Maintenance Management Regime for Off-Grid Solar PV Renewable Energy System in Nigeria

Zacchaeus A. Adetona, Joel Ogunyemi, and Irmiya Bitrus

***Abstract* — The perennial inadequate power supply problem in Nigeria, the worldwide call for green energy and the unavailability of grid electrical supply or difficulty in accessing it have created a need for the adoption of renewable energy such as solar PV systems. PV systems have a lifespan ranging from 10 to 25 years if well maintained but it has been observed that PV systems do not last up to their useful lifespan in Nigeria. A preliminary survey carried out showed that 71.2% of sample did not carry out any maintenance on their PV installations, 85.7% agreed that a lack of maintenance was responsible for their nonfunctional PV systems and 95% of the respondents agreed that there was a lack of maintenance on PV installations in Nigeria. A maintenance regime was developed for PV systems whereby a maintenance personnel is appointed to carry out routine or breakdown maintenance on solar panels, charge controller, battery, inverter, and cabling. The regime starts with turning off power coming from the solar panels. The maintenance of the solar panels follows; next is maintenance on all cable wiring and terminations. After all cable terminations have been checked, the battery maintenance follows. The charge controller is then checked for maintenance and subsequently, power from solar panels can be switched on to restore charging. Two protective installations were recommended in the maintenance regime namely the installation of earthing and DC circuit breakers to protect the solar system installation.**

***Index Terms* — Energy Conversion, Off-Grid Solar System, Maintenance Management Regime, Maintenance Personnel, Renewable Energy, Solar PV System.**

I. INTRODUCTION

The perennial inadequate power supply problem in Nigeria and the constant call for green energy worldwide have created a need for the adoption of renewable energy such as solar photovoltaic (PV) system. Due to the cost of installation of the solar PV system, it is often employed as a stand-alone system solar. PV system in particular has become a preferred alternative electrical power source especially in areas where grid electrical supply is unavailable or difficult to access. Many rural communities have adopted this system of energy provision. Many government and non-governmental organisations (NGO) have commissioned such systems to provide energy for rural dwellers. Furthermore, the epileptic power supply problem in Nigeria requires that homeowners seek for an alternative energy source. For this, stand-alone PV systems have come to the rescue in many rural and urban homes throughout the country. Indeed, among the available renewable energy resources, the energy through the PV system can be considered the most essential because solar energy is ubiquitous, abundant, and highly sustainable [1]. This is rightly so because electric energy is a highly desired commodity and a prerequisite to (for) rural development in long term perspective [2].

Many of these PV systems have a lifespan ranging from 10 to more than 25 years if well maintained. It has been observed, however, that these PV systems do not last up to their useful lifespan. Many newly commissioned solar PV installations by governmental and many NGO to provide sorely need (needed) power for rural communities usually work for only a few years and then become moribund thereby wasting huge resources put into the high cost of installation.

The general perception is that solar PV systems do not require any maintenance whatsoever. Thus when commissioned anew most PV system installations were left unattended for many months thus making them work for some months or few years at best then become inoperative. Granted, solar renewable energy systems require very minimal maintenance especially when compared with fossil fuel-powered generator, but as with any piece of equipment or electrical system, performing regular maintenance and inspection of components will help ensure system performance and minimize disruption due to component failure.

Shown in Fig. 1 is a typical rural PV water pumping system that had become moribund perhaps just after few years of commissioning. Such systems abound in Nigeria as a country. With the lifespan of 20- 25 years, it is obvious that the numbers of moribund solar installation cannot be as a result of “expired” panel as average age of mass installation of solar system in Nigeria is less than that. Thus there is the need to create awareness and get PV renewable energy funders in rural areas, the users of such systems and other system owners in urban centers to be aware of the need to carry out necessary maintenance and what to be maintained in the PV systems so as to reduce their rate of premature failure. The general perception to ensure that the PV systems are sustainable requires paying attention to forming or adopting formal institutions, as well as ensuring their enforcement while corrupt behaviour is avoided [3].

Two types of solar solutions are commonly available in Nigeria namely Solar Pico Systems (SPS) and the Solar Home Systems (SHS). The SPS is limited to a power range of up to 10 watts and used for small scale lighting and charging of electronic devices. SHS usually have a capacity of between 10–250 watts peak and has been installed in

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many households. Such a system can supply power to more devices, such as several lamps, a radio and TV and other portable electronic devices. SHS systems usually comprise PV cells, batteries, an inverter and a charge controller. All these parts are necessary in SHS and make the system an expensive one than SPS. It is estimated that there are more than six million SHS installed globally. Larger stand-alone PV systems called Solar Residential Systems (SRS) have also been installed in many parts of the country. These systems usually provide electricity to large individual installations like hotels, hospitals, schools, factories etc. [4]-[6].

Many problems bedevil application of solar PV renewable energy in Nigeria. These problems range from affordability, poor awareness level, over-reliance on importation for component parts, high initial cost of solar equipment, theft and vandalization of systems setup, systems malfunctioning or performance deterioration arising from poor maintenance, lack of technical know-how, Lack of tailored financing package, to inadequate training of end-users [7]-[9]. It has been shown in the literature that there is a link between field maintenance practices and performance of solar PV systems [10]. Thus, this paper aims at exemplifying the need to practice maintenance culture on solar PV systems installations so as to get the systems to the best performance and increase its availability or reliability. This is necessary now because if properly deployed and maintained, the solar PV system can be made financially attractive [11]. There is lacking a government policy regarding the maintenance of PV systems in Nigeria even as the government is an important funder of solar systems. This study further discusses what areas need maintenance in PV system installation and how to carry out maintenance on them. It elaborates on the need to develop a maintenance management regime for solar PV systems in Nigeria, whom to maintain the systems, when to maintain and how a routine for maintenance can be set up in an installation.

Fig. 1. A moribund solar-powered borehole in Akure Ondo State [12].

II. Effective Maintenance Management for PV Systems

The PV system comprises of various parts put together to form the whole. The various parts of a solar PV system have different lifespan and maintenance needs. Thus the knowledge of how the parts interrelate to form a whole is needed so as to carry out the needed maintenance on the component parts. A typical off-grid PV system such as shown in Fig. 2 comprises the solar panel mounted somewhere in the open to receive solar energy and convert same to electric current used to charge special batteries (flooded (tubular), Gel, and (Absorbed Glass Mat) AGM sealed batteries). The charging of these batteries is controlled by a special device, the solar charge controller. The charge controller ensures that the battery receives adequate quantity of electric charge from the solar panels and prevents the solar panels from "flooding" the battery with charge. It also ensures that when under use the battery is not over-discharged to an unsafe level. To utilise the energy stored in the battery, an inverter is usually employed to convert the DC energy to AC for utilisation by the electric appliances.

For a solar PV system to work effectively, maintenance management is essential for the various components of the PV system shown in Fig. 2. Mgonja & Saidi [10] established that lack of field maintenance practices of solar PV systems caused failures in PV systems. Thus, it is imperative that for every PV system commissioned, there should be formal maintenance management put in place for the system. The maintenance management involves identifying areas that need maintenance and appointing personnel that would be responsible for the maintenance. Further, the personnel should be trained on what to maintain, how to maintain, and when to carry out maintenance on the system. Thus, it is clear, that system maintenance should start with people before equipment.

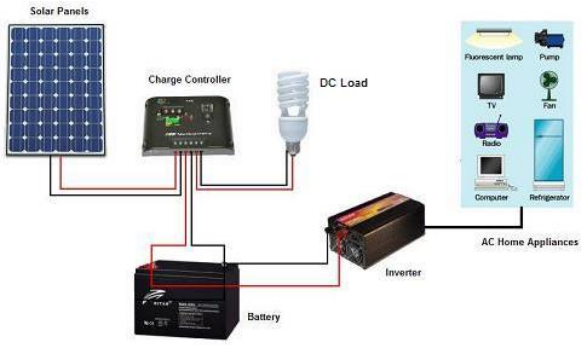

Fig. 2. Typical solar home system components [13].

An effective maintenance management system should start from the period of commissioning the system. When a government or an NGO commissions a PV project or series of projects in a locality, of necessity, maintenance personnel must be appointed. The personnel to maintain the system should have the technical knowledge of the installation of the system and should be adequately informed about what is involved in the installation, how various parts are connected to form the whole and what are the critical parts of the system that require maintenance. He should be personnel with technical know-how who had been previously trained in such work. The duration of routine maintenance should be established from the period of commissioning. In case of rural areas where trained personnel might not be available, the beneficiary community would be required to appoint someone from the community who would be trained from the start of the installation on how the system works and

how it should be maintained. Such an individual shall be provided with a few necessary tools to carry out routine or breakdown maintenance.

The maintenance personnel will be required to carry out periodic maintenance on the installation. When the system requires more than minor routine checks it may be necessary for the personnel to seek further help. Thus, the project initiator shall be required to provide their contact phone number so that the on-site personnel can make instant contact when necessary. This is important because certain expensive component parts of the PV solar system may not be left in a nonfunctional state for more that short period of time else such parts go bad and would need eventual replacement.

III. Maintenance Awareness Survey

A preliminary solar PV maintenance awareness survey was carried out to establish the level of awareness of solar PV users and technical personnel understanding of solar system maintenance. Since the subject of interest, solar energy, was gradually becoming a household item in the society, a web-based polling system was adopted to obtain the data needed from the identified population using a randomised sampling technique. The respondents were from various age-grades, professions and locations. Respondents targeted included students, workers, homeowners, solar system technical personnel and solar PV end-users. Descriptive analysis was employed to show the results for the survey as in Table I. As shown in the table, the results show a high level of lack of awareness on the necessary maintenance needed to be carried out on PV system installation. Of all respondents, 71.2% did not carry out any maintenance on their installations and 85.7% agreed that a lack of maintenance was responsible for their nonfunctional PV system. The respondents generally agree (95% respondents) that there was a lack of maintenance on PV installations in Nigeria. These results and others as shown in the table prompted the development of a maintenance regime for the PV system in Nigeria. The survey has been reported in [17].

IV. Off-Grid PV System Maintenance

To achieve optimum performance, adequate sizing of the PV system component parts is very important. When appropriate sizing has been carried out, the maintenance work is easy. In the off-grid PV system, five critical parts need maintenance for an effective, durable and cost-effective system. The parts are solar panel, charge controller, battery, inverter and cabling. A discussion on the various components to be maintained and how the maintenance should be would follow. In addition to the maintenance of various parts, there should be an installation of protective equipment. The discussion on the importance of the protective equipment will come after the maintenance sections.

The PV system maintenance can follow the developed (proposed) routine shown in Fig. 3 whereby the maintenance check starts by turning off power coming from the solar panels by switching off the circuit breaker. Then the maintenance of the solar panels would be checked for maintenance as highlighted in this study. Next is to carry out maintenance on all cable wiring and terminations. After all cable terminations have been checked, the battery type is considered if dry or wet cell type. If wet cell type, the water level of each cell should be checked and replenish as necessary. The charge controller is the next to be checked to ensure that it's functional. If non-functional it should be replaced. If the charge controller is in good working condition that signifies that the maintenance routine has come to an end and the circuit breaker can be switched on to restore charging of the batteries from the solar panels.

TABLE I: Maintenance Awareness Survey Results [17]

ITEM	*N*	%
Awareness of maintenance needed for PV system installation		
Yes	23	39.7
No	35	60.3
Past investment in solar energy		
Yes	24	38.7
No	38	61.3
Personal funding or contribution to solar PV system		
Yes	25	40.7
No	36	59.3
Age of Solar installation		
Less than 1 year	10	18.9
1-2 years	20	35.8
3-5 years	21	39.6
6-10 years	4	5.9
More than 10 years	0	0
Any maintenance carried out on solar system		
Yes	17	28.8
No	42	71.2
Reasons for nonfunctional Solar system installation		
Incompetent personnel	32	50.8
Lack of funding	15	25.4
Lack of maintenance	54	85.7
Others	19	30.2
Personal opinion: Is maintenance lacking in solar installations in Nigeria?		
Yes	57	95
No	3	5

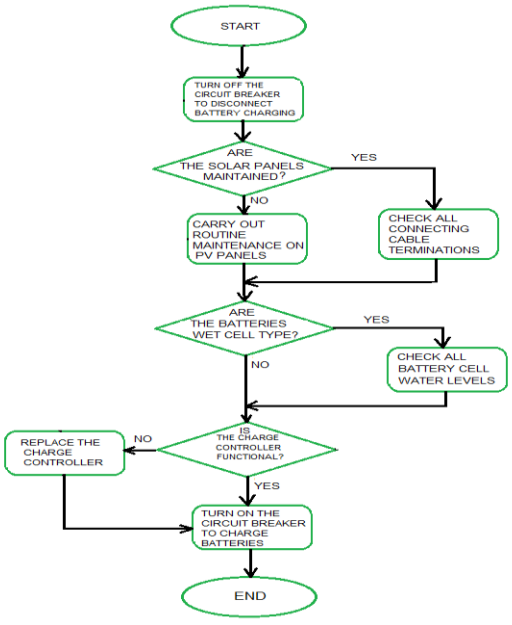

Fig. 3. Proposed PV solar system maintenance routine flowchart.

A. Solar Panel Maintenance

Most of the top-quality solar panels available commercially are well suited to be exposed to the elements and harsh weather conditions. But the PV panel is affected by the following conditions that diminish its performance:

- Shadowing
- Dust Collection
- An average failure percentage of 5% due to broken or stolen modules.

Thus, the PV panel should be maintained well to ensure optimum functioning. The PV panel must be installed away from structures such as buildings, electric poles, masts trees etc. to avoid shadows casting upon it. Casting shadows will prevent optimum energy from the sun to reach the surface of the panels thus reducing the energy conversion rate. PV panels should be installed on the roof of a building to avoid damages such as from falling objects. The installation of non-sun-tracking panels should be such that the panels face the sunset so that maximum energy conversion per day shall be achieved.

Dust accumulations do occur over time on the surface of PV panels installed over time. This will reduce the efficiency of the panels. Thus the surface of the panels should be washed once in six months. Washing the surface of the panels can be a dangerous venture with the presence of soapy water which can cause a wet slippery roof surface. Extreme care should be taken when cleaning solar panels on roofs and the hazard of working at heights should also be considered. If there is easy access to the panels and they are not too dirty, then a simple wipe with some standard glass cleaner and a rag can be sufficient. Precautions should be taken against causing any damage to the electrical components and wiring by water. Water should not be poured directly on to any electrical connections or junction boxes. Such connections and terminations should be well sealed. For systems with micro-inverters installed usually mounted underneath the solar panels, care should be taken to protect them from the elements. They should be well sealed to avoid getting wet. Avoid using laundry soap or dishwashing liquid as these types of soaps can be highly corrosive to some metals. Rather, a small amount of car wash is a better choice [14].

B. Maintenance of Charge Controller

The charge controller regulates charging when the battery is fully charged and can disconnect the load when there is excessive current demand from the battery. It also functions to block reverse current electricity and prevent battery overcharge. Certain controllers, in addition to these functions, also limit battery over-discharge and display the flow of power between the inverter and the solar battery. The charge controller requires little maintenance but must not be overlooked.

The charge controller should be switched off before maintenance checks. That is, power from the solar panels should be switched off before maintenance. If it's necessary to disconnect the wires from the solar panel, battery and the load, ensure that the right sequence of disconnect and reconnect is followed. Certain controllers get damaged by the wrong sequence of connections. Thus the controller manual should be consulted before this is done. The charge controller terminals should be checked for loose, broken, corroded or burnt connections. Ensure that there are no loose strands of wire in a stranded wire as this can cause a short-circuit with adjacent terminals. The charge controller cover can be removed to look for dirt, insects, cobwebs, animal dungs, corrosion, etc. at the inner parts. These should be carefully removed if found.

For controllers with temperature compensation, check the temperature compensation probe. If the probe wiring needs to be extended, ensure that the same type of wire as the thermocouple is used and the wires soldered.

C. Battery maintenance

Batteries are employed to store the converted energy from the sun by the PV panels and they are very critical to the PV solar system installation. Battery maintenance is very important as an integral part of the solar-powered inverter system as it determines the availability of supply as well as its duration. However, in many instances, the appropriate procedure for battery maintenance is often neglected and causing the early pack-up of the entire system. Most often, the battery is the weakest link in the chain of solar-powered inverter system in any installation and as such requires careful maintenance. Fig. 4 shows various types of batteries installed in a multi-system solar system installation.

With an increase in application of renewable energy in the face of energy crisis, and newer batteries with higher energy density and reliability have been produced owing to the advancement of material science and packaging technologies. Failure in managing and caring for the battery, often result in shortening the lifespan substantially of such battery. Preventive maintenance is designed to minimize the risk of system downtime, maximizes up-time and extends battery life by eliminating problems before they happen. For proper functioning, there should be considerations for cleaning of cases, battery terminals and water additions. The following performance checks are required:

- specific gravity recordings (for the wet type),
- conductance readings,
- temperature measurements,
- cell voltage readings and
- capacity test.

Fig. 4. Various types of battery in a typical solar system installation.

Battery lifetime is dependent upon a number of design and operational factors, including the components and materials of battery construction, temperature, frequency and depth of discharges, average state of charge and charging methods. Over-discharging of batteries should be

avoided. This will be ensured with a good charge controller for solar charging and inverter in case of mains charging. The deeper batteries are discharged the shorter their lifespan. Batteries should not be discharged more than 50%. This is equivalent to about 12 V on a 12V (see Table II) nominal system under a small load. The state of charge (SoC) of a battery would reveal the condition of the battery. Table I gives the condition of a battery based on its terminal voltage. As seen in the table, optimum performance of the battery is obtained at 70% to 100% discharge or from 12.7 - 12.3 V. Care should be taken to ensure that a battery is not discharged below 30% or 11.9 V.

TABLE II: BATTERY VOLTAGE CHART

Battery Voltage Chart	
% of Full Charge	Voltage (V)
100 % charged	12.7
90 % charged	12.6
80 % charged	12.5
70 % charged	12.3
60 % charged	12.2
50 % charged	12.1
40 % charged	12.0
30 % charged	11.9
20 % charged	11.8
10 % charged	11.7
completely discharged	11.6

Batteries should be returned to a full charge on a regular basis. Ideally, it is recommended that the batteries reach a full-charge every day. However, if this is not possible batteries should be returned to 100% full at least once a week to prevent battery *sulfation* and extend the life of the batteries. If the solar is not providing enough charging to accomplish this, then it will be necessary to use the generator as often as needed to provide the balance. It can sometimes be difficult to determine if the batteries are reaching 100% state-of-charge, hence a good battery monitor is recommended. Additionally, if the solar charge controller has reached the "float" stage of charging, this is generally a good indication that the batteries have reached a full charge.

Sealed Lead-Acid, AGM or Gel batteries require less maintenance overall, but the following checks are necessary once in two months:

i. Cable and terminal connection should be visually checked to ensure that they are securely tightened, clean and free from any dust, rodent faeces and urine, corrosion or leakage. Corrosion can cause resistance in the battery connections and reduce the even flow of electrons throughout the bank and this can prevent proper charging and reduce battery lifespan.
ii. For large battery installations, an infrared thermometer can be used to detect a high temperature at a battery terminal. A high temperature indicates partial contact at the terminal that can prevent good charging of the battery or result in a fire if left unchecked.
iii. Lithium-Ion Battery Maintenance batteries require the least maintenance. However, after installation, a professional technician must check whether their holding charge well.

D. Inverter Maintenance

The inverter converts DC energy to AC energy for utilisation by all AC appliances in the building. Thus, the inverter is the last supplier of energy in the building. The device must be located in a well-ventilated and dry place. It must be away from heat sources and battery gassing, and the ventilation spaces have not to be opened. The inverter should be easily accessible for routine maintenance while access to it is restricted to unauthorized persons.

The maintenance of inverter actually should start from the time of installation. The system should be properly installed such that subsequent maintenance is not difficult. Inverter maintenance is summarized in Table II. Generally, the following points should be observed for proper maintenance of inverters:

i. The inverter and battery must be installed in a well-ventilated enclosure, if possible, away from the domestic areas of a house. They must not be too close to the batteries as batteries can produce heat and gas. The area in front of the installation space should be reserved to provide operators with the opportunity to see the front panels of the inverter. It is advisable that the inverter system if not mounted on the wall should be installed atop a metal rack where children cannot reach or where there are not many disruptive domestic activities

ii. For inverters with cooling fans that regulate the temperature, ensure that the airflow around the inverter is not obstructed to allow for adequate cooling. As a general rule, leave at least 12 inches space around the inverter.

iii. Operating instruction should be printed, laminated and posted on the wall beside the installed system operators can easily see it for guidance.

iv. Ensure that the inverter is from the mains when conducting periodical inspections or switch off the entire system.

v. Check the terminals of the inverter for nay loosened part and re-tighten it with a screwdriver. The terminal of the inverter should be checked for loosened part and re-tightened it with a screw driver

vi. Check the inverter terminals for any unusual change in temperature. That will indicate poor terminations needing correction. Check for any damage on wire or cable and replace as necessary.

vii. Carry out the cleaning of the inverter case using a dry rag to remove dust.

viii. Any unusual changes in the state of the inverter including beeps must be reported immediately to the maintenance personnel.

Installation of large inverters require special maintenance checks on parts such as cooling fan, cooling liquid, pH of coolant, coolant corrosion inhibitor, heat exchanger cleaning, expansion tank air pressure, cooling liquid pipe connections, air filters, etc. These maintenance checks should be carried out as stipulated in the manufacturer's manual and according to the stated periods.

TABLE III: INVERTER MAINTENANCE ACTIVITIES [16]

Subject of inspection	Gist of inspection			Criteria of judgment
	Inspection item	Inspection cycle	Inspection method	
1. Indoor environment	1) Dust, humidity, gas 2) Dropping of water and other liquid 3) Room temperature	As occasion demands	1) Eye-check, thermometer, sense of smell 2) Eye-check 3) Thermometer	1) Improved bad atmosphere. 2) Pay heed to trace left of water drop. 3) Maximum temperature 40 ° C (50 °C inside cabinet)
2. Component parts and units	1) Vibration, noise		By feel (touch) of outside of the board	If there is something abnormal, open the door and check transformer, reactor, contactor, relay, cooling fan etc. Stop the inverter as occasion demands.
3. Operation data (output side)	1) Load current 2) Voltage 3) Temperature		Moving-iron type AC ammeter Recitifier type AC voltmeter Thermometer	Within the rating. Liithle difference from data on normal status.

E. Installation of Protective Equipment

Oftentimes solar system installations suffer from overcurrent as a result of electric current from lightning. This often spoils component parts in the installation. Solar panels are sensitive to high-intensity light that accompanies thunder and lightning. Whenever there are thunder and lightning, solar panels do convert the high-intensity light into a high voltage that drives high current towards the solar charge controller, the battery and the inverter. Any of these parts can get damaged by the resulting high current as a result of this. Thus, it is important to protect the solar system installation from this excessive current.

The main objective of earthing system generally is to protect the user or personnel from electrocution due to leakage current, fire due to earth leakage of current through an undesired path and to ensure that the potential of a current-carrying conductor does not rise with respect to the earth than its insulation.

To ensure that the solar system is protected, two protective installations are required. First is the installation of earthing. The system must be adequately earthed by professionals who will carry out needed tests to ensure that the installation is protected. All metal parts of solar panels and, inverter case and equipment stand must be well-grounded. If installed in a building, the earthing points of all the components should be connected to the earth continuity conductor in the building. Otherwise, an earthing system can be introduced to protect the installation.

Second, is the installation of circuit breakers to protect the component parts in the solar system installation. A DC circuit breaker should be installed before the charge controller to protect the installation from excess current from the solar panel during lightning and thunder. This should be properly sized to ensure that normal operating current from the panel is allowed while excess current is prevented. Fig. 5 shows a solar system incorporating the DC circuit breaker installed just before the charge controller. Another DC circuit breaker is required to protect the batteries from short-circuit. This should be installed on the cable line from the battery to the inverter. When there is a short-circuit, the circuit breaker is expected to energize and cut power away from the batteries thus protecting them from damage.

Fig. 5. Solar system installation showing solar controller, batteries, inverter, and DC circuit breaker installation for protection.

V. CONCLUSIONS

This study presented a maintenance regime for off-grid solar PV systems in Nigeria to extend the years of service of the systems. The maintenance should be made mandatory on all installations and as such maintenance personnel must be appointed where necessary to take care of the maintenance work. There should be a government policy developed regarding the maintenance of PV systems in the country.

Government at various levels in Nigeria and NGO installations of PV system require such a personnel appointment. Individual homeowners can take up the challenge by inviting their installation personnel for regular routine maintenance. This can be carried out bi-monthly and when any unusual malfunction is observed. It will be necessary to have a log of maintenance checks posted close beside every installed PV system. The log will contain a maintenance checklist on what activities to be carried out for each maintenance session. This will provide a constant reminder of how often the maintenance should be carried out. After each maintenance session, the log should be completed to indicate the date of maintenance and what activities are completed in the maintenance session. By regularly checking the log, each maintenance personnel or homeowner will keep track of the system maintenance and act on it as required.

When this maintenance regime is followed, the lifespan of PV systems will be extended, the overall cost of replacing expensive critical parts of the system will be minimized and power will be made available as expected. It is a known fact that the cost of the solar PV system is skyrocketing and this

has made it difficult for both government and NGOs to implement more systems. Adequate maintenance on the existing systems will enable the end-users to get value for the investment in the systems.

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