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Troubleshooting Maintenance of Concentrated Photovoltaic System – A Case Study

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ABSTRACT
Concentrated photovoltaic (CPV) is a photovoltaic technology that generates electricity from sunlight. Contrary to conventional photovoltaic systems, it uses lenses to focus the sunlight onto small, but highly efficient, multi-junction solar cells. Two modules of CPV with a capacity of 6.4 kW (3.2 kW for each) were imported from Azur-Space Solar Power GMBH (Germany) and installed in Middle East University, Jordan, for testing purposes as a pilot project for this niche technology. It is worth mentioning that the installation of the units had been carried out by the faculty members. A range of technical obstacles were encountered in the process due to unclear instructions/steps from the manufacturer. A series of maintenance techniques and corrective measures were implemented in the system after one year of installation since the power output was unsatisfactory. Accordingly, the units were dismantled, and various procedures were conducted in order to ensure that the conditions of the system were on optimum level. In this paper, technical reviews and preventive setup were explained and presented.

Keywords: solar power, concentrated photovoltaic, concentrated, photovoltaic

INTRODUCTION

Several technologies could be used to generate energy from the solar radiation, for instance thermal and electricity. This publication aims at providing a guideline for fixing and maintaining concentrated photovoltaic (CPV) as one of technologies that might be utilized to produce energy and contribute to the energy mix to reach 20% of energy from renewables by 2020 as part of the strategic plan set by the Government of Jordan.

Most of the solar systems on the market today can be divided into two major categories: the direct and the indirect solar power. The direct solar power refers to a system that converts the solar radiation directly to electricity using a photovoltaic (PV) cell. The indirect solar power refers to a system that concentrates the sunlight first to generate heat. The heat is then used to generate steam and run a conventional turbine, as in the case of a concentrated solar power (CSP). The concentrated photovoltaic cell is considered a technology in between the direct and indirect solar power. In other words, CPV is the hybridization of the two solar power systems. In CPV, concentrated solar flux (about 300 suns) is focused on highly efficient solar cells such as the multi-junction solar cell (about 40% efficient). This results in a superior output, many times that of the ordinary photovoltaics. The expensive solar materials in solar PV are replaced with mirrors and lenses made of cheap glass in CPV. The total reliable efficiency of the entire system is up to 35% [Chukwuka and Agbenyo 2014].

How it works?

The key principle of CPV is the use of cost-efficient concentrating optics, usually based on Fresnel lenses that dramatically reduce the cell area, allowing for the use of more expensive, high efficiency cells and potentially the cost of electricity competitive with standard Photovoltaics technology in certain sunny areas with high annual Direct Normal Irradiance (DNI). The use of optical elements to concentrate the sunlight is convenient only when using very high efficiency solar cells. The CPV systems can concentrate a large amount of sunlight into a smaller one by applying lenses or curved and flat mirrors as shown in Figure 1. However, the additional costs on concentrating optics and cooling systems made CPV less common than non-concentrated photovoltaic [Wiesenfarth et al. 2017, Liu 2017].

The photovoltaic solar energy is based on semiconductor materials which collect the sunlight and convert it directly into electricity., an electric field is created between the layers of the semiconductor material, through the impact of the sunlight photons. Electrical energy is created in direct current (DC), which is then transformed to alternating current (AC) by using Inverters.

A concentrated photovoltaics module can be divided in two main layouts: having the concentrating optics in lenses (usually Fresnel lenses) or in mirrors. The Fresnel lenses shown in Figure 2 can be made of a thin film silicon-on-glass, known as acrylic glass or transparent thermoplastic. A mirror can be made of glass or plastic covered by a thin layer of Aluminum or silver protected against oxidation. There are many different considerations that lead the designer toward one layout or the other. However, the installed CPV in the site is based on the Fresnel lens technology [Antonini et al. 2014].

It is worth mentioning that the installation of the two units has been implemented by the faculty members despite the presence of many technical obstacles during setup due to unclear guidelines and instructions provided in the manual. The installation commenced by picking a shade-free site, for instance, with no buildings or trees around. Then, digging was started and the footings were sealed to protect them from moisture. Finally, concrete foundation with dimension (W: 2.5m × L: 2.5m × D: 0.9m) was laid to support the weight of the CPV structure. In order to fit the poles with their holes onto the anchor rods, they had to be mounted on the foundation properly. The sequence of processes is depicted in Figure 3.

On the other hand, steel structure frames and beams were assembled together. The tracking motor was mounted on the top of the structure. These components are responsible for holding the movable panels of CPV as shown in Figure 4. The final appearance of the CPV system is illustrated in Figure 5. It should be noted that two units were installed on the site, each including 8 panels with 400 Wp for every panel. A single panel comprises 60 photovoltaic cells. Thus, one unit consists of 480 cells that generate 3.2 kWp.

Maintaining of CPV system components

After a year of installation, it was noticed that there was an issue regarding the voltage and

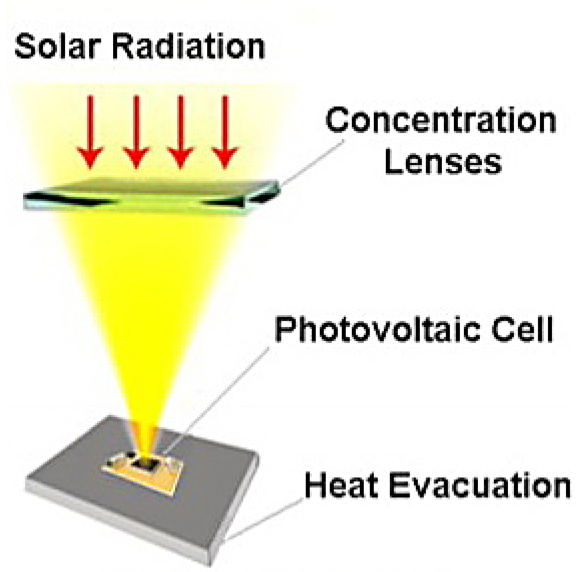

Figure 1. PV cell exposed to concentrated solar radiation

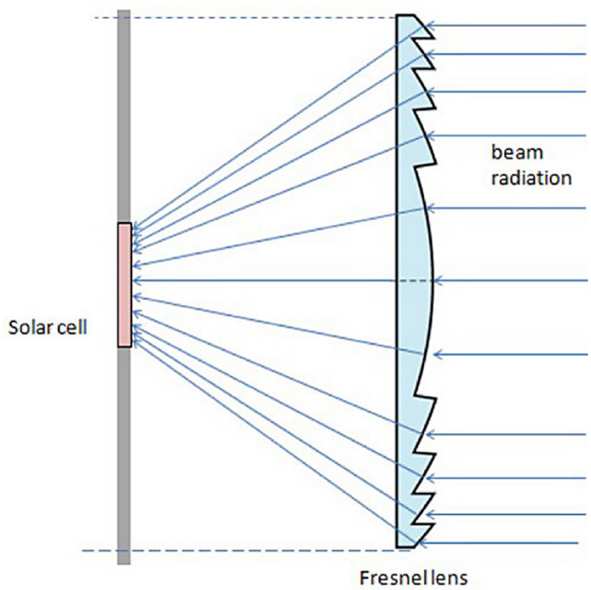

Figure 2. A concentrated photovoltaic optical layout.units installation

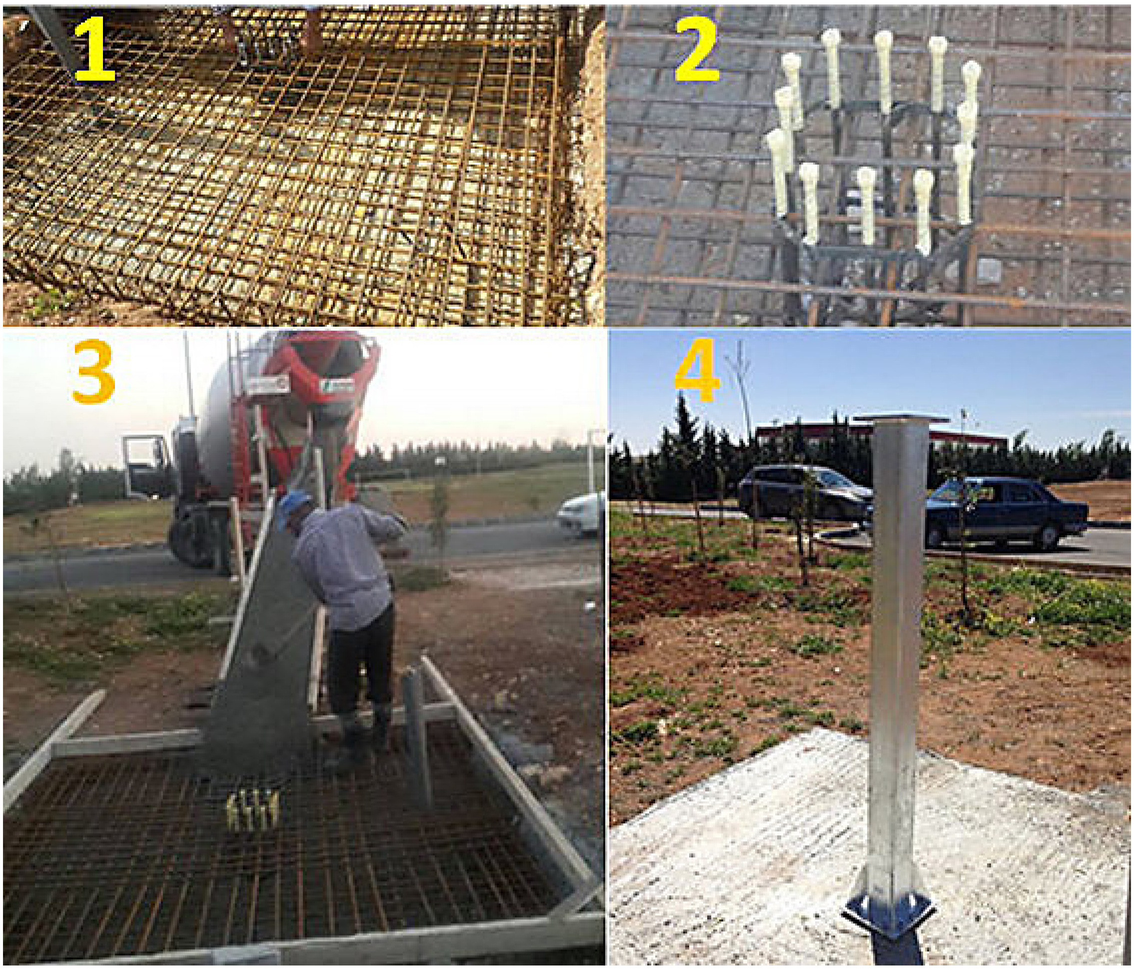

Figure 3. Steps of building concrete foundation process

current output readings. Thus, a series of maintenance procedures were conducted by dismantling all the CPV components in order to troubleshoot everything related to the panel operation. The main parts that were fixed are:

a) Concentrators

The most commonly used concentrators are concentric mirrors or lenses with the magnifying effect that concentrate the sunlight on the photovoltaic cell as shown in Figure 6. However, when the units of the system were completely dismantled for maintenance purposes, and the sealing of silicon on the edges of panels were removed, large quantities of water that accumulated inside the panels, as well as a certain amount of condensed water trapped between the layer of Fresnel film and the glass were found, as illustrated in Figure 7.

The best scenario for eliminating the water and moisture content was accomplished by applying heat as well as using a syringe to suck the water out from between the layers, due to the fact that glass is very fragile and might break spontaneously. In fact, this process took a lot of time and had to be performed carefully, due to the fact that the Fresnel layer is made from thin transparent thermoplastic rubber. Figure 8 shows part of the Fresnel layer used in the CPV modules. Multiple layers of rubber and silicon were used to reseal the panels in a better way to avoid the issue of water leakage inside the panels recurring under rainy conditions.

b) Photovoltaic cell

The photovoltaic cell is situated in the focal axis of the reflective or of the lens and it is mounted on the bottom of panels. The photovoltaic cells are responsible for transforming the sunlight into electricity. The PV cell is composed of two or three layers of different materials (e.g. GaInP/GaInAs/Ge) each part optimized to convert all the electromagnetic spectrum of sunlight into direct current [Ceballos 2015]. The photovoltaic cells are connected in series and part of them is illustrated in Figure 9.

Figure 4. Steel structure of CPV

Figure 5. One of the CPV units installed in the site

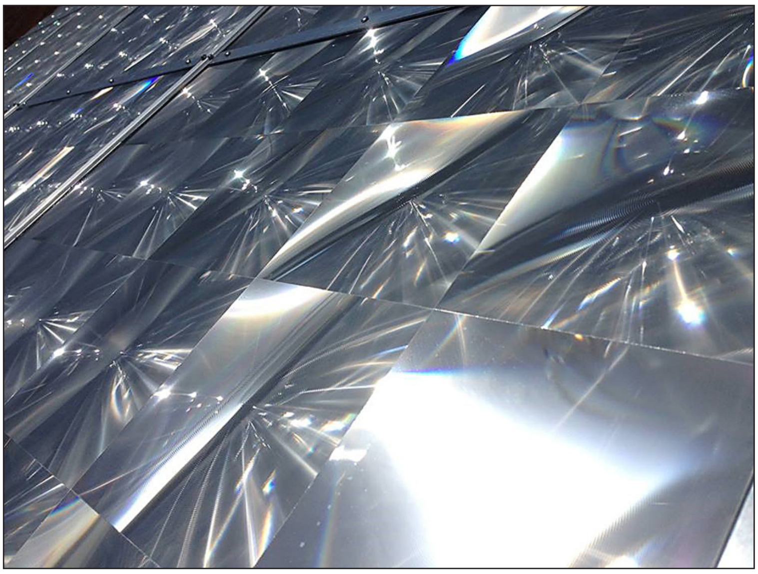

Figure 6. Top view of panels (Concentrator lenses)

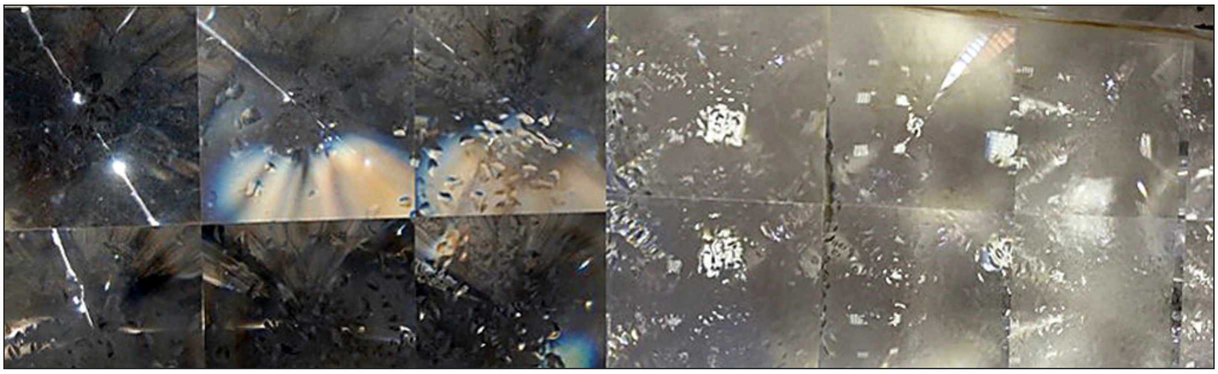

Figure 7. Water leakage between glass and Fresnel lens

Figure 8. Fresnel layer made from transparent thermoplastic rubber

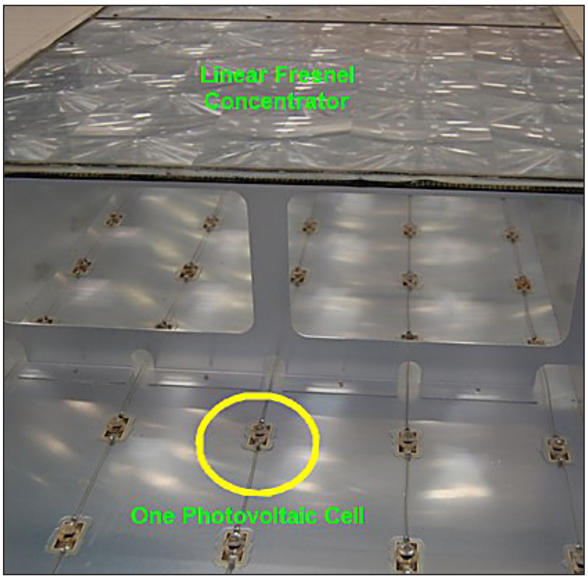

Figure 9. Photovoltaic cells

It should be noted that when the silicon sealing was removed, some photovoltaic cells were found damaged due to the water leakage inside panels for long time, while some of them were found calcified; moreover, rust accumulated on the wiring connection between cells, as shown in Figure 10. The following immediate corrective actions were carried out:

- Cleaning every cell from dust and fixing the external wiring connection. Figure 11 shows a cleaned cell.
- Replacing the damaged photovoltaic cell with a new one imported from the manufacturer.
- Testing and validating each cell separately in order to guarantee that the output voltage is 3.2 V, as designed by the manufacturer.

Figure 12 illustrates how the testing procedure is being carried out on the photovoltaic cells. This procedure was repeated for the installed two units, eight panels for each. In other words, the process was conducted on 960 photovoltaic cells.

c) CPV Software

The CPV unit is controlled through a Raspberry-pi controller. This offers two different operational options; manual and automatic. In the manual mode, the controller can be directly fed with orders through an Ethernet connection to a PC and the entire structure can be rotated horizontally and vertically on command. This manual

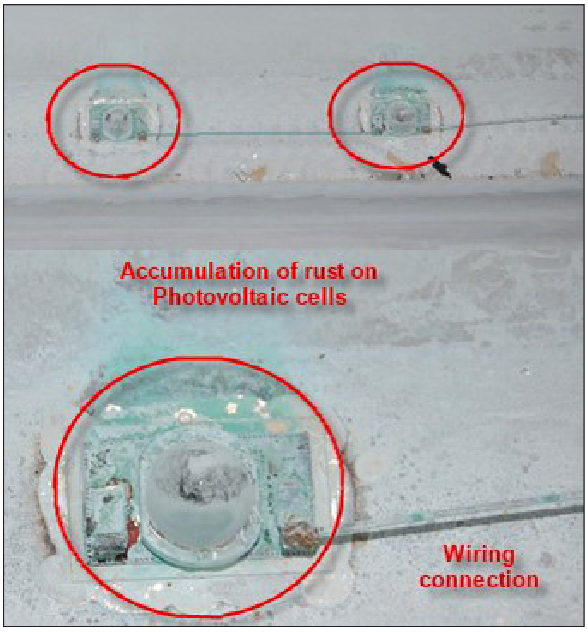

Figure 10. Calcified photovoltaic cells

approach is essential in setting up the system and calibrating it before transferring to the automatic sun-tracking mode. In the latter case, the controller operates based on the pre-recorded tables that correlate time to the Sun-location.

The CPV module has no irradiation-sensing element installed despite having the potential to have one built-in. The manual calibration poses a challenge as it requires a visual-based process in which the operator needs to feed the controller software with arbitrary elevation and azimuth parameters, and then observe the focal point of the irradiation. By identifying how much the focal point falls off the PV cell, the operator then adjusts the elevation and azimuth through the software. The full procedure needs to be repeated several times until a reasonable alignment is achieved.

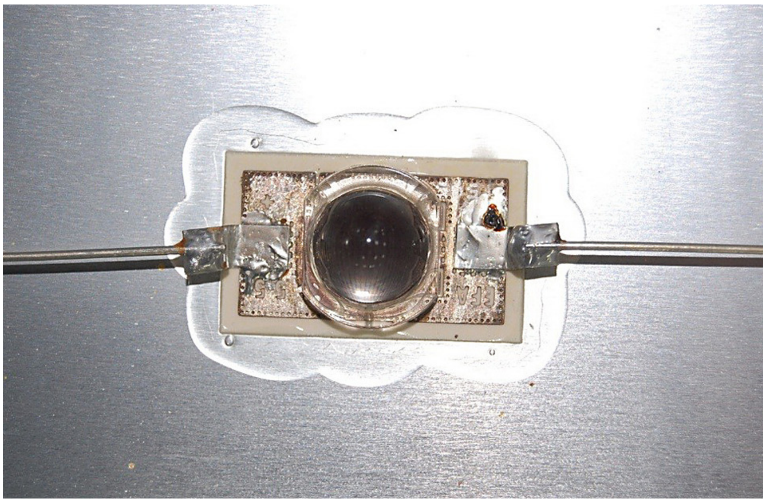

Figure 11. Photovoltaic cells after cleaning

Figure 12. Testing and validating results of Photovoltaic cells after cleaning

It has been observed in the course of monitoring the CPV system that this procedure needs to be repeated roughly on a monthly basis to ensure the optimal performance. It is worth pointing out that the Raspberry-pi acquires an IP address allowing remote monitoring and control of the system. This can be exceptionally useful under rough weather conditions when no operator is available on site and the system is to be adjusted into a less hazardous setting.

d) Solar Tracking System

The CPV system contains two motors to follow the Sun, the first being the linear actuator motor, which is a machine responsible for realizing the vertical component of movement necessary in tracking the Sun. The actuator operates by transforming the rotational movement into a linear one. This actuator is shown in Figure 13. The second is the circular motion motor, which is a machine responsible for rotating the entire system. This mechanism could involve the use of a gearbox as is the case in the CPV system installed at MEU.

Gear boxes are important, as they are essential devices found everywhere in manufacturing facilities. They provide even distribution of power and torque wherever needed to improve the productivity and profits of the manufacturing process. Despite how ubiquitous gearboxes may be, they require periodic maintenance to ensure smooth and continuous operation of the systems involved. Neglecting the routine maintenance of gearboxes could lead to grave consequences. In order to maintain productivity, it is necessary to carry out frequent inspections and regular maintenance procedures. This can ultimately maximize the life span of the system.

However, to prevent costly repairs or downtime, continuous maintenance is required to preclude problems before they occur. Unfortunately, both motors of the CPV system at MEU broke down. This breakdown was not due to lack of maintenance but had more to do with manufacturing problems.

Moreover, as the CPV system has problem with both motors, the first step was to identify the issues by using the auditory or tactile test, then special diagnostic tools were utilized to understand where the required repair was needed to solve these problems.

The linear actuator motor was dismantled after being found not to function properly. On inspection, it was found that the motor itself was running but failing to move linearly. All the constituting elements were then disassembled as shown in Figure 14. Multiple tools were required to take out the gearbox, including a stud (80 cm) to remove the inner bolts; after the cover was removed and all limit switches were dismantled from the linear housing, the electrical motor was separated from the gearbox. A visual inspection was performed for the gear teeth inside the linear actuator gearbox. The gear teeth were found to be broken as shown in Figure 15.

Figure 13. Both motors for CPV system

After dismantling the gearbox (containing three layers of gears), one layer was found to include interfaces between the metal and plastic gears. The breakage occurred precisely at these coupled gears. Figure 16 shows an image of the gears in question. An inspection was carried out for gear-fatigue such as cracking or flaking, as well as cracks on the teeth. In one the layers, all of the plastic gears were broken. In order to solve this problem, a lathing machine was to lathe alternative gears using Teflon which were subsequently installed in the gearbox as shown in Figure 16. The new gear-box is marked in yellow. The entire assembly was put together again with all layers greased. A test was then carried out to double check that everything was running smoothly. This

Figure 14. The linear actuator motor after dismantled

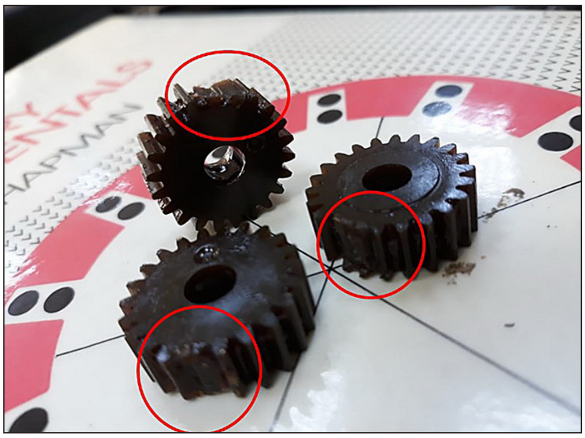

Figure 15. Linear actuator motor Gear-box

was followed by an inspection for the motor bearing (the front and the rear) by using the auditory or tactile test for determining fatigue on the ball bearing such as loose, cracking or flaking. Then a test was carried out on the gearbox with the motor attached. This showed a perfect homogeneity between the motor and the gearbox.

For the circular motion motor, an inspection was done using the auditory or tactile test as discussed previously. The problem turned out to be in the attachment between the motor and the gearbox, and was solved by replacing the four coupling bolts, as the old ones were bent. The same test was performed for this motor (as the previous test). This showed that it was now working perfectly. Details are given in Figure 17.

CONCLUSIONS

Technical reviews and preventive maintenance of CPV components were presented. The research aimed at providing a guideline for fixing Concentrated Photo-voltaic which is one of the renewable energy technologies that might be utilized to produce energy and contribute to the energy mix in Jordan, despite the fact that this technology is niche and still young in Middle East. The actions taken and presented in this paper were sufficient to solve the issues related to the CPV operation and to ensure hermetic sealing of the panels and avoid future water leakages under rainy conditions.

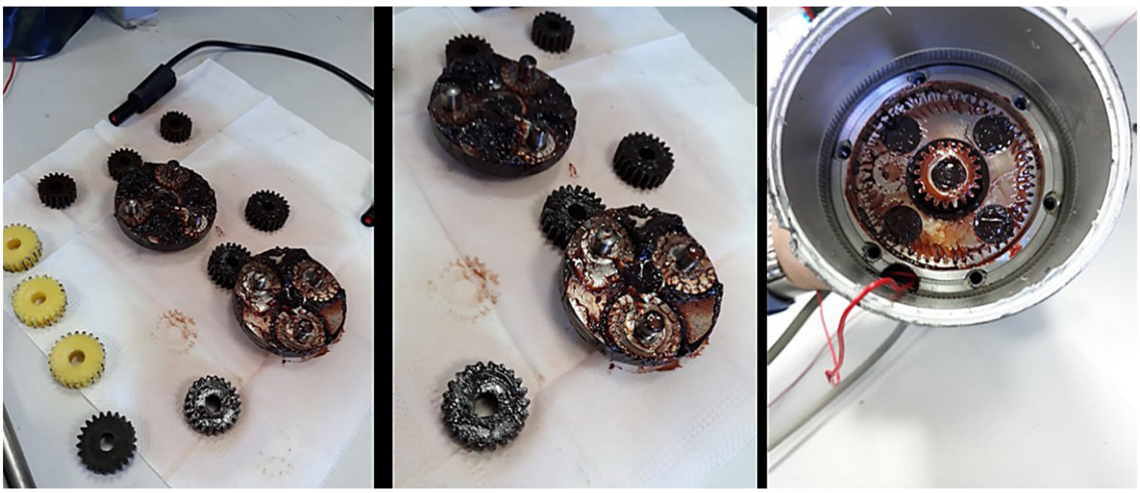

Figure 16. Linear actuator motor Gear-box before and after lathing

Figure 17. The circular motion motor Gear-box

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