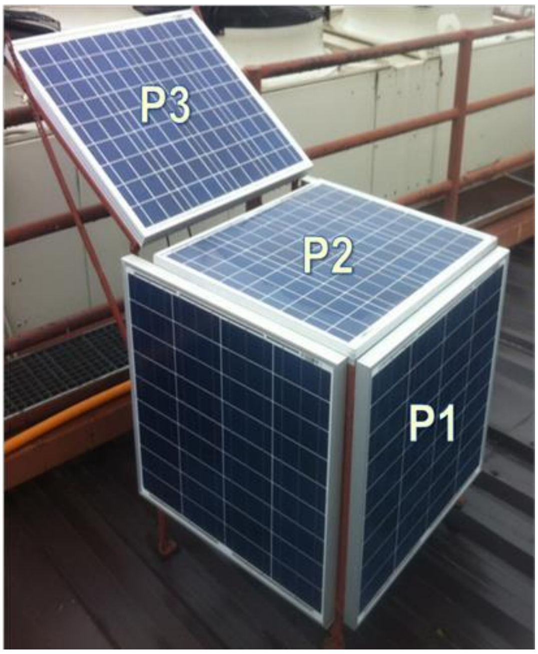

Figure 6. SolarBox with 50 W polycrystalline solar modules

Dual-axis tracking PV system

In mid-October 2017 a dual-axis tracking PV system was installed on the roof of ASARS in Banja Luka (Fig. 7). Dual-axis tracking PV system consists of: 50 W polycrystalline silicon solar module, electronic, mechanical and measuring subsystem.

Figure 7. Experimental dual-axis tracking PV system with 50 W polycrystalline silicon solar module

The electronic part of the PV system contains: sensors (two per axis of rotation), differential amplifier, output degree for motor control and degree for determining the minimum amount of light. Mechanical subsystem is a special mechanical assembly with steel structure and gears that allow automatic optimal orientation of the solar module with regulation by step motors. The total angle of clearance along the vertical axis is about 50° (from 20° to 70°), and on the horizontal axis 150° (± 75°). The measuring part of this system consists of measuring devices (PV-KLA analyzers) located in the Solar Energy Laboratory at the ASARS.

7. RESULTS

The measurement of daily power and temperature of fixed and dual-axis tracking system shown on Figures 6 and 7 was done in October 2019.

Daily power of P1, P2, P3 and P4 solar modules are given in Figure 8.

On the Figure 8. can be seen that the minimum daily power has P2, higher P1, slightly higher P3 and the highest P4 module, respectively.

The obtained results are in agreement with results which can be found in the literature for such kind of systems.

The average temperature in Banja Luka for 2019 was 15.47°C, in the October it was 14.37°C, while hours average for the measured days in October was from 1°C to 15.6°C. The total solar intensity radiation on horizontal surface in October of 2019 was 158.77 W/m^2. The average measured wind speed in October of 2019 was 0.2 m/s and maximal 0.6 m/s.

The measured temperature of P1 module was 14°C, of P2 module 6.5°C, of P3 module 12°C and of P4 module 16°C.

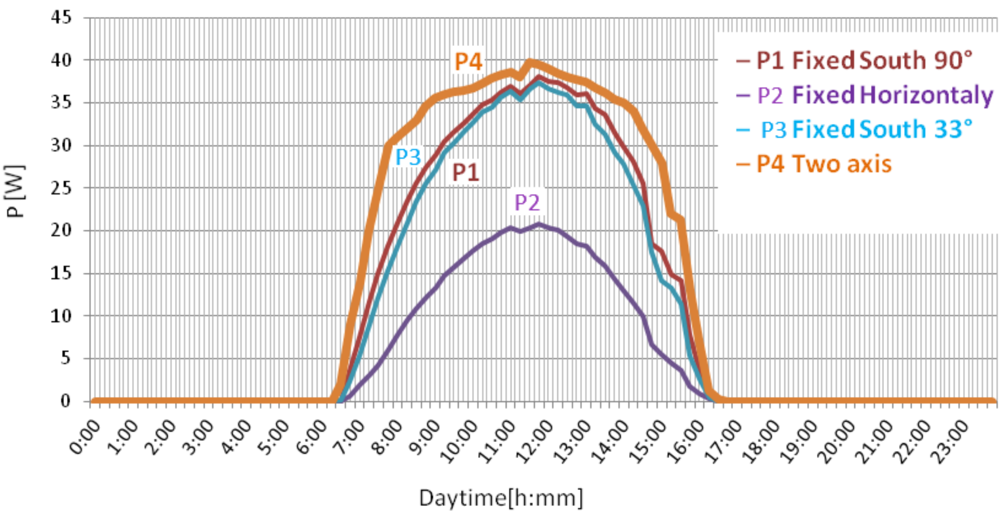

Figure 8. Daily power of fixed (P1, P2, P3) and dual-axis tracking (P4) solar modules

8. CONCLUSION

Based on the above mentioned, it can be concluded that fixed, one-tracking and dual-tracking PV solar power plants are used in the world today. PV solar power plant consists of suitable supporting structures, solar modules, inverters and monitoring systems. PV solar power plants use solar modules made of monocrystalline and polycrystalline silicon, a-Si, CdTe and CIS solar cells, etc. The energy efficiency of PV solar power plants basically depends on the type of solar cells used. Monocrystalline silicon solar cell energy efficiency is 17%, polycrystalline silicon 15%, α-Si solar cells about 5%, CdTe solar cells about 16% and CIS solar cells about 9%, respectively. Energy efficiency of one-axis tracking PV solar power plant increased by 28% in areas with abundant solar resources and by 16% in areas with poor solar resources, in comparison to fixed PV solar power plant. Energy efficiency of dual-axis tracking PV solar power plant increased by 37-45% in comparison to fixed PV solar power plant. Installation and maintenance cost of the one-axis tracking and dual-axis tracking PV solar power plants are higher than the cost of PV solar power plants.

On the basis of the above mentioned it can be concluded that the minimum daily power has P2, higher P1, slightly higher P3 and the highest P4 module, respectively, and the temperature of P1 module was 14°C, P2 module 6.5°C, P3 module 12°C and P4 module 16°C.

9. ACKNOWLEDGEMENT

This paper was done with the financial support of the project TR 33009 approved by the Ministry of Education and Science of the Republic of Serbia and the projects 19/6-020/961-31/18 and 19/6-020/961-30/18 approved by the Ministry of Science and Technology of the Republic of Srpska.

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КОМПАРАТИВНО ПРОУЧАВАЊЕ ЕНЕРГЕТСКЕ ЕФИКАСНОСТИ ФИКСНИХ И РОТИРАЈУЋИХ СОЛАРНИХ ЕЛЕКТРАНА

Сажетак: У раду су дате основне информације о фиксним (стационарним) и једноосно и двоосно ротирајућим соларним електранама. У вези са тим, дат је шематски приказ соларне електране и њених основних компонената (соларни модули, инвертори, мониторинг систем, итд.). Даље је дат опис фиксне, једноосно и двоосно ротирајуће соларне електране и њихова енергетска ефикасност. На крају су дати резултати мерења снаге и температуре фиксних соларних модула и двоосно ротирајућег соларног модула од 50 W у Лабораторији за соларну енергетику Академије наука и умјетности Републике Српске.

Кључне ријечи: соларна енергија, соларна електрана, једноосно ротирајућа соларна електрана, двоосно ротирајућа соларна електрана.

Paper received: 30 June 2019
Paper accepted: 10 October 2019