Chapter

# On-Field Operation and Maintenance of Photovoltaic Systems in Cameroon

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## Abstract

The objectives of this work are to examine the causes of the breakdown in the photovoltaic power systems, to propose strategies to solve them, and to evaluate the field lifetime of some elements of the PV systems. The data analyzed were obtained from maintenance records and measurements over a period of 9 years (from 2007 to 2015) for the backup PV systems and 2 years (from 2016 to 2018) for photovoltaic water pumping (PVWPS) systems. It appears from this analysis that 29% of the batteries went bad (leading to curative intervention); this contributed to about 64.9% of the total breakdown registered. Using the failure modes, effects and criticality analysis (FMECA) method for PVWPS, criticality is 252, 402, and 504 for inverters, PV module, and motor pump, respectively. This demonstrates that motor pumps are more sensitive than other elements in the PVWPS. This study also permitted not only to evaluate the quantity of preventive and corrective maintenance impacts on solar PV systems but also to propose maintenance strategies to rapid diagnosis of PV systems.

**Keywords:** breakdown diagram, life expectancy, maintenance strategies, backup PV systems, PV pumping systems

## 1. Introduction

The production of energy is an immense challenge for the coming years. Indeed, the energy requirements for industrialized societies are increasing [1]. Nowadays, 80.9% of world production of primary energy is supplied from fossil resources [2]. The scarcity of conventional energy and the environmental problems caused by its use have led to the usage of other renewable sources such as solar photovoltaic energy. It is stimulated first by the availability of solar resources in most part of the globe particularly in Africa where there is a strong solar resource and secondly by the decrease in the cost of photovoltaic equipment during the last decade [3], an average of 0.7 $/kWh in 2016 and 0.5 $/kWh in 2020. The production capacity of solar photovoltaic energy within the last three decades has witnessed a yearly increase of 44.2% between 1990 and 2010, to reach a production capacity of 99.2 GW in 2012 [4]. Global installed PV capacity at the end of 2016 was reported as 310 GWp [5]. The price of photovoltaic module dropped by 80% between 2009 and 2015 to reach the actual cost which is less than 1 USD/Wp [6]. PV is widely used in many applications nowadays [7].

The use of renewable energies has increased significantly in Cameroon these recent years since it is demonstrated that the access to modern forms of energy can contribute effectively to the revival of economy and reduction of poverty. In many countries around the world, the use of renewable energy contributes expanding employment opportunities which lead to promoting human development [8]. Recently Cameroon has embarked on the use of renewable energy, which has led to the creation of a directorate of renewable energy in the ministry of energy and water. Investments have been made in the public investment budget (PIB) for the installation of renewable energy systems particularly solar energy [1], for example, public lighting in cities and the countryside by using solar street lights, solar power plants for the villages' electricity supply, battery charging stations in villages, and solar power supplies for community centers. However, as they are installed in outdoor environment, continuous exposure to harsh environmental conditions (sun beam, rainfall, etc.) may reduce the optimal performance of the system. PV systems are difficult to implement because they encounter problems among which is the problem of servicing and maintenance. An effective operation and maintenance (O and M) program enables PV system production to reach its expected level of efficiency, which will consequently strengthen end users' confidence in such systems [9].

The field performance of photovoltaic systems has been extensively studied for many applications especially in countries with strong database of solar resource [9]. However, these databases are used exclusively for assessing the electrical performance of the system [10]. To model the annual performance of photovoltaic modules, their performance characteristics are needed [11, 12]. The available information from manufacturers are typically limited to temperature coefficients, short circuit current $I_{sc}$, open circuit voltage $V_{oc}$, and maximum power $P_{max}$, at rating conditions (G = 1000 W/m$^2$, Tc = 25°C, AM = 1.5). The information is useful when one want to compare photovoltaic module performance at rating conditions but are inadequate to predict annual field performance under typical operating conditions [13]. It is demonstrated that there is difference between expected power production forecasts and field experience of photovoltaic arrays [14]. It has been shown that the relative performance ranking at rating conditions may not agree with the ranking based on monthly or annual performance. Faults in PVS may cause a huge amount of energy loss. A monitoring study was conducted on a test PV system by Firth et al. [15], and it was reported that the annual power loss due to various faults is about 18.9%.

Failures that occur in the PV systems can cause system shutdown. The main components involved are PV modules, cabling, protections, converters, and inverters. Failures are mainly caused by external operating conditions which are shading effects, module soiling, inverter failure, and aging of PV modules [16]. The line-to-line fault (LLF), ground fault (GF), and arc fault (AF) are tree catastrophic failures encountered in PV arrays [17]. PV system maintenance and performance are related to good inspection and monitoring. These are important in determining life-cycle costs and servicing requirements. Photovoltaic energy is seen as a viable option for decentralized energy production; the sustainability of these systems does not only depend on the initial system cost but also on the cost of maintenance and the lifetime related to the maintenance operations used [18, 19]. This chapter presents an overall of existing faults encountered in both DC and AC sides over a period of 9 years in more than 20 PV systems in Cameroon; this chapter also proposes detection techniques with a fault detection procedure (the breakdown tree diagram) that is intended to facilitate interventions on all components of PV systems.

## 2. Maintenance strategies

Maintenance strategies are the "heart" of the maintenance planning process. They are responsible for defining the "maintenance actions" based on the information obtained from the system and preprocessed. Maintenance strategies are corrective, preventive, condition-based, opportunistic, focused-on-reliability, and production strategies [20]. The questions when, what, who, where, why, and how are the system interventions that should be executed or not, in order to keep the system functions alive [21]. One of the maintenance objectives is to reduce the failure occurrence, increase the availability, and extend the system life (or at least in the mean time until the next failure).

## 3. Maintenance technique management

A maintenance schedule, planning, and management are important for the evaluation of the health condition components and the incipient fault diagnosis. Different aspects of the operation and maintenance of renewable energy systems were proposed by [20, 22]. A generic structure of asset management which integrates business decisions to optimize investment decisions related to maintenance is presented by [23], and it consists of eight blocks of sequential management. In physical asset management, the maintenance optimization is a concern, because in general, the assets deteriorate as it is being raised and both the failure risk and cost increase [24]. Maintenance management model of assets is presented in **Figure 1** below.

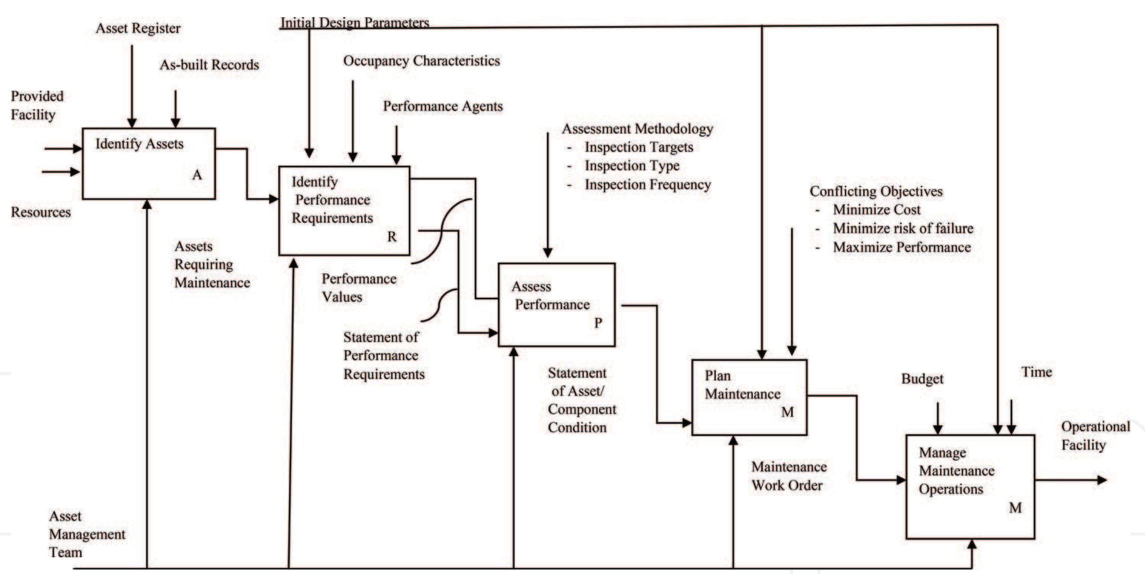



**Figure 1.**
*Maintenance management model [25].*

## 4. Operation and maintenance of the photovoltaic systems

### 4.1 Preventive maintenance

Preventive maintenance consists of a regular observing passage and a frequent replacement of exhausted constituents of the system. Preventive maintenance can be systematic or conditional. Systematic preventive maintenance consists of changing worn out materials according to a preestablished schedule [26]. Preventive maintenance is scheduled at regular time intervals, independent of component wear, or if it still executes its function satisfactorily [26]. Preventive maintenance scheduling could be done using several strategies; the most common are usually with a minimal cost target that are based on the budget allocation for maintenance in accordance with the system priorities [27, 28]. The objective of this type of maintenance is to ensure the reliability of the system and to maintain the system in its state of initial efficiency [29].

### 4.2 Corrective maintenance

It consists of the setup of a breakdown system. It is usually done in two stages: palliative corrective maintenance (fixing) which involves the start off of a system which is partially or totally broken up while waiting for a permanent repair of this system. In this case, the speed with which interventions are done is considered, and the action must take place as fast as possible for quicker start off of this system [20]. The goal of this action is not to repair the breakdown but to permit the system to fulfill part or the totality of it function [20]. Curative corrective maintenance (repairing) is a final setup of all the worn out elements of the system. Contrary to the fixing action, the repairing action is a planned one. In this case, the quality of the intervention is more important than speed. In the case of corrective maintenance on photovoltaic systems, diagnosis diagrams are first done in order to ease and help workers to determine the worn out elements knowing the causes of the breakdown. The essence of the approach "run-to-failure" or corrective maintenance is to replace the component with a new one when it is not able to perform its function [26].

### 4.3 PV systems fault detection techniques

There are several techniques for the detection of faults in PV systems; these techniques are summarized in **Figure 2**. These techniques have helped in improving the system reliability and lifetime of PV systems. The classification of different fault

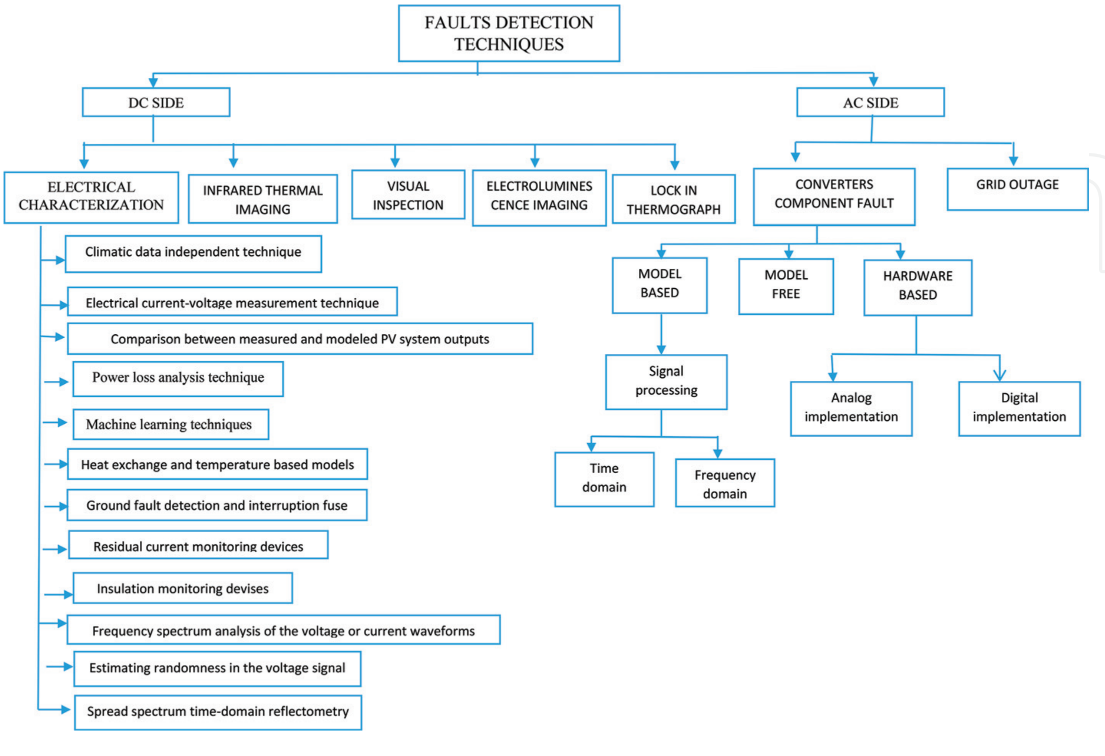



**Figure 2.**
*Fault detection techniques in DC and AC side of PV system [27, 29].*

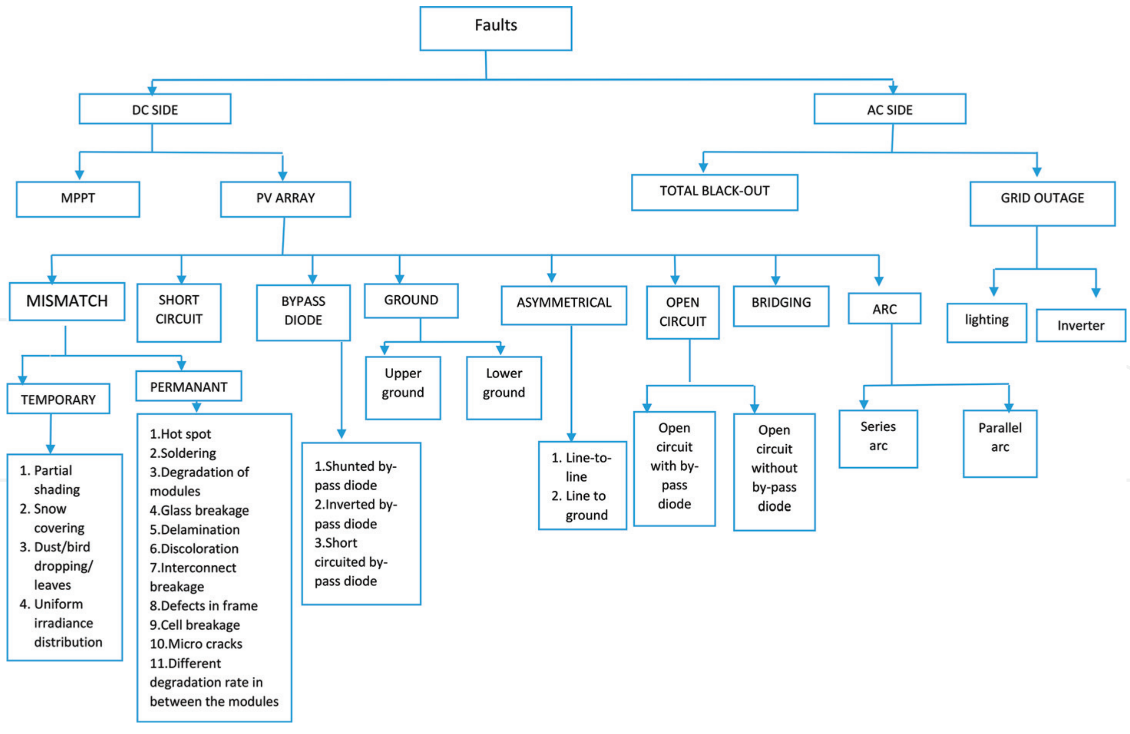



**Figure 3.**
*Classification of faults in DC and AC side of PV systems [27].*

detection techniques to identify the type and location of the fault occurring in DC and AC sides of PV system is given in [27, 16, 28]. Although other techniques are simple to implement, most of them require monitoring and analysis of the electrical performance of photovoltaic (PV) systems.

### 4.4 Types of faults encountered in PV systems

In the field conditions, a number of factors can cause a PV array to reduce its output power. Any factor which reduces the output is considered as "fault" [27, 30]. Generally, faults in PV systems can be classified into two main categories: permanent and temporary. The classification of the most common types of fault in PV system is presented in **Figure 3**. The main faults encountered in PV systems Installed are presented in the **Figure 4** for shading, **Figure 5** for soiling and dust, **Figure 6** for PV jonction fault and discoloration, **Figure 7** for wiring fault, **Figure 8** for circuit breaker and inverter, **Figure 9** for sulfatation and deep discharge of batteries.

## 5. Characteristics of the studied PV system

### 5.1 Backup PV systems

To overcome the problem of power cuts, 20 backup systems have been installed in 20 cities in Cameroon at the end of 2006. These systems are essentially made up of monocrystalline solar modules (Hélios, 80Wc), batteries (Midac, 400 Ah) to backup during power cuts, and charge controllers (Steca, 20A) which regulates the energy flux and protects the batteries from overloading and deep discharge. There are generally three types of controllers [31, 32]: shunt controllers, series controllers, and maximum power point tracking (MPPT) system. The inverter called "inverter-chargers" can be connected to the


(a) (b)

**Figure 4.**
*(a) Shading and (b) vegetation and building.*

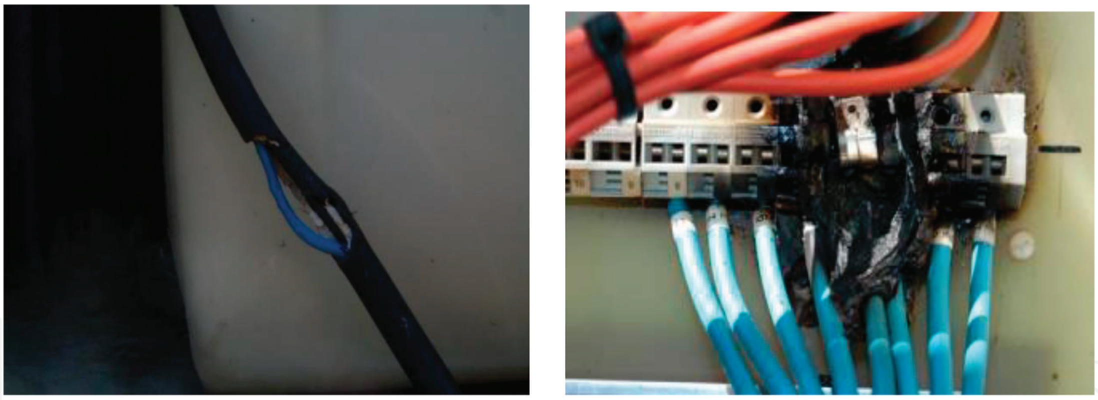
(a) (b)

**Figure 5.**
*(a) Soiling and dust accumulation and (b) vegetation.*

(a) (b)

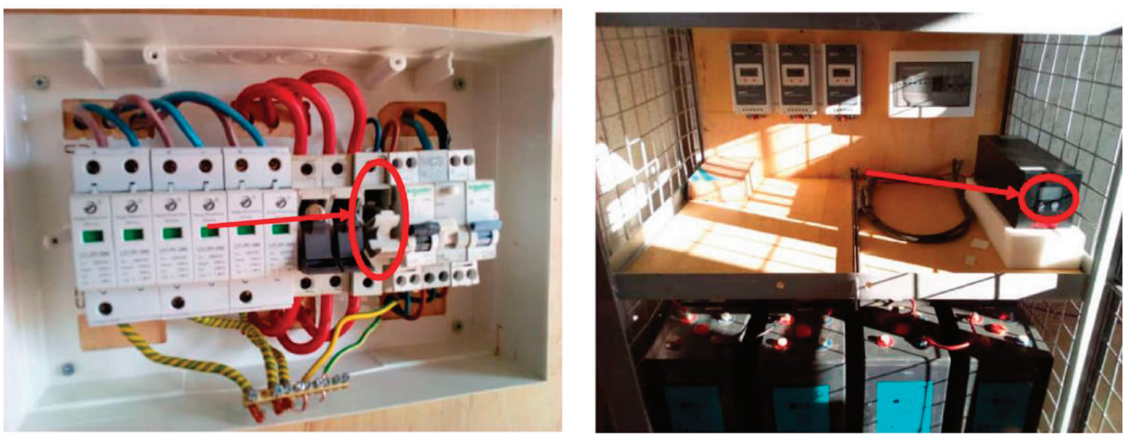
**Figure 6.**
*(a) PV junction box and (b) delamination and discoloration.*

electricity network in the purpose of supplying the energy of the network, two types of inverters are used C1600-12 and C2600-24 (Studer compact) (**Figures 4–9**).



(a) (b)

**Figure 7.**
*(a) Wiring system fault and (b) poor tightening of connections fault.*



**(a)** **(b)**

**Figure 8.**
*(a) Circuit breaker fault and (b) inverter fault.*

(a) (b)

**Figure 9.**
*(a) Deep discharge of batteries and (b) sulfation of batteries due to lack of maintenance.*

## 5.2 Photovoltaic water pumping system

Two water pumping systems are installed to provide water to the population of an isolated site located at 10°23 N and 14°26 E. Each system has 13 kWp of PV generator associated to an automatic inverter. The pumping takes place over the

| Denomination | Symbol | Value |
|---|---|---|
| Rated maximum power ($P_{max}$) | $P_{max}$ | 255 Wp |
| Maximum power current (Imp) | $I_{max}$ | 8.13 A |
| Short circuit current ($I_{sc}$) | $I_{sc}$ | 8.61 A |
| Maximum power voltage ($V_{mp}$) | $V_{mp}$ | 31.52 V |
| Open circuit voltage ($V_{oc}$) | $V_{oc}$ | 37.92 |
| Maximum system voltage | | 1000 V |
| Operating temperature | | (−40 + 85)°C |
| Temperature coefficient of $I_{sc}$ | $\alpha_{Isc}$ | −0.58%/°C |
| Temperature coefficient of $V_{oc}$ | $\beta_{Voc}$ | −0.33%/°C |
| Temperature coefficient of power | | −0.41%/°C |

**Table 1.**
*Characteristics of the PV module used in PVWPS.*

| Inverter Solartech PB11KH | | Grundfos SP17-10 pump | |
|---|---|---|---|
| **Denomination** | **Value** | **Denomination** | **Value** |
| Rated power | 11 kW | Motor type | MS4000 |
| Max solar input power | 16 kW | Rated power—P2 | 5.5 kW |
| Input string | 4 | Power (P2) required by pump | 5.5 kW |
| Max input current of each string | 15 A | Mains frequency | 50 Hz |
| Max DC input voltage | 750 V | Rated voltage | 3 × 380–400–415 V |
| Recommended MPP voltage | 500–600 V | Rated current | 13.0–13.0–13.4 A |
| Adapting motor power | 9.2–11 kW | Starting current | 480–530–550% |
| Adapting motor voltage | 3PH 380-440 V | Cos phi—power factor | 0.85–0.81–0.76 |
| Rated AC output current | 24A | Rated speed | 2850–2860–2870 rpm |
| Output frequency | 0–50/60 Hz | Starting method | Direct online |
| Conversion efficiency | Max 98% | Rated flow | 71 $m^3$/h |
| Ambient temperature | −10 to 50°C | Rated head | 81 m |

**Table 2.**
*Characteristics of the inverter and the motor pump.*

sun. The configuration of a field is performed as follows: 51 solar panels all divided into 03 strings of 17 panels. Two pumps P1 and P2 were associated. The characteristics of the PV module used, inverter and motor pump, are specified in **Tables 1** and **2**.

## 6. Maintenance and fault detection techniques in PV systems

The field inspection process is a key to the development of healthy and safe PV systems. Many works consolidated the most important aspects of a field inspection of photovoltaic system which is the competency of the contractor and installer without taken into account life service of each element and their implication on the failure of the system [33, 34]. Diagnosis procedures consist on visual inspection procedures (array inspection, wire inspection, inverter inspection, inspection of module, and array grounding) and performance monitoring (performance verification, displays, design software, data acquisition systems, sensors) [34]. One of the most valuable techniques for identifying existing problems and preventing future problems is to walk to the site and conduct a thorough visual and hands-on

| Parameter | Symbol | Unit |
|---|---|---|
| *Meteorology* | | |
| Total irradiance (global), in the plane of the array | $G_I$ | W m$^{-2}$ |
| Ambient air temperature in a radiation shield | $T_{am}$ | °C |
| Wind speed (may be required by special contract or if the PV array is subject to extreme operating conditions) | $S_W$ | m s$^{-1}$ |
| *Photovoltaic array* | | |
| Output voltage | $V_A$ | V |
| Output current | $I_A$ | A |
| Output power | $P_A$ | kW |
| Module temperature | $T_m$ | °C |
| Tracker tilt angle (optional for systems with tracking arrays) | $\phi_T$ | Degrees |
| Tracker azimuth angle (optional for systems with tracking arrays) | $\phi_A$ | Degrees |
| *Energy storage* | | |
| Operating voltage | $V_S$ | V |
| Current to storage | $I_{TS}$ | A |
| Current from storage | $I_{FS}$ | A |
| Power to storage | $P_{TS}$ | kW |
| Power from storage | $P_{FS}$ | kW |
| *Load* | | |
| Load voltage | $V_L$ | V |
| Load current | $I_L$ | A |
| Load power | $P_L$ | kW |
| *Utility grid* | | |
| Utility voltage | $V_U$ | V |
| Current to utility grid | $I_{TU}$ | A |
| Current from utility grid | $I_{FU}$ | A |
| Power to utility grid | $P_{TU}$ | kW |
| Power from utility grid | $P_{FU}$ | kW |
| *Backup sources* | | |
| Output voltage | $V_{BU}$ | V |
| Output current | $I_{BU}$ | A |
| Output power | $P_{BU}$ | kW |

**Table 3.**
*Parameters to be measured in PV systems in real time [35].*

inspection of the PV system components. During these inspections, the parameters to be measured in real times are specified in **Table 3**.

When problems are identified, we can use breakdown tree diagrams [36, 37]. Breakdown tree diagram gives a graphical description of the different events that lead to a breakdown resulting to the non-reliability and the stop of the system [37]. The breakdown tree diagram is constructed in a deductive manner. It starts with the peak event right up to the elementary event in arborescence. The peak event for which we seek the probability is often called "feared." We generally use AND and OR logic gates to define the probability of what is at the cause of the event, to put the situation (what is to be resolved) at the head of the diagram and link it to its causes (events that can be at the origin) by the gate. Once the diagram has been archived, if there is any breakdown, interventions are done from the bottom of the diagram to the top where the problem is detected in the system. **Figure 10** shows that for the "feared" event to archived, either event E1 or E2 must have been archived. In the same manner, for the event E1 to be archived, either the base event e1 or e2 must have been archived, and for the event E2 to be archived, both base events e1 and e2 must have been archived at the same time.

The failure modes, effects and criticality analysis (FMECA) which is a rigorous and preventive method for identifying potential failures of a system and elements, actions have been defined to be taken to eliminate these failures, reduce their effects, and detect and prevent causes. The method is part of an eight-step process [38] as seen in **Figure 11**. Several criteria can be used to determine the criticality index. In practice, we assign three notes (each on a scale of 1–10) for each trio cause-mode-effect:

- The grade G: severity of the effect, the consequences on the client/user
- The grade O: the probability of occurrence, the frequency of occurrence
- The grade D: the probability of non-detection, the risk of non-detection

$$\text{The criticality index is obtained by } C = G * O * D \tag{1}$$

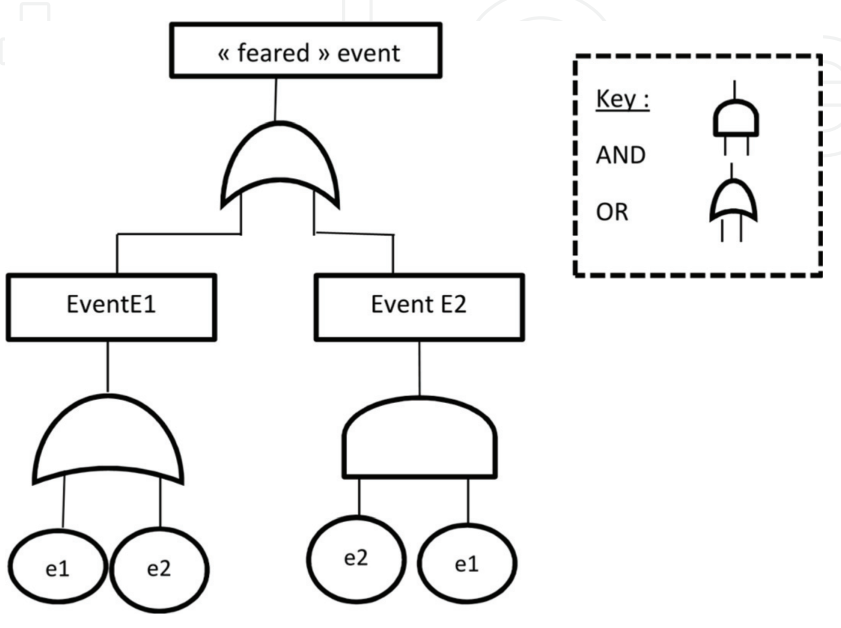



**Figure 10.**
*Breakdown tree method.*

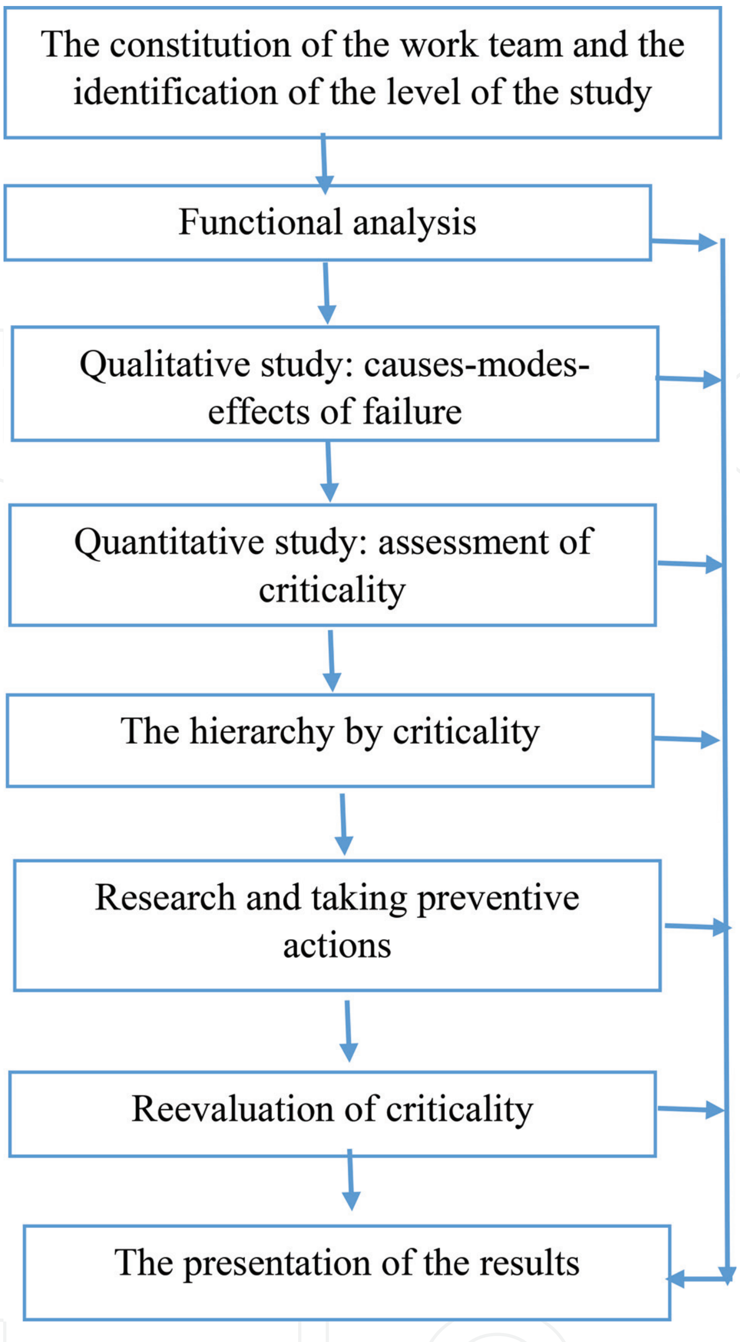



**Figure 11.**
*FMECA approach.*

## 7. Case study

### 7.1 Photovoltaic backup systems

In order to better study the impact of the two types of maintenance on the system, **Figure 12** shows the frequent preventive and corrective maintenance operations carried out on installed PV backup systems during the period 2012–2015, which were kindly followed.

**Figure 12(a)** presents the number of preventive and corrective interventions realized on one site within a period of 4 years. This illustration shows the importance of preventive maintenance on PV systems. In effect, the more preventive maintenance are done, the less there are corrective operation realized. It is the case for the years 1, 3, and 4. To estimate the element lifetime before failure, the exploitation of the maintenance files indicated that 25 batteries were damaged on the 82 installed as shown in **Figure 12(b)**; thus, batteries contributed to 64.9% of the breakdowns

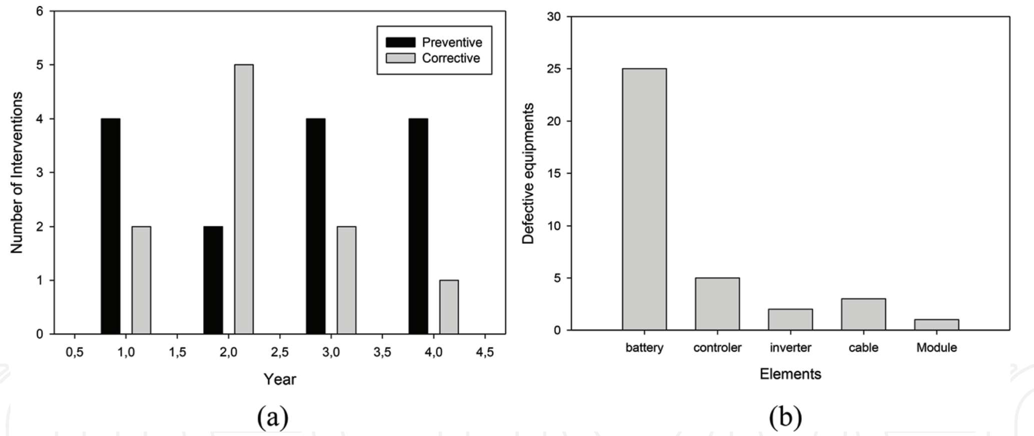



**Figure 12.**
*(a) Number of corrective and preventive maintenance per year on a PV systems and (b) recorded breakdowns per elements.*

generated during this studying period. This result shows also that batteries are the most sensitive elements of the PV system charge controllers, cables, and inverters, which contribute, respectively, 13, 8.3, and 5.5% of the breakdown registered.

### *7.1.1 The causes of breakdown at each element*

#### *7.1.1.1 Causes of the battery and cable breakdown*

Batteries being one of the vulnerable elements of a PV system, the direct causes of their breakdown are due to late interventions and aging. **Figure 13(a)** shows the causes of the breakdown of batteries. It appears that five battery breakdowns were caused by the lack of control of the good functioning of charge controllers, and four damaged batteries were due to a late refill of the electrolyte. It has also been noticed that the bad sizing of the generator system and the climatic factors (temperature, humidity) which were not adapted to the good functioning of the batteries cause their breakdown. The most frequently observed breakdown causes of the cables are (**Figure 13(b)**) cable break age and corrosion which lead to short circuits and worn out cables, and great length cables can also cause the voltage drop and energy losses at the end of the system.

#### *7.1.1.2 Causes at the level of the inverter and PV module*

Breakdown on inverters is frequently caused by overvoltage (**Figure 14(a)**)). They have as origin the nonfunctioning of charge controllers and the frequent interruption of electricity of the network. For PV modules the most frequent causes

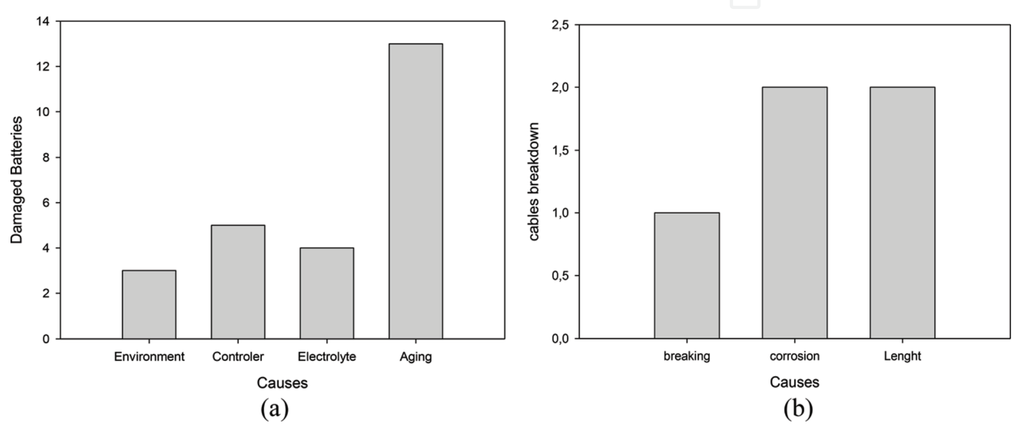



**Figure 13.**
*(a) Damaged batteries and their causes and (b) cables breakdown versus causes.*

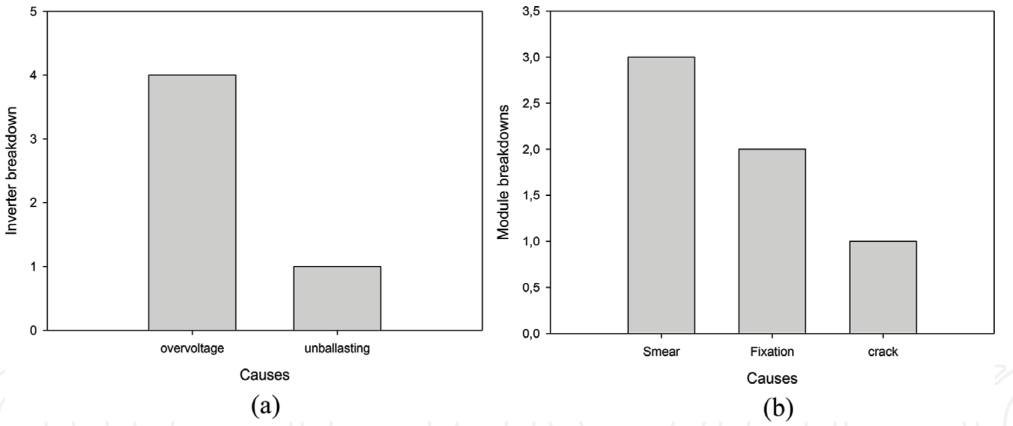



**Figure 14.**
*(a) Inverters faults versus causes of breakdown and (b) PV module breakdowns versus causes.*

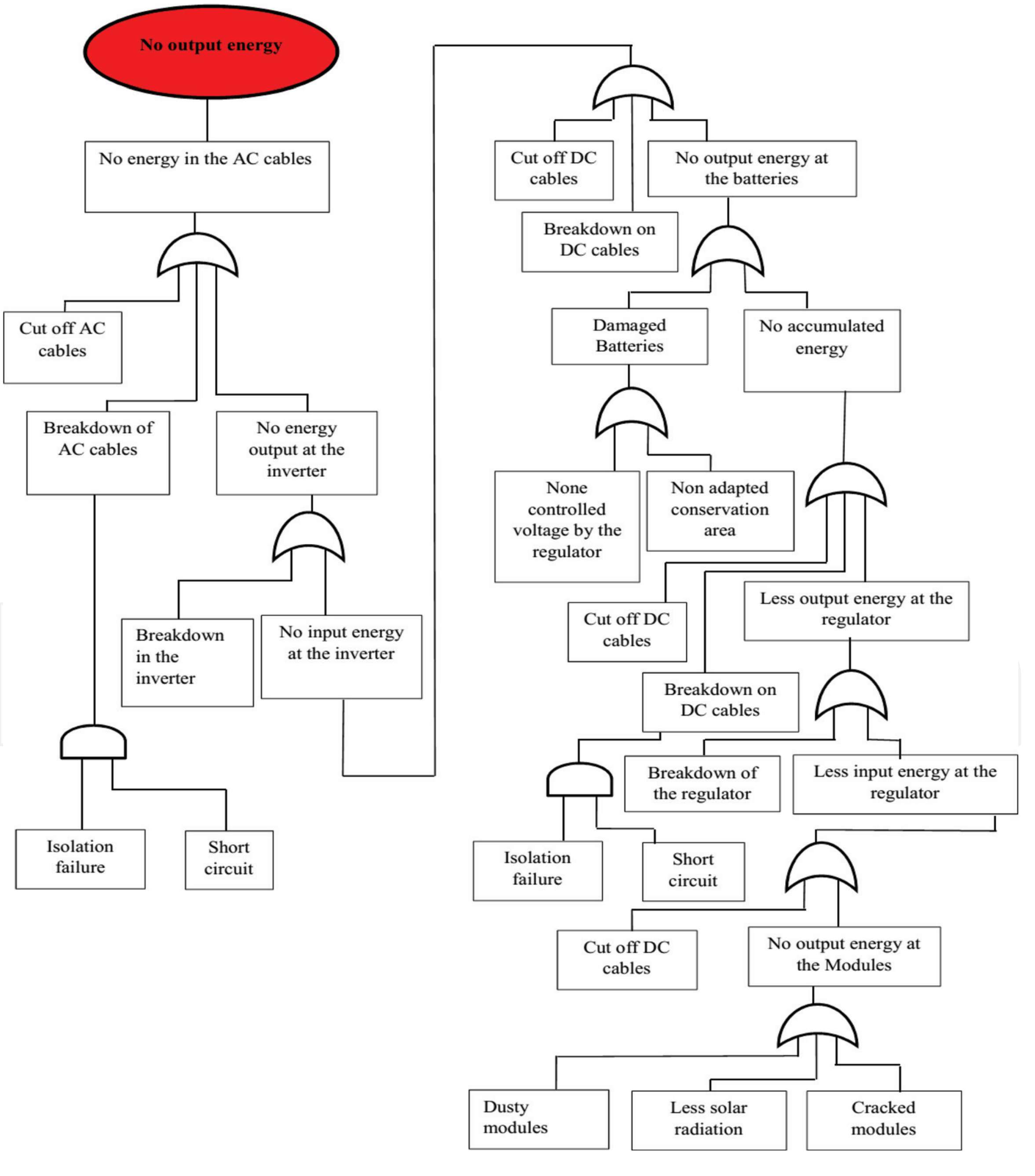



**Figure 15.**
*Breakdown tree diagram for detecting breakdowns in a PV system.*

are **Figure 14(b)**: dust deposit, bad fixing on their supports, and accidental cracking. The first two causes which do not lead to the stop of the system decrease the efficiency of the system (output energy), while the third cause leads to the stop of the system which necessarily needs a replacement.

### *7.1.2 The breakdown tree diagram used for the diagnosis of the breakdown in the studied system*

During corrective interventions, most of the workers overcome the breakdown without trying to eliminate their causes or without investigating on the causes of the breakdown. The exploitation of maintenance files shows that many elements were replaced within a short period of time. This situation led to frequent breakdown of the system even though the bad element was replaced. It became very important to put in place a breakdown diagnosis method in order to eliminate breakdown and causes. The breakdown tree technique helps to graphically represent the possible combinations of the events that permit the realization of a non-needed predefined event. The breakdown tree is then made of levels of events linked by gate (initially logic gate). By using this representation and a logical deduction (moving from

| Components | Failures | Possible causes | Effects on the system | Observable parameter | Criticality | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | G | O | D | C |
| Photovoltaic generator (PVG) | $V_{m,PV} < V_{ref,PV}$<br>T = 25°C<br>E = 800 W/m$^2$ | • Diode bypass short circuit<br>• Defective module in serial | • Decrease of tension | • Voltage | 5 | 2 | 2 | 20 |
| | $I_{m,PV} < I_{ref,PV}$<br>T = 25°C<br>E = 800 W/m$^2$ | • Cutting connection wires<br>• Defective anti-return diodes | • Decrease in current and flow | • Current | 3 | 5 | 2 | 30 |
| | $P_{mPV} < P_{refPV}$<br>T = 25°C<br>E = 800 W/m$^2$ | • Shadow-related design flaw<br>• Dirt of the panels | • Low water flow | • Voltage<br>• Current | 5 | 5 | 4 | 100 |
| | $P_{m,PV} = 0$<br>T = 25°C<br>E = 800 W/m$^2$ | • Corrosion or looseness of the connection terminals<br>• Defective fuse | • No power | • Voltage<br>• Current | 9 | 7 | 4 | 252 |
| Inverter | $P_{Inv} = 0$<br>T = 25°C<br>E = 800 W/m$^2$ | • Inverter failure<br>• Defective power cables or poor tightening at the inverter input | • No water flow | • Input power<br>• Power output | 9 | 7 | 4 | 252 |
| Pump | $Q_m = 0$<br>Not functioning (pumping stop)<br>E = 800 W/m$^2$ | • Clogged strainer<br>• Defective wheels<br>• Lowering of the water level | • No flow of water | • Flow rate | 9 | 7 | 4 | 252 |
| Engine | $Q_m = 0$<br>Not starting<br>E = 800 W/m$^2$ | • Defective phases<br>• Low voltage<br>• Defective mechanical sea | • No flow of water | • Voltage<br>• Current | 9 | 7 | 4 | 252 |

**Table 4.**
*Possible failures on the photovoltaic pumping system according to FMECA.*

| Components | Failures | Possible causes | Solution |
|---|---|---|---|
| Photovoltaic generator (PVG) | $V_{m,PV} < V_{ref,PV}$<br>T = 25°C<br>E = 800 W/m$^2$ | • Diode bypass short circuit<br>• Defective module in serial | • Replace the diode<br>• Check and replace the faulty module |
| | $I_{m,PV} < I_{ref,PV}$<br>T = 25°C<br>E = 800 W/m$^2$ | • Cutting connection wires<br>• Defective anti-return diodes | • Check and replace the connection wire<br>• Replace the faulty diode |
| | $P_{mPV} < P_{refPV}$<br>T = 25°C<br>E = 800 W/m$^2$ | • Shadow-related design flaw<br>• Dirt of the panels | • Clear the objects causing the shadow<br>• Clean the modules |
| | $P_{m,PV} = 0$<br>T = 25°C<br>E = 800 W/m$^2$ | • Corrosion or looseness of the connection terminals<br>• Defective fuse | • Tighten or change the connection terminals<br>• Change the fuse |
| Inverter | $P_{Inv} = 0$<br>T = 25°C<br>E = 800 W/m$^2$ | • Inverter failure<br>• Defective power cables or poor tightening at the Inverter input | • Replace the inverter<br>• Remove or replace the power cable |
| Pump | $Q_m = 0$<br>Not functioning (pumping stop)<br>E = 800 W/m$^2$ | • Clogged strainer<br>• Defective wheels<br>• Lowering of the water level | • Unclog the strainer<br>• Change the wheels<br>• Check the water level is at least 1 m above the suction body of the pump during operation |
| Engine | $Q_m = 0$<br>Not starting<br>E = 800 W/m$^2$ | • Defective phases<br>• Low voltage<br>• Defective mechanical sea | • Replace the phases<br>• Change the seals |

**Table 5.**
*Their solutions to the possible failures in a photovoltaic pumping system according to FMECA.*

effects to causes), it is possible to cast out the causes from the effects, from the non-needed event to base events, independent to one another and probable (**Figure 15**).

### 7.2 Photovoltaic water pumping systems

In PV water pumping systems, the main objective is to collect data, diagnosing the system and proposing and implementing solutions that will optimize the operation of the system in order to satisfy the water need of the population all over the year. Indeed from the collected and measured data, **Tables 4** and **5** show the

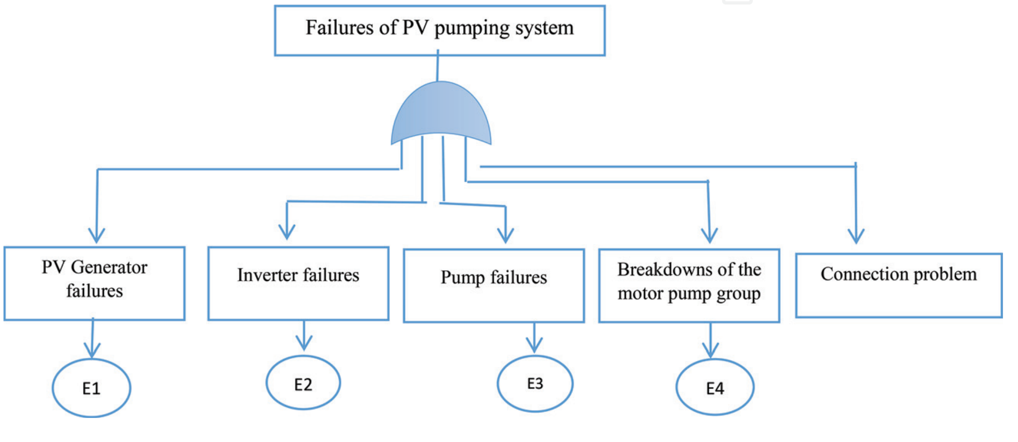



**Figure 16.**
*Failure of the photovoltaic pumping systems (events E1, E2, E3, and E4 are shown in **Figures 17–20**).*

failures we may encounter in our installation as well as the possible causes and solutions.

To facilitate the procedure of these pumping stations, breakdown tree diagram is constructed in a deductive manner as highlighted in the **Figure 16**. For each event E1, E2, E3 and E4 in the **Figure 16**, breakdown tree diagram for failures encountered are presented respectively in the **Figures 17–20**.

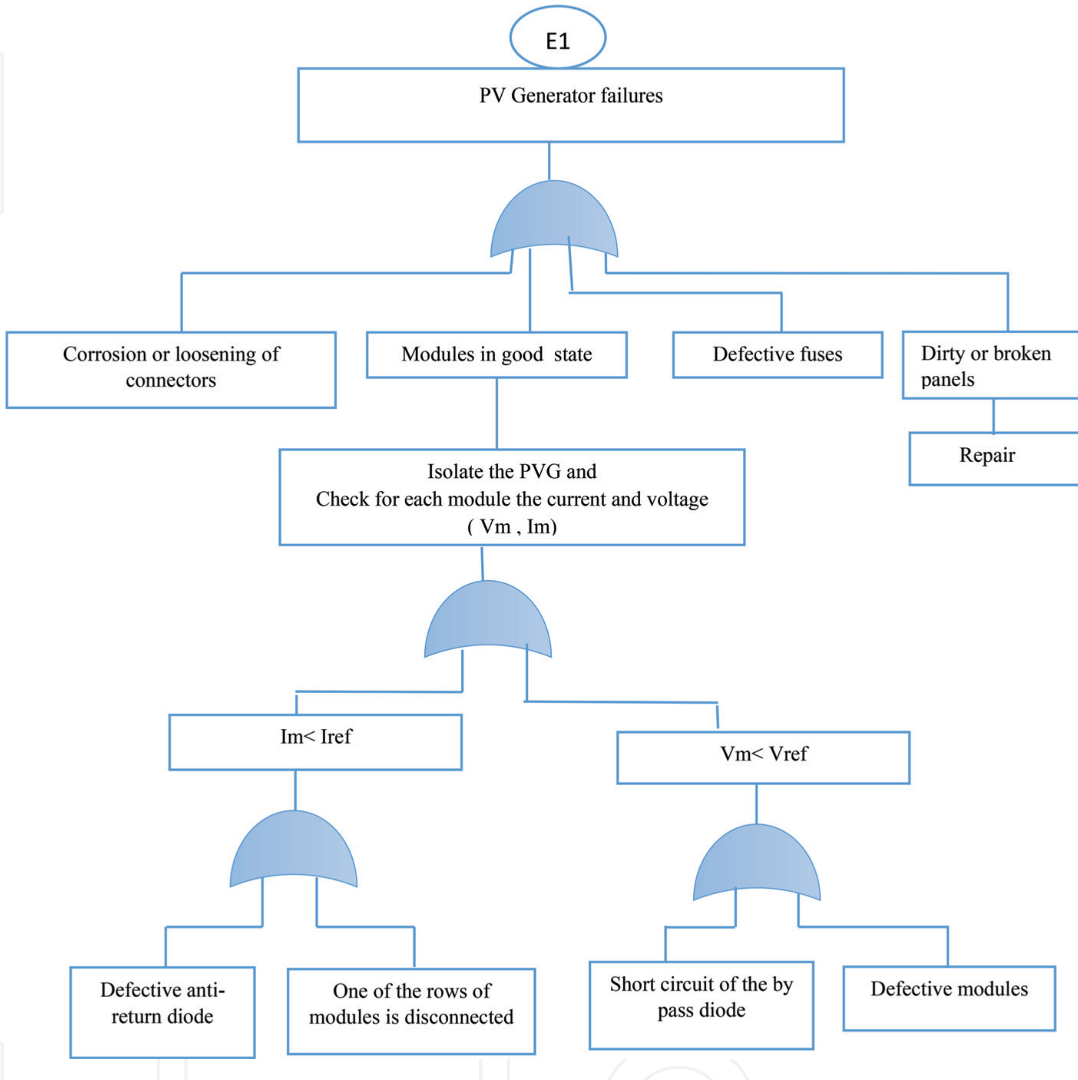



**Figure 17.**
*Photovoltaic generator failure tree.*

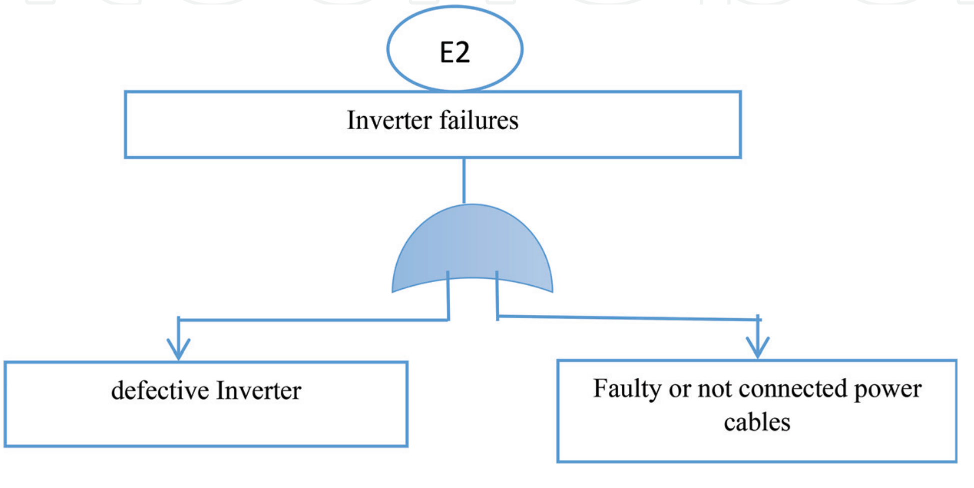



**Figure 18.**
*Inverter failure tree.*

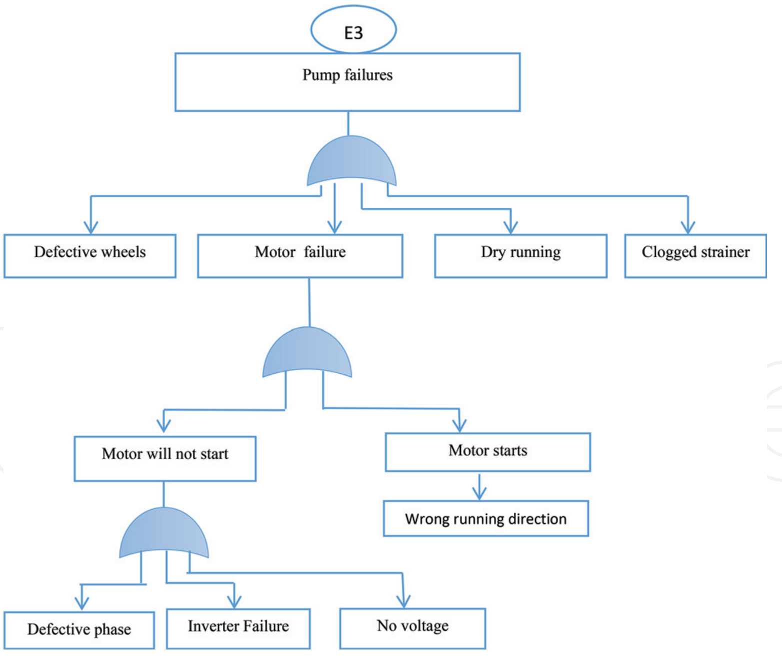



**Figure 19.**
*Pump failure tree.*

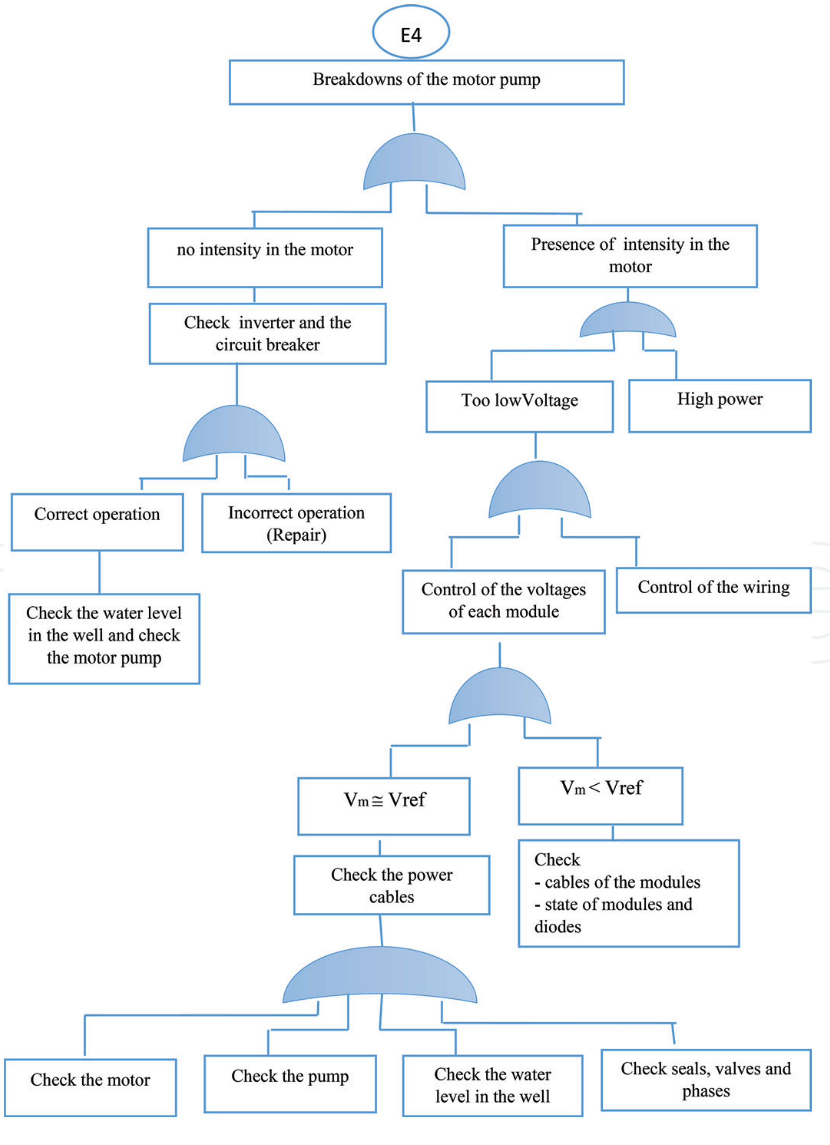



**Figure 20.**
*Pump unit failure diagram.*

## 8. Conclusion

Maintenance operations have a crucial interest in the viability evaluation and the analysis of the life expectancy of a PV system. In this study, we have shown the maintenance techniques which can enable the best diagnosis of breakdown. After the exploitation of maintenance file report data of the twenty backup PV systems and two PV water pumping systems installed in more than 15 towns in Cameroon, it can be concluded that the most vulnerable element of a solar PV system is the battery since this element represents 64.9% of the breakdown recorded. Among the 20 backup PV systems subject of our study, it appears that 50% received their first curative intervention from the 5th year. The FMECA method for PVWPS shows that the criticality of the installation varies from 252 for the inverter, 402 for the PV generator, and 504 for the motor pump. Particular attention must be paid on preventive operations in order to eradicate causes of frequent breakdowns of the components in general and motor pump and batteries in particular. That is why breakdown tree diagram is proposed for the rapid determination of breakdowns on the studied PV systems and the steps or order of detecting breakdowns on a system.

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