| Eskom | Standard | Technology |
|---|---|---|

Title: **MAINTENANCE STANDARD FOR SMALL SCALE EMBEDDED GENERATORS (SSEG)**

| | |
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PCM Reference: **Maintenance**

SCOT Study Committee Number/Name: **Plant Delivery Maintenance SC**

## Content

**Tables**

# 1. Introduction

The requirement to document maintenance strategies, which define maintenance that is applicable to the power delivery assets, is not new. However, the initiatives to standardize the engineering design processes have dictated that a Maintenance Strategy shall be compiled as part of the process to design and specify asset classes/systems.

The Maintenance Engineering Strategy is developed as a result of the engineering performed during the design process, (or retrospectively, taking cognizance of the original design intent), to define the maintenance requirements of the asset classes.

This standard also indicates how maintenance triggers may be affected based on the specific asset's functional importance, operating environment, usage/duty cycle and health. In addition, an ageing analysis indicates intended design life, asset ageing mechanisms, specific asset health indices and calculations to determine useful end of life. This also serves as primary input to the technical and economic end-of-life assessments.

# 2. Supporting clauses

## 2.1 Scope

This Maintenance Standard is applicable to Small Scale Embedded Generator systems, specifically based on solar PV and Battery energy storage components and related control equipment as identified in the FMECA table. All minimum maintenance activities are described along with the triggers for said maintenance activities and the associated logistics requirements.

This standard covers the following:

- maintenance engineering strategy,
- maintenance execution strategy,
- manage asset excursions,
- asset health, and
- asset performance.

The following are excluded:

- Petrol and diesel generators
- Hydro and Wind turbines
- Biomass energy power plants
- All other batteries besides $LiFePO_4$ are excluded.

Firmware upgrades on BMS's, Inverters, Charge Controllers

The correct and fully operational firmware must be installed, tested and verified before a system is deployed for commercial operation.

### 2.1.1 Purpose

The purpose of this document is to stipulate the engineering requirements for maintenance of Eskom owned Small-Scale Embedded Generator systems installed in Distribution networks, as utilized in specific functional locations, and to indicate how the health of said asset is to be monitored such that the appropriate capital and operational investments can be made, at the appropriate times, to sustain the operational capability of the asset.

### 2.1.2 Applicability

This document is applicable to the Eskom Distribution Division.

## 2.2 Normative/informative references

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

### 2.2.1 Normative

[1] ISO 9001:2015 Quality management systems - Requirements

[2] Guide to Integrated Risk Management, ©Eskom Ltd, 2009

[3] Act No. 85 Occupational Health and Safety Act, 1993

[4] 474-190 Design Base Standard

[5] 240-170000998 Manufacturing Specification for a Containerized Micro-grid Generator and Energy Storage System

[6] 240-88478369 Training Manual for the Operation and Maintenance of Solar PV Plants

[7] 240-45920941 Process Control Manual (PCM) for Manage Asset Excursion

[8] 240-61182045 Maintenance Engineering Standard for Batteries and Chargers

[9] NRS 097 compliant inverters

### 2.2.2 Informative

[10] 240-49230046 Failure Mode and Effects Analysis Guideline

[11] 240-49230148 Maintenance and Logistics Support Design Guideline

[12] 240-49230067 Life Data Analysis Guideline

## 2.3 Definitions

### 2.3.1 General

| Definition | Description |
|---|---|
| **Corrective Maintenance** | The maintenance carried out after a failure has occurred or is about to occur and intended to restore an item to a state in which it can perform its required function. |
| **Functional Importance – Critical** | Applicable to an asset that must operate, as designed, in order:<br>to meet to meet legal requirements; or<br>to meet regulatory requirements; or<br>to ensure safety of people; or<br>to prevent irreversible environmental harm; or<br>to prevent economic loss (net profit) of > R99 million; or<br>to ensure continuity of supply, where not doing so would imply failure to meet one of the above points in the Eskom or public domain. |

| Definition | Description |
|---|---|
| **Functional Importance – Economic** | Applicable to an asset which must operate, as designed, in order<br>to ensure continued income through the provision of services and accurate billing; or<br>to prevent damage to, or accelerated ageing of asset resulting in economic loss, such that any economic losses (net profit) are limited to between R100 000 and R1 million. |
| **Functional Importance – Run to Failure** | Applicable to an asset where the consequences of failure are acceptable, without preventative maintenance being performed, for a period of time until normal inspection and test activities will determine the failure and correction actions can be carried out. Economic losses are limited to < R100 000. |
| **Functional Importance – Significant** | Applicable to an asset which must operate, as designed, in order<br>to prevent impact on personnel and public; or<br>to prevent measureable impact on environment; or<br>to prevent damage to, or accelerated ageing of asset resulting in economic loss;<br>to ensure continued income through the provision of services and accurate billing; or<br>to protect the Eskom brand and reputation,<br>such that any economic losses (net profit) are limited to between R1 million – R99 million. |
| **Maintenance Engineering Strategy** | Maintenance Engineering Strategy refers to the engineering performed during the design process (logistic support analysis) to define the maintenance requirements of the System, Structure or Component (SSC) (which typically include the following: minimum critical spares requirements; maintenance tasks definition; in-service inspection and test requirements; maintenance periodicities and triggers; training requirements; facilities; expected SSC life, etc.) that serves as primary input to the maintenance execution strategy. |
| **Asset** | Any infrastructure that has been established to enable the generation, transmission, distribution and sale of electricity. |
| **Preventative Maintenance** | The maintenance carried out at predetermined intervals or corresponding to prescribed criteria (such as measured condition or number of operations), and intended to reduce the probability of failure or the performance degradation of an item. |
| **Inverter** | A device that transforms AC to DC and vice versa |
| **Photo Voltaic (PV) Cell** | A cell that is a specialized semi-conductor diode that converts visible light (e.g. sunlight) into Direct Current (DC) |

### 2.3.2 Disclosure classification

**Controlled disclosure:** controlled disclosure to external parties (either enforced by law, or discretionary).

## 2.4 Abbreviations

| Abbreviation | Description |
|---|---|
| **CM** | Corrective Maintenance |
| **CMMS** | Computerized Maintenance Management System |

| Abbreviation | Description |
|---|---|
| **CoE** | Centre of Excellence |
| **FAT** | Factory Acceptance Test |
| **FMEA** | Failure Modes and Effects Analysis |
| **FMECA** | Failure Modes, Effects and Criticality Analysis |
| **I** | Inspection |
| **IT** | Inspections and Tests |
| **PM** | Preventative Maintenance |
| **SAT** | Site Acceptance Test |
| **SSC** | System, Structure or Component |
| **PV** | Photo Voltaic |
| **BMS** | Battery Management System |
| **DC** | Direct Current |
| **AC** | Alternating Current |
| **CT** | Current Transformer |
| **SCADA** | Systems Control and Data Acquisition |
| **DB** | Distribution Board |
| **VT** | Voltage Transformer |
| **S/A** | Surge Arrestor |
| **SAIFI** | System average interruption frequency index |
| **SAIDI** | System average interruption duration index |
| **LFP** | Lithium Iron Phosphate |
| **DOD** | Depth of Discharge |

## 2.5 Roles and responsibilities

The Manager - Design Base Asset Maintenance is responsible for the consistency and process of compiling this maintenance standard. The Distribution OUs / Clusters are responsible for the selection of asset specific maintenance execution strategies per individual asset.

The Distribution OUs / Clusters are also accountable for developing Maintenance Plans in line with this maintenance standard and the subsequent scheduling, work execution and capturing of the relevant information as specified by this standard, task manuals and job plans in the CMMS's.

Compliance with the requirements of this standard is MANDATORY, and where the affected OUs / Clusters cannot comply with any of the specified requirements, such deviations shall be managed as per the Manage Asset Excursion process.

Any other maintenance documents developed must comply to the requirements of this maintenance standard.

In the absence of an Asset Performance Management (APM) tool, the Manager – Design Base Asset Maintenance is accountable to provide templates which allows for manual implementation of the requirements of this standard.

## 2.6 Process for monitoring

The Manager - Design Base Asset Maintenance will monitor the effectiveness and consistency of adoption of this standard through established report formats which will be based on the required information from the Distribution OUs / Clusters.

## 2.7 Related/supporting documents

Not applicable.

# 3. Requirements

## 3.1 Asset identification

Refer to the FMECA Table below. Also note the exclusions in section 2 above.

## 3.2 Design intent

Maintenance requirements contribute to achieving the design intent, i.e. what the maintenance should sustain. In order to accurately specify the maintenance requirements, it is necessary to understand the design intent in terms of the intended:

- Purpose of the asset – to provide and store renewable energy.
- Performance of the asset and associated indicators – the solution provides similar or better reliability, maintainability, dependability and security compared to a grid connection.
- Operating (physical and electrical) environment the asset can tolerate – the solution should be suitably designed to withstand the prevailing elements and environmental conditions.
- Operating limits – solutions should be suitably designed to satisfy the energy requirements where deployed. Operating limits will vary as per design and customer requirements and a particular location.
- Intended design life of the asset. Main components: PV Panels: 20yrs, Inverters: 5 yrs. Lithium-iron Batteries: 10yrs

## 3.3 Maintenance Engineering Strategy

The Maintenance Engineering Strategy refers to the engineering performed during the design process (logistic support analysis) or retrospectively, taking cognizance of the original design intent, to identify the asset care requirements of the components of the SSEG, which includes:

1) Maintenance activity determination (3.3.1)
2) Asset and maintenance data required (3.3.2)
3) Identify the required Task manuals (3.3.3)
4) Maintenance spares (3.3.4)
5) Facilities and training requirements (3.3.5)

### 3.3.1 Maintenance Activity Determination

The maintenance activities and associated triggers are derived from an FMECA study as per Appendix A. The complete Appendix A is available from the compiler upon request.

### 3.3.2 Asset and maintenance data required

#### 3.3.2.1 Asset data

The following minimum asset data for the critical components must be captured in the Computerized Maintenance Management System (CMMS) to suitably describe the specific assets. Critical Components include Solar Panels, Inverter, Battery, BMS, Charge Controllers and ancillary equipment, SCADA, Stats metering.

- Manufacturer
- Serial Number
- Manufacturer Type No.
- Manufacturing Year
- Year Commissioned
- Single or three phase
- Inverter and Battery DC Voltage (48V - DC)
- Inverter and Battery AC Voltage (230V – AC)
- Power ratings (kW) for panels & inverter
- Energy Rating of Battery (kWh)
- BMS - Communication protocol
- SCADA communication protocol

#### 3.3.2.2 Maintenance data

The capture of maintenance data is of critical importance to enable the determination of the next / follow up maintenance cycle, the determination of asset health and the determination of asset performance.

No work orders without the required feedback should be closed.

The maintenance data must be captured in accordance with condition monitoring (Inspections and Tests (IT)), Preventative Maintenance (PM), Corrective Maintenance (CM) and Investigation (I) results as listed in specific job plans / task lists.

The following minimum asset data shall be captured in the CMMS.

**Table 1: Maintenance data fields**

| Maintenance task/data | Data type | Source | Source activity |
|---|---|---|---|
| 1. Planned Maintenance | | | |
| 1.1 Routine inspection of all components of SSEG | | | |
| 1.1.1 Structures | Condition rating (A-E). Refer to AHI | Inspection sheet | Routine inspection |
| 1.1.1.1 Container,<br>1.1.1.2 Panel mountings,<br>1.1.1.3 Civil,<br>1.1.1.4 Steel work, | | | |

| Maintenance task/data | Data type | Source | Source activity |
|---|---|---|---|
| 1.1.2 PV System (Panel + Wiring) | Condition rating (A-E). Refer to AHI | Inspection sheet | Routine inspection |
| 1.1.3 Battery / Storage system (Lithium-Iron ($LiFePO_4$) LFP batteries) | Condition rating, | Visual Inspection sheet / Webview | Routine inspection |
| | % cell voltage deviation from specification | Visual Inspection sheet / Webview via BMS | Routine inspection, remotely |
| | % individual cells temperature deviation from specification | Visual Inspection sheet / Webview via BMS | Routine inspection, remotely |
| | Battery % DOD cycling | Visual Inspection sheet / Webview via BMS | Routine inspection and or remotely |
| | kWh / MWh (Battery energy throughput or Charge / Discharge cycles) since commissioning / No of cycles since commissioning | BMS | Remotely |
| 1.1.4 Inverters | Condition rating (A-E). Refer to AHI | Inverter / Webview / Inspection sheet | Routine inspection, remotely |
| | Firmware version | Visual / Inspection sheet / Webview | Routine inspection, remotely |
| 1.1.4.1 Solar Regulators (where applicable) | Condition, Firmware version | Visual / Inspection sheet / Webview | Routine inspection, remotely |
| 1.1.5 BMS | Firmware version | Visual / Webview | Routine inspection, Remotely |
| 2. Corrective Maintenance | As per design | | |
| 2.1 Failure rates of all components | Number | Unplanned work / Repairs Log in Maximo | Root cause tree |
| 2.2 Failure causes of all components | Description | Unplanned work / Repairs Log in Maximo | Root cause tree |
| 2.3 As directed by the OEM | As per OEM | As per OEM | As per OEM |

### 3.3.3 Required task manuals

1) Inspection & Defect Clearing for SSEG (PTO)
2) Inspection & Defect Clearing for SSEG (CPM Technician)
3) Cleaning of Solar Panels
4) Cutting of grass at solar panels
5) Clearing of trees around containers, structures, and fences
6) Commissioning / Maintenance Manual (including maintenance spares)
7) Firmware upgrades on BMS's, Inverters, Charge Controllers. OEMs to design and upgrade this firmware and be instrumental in updating firmware remotely. They shall also be accountable for Version control.

### 3.3.4 Maintenance spares

OU's / Clusters must determine the stock levels required. Refer to Task Manual for specific items.

Since most of the main components are very attractive and usable in the market, these items shall be secured, controlled and effectively managed and or tracked.

### 3.3.5 Facilities and training material

Details of training material can be found in 240-88478369 - Training Manual for the Operation and Maintenance of Solar PV Plants.

## 3.4 Maintenance Execution Strategy

A Maintenance Implementation Standard shall be developed once this MES is published.

The Maintenance Execution Strategy refers to the asset specific maintenance tasks and triggers which the Grids and OUs use for the creation of Maintenance Plans. The maintenance tasks are collated based on the following:

- Common outage requirements for the maintenance to be undertaken
- Common craft requirements for the maintenance to be undertaken
- Common trigger as to when the maintenance must be undertaken

These tasks become job plan titles in Maximo and task list titles (for Tx Grids) in SAP PM. The activities form the job operational steps in job plans / task lists

An asset risk framework (Asset classification) is adopted, which is based on defined Asset Conditions (health), Environment, Usage / Duty Cycle and Functional importance (Criticality based on consequence of failure and Operational factors) within the parameters of the Maintenance Engineering Strategy.

To select the optimal maintenance triggers for the creation of PMs, the following components of the maintenance execution strategy are to be carried out:

1) Asset classification (3.4.1)
2) Maintenance task selection (3.4.2)
3) Functional equipment grouping (3.4.3)

### 3.4.1 Asset classification

In order to ensure that the Operating Units and / or Grids classify individual assets in a consistently similar manner, tables are provided below.

Questions to be answered below are designed to lead to the most appropriate maintenance strategy for SSEG. The first 'Yes' answer will determine the classification of SSEG and the remaining questions for that section are to be ignored.

**Table 2: Asset classification**

| A. Functional Importance | Critical |
|---|---|
| Solar PV systems are considered Critical in this MES | Yes |

| B. Duty Cycle | High |
|---|---|
| Duty Cycle for PV Systems shall always be considered high for this MES | Yes |

| **C. Operating Environment** | **Harsh** | **Mild** |
|---|---|---|
| Is the substation in areas with extreme ambient temperatures (45-50deg) or < 0 degrees? | Yes | |
| Is the substation within air borne pollutants? | Yes | |
| Is the substation within the coast with severe pollution? | Yes | |
| Is the substation within a mining, industrial or metro area? | Yes | |
| Is the substation at a Coal-fired Power Station? | Yes | |
| Is the answer to all the questions above 'No'? | | Yes |

### 3.4.2 Maintenance task selection

The Interpretation of the maintenance task table is as follows:

- **Trigger Modifiers:** The trigger modifiers are defined as per the Asset Classification tables in section 3.4.1 and they determine how often maintenance tasks should be done (frequencies).
- **Permutations:** The permutations are a combination of the different trigger modifiers response options. An asset can be in either a harsh or mild environment, but never both.
- **No's 1,2,3…..n:** Each of these numbers represent a unique maintenance execution strategy for the asset that has been classified. Each maintenance task is subsequently referenced to the column where this number lies.
- **Maintenance Tasks:** Maintenance tasks represent a grouping of maintenance activities.
- **FMECA: reference:** The FMECA reference provides the link between the maintenance tasks and the FMECA study in appendix A.
- **Trigger:** The trigger indicates whether the maintenance should be carried out based on condition status; time based or even run to failure where a corrective maintenance is initiated.
- **Key:** It's a legend for the maintenance frequencies identified. E.g. 6M means that the maintenance task needs to be carried out every six months.
- **Outage:** A 'Y' indicates that an outage is required to carry out the maintenance task.
- **Skills level:** Where specified, this indicates whether specialised skills are required to carry out a specific task or not.

## Table 3: Maintenance Tasks

| | | | | | | |
|---|---|---|---|---|---|---|
| **Equipment Class:** | | Distributed Energy Resources (DER) | | | | |
| **Equipment Sub Class:** | | Small Scale Embedded Generators (SSEGs) | | | | |
| **Equipment Sub Class Family:** | | | | | | |
| Trigger Modifiers | | **Permutations** | **1** | **2** | **3** | **4** |
| | **Functional Importance** | Critical | X | X | X | X |
| | **Usage / Duty Cycle** | High | X | X | X | X |
| | **Environment** | Harsh | X | | X | |
| | | Mild | | X | | X |
| | **Health** | Very Good / Good | X | X | | |
| | | Fair / Poor / Very Poor | | | X | X |

| **Key** | |
|---|---|
| 1M | One monthly |
| 3M | Once every three months |
| 6M | Once every six months |
| 1Y | Once every year |
| 2Y | Once every two years |
| 3Y | Once every three years |
| 4Y | Once every four years |

| Activity no. | Maintenance Tasks | Activity Ref No | Trigger (Time and/or Status) | | | | Outage Y/N | | Skill Level |
|---|---|---|---|---|---|---|---|---|---|
| **Condition Monitoring** | | | | | | | | | |
| 1 | Online monitoring of local SCADA/control systems, routers, inverters, batteries | **1.1 - 1.3, 1.5 - 1.13** | **SCADA Alarms** | | | | | **N** | **CPM Technician** |
| **Preventative Maintenance based on time** | | | | | | | | | |
| 2 | Routine inspections of whole system and all internal components | **1.1 - 1.13** | **3M** | **6M** | **1M** | **1M** | | **N** | **Engineer/Senior Technician (CPM)/PTO** |
| 3 | Cleaning of solar panels | **1.3.1** | **6M** | **6M** | **1M** | **6M** | **Y** | | **Technical Official (TO)** |
| 4 | Clearing of vegetation and cutting of grass at solar panels, around structures and fence | **1.1 - 1.3, 1.13** | **3M** | **6M** | **3M** | **6M** | | **N** | **Accredited Low skilled Labor (TO)** |
| 5 | Trimming/removal of trees at solar panels & fence | **1.1 - 1.3, 1.13** | **3M** | **6M** | **3M** | **6M** | | **N** | **Technical Official (TO)** |
| 6 | Software updates for BMS | **1.5, 1.6, 1.8** | **1Y** | **1Y** | **1Y** | **1Y** | **Y** | **N** | **Specialised Skill Trained Technician or Engineer** |
| **Preventative Maintenance based on condition** | | | | | | | | | |
| | | | | | | | | | |
| **Corrective Maintenance: Power outage restoration of plant** | | | | | | | | | |
| 7 | Software updates for equipment including local SCADA/control systems, routers, inverters | **1.5, 1.6, 1.8** | **As required** | | | | | **N** | **Specialised Skill Trained Technician or Engineer** |
| 8 | Circuit breaker tripped, Investigate & restore supply | **1.6, 1.7** | **SCADA Alarms** | | | | **Y** | | **Electrical Technician** |
| 9 | Replacement of faulty cables, switch gear (circuit breakers), repair of faulty cable joints or connectors | **1.6, 1.7** | **SCADA Alarms** | | | | **Y** | | **Electrical Technician** |
| 10 | Replacement of faulty equipment including local SCADA/control systems, computer, routers, inverters, batteries, solar modules, aircon | **1.3,1.5,1.6,1.8,1.9** | **SCADA Alarms** | | | | **Y** | | **Specialised Skill Trained Technicians or Engineers** |
| **Corrective Maintenance: Restoration of power outage at consumer distribution box/ premises** | | | | | | | | | |
| 11 | Circuit breaker tripped, Investigate & restore supply | **1.11** | **SCADA Alarms** | | | | **Y** | | **CNC PTO** |
| 12 | Replacement of meters, fuses or circuit breakers at customers distribution point | **1.11** | **SCADA Alarms** | | | | **Y** | | **CNC PTO** |
| 13 | Replacement of faulty wires, transformer, poles or repair of cable joints or connections | **1.11, 1.12** | **SCADA Alarms** | | | | **Y** | | **CNC PTO** |
| **Statutory Maintenance** | | | | | | | | | |
| 14 | None for Eskom | | | | | | | | |

### 3.4.3 Functional equipment grouping

To minimise outages, maintenance tasks for multiple assets in same bay / circuit / substation should be grouped and executed during the same outage.

This functional grouping must be completed prior to the compilation of the maintenance plan.

## 3.5 Manage Asset Excursions

Asset excursions should be managed as per the Process Control Manual (PCM) for Manage Asset Excursion (240-45920941).

## 3.6 Asset health

### 3.6.1 Design life expectancy and failure issues

The Asset Health Index (AHI) provides an indication of the end of life of the asset. Component defects and failures are expected during the useful life of the asset. If defects and failures are not condition related, they will not be included to the asset health index. Age and condition related measures shall be selected to determine the asset health (end of life) for SSEG.

The following key components are considered for the SSEG AHI. Their corresponding % weights are included in the table below.

**Table 4: Key components for the SSEG**

| No. | Component | Weight Option 1 | Weight Option 2 |
|---|---|---|---|
| 1. | Batteries (LiFe) | 55% | 55% |
| 2. | Battery chargers* | * | 5% |
| 3. | BMSs* | * | 5% |
| 4. | Hybrid Inverters (incl. Solar Regulators, Battery chargers, BMSs) | 20% | 5% |
| 5. | Solar Regulators* | * | 5% |
| 6. | Communications (Data Loggers, SCADA interfaces) | 5% | 5% |
| 10. | PV Panels | 10% | 10% |
| 11. | Structures (Containers & PV Panel mountings) | 5% | 5% |
| 12. | Air Conditioners | 5% | 5% |
| 13. | Ancillary Equipment | 0% | 0% |

**Note:** For option 1, items marked * are included in item 4

Indicate the design life of the network components above and factors that shall contribute to the deterioration of the life of these components. Where possible, indicate specific ageing material and components with scenarios/conditions, which may be measured or determined, and the associated impact on the remnant life.

Specific Asset Health Indicators are to be developed, based on actual asset condition measures, age, operational history and environment, and the associated health index calculations given.

This information can be represented in tabular format as follows:

**Table 5: Health Index Score for SSEG components**

| | Asset health index criteria | Weight (1-4) | Condition rating | Factors | Maximum score | Score |
|---|---|---|---|---|---|---|
| 1 | Parameter A | 4 | A,B,C,D,E | 4,3,2,1,0 | 16 | |
| 2 | Parameter B | 2 | A,B,C,D,E | 4,3,2,1,0 | 8 | |
| 3 | Parameter C | 1 | A,B,C,D,E | 4,3,2,1,0 | 4 | |
| 4 | Parameter D | 2 | A,B,C,D,E | 4,3,2,1,0 | 8 | |
| | Max. Score: 36 | | | | | Total Score |

Where (condition rating):

- ‘A’ means the component is in ‘as new’ condition;
- ‘B’ means the component has some minor problems or evidence of ageing;
- ‘C’ means the component has many minor problems or a major problem that requires attention;
- ‘D’ means the component has many problems and the potential for major failure; and
- ‘E’ means the component has completely failed or is damaged or degraded beyond repair.

**Note:** That the Factor is simply a numeric associated with the Condition Rating for the purposes of calculating the score.

The Health Index is calculated as Total Score × 100/Max. Score

**Note:** When considering the condition of each element required for the AHI, the FMECA failure modes, mechanisms, and causes, as per Annex A1 can be used as guidance.

### 3.6.2 AHI criteria for Batteries

**Note:** That certain parameters such as cell voltage imbalances, battery state of charge and battery cell temperatures can be obtained remotely by communication through the BMS.

**Table 6: Condition of batteries**

| Condition Rating | Description |
|---|---|
| **A** | No visible damage – good condition |
| **B** | There are some minor problems or evidence of ageing, e.g., Minor cell voltage imbalances if displayed, hot connections on terminations |
| **C** | There are many minor problems or a major problem that requires attention, e.g., Cell voltage imbalances + inability to charge to 100% capacity (if displayed), burnt connections on terminations. |
| **D** | There are many problems (e.g. major cell unbalance, excessive heat generation, loss of capacity below 70%) |
| **E** | Battery has completely failed or is damaged or degraded beyond repair, e.g., burnt |

### 3.6.3 AHI criteria for battery chargers

**Note:** That certain parameters such as DC circuit temperatures, overload conditions, etc may be obtained remotely by communication through the SCADA if provided.

**Table 7: Condition of battery chargers**

| Condition Rating | Description |
|---|---|
| **A** | No visible damage – good condition |
| **B** | There are some minor problems or evidence of ageing, e.g., minor over-heating, display deficiencies, hot connections on terminations |
| **C** | There are many minor problems or a major problem that requires attention, e.g., discolouration due to continuous overheating, burnt connections on terminations. |
| **D** | There are many problems which have the potential for major failure, e.g., erratic overheating and erratic charging |
| **E** | Battery charger has completely failed or is damaged or degraded beyond repair, e.g., completely burnt or failed |

### 3.6.4 AHI criteria for BMSs

**Note:** That certain parameters such as BMS temperatures, BMS functionality can be obtained remotely by communication through the BMS.

**Table 8: Condition of BMSs**

| Condition Rating | Description |
|---|---|
| **A** | No visible damage – good condition |
| **B** | There are some minor problems, e.g., un-explained status changes |
| **C** | There are many minor problems or a major problem that requires attention, e.g., status changes of the BMS that may impact the battery health, not effectively controlling battery cell voltage imbalances. |
| **D** | There are many problems which have the potential for major failure, e.g., BMS not functioning properly in safely managing the battery parameters. |
| **E** | The BMS has completely failed or is damaged or degraded beyond repair, e.g., burnt or completely failed / not working. |

### 3.6.5 AHI criteria for Solar Regulators

**Note:** That certain parameters such as regulator temperatures, overload conditions, string voltages, etc may be obtained remotely by communication if provided.

**Table 9: Condition of Solar Regulators**

| Condition Rating | Description |
|---|---|
| **A** | No visible damage – good condition |
| **B** | There are some minor problems or evidence of ageing, e.g., minor over-heating, display deficiencies, hot connections on terminations |
| **C** | There are many minor problems or a major problem that requires attention, e.g., discolouration due to continuous overheating, burnt connections on terminations |
| **D** | There are many problems which have the potential for major failure, e.g., erratic overheating and erratic charging |
| **E** | Solar Regulator has completely failed or is damaged or degraded beyond repair, e.g., completely burnt or failed |

### 3.6.6 AHI criteria for Inverters (incl. Solar Regulators, Battery chargers, BMSs)

**Note:** That certain parameters such as inverter AC & DC temperatures, overload conditions i.e. string voltages, battery state of charge and battery cell temperatures can be obtained remotely by communication if provided.

**Table 10: Condition of Inverters (incl. Solar Regulators, Battery chargers, BMSs)**

| Condition Rating | Description |
|---|---|
| **A** | No visible damage – good condition |
| **B** | There are some minor problems or evidence of ageing, e.g., minor over-heating, display deficiencies, hot connections on terminations |
| **C** | There are many minor problems or a major problem that requires attention, e.g., discolouration due to continuous overheating, operation outside of set voltage and current parameters, burnt connections on terminations |
| **D** | There are many problems which have the potential for major failure, e.g., erratic overheating and erratic charging, operation outside of set voltage and current parameters |
| **E** | Inverter has completely failed or is damaged or degraded beyond repair, e.g., completely burnt or failed |

### 3.6.7 AHI criteria for Communications (Data Loggers, SCADA interfaces)

**Table 11: Condition of Communications (Data Loggers, SCADA interfaces)**

| Condition Rating | Description |
|---|---|
| **A** | No visible damage – good condition |
| **B** | There are some minor problems or evidence of ageing, e.g., intermittent communication, heating, damaged antennas and or comms cables |
| **C** | There are many minor problems or a major problem that requires attention, e.g., intermittent communication and excessive heating |
| **D** | There are many problems which have the potential for major failure, e.g., intermittent communication damaged antennas and or comms cables. |
| **E** | The Communication system has completely failed or is damaged or degraded beyond repair, e.g., no communication, burnt or failed equipment and or cables. |

### 3.6.8 AHI criteria for PV Panels

**Table 12: Condition of PV Panels**

| Condition Rating | Description |
|---|---|
| **A** | No visible damage – good condition |
| **B** | There are some minor problems or evidence of ageing, e.g., excessive soiling, |
| **C** | There are many minor problems or a major problem that requires attention, e.g., excessive soiling, damaged PV cables and or connectors. |
| **D** | There are many problems which have the potential for major failure, e.g., cracked panels, visible hotspots on panels and junction boxes |
| **E** | The PV Panels have completely failed or is damaged or degraded beyond repair, e.g., panels and or junction boxes have failed |

### 3.6.9 AHI criteria for Structures (Containers & PV Panel mountings)

**Table 13: Condition of Structures (Containers & PV Panel mountings)**

| Condition Rating | Description |
|---|---|
| **A** | No visible damage – good condition |
| **B** | There are some minor problems or evidence of ageing, e.g., loose structures and panel clamps |
| **C** | There are many minor problems or a major problem that requires attention, e.g., broken structures and or panel clamps |
| **D** | There are many problems which have the potential for major failure, e.g., structures starting to collapse |
| **E** | The Structures have completely failed or is damaged or degraded beyond repair, e.g., failed / completely collapsed structures and or clamps |

### 3.6.10 AHI criteria for Air Conditioners

**Table 14: Condition of Air Conditioners**

| Condition Rating | Description |
|---|---|
| **A** | No visible damage – good condition |
| **B** | There are some minor problems or evidence of ageing, e.g., blocked or broken dust filters |
| **C** | There are many minor problems or a major problem that requires attention, e.g., in-efficient cooling and lack of cycling (i.e automatic operations) |
| **D** | There are many problems which have the potential for major failure, e.g., not cooling at all, heating instead of cooling |
| **E** | The Air Conditioner has completely failed or is damaged or degraded beyond repair, e.g., not working |

### 3.6.11 Health Index Formulation

Health indexing quantifies equipment conditions relative to long-term degradation factors that cumulatively lead to an asset's end-of-life. Health indexing differs from maintenance testing, which emphasizes finding defects and deficiencies that need correction or remediation to keep the asset operating during some time period.

For purposes of formulating the Health Index for this asset class, the letter condition ratings listed above also received the following numbers shown as "factors" in Table 15 below:

- "A" = 4;
- "B" = 3;
- "C" = 2;
- "D" = 1; and
- "E" = 0.

The AHI criteria for the components shown in the tables above shall be weighted based on their importance in determining the components end-of-life. For example, those that relate to primary functions of the component receive a higher weight than those that relate to more ancillary features and functions.

The condition rating numbers listed above (i.e. A = 4, B = 3, etc.) will be multiplied by the assigned weights to compute weighted scores for each component criteria. The weighted scores will be totaled for each asset class component.

Totaled scores will be used in calculating final Health Indices for each asset class component. For each component, the Health Index calculation involves dividing its total condition score by its maximum condition score, then multiplying by 100. The latter step normalizes scores by producing a number from 0-100 for each asset class component.

**Table 15: Health Index Score for SSEG**

| **#** | **Asset health index criteria** | | | | |
|---|---|---|---|---|---|
| | **Batteries** | **Weight** (1-4) | **Condition Rating** | **Factors** | **Score** |
| **1** | Condition of batteries - Table 6 | 4 | A,B,C,D,E | 4,3,2,1,0 | |
| | | | | Total score | TBD |
| Max Score = (4 x 4) = 16 Total Score achieved =TDB<br>HI = 100*Score/Max = TBD /16*100 = | | | | | |
| **#** | **Battery chargers** | **Weight** | **Condition Rating** | **Factors** | **Score** |
| **1** | Condition of battery chargers - Table 7 | 4 | A,B,C,D,E | 4,3,2,1,0 | |
| | | | | Total score | TBD |
| Max Score = (4 x 4) = 16 Total Score achieved = TBD<br>HI = 100*Score/Max = TBD /16*100 = | | | | | |
| **#** | **BMS** | **Weight** | **Condition Rating** | **Factors** | **Score** |
| **1** | Condition of BMS - Table 8 | 4 | A,B,C,D,E | 4,3,2,1,0 | |
| | | | | Total score | TBD |
| Max Score = (4 x 4) = 16 Total Score achieved = TBD<br>HI = 100*Score/Max = TBD /16*100 = | | | | | |
| **#** | **Solar Regulators** | **Weight** | **Condition Rating** | **Factors** | **Score** |
| **1** | Condition of Solar Regulators - Table 9 | 4 | A,B,C,D,E | 4,3,2,1,0 | |
| | | | | Total score | TBD |
| Max Score = (4 x 4) = 16 Total Score achieved = TBD<br>HI = 100*Score/Max = TBD /16*100 = | | | | | |
| **#** | **Inverters (incl. Solar Regulators, Battery chargers, BMSs)** | **Weight** | **Condition Rating** | **Factors** | **Score** |
| **1** | Condition of Inverters - Table 10 | 4 | A,B,C,D,E | 4,3,2,1,0 | |
| | | | | Total score | TBD |
| Max Score = (4 x 4) = 16 Total Score achieved = TBD<br>HI = 100*Score/Max = TBD /16*100 = | | | | | |
| **#** | **Communications (Data Loggers, SCADA interfaces)** | **Weight** | **Condition Rating** | **Factors** | **Score** |
| **1** | Condition of Communications - Table 11 | 4 | A,B,C,D,E | 4,3,2,1,0 | |
| | | | | Total score | TBD |
| Max Score = (4 x 4) = 16 Total Score achieved = TBD<br>HI = 100*Score/Max = TBD /16*100 = | | | | | |

| # | PV Panels | Weight | Condition Rating | Factors | Score |
|---|---|---|---|---|---|
| 1 | Condition of PV Panels - Table 12 | 4 | A,B,C,D,E | 4,3,2,1,0 | |
| | | | | Total score | TBD |
| Max Score = (4 x 4) = 16 Total Score achieved = TBD<br>HI = 100*Score/Max = TBD /16*100 = | | | | | |
| **#** | **Structures (Containers & PV Panel mountings)** | **Weight** | **Condition Rating** | **Factors** | **Score** |
| 1 | Condition of Structures - Table 13 | 4 | A,B,C,D,E | 4,3,2,1,0 | |
| | | | | Total score | TBD |
| Max Score = (4 x 4) = 16 Total Score achieved = TBD<br>HI = 100*Score/Max = TBD /16*100 = | | | | | |
| **#** | **Air Conditioners** | **Weight** | **Condition Rating** | **Factors** | **Score** |
| 1 | Condition of Air Conditioners - Table 14 | 4 | A,B,C,D,E | 4,3,2,1,0 | |
| | | | | Total score | TBD |
| Max Score = (4 x 4) = 16 Total Score achieved = TBD<br>HI = 100*Score/Max = TBD /16*100 = | | | | | |

**Note:** If there are several components incorporated into one device, e.g. hybrid inverter which is inclusive of the solar regulators, battery charger, communication module, etc then these components will be excluded from the table above since they are covered in the inverter AHI as per table 10.

After performing all of the steps described above, apply the percentage weightings in Table 3 to the respective components HI. The Health Index rating scale shown in Table 16 below can be used to determine the overall condition of the SSEG.

**Table 16: Health Index Rating for SSEG**

| Health index | Condition | Description | Requirements |
|---|---|---|---|
| 85 - 100 | Very Good | Some ageing or minor deterioration of a limited number of components | Normal maintenance |
| 70 - 85 | Good | Significant deterioration of some components | Normal maintenance |
| 50 - 70 | Fair | Widespread significant deterioration or serious deterioration of specific components | Increase diagnostic testing, possible remedial work or replacement needed depending on criticality |
| 30 - 50 | Poor | Widespread serious deterioration | Start planning process to replace or rebuild considering risk and consequences of failure |
| 0 - 30 | Very Poor | Extensive serious deterioration | At end-of-life, immediately assess risk; replace or rebuild based on assessment. |

AHI shall be revised at a 5 Yearly frequency during the Maintenance Assurance activity. The Asset Health Model and CMMS requirements will be prescribed in the SSEG Maintenance Implementation Standard (to be developed).

## 3.7 Asset Performance

Indicate how the performance of SSEG will be measured.

E.g. To determine how well SSEGs are performing, the following measures are used:

1) Availability, and

2) Reliability

**Availability**

The availability is defined as the time that an asset is in service or is serviceable (can be put into service). Asset becomes unavailable when there is a failure that prevents it from performing the required function.

Unavailability can also be due to planned maintenance. For the purpose of monitoring the availability, SSEGs un-planned, un-availability and planned un-availability will be measured. The source data will be from the CMMS, for planned maintenance and from the asset performance system reports for un-planned maintenance. Planned un-availability of SSEGs can be minimised through performing certain maintenance activities while the SSEG remains in operation.

**Reliability**

Reliability is a measurement of the number of times an asset cannot perform its required function. In the case of SSEGs the measure is SAIFI. Similarly, the duration of these incidents can be measured by SAIDI.

**Note:** SSEG may require additional or different performance measures such as failure rates, mean time between failures (MTBF) etc.

### 3.7.1 Failure causes to be recorded in performance management systems

To enable the trending of failure causes and to monitor the effectiveness of the Maintenance Engineering and Execution Strategies in preventing failures, it is required that incidents be investigated, and the root cause/s of the failures be determined and captured in the appropriate systems. Standard failure causes, as identified in the FMECA, are listed below such that these specific names can be captured in the CMMS and Performance Management System. The main components are covered below. Please refer to the FMECA Table in Annex A1 for the rest.

**Table 17: Failure causes**

| Component | Failure mode | Root cause |
|---|---|---|
| Housing / Container | 1.Parts of container has eroded away due to corrosion | 1. Corrosion due to mods/scratching/metal poorly treated. |
| | 2. Container leaning | 2. Unstable (ground mounted) |
| | 3. Container damaged | 3. Vandalism |
| | 4. Holes on housing causing water leaks / dust ingress | 4. Due to corrosion / mods / maint. related / vandalism |
| | 5. Access points compromised | 5. Access compromised due to seals broken, UV degradation of seals, rodents, broken wooden floors, termite activity, fungus damage to floors |
| | 6. Excessive heat / humidity inside | 6. Failure of air conditioners / container |

| Component | Failure mode | Root cause |
|---|---|---|
| PV Structure | 1.Parts of PV structure has eroded away due to corrosion | 1. Corrosion due to mods/scratching/metal poorly treated. |
| | 2. Loose nuts and bolts | 2. Poor workmanship during assembly |
| | 3. Missing nuts & bolts & members | 3.Theft / Vandalism |
| | 4. Damaged sections | 4. Storms / strong winds |
| PV System (Panel) | 1. Cracked panel | 1&2. Bio / hail damage / vandalism / incorrect installation / negligent vegetation control (stones) |
| | 2. Fully broken panel | |
| | 3. Excessive pollution | 3. Environmental / industry / poor maintenance / bird droppings |
| | 4. Missing / stolen | 4. Theft & vandalism |
| | 5. Failed panel | 5. Hot spots due to poor manufacturing, poor installation, poor handling, transport, failed diode junction box |
| | 6. Shady panels | 6. Encroaching vegetation |
| PV System (Wiring) | 1. Damaged insulation wires | 1. Wear & tear due to wind vibration, rodent damage, UV degradation, vandalism |
| | 2. Broken wires | 2. Vandalism |
| | 3. Broken / damaged connectors | 3. Due to negligent vegetation control (contact with weed machinery) |
| | 4. Missing wires | 4. Theft & vandalism |
| Internal Mechanical supports (Cable racks) | Broken / damaged cable racks | 1. Poor workmanship |
| | | 2. Corrosion |
| | | 3. Vibration due to wind & transport |
| Internal Mechanical supports (Mounting brackets) | Broken / damaged support brackets | 1. Poor workmanship |
| | | 2. Corrosion |
| | | 3. Vibration due to wind & transport |
| Internal Mechanical supports (Mounting uni-struts) | Broken / damaged uni-struts | 1. Poor workmanship |
| | | 2. Corrosion |
| | | 3. Vibration due to wind & transport |

| Component | Failure mode | Root cause |
|---|---|---|
| | Broken / damaged steel members | 1. Poor workmanship<br>2. Corrosion<br>3. Vibration due to wind & transport |
| | 1. Batteries not functional<br>2. Damaged battery | 1. Poor installation<br>2. Manufacture defect<br>3. Inadequate charge / discharge |
| Battery / Storage system<br>(Lithium-Iron (LiFePO4) batteries) | No communication from Hub | 1. Poor installation<br>2. Power to hub failure<br>3. Manufacture defect |
| | 1. Loose cable connection<br>2. Damaged cable | 1. Poor workmanship<br>2. Overloading<br>3. Vibration due to transport<br>4. Rodents |
| | 1. Loss of SCADA System control<br>2. No communication | 1. Poor workmanship<br>2. Vibration due to transport<br>3. Loss of power supply<br>4. Over heating<br>5. EMC<br>6. Software glitch / undetected error |
| Battery / Storage system<br>(Lithium-Iron (LiFePO4) batteries) | 1. Alarm system sensor failure<br>2. Alarm panel failure<br>3. Power / battery failure<br>4. Damaged cable<br>5. DVR Camera failure<br>6. DVR failure<br>7. Network switch loose connection<br>8. Communication loss<br>9. Loose connections<br>10. Faulty / damaged power supply<br>11. Faulty Circuit breakers<br>12. Faulty Power supply fuses and holders<br>13. Faulty relays | 1. Poor workmanship<br>2. Vibration due to transport<br>3. Overheating<br>4. Loss of power supply<br>5. Power / lightning surge<br>6. Manufacturer defect<br>7. Rodents |
| | Enclosure exposes the internal components. | 1. Door / seals / blanking plates damaged / vermin proofing.<br>2. Broken<br>3. Impact damage to enclosure attachment.<br>4. Rust damage to enclosure<br>5. Enclosure missing / stolen / backplate damaged, loose, rusted, missing. |
| | Circuit breakers do not allow flow of electrical energy | 1. Brk inoperable<br>2. No electrical supply |
| | Remote control actuator does not actuate / switch ON/OFF and does not provide correct status. | 1. OEM faulty device |
| | Conversion & Load control switch | 1. Over-volage burning the coil |

| Component | Failure mode | Root cause |
|---|---|---|
| AC Switchgear Box + Control Box | relays not operating | 2. Burnt contacts |
| | Metering CTs:<br>1. Open circuit &<br>2. Inaccurate transformation | Accuracy drift due to faulty winding |
| | Metering VTs:<br>Protection device (Fuse) operates | Accuracy drift due to faulty winding |
| | AC & DC S/As fails to protect equipment from over voltages. | Incorrect installation (distance of S/A to equipment). |
| | | Broken earth down wire |
| | | Failed S/A |
| | AC & DC S/A continuously conducts power frequency current after failure | Incorrect S/A installation |
| | Blown VT fuse | 1. Faulty VT<br>2. Faulty load limiting data concentrator |
| | DX Block (Junction Block)<br>1. Termination failures<br>2. Loose connections resulting in hot connection | 1. Vibration due to transport<br>2. Poor workmanship<br>3. Metal fatigue |
| | Enclosure exposes the internal components | 1. Door / seals / blanking plates damaged / vermin proofing.<br>2. Broken<br>3. Impact damage to enclosure attachment.<br>4. Rust damage to enclosure<br>5. Enclosure missing / stolen / backplate damaged, loose, rusted, missing. |
| AC Switchgear Box + Control Box | Copper bus-bars:<br>1. Termination failures<br>2. Loose connections resulting in hot connection | 1. Vibration due to transport<br>2. Poor workmanship<br>3. Metal fatigue |
| | Blown Fuses<br>High Current Battery Fuses (100-250A), PV Fuses (10-18A) & Low Current Fuses (1-5A) | Excessive current |
| Inverters | No Battery Inverter (Master & Slave) output (no DC or no AC) | 1. Equipment failure<br>2. High temperatures & or failed fans<br>3. Surges not clamped by the SA's<br>4. Loose connections<br>5. Loss of DC input from the battery<br>6. Suspect Firmware type |
| | No PV Inverter output AC | 1. Equipment failure<br>2. High temperatures & or failed fans<br>3. Surges not clamped by the SA's<br>4. Loose connections<br>5. Failure of solar panels<br>6. Loss of DC input to the Inverter<br>7. Suspect Firmware type |
| | | 1. Circuit brk trip |

| Component | Failure mode | Root cause |
|---|---|---|
| | UPS Inverters:<br>1. Loss of AC supply to the inverter.<br>2. No output AC or DC | 2. Equipment failure<br>3. High temperatures & or failed fans<br>4. Surges not clamped by the SA's<br>5. Loose connections<br>6. Loss of AC & DC input to the Inverter<br>7. Suspect Firmware type |
| Aircon | Aircon does not provide the specified temperature required | 1. Dirty filters<br>2. Dirty fans<br>3. Compressor failure<br>4. Heater failure |
| Container inside temp sensor | Indicates a temperature outside of specified limits | 1. Faulty sensor<br>2. Faulty aircon |

## 4. Authorization

This document has been seen and accepted by:

| **Name and surname** | **Designation** |
|---|---|
| Amelia Mtshali | Senior Manager (Design Base & Outage CoE) |
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## 5. Revisions

| Date | Rev. | Compiler | Remarks |
|---|---|---|---|
| March 2023 | 1 | Ajith Persadh | First issue |

## 6. Development Team

The following people were involved in the development of this document:

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## 7. Acknowledgements

- Dumisani Mtolo

# Annex A – Maintenance analysis

## A.1 FMECA worksheet (New Designs)

| Ref | Component | Sub components | Function | Failure mode | Failure mechanism / cause | Failure effects | | | Detection method | Compensating provisions | Usage, Environment and Health | High / Harsh / Good | | | | High / Mild / Good | | | | High / Harsh / Poor | | | | High / Mild / Poor | | | | Maintenance Determination / Recommendation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Local | Next Higher | End | | | Functional Importance | Critical | Significant | Economic | Run to failure | Critical | Significant | Economic | Run to failure | Critical | Significant | Economic | Run to failure | Critical | Significant | Economic | Run to failure | |
| 1.1 | Housing / Container | | To house & provide protection for all the components and also to provide support for the PV structure | 1.Parts of container has eroded away due to corrosion<br>2. Container leaning<br>3. Container damaged<br>4. Holes on housing causing water leaks / dust ingress<br>5. Access points compromised<br>6. Excessive heat / humidity inside | 1. Corrosion due to mods/scratching/metal poorly treated.<br>2. Unstable (ground mount)<br>3. Vandalism<br>4. Due to corrosion / mods / main related / vandalism<br>5. Access compromised due to seals broken, UV degradation of seals, rodents, broken wooden floors, termite activity, fungus damage to floors<br>6. Failure of air conditioners / container | 1. Water/ dust ingress | 1. Cause trip / malfunction to the unit<br>2. Equipment damage<br>3. Equipment degradation | 1. System failure<br>2. Customers without supply | 1. Visual inspection<br>2. Temperature / humidity monitoring via sensors<br>3. Cameras | 1. Detection & maintenance | Probability[1] | B | | | | B | | | | C | | | | C | | | | |
| | | | | | | | | | | | Consequence[2] | | | | 1 | | | | 1 | | | | 1 | | | | 1 | |
| | | | | | | | | | | | Risk[3] | | | | IV | | | | IV | | | | III | | | | III | 1. Routine inspections<br>2. Online monitoring |
| 1.2 | PV Structure | | To provide mechanical support to the PV panels | 1.Parts of PV structure has eroded away due to corrosion<br>2. Loose nuts and bolts<br>3. Missing nuts & bolts & members<br>4. Damaged sections | 1. Corrosion due to mods/scratching/metal poorly treated.<br>2. Poor workmanship during assembly<br>3.Theft / Vandalism<br>4. Storms / strong winds | 1. Collapse of PV structure | 1. PV Panels broken / damaged<br>2. Possible injury | 1. System failure<br>2. Customers without supply | 1. Visual inspection<br>2. Remote inspection via cameras, PV string information | 1. Detection & maintenance | Probability[1] | B | | | | A | | | | B | | | | B | | | | |
| | | | | | | | | | | | Consequence[2] | | | | 1 | | | | 1 | | | | 1 | | | | 1 | |
| | | | | | | | | | | | Risk[3] | | | | IV | | | | IV | | | | IV | | | | IV | 1. Routine inspections<br>2. Online monitoring |
| 1.3 | PV System | Panel | Provides photo voltaic power to a suitable std (95%) | 1. Cracked panel<br>2. Fully broken panel<br>3. Pollution<br>4. Missing / stolen<br>5. Failed panel<br>6. Shady panels | 1&2. Bio / hail damage / vandalism / incorrect installation / neglegent vegetation control (stones)<br>3. Environmental / industry / poor maintenance / bird droppings<br>4. Theft & vandalism<br>5. Hot spots due to poor manufacturing, poor installation, poor handling, transport, failed diode junction box<br>6. Encroaching vegetation | 1. Reduced power production<br>2. Injury from broken panels | 1. Damage to equipment (eg inverters)<br>2. Reduced battery life | 1. System failure<br>2. Customers without supply | 1. Real time monitoring & notifications by checking the string information (monitor voltage & current)<br>2. Visual & infra-red inspections<br>3. Remote inspection via cameras for broken panel<br>4. Scan for hotspots prior to handover | 1. Ensure proper quality assurance<br>2. Caution during vegetation control<br>3. Detection & maintenance | Probability[1] | B | | | | B | | | | B | | | | B | | | | |
| | | | | | | | | | | | Consequence[2] | | | | 1 | | | | 1 | | | | 1 | | | | 1 | |
| | | | | | | | | | | | Risk[3] | | | | IV | | | | IV | | | | IV | | | | IV | 1. Routine cleaning of panels<br>2. Routine clearing of vegetation and cutting of grass, trimming of trees<br>2. Routine inspections<br>3. Online monitoring |
| | | Wiring | To transfer power from the panel to the DC enclosure to design stds. | 1. Damaged insulation<br>2. Broken wires<br>3. Broken / damaged connectors<br>4. Missing wires | 1. Wear & tear due to wind vibration, rodent damage, UV degradation, vandalism<br>2. Vandalism<br>3. Due to neglegent vegetation control (contact with weed machinery)<br>4. Theft & vandalism | 1. Risk of electrocution<br>2,3&4. No power to equipment | 1. Lost time injury / death<br>2. Reduced battery life | 1. System failure<br>2. Customers without supply | 1. Real time monitoring & notifications by checking the string information (monitor voltage & current)<br>2. Visual inspections | 1. Detection & maintenance<br>2. Caution during vegetation control | Probability[1] | B | | | | B | | | | B | | | | B | | | | |
| | | | | | | | | | | | Consequence[2] | | | | 1 | | | | 1 | | | | 1 | | | | 1 | |
| | | | | | | | | | | | Risk[3] | | | | IV | | | | IV | | | | IV | | | | IV | 1. Routine inspections<br>2. Online monitoring |

**Note 1:** Refer to table 2 – Likelihood Criteria, in Eskom's Guide to Integrated Risk Management [2].

**Note 2**: Refer to table 1 – Consequence Criteria, in Eskom's Guide to Integrated Risk Management [2].

**Note 3:** Refer to table 3 – Risk Matrix and Table 6 Priority for Attention, in Eskom's Guide to Integrated Risk Management [2].