ISSN 1986-583X

ODRŽAVANJE 2022

7. KONFERENCIJA
7TH CONFERENCE

Budva, Crna Gora
12 - 16. septembar 2022.

MAINTENANCE 2022

ZBORNIK RADOVA
PROCEEDINGS

UREDNICI / EDITORS:
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7. Konferencija „ODRŽAVANJE 2022“ / 7 th Conference „MAINTENANCE 2022“
12 - 16. septembar / september 2022., Budva, Crna Gora

Urednici / Editors:
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r. prof. dr. Darko Petković

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Za Izdavača / For publisher:
Prof. dr. Jusuf Duraković

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Mr. sc. Branka Petković, prof. bhs jezika i književnosti

Tehnička priprema / Technical assistance and DTP:
mr. Emir Đulić, Emir Čaplja

Štampa / Printed by:
GRAFORAD Zenica

Za štampariju / For printing shop:
Pero Letić

Izdanje / Issue:
200 primjeraka / copies

ISSN 1986-583X

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ANALYSIS OF MAINTENANCE STRATEGIES IN SINGLE-AXIS TRACKING AND FIXED-TILT GRID-CONNECTED SOLAR PV PLANTS

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ABSRACT
Increasing energy need, rising energy costs and the global climate crisis carries solar PV plants to an important place among renewable energy sources. There is an increasing trend in the installed power of PV plants. Although PV plants have a static structure and do not have moving parts, they still need maintenance. Because a good and appropriate operation and maintenance is required in order to obtain high efficiency and optimum power yield from PV plants. In this study, the maintenances of single-axis tracking and fixed-tilt grid-connected solar PV plants at 1 MW_e installed power were examined separately. Preventive, corrective and condition-based maintenance strategies applied to the major components of PV plants such as PV panels, cables, inverters and kiosk substation are explained in detail. The maintenance costs which are one of main parameters in the calculation of levelized cost of energy (LCOE) were determined for each component and systems. Preventive maintenance is generally dominant in both plants. But single-axis tracking PV system require more maintenance than that of fixed-tilt due to its structure. Although maintenance increases investment and operating costs, it has been seen that it contributes to employment and local regional development and more energy. It is thought that the results of the study will be beneficial to power plant owners, technical staff and institutions and organizations related to the solar energy sector.

Keywords: solar energy, PV plants, maintenance Strategies, management

1. INTRODUCTION

Countries have had to turn to renewable energy sources with the increasing energy need and global climate crisis. Although solar energy contains many technologies and applications, it is preferred among renewable energy sources due to its cost, installation, operation and easy availability. Solar Photovoltaics (PV) are prominent in generating electrical energy and rapidly becoming one of the most popular renewable technology options. Over the last decade, the amount of solar PV systems installed around the world has increased massively while their costs have declined drastically. solar PV is also an important pillar of clean energy transitions worldwide and supports efforts to meet international energy and climate goals [1].

Photovoltaic cells which are used in all PV technologies generates electrical energy. This electricity can be directly used, sent to the grid or stored. So, solar PV systems or plants are classified into three main groups; Standalone (Off-grid) PV Systems, Grid-connected (On-grid) PV Systems and Hybrid PV systems [2].
Flat plate PV modules can be mounted in fixed orientation, one-axis tracking, or two axis tracking. Fixed orientation mounting systems can be at different angles with the horizon in order to maximize annual energy production. Tilting results in increased annual energy production, but frequently at a higher mounting-structure capital cost. Two-axis tracking results in the highest annual energy production, but at a higher capital cost. Figure 1 show the effect of mounting structure on energy production. As shown in figure 1, More precise orientation for tracking generates more energy but the capital cost increases [3].




	Flat Plate	Fixed Tilt	One-Axis Tracking	Two-Axis Tracking
Indicative energy boost	0%	15%	22%	32%
Increased capital cost per m^2	0%	10%	15%	20%

Figure 1. Mounting Structure Impacts on Energy Production

Figure 2 shows a typical solar PV plant. The major components of a PV plant include PV modules, inverters, transformer kiosk, mounting structures and other parts (meters, system wiring, security cameras, performance monitoring system, communication system, etc.).

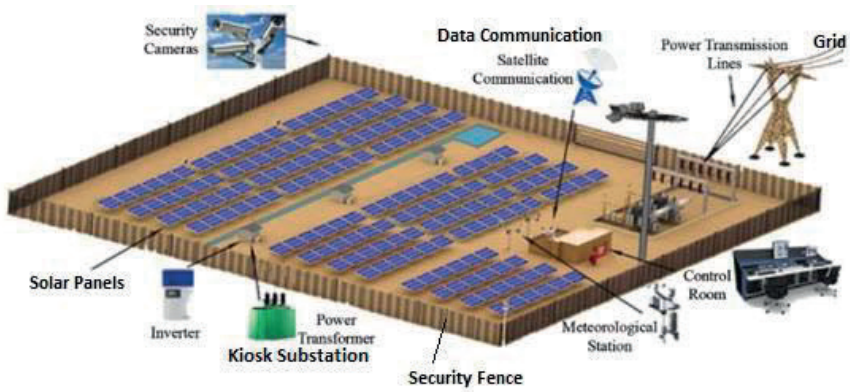


Figure 2. A Typical Solar PV Plant [4]

The PV plant is expected to operate with the highest efficiency and electrical output at all times. But there are several factors that will affect PV system performance over the operational lifetime. Dirt, shading, major components failure and meteorological conditions are main factors that impact on PV plant performance over the operational lifetime [2]. So, it needs operation and maintenance (O&M) strategies for the best possible energy generation. The PV O&M plan should be considered within the context of the performance period required for a PV system to generate a sufficient return on investment [5].

The solar PV systems are not maintenance free. In general, PV maintenance can be classified into three types of maintenance strategies: preventive maintenance, corrective maintenance and predictive (Condition-based) maintenance [5, 6]. Preventive maintenance is dominantly being used today. Scheduling and frequency of preventative maintenance is set by the operations function and is influenced by a number of factors, such as equipment type, environmental conditions (marine, snow, pollen, humidity, dust, wildlife, etc.) of the site, and warranty terms. Preventive maintenance is not only carried out in the event of a problem, but takes place regularly in order to ensure the optimum operation of the system. This prevents breakdowns and therefore saves costs. Corrective maintenance involves repairing the system when an error message is received. or replace failed components. Some corrective maintenance such as inverter resets or communications resets can be done remotely. Less urgent corrective maintenance tasks can be combined with scheduled, preventative maintenance tasks. Predictive maintenance involves intervention based on historical and real-time maintenance-relevant data. Condition-based maintenance is the practice of using real-time information from data loggers to schedule preventative measures such as cleaning, or to head off corrective maintenance problems by anticipating failures or catching them early. Because the measures triggered by condition are the same as preventative and corrective measures, they are not listed separately [5-7].
In this study, preventive, corrective and condition-based maintenance strategies applied to the major components of single-axis tracking and fixed-tilt grid-connected solar PV plants at 1 MW_e installed power were explained in detail. The maintenance costs for each component and the systems were calculated and compared each other.

2. MATERIAL

Single-axis tracking and fixed-tilt grid-connected solar PV plants are studied. The solar PV plants have been established near the town of Karaali in Şanlıurfa., which is located southeastern of Turkey (Latitude: 37º 00', Longitude 39º 11', Elevation 452 m) . The locations of the plants are shown in Figure 3. Figure 4 and 5 shows single-axis tracking and fixed-tilt grid-connected solar PV plant, respectively. The total cost of single-axis tracking and fixed-tilt grid-connected solar PV plants is $947 0000 and $839 000, respectively. Figure 6 gives yearly energy yield of the plants. It is seen that the tracking system generates more energy than fixed-angle one.

Figure 3. The locations of the plants

Figure 4. Single-axis tracking solar PV plant

Figure 5. Fixed-tilt solar PV plant

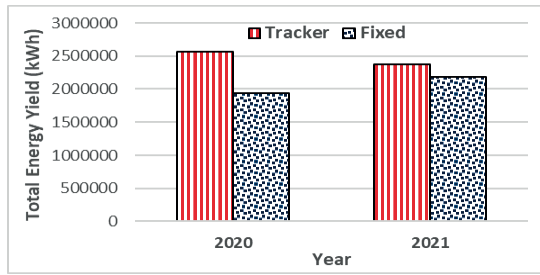


Figure 6. The yearly total energy generation of the plants

3. MAINTENANCE OF THE SOLAR PV PLANTS

The following maintenances are carried out in single-axis tracking and fixed-tilt grid-connected PV solar plants.

- PV panel cleaning
- Environmental cleaning
- I-V curve measurements
- Inverter maintenances
- Cable connections check
- Construction maintenance
- Kiosk substation maintenance
- Transformer maintenance
- Security camera system (CCTV) maintenance
- Unforeseen maintenance

Depending on the structure of the single-axis tracking plant, apart from the above maintenance, there are extra maintenances of the tracking system and its mechanical structure and unforeseen maintenances.

3.1. PV Panel Cleaning

Environmental factors such as dust, bird droppings and plant wastes accumulate on PV panels, reducing energy production and panel efficiency. Rain is not enough for cleaning PV panels. Dust and dirt can accumulate on the panel and form a layer and cause serious damage. Proper PV panel cleaning is an important maintenance and prolongs the life of the panels. Deionized pure water or alcohol-based cleaners are mostly used for panel cleaning to remove the dust and pollution layer on solar panels.

Panel cleaning is usually done twice a year with a mixture of commercially available PV Solar Cleaner Fluid and distilled water, and costs $900/MW per year. Panel cleaning is done with a special cleaning machine (Figure 7). Panel washing cost does not change for the tracking or fixed PV panels.

3.2. Environmental Cleaning in PV Plants

Wild herb cleaning is carried out as environmental cleaning in the power plant. Dry grass increases the risk of fire. In addition, the shading of tall herb on the panels can cause hot spots, damaging the panel and reducing the efficiency of the shaded panel.

Figure 8 shows weed control around the panels. This process is done with chemical control before weeds grow. Its approximate cost is 800 $/MW per year, and it is done twice, in early March and mid-April.

Figure 7. Panel cleaning with cleaning machine

Figure 8. Weed control in the plant

3.3. I-V Curve Measurements

As predictive or condition-based maintenance, I-V Curve Measurements are made to detect the following conditions [8].

• Whether the PV Panel powers are consistent with the given data by factory.
• Whether there is a loss due to light induced degradation (LID) or potential induced degradation (PID) in PV panels
• Whether there is contact with the ground or leakage due to any cuts/mouse-eating in the DC cables.
• Whether there is any problem with the by-pass diodes in the PV panels.
• Detection of shading-related problems and possible faulty connections in PV Panel series.

I-V curve measurements on all strings in the switchboard are made by technical personnel once every 2 years or annually optional (Figure 9). The approximate cost per MW is $200 per year.

3.4. Inverter Maintenance:

One of the main components of a solar PV plant is inverters. Two different types of inverters are used in solar power plants as String Inverters and Central Inverters. Due to factors such as dusting or raining; insulation and filters of inverter fans, heat sinks and panel cabinets against heat, humidity and dust should be checked. Thanks to these controls, the risks of malfunction due to atmospheric conditions and harmful insects are minimized, and inverter efficiency is maintained. Inverter cabinets, inverter housing and medium voltage (MV) / Low Voltage (LV) panels; the operability of door, barrier and lock mechanisms and moving mechanisms should be checked regularly. Thus, as preventive maintenance, malfunctions caused by unauthorized people's intervention on the equipment and adverse atmospheric conditions are prevented [9].

The thermal magnetic switch belonging to the inverter is controlled by the thermal device and the inverter fan maintenance is carried out (Figure 10). It is done once a year with a thermal camera. It costs $100 in the overall service cost.

Figure 9. I-V Curve Measurement

Figure 10. Inspection of inverter with thermal camera

3.5. Cable Connections

Cable connection checks are given below as preventive maintenance:

• Controls of cables at panel junction box, MC4 connectors (periodical maintenance of DC connections against isolation formation)

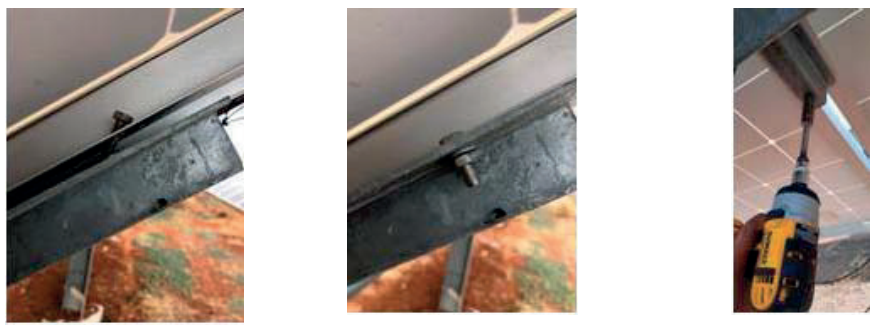
• Controls of the underground AC cables between the Inverter and the Low Voltage (LV) Panel (Detecting and intervening in advance of the failure to occur)

• Connection points and cable controls of AC cables between LV Panel and Transformer

• Connection points and cable controls within High Voltage (HV) Breaker Chamber and Transformer

3.6. Construction Maintenance

Mounting construction are carrier systems. The third most important system after panels and inverter is the mounting construction. Construction maintenance should be done seasonally and annually. As a result of the excavation process, if there are insufficient concrete pouring and deviations from other columns on string, they should be corrected and the damaged parts should be renovated over time. Within the scope of maintenance services, bolt connections and steel columns and profile connections are checked and tightened with applying proper torque (Figure 11). Construction maintenance is done once a year. The cost is about $150 per year.



Before *After* *Tightening*

Figure 11. Checking the bolt connection and fixing it.

3.7. Kiosk Substation Maintenance

Kiosk buildings are structures that protect the electronic equipment of power plants against external factors and contain the power transformer. The maintenance of the kiosk substation buildings is carried out 4 times a year at the beginning of each season by the fault and maintenance managers. There is no significant cost. Here are the things to do in the maintenance schedule:

• Cleaning the elements such as dust and mud inside the building.
• Cleaning insects inside the building prevents arcing or isolation in electrical connections.
• Controlling cracks in the roof or in the wall of building for preventing rain or insects entering the building.

3.8. Transformer Maintenance

Transformer maintenance includes many works such as general external cleaning of the transformer, cleaning of the transformer center, taking oil samples for testing, oil change, controls of the breaker-separator cells, controls of the protection relays. Transformer maintenance stages require special work on their own. Occupational safety rules must be strictly followed in transformer maintenance. Before starting the work, steps such as cutting, disconnecting and grounding should be applied, and finally, after making sure that there is no energy, then the work should be started [10].
Transformer maintenance should be done by authorized persons on a monthly routine basis. The annual cost is $530.

3.9. Security Camera System Maintenance

Camera systems are the most preferred security measure in solar power plant. Security camera systems, which are an important tool in cases such as possible theft, determination of events in the plant, control of wild animals, should be maintained periodically by professional teams. A comprehensive and detailed agreement on camera system maintenance should be made with the relevant maintenance companies. The following can be done as maintenance in the security camera system (CCTV) [11]:
• Cleaning the camera lenses and checking the security camera body.
• Make sure the camera view angle is not in the blind spot and adjust the angle.
• Pay attention to periodically checking the camera for corrosion.
• Checking all the cables that make the system work and the units it is connected to.
• Checking the status of the power supply to the camera system.
• Checking at least once a week for recordings and backing up the hard drive.
• Frequently checking whether the lighting is well adjusted.
• Set time and date to avoid confusion of camera recordings.
With condition-based maintenance is done according to the situation for security camera. The annual maintenance service cost is $330.

3.10. Unforeseen Maintenance

It includes maintenance and controls that are not in the maintenance schedule. For example, the problems of wire fence and concrete poles of wire fences should be checked. Repair of cut or damaged wire fences and maintenance of concrete poles that have been knocked down or damaged by landslides or other reasons. Maintenance should be done against faults that may occur in the SCADA and communication system. The annual cost is $100.

4. MAINTENANCE IN SINGLE AXIS TRACKING SOLAR PV PLANT

In single-axis tracking solar power plants, PV panels are in motion to receive the highest solar radiation. With the panel following the sun, the efficiency of the Solar PV plant can be increased by 15% to 25% compared to fixed angle PV systems. The panels follow the sun on the east-west line. In addition to the maintenance in fixed-angle power plants, the following maintenances are carried out in single-axis tracking solar power plants.
1- Tracker system maintenance (in case of failure)
2- Mechanical maintenance (in case of failure)

Annual maintenance costs for 1 MW power plants are given in Table 1. Annual maintenance costs for single axis and fixed angle solar PV plants at 1 MW_e power are $9100 and $5500, respectively. A single axis PV plant has 40% more maintenance costs. It has been observed that the highest maintenance cost is in panel and environmental cleaning. The high cost in environmental cleaning is due to the chemicals used. In the system, the cost is the highest in transformer maintenance.

Table 1. The cost of maintenances for Solar PV plants at 1 MW_e

	Cost ($/Year)	
Maintenance	Fixed-tilt solar PV plants	Single-Axis tracking solar PV plants
PV Panel Cleaning	900	900
Environmental Cleaning	800	800
I-V Curve Measurement	200	200
General Packaged Maintenance (Inverter, construction, cable connections, building cleaning, transformer, tracker, camera)	3600	7200
Total	5500	9100

5. CONCLUSION

In order to get the expected efficiency and electrical energy from solar PV plants, preventive, corrective and maintenance should be done according to the situation. In general, preventive maintenance is predominant in single-axis and fixed-angle PV solar power plants. Compared to fixed angle plants, there is an additional maintenance due to the movement of the PV panels in the PV plant with a single axis tracker. Although maintenance increases investment and operating costs, it has been seen that it contributes significantly to employment and regional development. It is thought that the results of the study will be beneficial to solar PV power plant owners, technical staff and institutions and organizations related to the sector.

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