

# Palau National Infrastructure Investment Plan 2021–2030



## Appendix 6

### Infrastructure Asset Maintenance Guide



# Contents

- 1. Infrastructure Maintenance Requirements – General..... 4
- 2. Buildings Maintenance: ..... 5
- 3. Road Maintenance: ..... 7
- 4. Airport Runway Maintenance: ..... 9
- 5. Wharfs and Boat Harbor Maintenance:..... 10
- 6. Coastal Protection Structures:..... 12
- 7. Solid Waste Management Facility:..... 13
  - 7.1. Landfill Facility..... 13
  - 7.2. Medical Waste Incinerator ..... 13
- 8. Sewage Treatment Plant:..... 15
- 9. Motor Vehicle Fleet:..... 16
- 10. Boats/Ferries:..... 17
- 11. Telecommunications Infrastructure: ..... 18
- 12. Electricity Infrastructure: ..... 19
  - 12.1. Generating Sets:..... 19
  - 12.2. Solar Panels, Inverters and Batteries ..... 19
  - 12.3. Overhead Lines: ..... 20
  - 12.4. Pad-mounted Distribution Transformers and RMUs:..... 22
  - 12.5. Medium Voltage and Low Voltage Cables: ..... 23
  - 12.6. Revenue Meters: ..... 23
- 13. Water Supply Systems: ..... 24
  - 13.1. Rain Water Harvesting System: ..... 24
  - 13.2. Water Desalination Plant:..... 25
- 14. Maintenance Cost Estimates..... 26

## **Infrastructure Asset Maintenance Guide**

In order to achieve safe, reliable and economical efficient operation of infrastructure, all infrastructure assets require a maintenance plan. It is recommended that for engineered structures and complex equipment, a maintenance plan be developed as part of the engineering scope, during procurement of equipment and construction and installation of assets. The maintenance guidelines provided in this document are very general and generic and will need to be tailored to meet the asset specific requirements by a civil engineer for structures. The frequency of maintenance activities recommended in this document, are indicative only and should be adjusted by taking into account risks and performance history.

# 1. Infrastructure Maintenance Requirements – General

All infrastructure assets will require the following maintenance activities:

- (a) Scheduled Inspections and Minor Maintenance** – Scheduled inspections and minor maintenance at regularly scheduled intervals is required to perform minor repairs and/or replacement of degraded parts identified through inspections, to avoid more serious damage and asset impairment. The scope and frequency of minor maintenance varies depending on the asset. The minor maintenance activities are covered through O&M budgets.
- (b) Reactive maintenance** – involves repairing or replacing asset components, when they have failed in service, in order to maintain asset functionality, meet the required service levels and also to prevent further asset impairment. The reactive maintenance is generally covered through O&M budgets but may occasionally involve capital expenditure, depending on the scope of required repairs.
- (c) Planned Condition Assessment** – Planned condition assessment is carried out by subject matter experts and is performed less frequently than the scheduled inspections. It involves comprehensive assessment of all asset and its components to determine their physical condition and to reveal the need for major repairs or refurbishment or replacement of components and their timing (i.e. determining the need for roof replacement of a building).
- (d) Planned Major Repairs and Refurbishment** – These maintenance activities are performed in response to the repair/refurbishment needs identified through planned condition assessment and these are generally covered through capital budgets. When repairs or refurbishment of an asset is not considered economically efficient, the asset is retired from service and replaced.

Typical maintenance activities for various assets are described in the following sections, but as mentioned earlier, for engineered structure and complex assets, these should be further improved and augmented with input from subject matter experts.

## 2. Buildings Maintenance:

The maintenance plan for a building should be tailored to its specific design and construction, therefore the maintenance plan should be developed at the same time when a new building is being designed and constructed. It is important to keep a complete set of "as built" drawings for the building and any changes made during major maintenance should be recorded on the drawings.

- a) Scheduled inspections and minor maintenance for buildings is recommended to incorporate the following activities, performed once a year:
  - i. Grading inspection around the building foundation to confirm water is draining away from the foundations and raising the top soil level near foundations, where required.
  - ii. Inspection of foundations to identify structural cracks or concrete spalling
  - iii. Inspection of masonry walls to identify cracks or damage to walls
  - iv. Inspection of exterior walls and roof to identify all sources of water leak into the building interior and performing emergency repairs where required to prevent water ingress into the building.
  - v. Inspection of eaves and gutters to ensure they are not detached from the building or blocked by leaves or other debris. Repairs should be made where required.
  - vi. Inspection of floors and interior walls to identify any damage, which would affect functionality of the buildings and making emergency repairs, where required.
  - vii. Inspection of doors and windows to identify warped frames or broken glass and performing repairs, when required.
  - viii. Inspection of plumbing system to identify damaged plumbing fixtures, blocked or leaked drains or damaged pipes or defective pumps and performing repairs as required
  - ix. Inspection of electrical systems including lighting fixtures and performing repairs as required
  - x. Inspection of ceiling fans, air conditioners, identify extent of rust, inspect for proper operation and repairs as required.
  - xi. Inspection of safety equipment (e.g. fire extinguishers and alarms).
  - xii. Inspection for presence of termites.
- b) Planned Condition Assessment – Building condition assessment is generally performed once every five years or after a major cyclone. It involves comprehensive assessment of all building components to determine the physical condition of building components and assess their operating performance and remaining useful life. The condition assessment is undertaken to reveal the need for major repairs or refurbishment or replacement of components during the next five-year period. (i.e. determining the need for roof replacement).
- c) Reactive maintenance for buildings involves repairing specific building components when they fail, to maintain building functionality and service levels and to prevent further impairment, i.e. replacing an air conditioner compressor after it has failed. Reactive

maintenance could be triggered based on the findings of annual inspection or planned condition assessment or any serious asset impairment reported by the asset users.

- d) Planned Major Repairs and Refurbishment – These maintenance activities are performed in response to the repair/refurbishment/replacement needs identified through planned condition assessment, i.e. replacement of roof, when it is determined to have reached the end of its life.

### 3. Road Maintenance:

The maintenance plan for roads should be developed at the same time when a new road is being designed and constructed. For the purpose of keeping records and performing inspections and maintenance, the road network should be divided into sections of approximately one km long and records of inspections, maintenance and condition assessment should be kept for each section. In order to plan for road maintenance needs, it is important to keep a complete set of "as built" plans and records of all maintenance operations and observations. The as built plan should contain photographic records, location and observations of any unstable conditions in relation to the road location, location of culverts and other drainage features, changes made to the road from original plan.

Maintenance activities required during each of the four maintenance categories are listed below:

- (a) Scheduled inspections and minor maintenance on roads is recommended to be performed on a two-year cycle. Recommended inspection and maintenance activities are listed below:
  - (i) Perform road and footpath inspections to identify potholes, cracks, damaged curbs and swales and clogged sumps allowing water to collect and perform emergency repairs, where required, to avoid more serious damage and impairment to pavement
  - (ii) Perform inspection of drainage sumps to ensure they are clear of debris, leaves and plastic, which could block drainage. Critical drains and waterway crossings should also be inspected after large storm events.
  - (iii) Perform road and footpath inspections to identify tree branches or locations of brush overgrowth, which may interfere with safe traffic flow or safety of pedestrians and perform tree trimming where required.
  - (iv) Perform road inspections to identify locations where abandoned vehicles or debris left along the right-of-way poses hazard to safe traffic flow and remove such debris.
- (b) Planned condition assessment – performed once every five years – comprehensive condition assessment of all roads and footpaths to determine physical condition of the roads, curbs, drainage sumps and footpath and assess need for resealing, repaving or other repairs and their timing.
- (c) Reactive maintenance – to fix and repair pot holes in roads, minor footpath defects that impact public safety or clogged drainage sumps in specific locations in response to public complaints. During pothole repairs, road surfaces should be reworked as necessary to provide a smooth, driveable surface and a good crown or slope for drainage.
- (d) Planned major repaving of roads or major repairs to footpaths, road curbs or drainage system– This involves repaving of the roads or major (capital) repairs to footpaths, road curbs or drainage sumps, found in poor or very poor condition. Some roads may involve

strengthening of the base and reconstruction of concrete curbs. Rutting and loss of ballast often occurs during rainy season use. A plan should be in place to provide ballast when necessary to maintain continued use of the road.

In case of unsealed roads, maintenance activities, involve

- (a) Planned condition assessment – performed once every five years – to identify any major impairments and identify the need for regrading of existing base or additional gravel, in locations with serious soil erosion where gravel base has eroded away.
- (b) Reactive maintenance – to fix and repair road base in locations, where such repairs are warranted immediately.
- (c) Planned major regrading. A grader on the first pass should move material from the shoulder to a windrow in the center of the roadway. On the second pass, the blade should be centered on the windrow and continue working along the roadway. The blade should be adjusted so as to provide a slight slope or crown and should avoid cutting too deep into the road surface.

## 4. Airport Runway Maintenance:

In order to plan for airport runway maintenance needs, it is important to keep a complete set of "as built" plans and records of all maintenance operations and observations. The as built plan should contain complete history of project from planning stage to construction, photographic records, location and observations of any unstable conditions, wet areas that may have required additional excavation and replacement with more suitable ballast backfield materials and all major changes made to the original plan. The most valuable tool for the maintenance program is the knowledge and experience gained by individuals performing the maintenance.

The maintenance activities recommended in this report do not include details of the regular operational safety inspections required to make sure there are no hazards on the run-way that may impact aeroplanes landing or taking off.

Specific activities during each of the four types of maintenance categories include:

- (a) Scheduled inspections and minor maintenance is recommended to be performed once a year. Recommended inspections and maintenance activities are listed below:
  - (i) Perform airstrip inspections to identify potholes, cracks, and depressions in runway surface, which would interfere with safe landings or takeoff of aircraft and perform emergency repairs, as needed.
  - (ii) Perform airstrip inspections to identify locations with poor water drainage, which would lead to ponding on airstrip surfaces during heavy rain and perform emergency repairs, where required, to avoid more serious damage and impairment to pavement.
  - (iii) Perform airstrip inspections to identify locations of brush overgrowth along the airstrip, which may interfere with safe movement of aircraft and perform brush clearing where required.
  - (iv) Perform inspections of airstrip markings and repaint surfaces where the markings have faded away.
  - (v) Perform inspections of the security fences to confirm their effectiveness in blocking entry of unintended animals and vehicles during aircraft movement.
- (b) Planned condition assessment – performed once every three years – comprehensive condition assessment of the runway to determine physical condition of the pavement to determine its remaining useful life and assess need for resealing or repaving and its timing. Air navigation equipment is inspected by qualified contractors following strict procedure and schedule dictated by International aviation standards and safety protocols.
- (c) Reactive maintenance – which involves reactive maintenance to perform repairs to runway, the drainage system or security fences, in specific locations, to rectify identified defects and impairment.

- (d) Planned major repaving – This involves repaving of the runway when its condition reaches poor or very poor condition.

## **5. Wharfs and Boat Harbor Maintenance:**

The maintenance plan for wharfs and boat harbors should be tailored to their specific design and construction, therefore the maintenance plan should be developed at the same time when a new wharf, jetty or channel is being designed and constructed. It is important to keep a complete set of "as built" plans and records of all maintenance operations and observations.

The maintenance activities for wharfs and jetties require four types of maintenance activities:

- (a) Scheduled inspections and minor maintenance should be performed once a year. Since the concrete structures employed in wharfs generally employ complex designs, the inspections should be performed using a plan developed by the subject matter expert (structural engineer). The following is check list of activities to be included in planned inspections and minor maintenance:
  - (i) Visual inspection of concrete structures, including piers to identify and measure the size of surface cracks, spalling, rust staining, exposed rebar;
  - (ii) Visual inspection of steel members to identify and quantify the degree of corrosion, pitting, mechanical damage or reduction in cross-section due to corrosion;
  - (iii) Inspection of bumper pads to identify damage;
  - (iv) Visual inspection of paved areas to identify and benchmark surface conditions, pot holes, drainage condition etc.;
  - (v) Inspection of mooring systems to confirm the buoy and its topside hardware, fenders, and chafing strips are in satisfactory condition and to verify that the mooring has not been dragged from its proper location.
  - (vi) Inspection of safety railings to identify the degree of damage or corrosion.
  - (vii) Inspection of access channels to confirm adequate depth for safe ship movement to the port.
- (b) Planned condition assessment of wharf structures, mooring systems and approach channels should be performed by a structural engineer with expertise in marine structures, once every five years – it should include both above water and under water inspections supplemented with non-destructive tests to benchmark the degree of corrosion on steel members and degradation of concrete structures and to identify serious structural deficiencies and defects in structures, requiring structural repairs or refurbishment and renewal of structural components.
- (c) Reactive maintenance – involves site specific repairs, refurbishment or renewal to address deficiencies, prevent further impairment of structures and to ensure the structures continue to meet the functional requirements.

(d) Planned major repairs – This involves repaving of the wharf surfaces or major repairs to structures or re-dredging of the channels to remove silt. The specifications for such repairs must be prepared by subject matter expert with experience in marine structures.

## 6. Coastal Protection Structures:

The maintenance activities for coastal protection structures, including sea walls or rock revetments, requires the following four types of maintenance activities:

- (a) Scheduled Inspections and Minor Maintenance – should be performed annually and it should include visual inspections and minor maintenance of both engineered and masonry sea walls, as well as rock revetments. It should consist of the following specific activities:
  - i. For engineered concrete sea walls or masonry walls, visual inspections should be performed annually with the objective of identifying incidents of damage, either in form of structural cracks, concrete spalling, exposed rebar, missing section of the masonry wall or soil erosion at the base of the wall, caused by wave action or incidents of overtopping of the sea wall by strong waves.
  - ii. For rock revetments annual inspections should be performed to determine if the rock revetments have moved from their original location or if earth under the structure has settled or eroded away or if section of the rock revetment have been washed away by wave action.
  - iii. Any minor damage that is repairable through the use of maintenance budget and local resources, should be repaired during routine maintenance.
  - iv. When severe structural damage is identified during visual inspections, it should be used a trigger to perform a more detailed inspection by a structural engineer
- (b) Planned Condition Assessment – The condition assessment for the sea wall structures should be performed by a structural engineer, with expertise in marine structures and it should involve detailed inspections, measurement of the extent of structural damage that has occurred to the sea walls and development of a plan to repair the damage and address the deficiencies to curb additional impairment to the structures and ensure they continue to provide their intended functions. The recommended mitigation measures may involve reactive maintenance to be performed immediately to address public safety concerns or/or comprehensive mitigation measures as permanent solution.
- (c) Reactive maintenance – involves immediate site specific minor repairs, refurbishment or renewal to address deficiencies, prevent further impairment of structures and to ensure the structures continue to meet the functional requirements, following plans developed in step (b).
- (d) Planned major repairs – involves major repairs and renewal of the sea walls to comprehensively address all deficiencies to ensure the structures continue to meet the functional requirements, following plans developed in step (b).

## **7. Solid Waste Management Facility:**

### **7.1. Landfill Facility**

A maintenance and management plan for the solid waste disposal site should be prepared by a subject matter expert and it should cover:

- (a) Landfill inspections and reporting;
- (b) Landfill planning and monitoring; and
- (c) Landfill deficiency corrective actions.

The maintenance plan should include:

- (i) An inventory of required assets to be maintained;
- (ii) Quality standards to which assets are to be maintained;
- (iii) Maintenance procedures;
- (iv) Maintenance schedule;
- (v) Methods of collecting data and reporting results related to environmental safeguards;
- (vi) method to develop annual budgets and work programs;
- (vii) method to determine and record the annual weight and/or volume of waste disposed using either weigh scales or estimates of volumes from truck box measurements;
- (viii) method of identifying and recording the hazardous wastes entering and leaving the site
- (ix) methods of ground water and soil sampling near the land fill facility

### **7.2. Medical Waste Incinerator**

The medical waste incinerator is a specialized equipment. The maintenance plan should be developed following the original manufacturer's recommendations for maintenance and the maintenance plan should be followed strictly. Table 1 indicates the maintenance activities and their schedule, which should be included in the maintenance plan for the medical waste incinerator.<sup>1</sup>:

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<sup>1</sup> Best Practices for Incinerators – World Health Organization - [http://www.who.int/water\\_sanitation\\_health/medicalwaste/en/smincinerators3.pdf](http://www.who.int/water_sanitation_health/medicalwaste/en/smincinerators3.pdf)

**Table 1: Medical Waste Incinerator Maintenance Schedule**

<i>Activity Frequency</i>	<i>Component</i>	<i>Procedure</i>
Hourly	Ash removal	Inspect and clean as required
Daily	Temperature, pollution monitors, if any	Check operation
	Underfire air ports	Inspect and clean as required
	Door seals	Inspect for wear, closeness of fit, air leakage
Weekly	Ash pit	Clean after each shift
	Latches, hinges, wheels, etc.	Lubricate if applicable
Monthly	External surfaces of incinerator and chimney (stack)	Inspect external hot surfaces. White spots or discoloration may indicate loss of refractory
	Refractory	Inspect and repair minor wear with refractory cement
	Upper/secondary combustion chamber	Inspect and remove particulate matter accumulated on chamber floor
Semi-annually	Hot external surfaces	Inspect and paint with high temperature paint as required
	Ambient external surfaces	Inspect and paint as required

## 8. Sewage Treatment Plant:

A maintenance and management plan for the sewage treatment plant should be prepared by a subject matter expert and it should cover:

- (a) Scheduled inspections and minor maintenance;
- (b) Planned condition assessment;
- (c) The scope of reactive maintenance and planned major repairs should be based on the results of the planned condition assessment and recommendations of the subject matter expert.

The maintenance plan should include:

- (i) An inventory of required assets to be maintained;
- (ii) Quality standards to which assets are to be maintained;
- (iii) Maintenance procedures;
- (iv) Maintenance schedule;
- (v) Methods of collecting data and reporting results related to environmental safeguards;
- (vi) method to develop annual budgets and work programs;
- (vii) method to determine and record the annual weight and/or volume of waste disposed using either weigh scales or estimates of volumes from truck box measurements;
- (viii) methods of ground water and soil sampling near the sewage treatment facility
- (ix) methods for measuring the level of obnoxious gases near the sewage treatment facility.

## 9. Motor Vehicle Fleet:

All motor vehicles come with a vendor recommended maintenance plan, requiring time based and mileage-based maintenance activities, which should be strictly adhered to. Typical maintenance activities for motor vehicles are summarized below:

- (a) Monthly Inspections: Monthly motor vehicle inspections and corrective actions are listed below:
  - (i) Check all the lights, including head lights, brake lights, signal lights and reverse lights are working and replace any fused lamps.
  - (ii) Check the tire air pressure to confirm the tires are correctly inflated as recommended by manufacturer and fill air in tires when pressure falls below the recommended inflation level.
  - (iii) Make sure the tires have sufficient tread and plan to replace worn out tires.
  - (iv) With the engine running, listen for any strange sounds, inside and out and investigate the sources of abnormal noise.
  - (v) Inspect the condition of all belts. Be aware of the life of the engine timing belt and make sure it is replaced before it fails
  - (vi) Check fluid levels for engine oil, transmission fluid, engine coolant, power steering, brake fluid, wiper fluid and top up when required. Look for any fluid leaks under the parked vehicle.
  - (vii) Inspect batteries for any leaks or corroded connections.
  
- (b) Fluid and Filter Changes: Follow equipment manufacturer's recommendations for fluid and filter changes, which are commonly time based and mileage based. These include
  - (i) Lubricating oil changes and oil filter changes
  - (ii) Air filter changes when they get dirty
  - (iii) Engine coolant flush and fill
  - (iv) Transmission fluid change.
  
- (c) Tires, Wheels and Brakes: Follow equipment manufacturers recommendations for tires, wheel and brake maintenance, which are typically condition based. These include:
  - (i) Tires rotation and wheel balancing
  - (ii) Wheel alignment checking
  - (iii) Replacement of brake pads and rotors reconditioning or replacement when required.
  
- (d) Engine Tune Up: Get the engine tuned up in line with manufacturer's recommendations, including change of spark plugs and spark plug cables, when they are worn out or covered in buildup.
  
- (e) Corrosion Protection: Reapply the corrosion protection to the vehicle underside to protect against rust.

## 10. Boats/Ferries:

Boats (Ships) are extremely complex form of mobile structures and machinery that spend most of the time in corrosive ocean environment and they require frequent maintenance and scheduled overhauls to remain operational. The scope and frequency of maintenance work is specified initially by boat manufacturers and then by companies that perform condition assessment of the boats.

A maintenance manual must be prepared by a subject matter expert for each ship, and it should include:

(a) Recommended planned maintenance:

- including a check list of inspections and maintenance activities to be performed on-board, indicating both the frequency and scope of maintenance activities; and
- a check list of inspections and maintenance activities to be performed at dock, indicating both the frequency and scope of maintenance activities.

Typical maintenance activities for large motor boats (ships) include the following tasks:

- (i) Reconditioning of the hull, including blasting of surfaces to remove rust and repainting of the boat's hull, freeboard, superstructure, interior tanks and work areas;
- (ii) Maintenance and major overhauls of the engine room machinery, i.e. diesel engines, turbines, generators and pump stations; including checking and maintaining in fluid levels for engine oil, engine coolant, inspecting batteries and connectors etc.
- (iii) Propeller and rudder repairs, modification and alignment
- (iv) Flushing, testing and installation of piping systems;
- (v) Repairing or replacing outdated components in navigational systems and communication systems; and
- (vi) Structural modifications to suit e.g., cutting-out of existing steel structure and  
Inspect the condition of all belts. Be aware of the life of the engine timing belt and make sure it is replaced before it fails

## 11. Telecommunications Infrastructure:

Initial generations of "state-of-the-art" solid state components and devices required significant adjustments by operations and maintenance personnel. The early vintage solid state telecommunications equipment was manufactured with external controls to allow adjustments (recalibration) to move the device back to specified parameters. Modern equipment is less affected by its environment, and most manufacturers have eliminated the external adjustment controls. The use of fixed value components minimizes the need for adjustments.

Under the current design, communication devices either perform as specified, or they must be replaced. Manufacturers have created "board level" systems with all necessary components required for a device placed on digital cards, commonly referred to as printed circuit boards. Most communication system component hardware is constructed on a single printed circuit board that can easily be replaced by a qualified technician. The components are so small that they can't be repaired, or replaced in field. Simply replacing the board with the failed component saves time and money.

Most communications equipment is built with internal monitoring capabilities. Diagnostics are displayed in one of two general ways: external display on the equipment, or via diagnostics terminal (or as a program on a PC). Most modems have L.E.D. indicator lamps to show that the device is functioning in a proper manner. A multiplexer or router will provide diagnostics via directly connected terminal, or through a device setup and management program on a PC.

Telecommunications devices, therefore, require the following types of maintenance activities:

- (a) Reactive maintenance – which involves reactive maintenance to replace defective components and devices, which is done by replacing digital circuit boards. It is also important to maintain a record in form of log book of all maintenance activities, device failures and replacement of defective cards in a data base. Failure of climate control systems also require immediately replacement. In the field, damaged cables should be replaced immediately.
- (b) Planned minor maintenance is recommended to be performed once a year and it should include the following activities:
  - (i) This task involves field verification in form of inventory taking to confirm the installed equipment against data base.
  - (ii) All equipment mounted outdoors is subjected to corrosion of the connectors. Therefore the connectors should be inspected for corrosion and cleaned, when required.
- (c) Planned condition assessment should be performed once every five years – and it should include comprehensive condition assessment of the existing system capability against the current needs to see if the system should be replaced with the next generation of tele-communication devices. The failure rates (MTBF) should be also be reviewed to assess if MTBF for existing system devices is still within acceptable level.
- (d) Asset Upgrades – to replace equipment when it has reached "poor" or "very poor" condition.

## **12. Electricity Infrastructure:**

The maintenance plan for electricity infrastructure should be tailored to the specific equipment design and construction and therefore the maintenance plan should be developed at the same time when a new asset is procured and installed. The maintenance plan must reflect the requirements specified by the original equipment manufacturer.

Maintenance activities required for major assets are described below:

### **12.1. Generating Sets:**

Electricity Generating sets are an extremely expensive and maintenance intensive asset. If they do not receive the required maintenance, their service life is significantly reduced. Therefore, electricity generators require scheduled maintenance, strictly in accordance with the manufacturer's recommendations.

#### **(a) Scheduled Inspections**

Routine Maintenance and Inspections of generating plant are performed daily and include:

- (i) Checking lubricating oil levels and leaks;
- (ii) Checking coolant levels and leaks;
- (iii) Inspecting exhaust pipes;
- (iv) Inspecting fuel lines; and
- (v) Inspecting control batteries and testing voltages.

#### **(b) Scheduled Minor Maintenance:**

Planned minor maintenance activities involve change of oil and oil filters, change of air filters, change of fuel filters and change of coolant. The minor maintenance activities include:

- (i) Tasks recommended to be performed by vendor once every 600 hours for medium speed engines, i.e. change of oil and oil filters and air filters;
- (ii) Tasks recommended to be performed by vendor once every 6000 hours for medium speed engines, i.e. change of air fuel filters and coolant;

#### **(c) Planned Condition Assessment and Major Maintenance:**

Planned major maintenance activities involve engine over-haul and is required after about 60,000 operating hours, in case of medium speed engines.

High speed generators, due to their higher operating speed experience greater wear of the moving parts and they require maintenance even more often, as specified in the manual.

### **12.2. Solar Panels, Inverters and Batteries**

Because there are many types of solar panels, inverters and batteries in use, the maintenance for these solar PV plant should be performed strictly in accordance with the manufacturer's

recommendations indicated in the owners operating manual. The following recommendations for maintenance represent general guidelines:

Solar panels and inverters are considered generally maintenance free for the service life of 20 years and do not require any maintenance with the exception of planned minor maintenance.

**(a) Scheduled Routine Inspections and Minor Maintenance (Performed at 3-month Intervals):**

The following maintenance activities should be performed once every 3 months:

- (i) Washing of the panels with water to remove dust, dirt and bird droppings. The panels can be rubbed with soft sponge to remove bird dropping if required, but no hard brushes or chemicals should be used for cleaning.
- (ii) Inspection of the panel wiring to make sure the connections are tight and wires are properly secured.
- (iii) The panel output power should be monitored.
- (iv) For the storage batteries, the electrolyte level should be checked and topped when required.

**(b) Planned Detailed Inspections and Maintenance (Performed once a year):**

- (i) Perform visual inspection of the panels and check for defects in the modules such as cracks, chips, de-lamination, fogged glazing, water leaks and discoloration. If any defects are found, note their location in the system logbook, so they can be monitored in the future in case further deterioration affects the modules' output.
- (ii) Inspect solar panel mounting frame for damage or rusting and repaint surfaces when required.
- (iii) Inspect the inverter and remove any dust accumulation with dry cloth. Inspect to confirm that all the indicators such as LED lights are working and that the wires leading to and from this device are not loose. Note that the charge controller should indicate that the system is charging when the sun is up.
- (iv) Check the wiring and conduits to confirm they are free from damage.

**12.3. Overhead Lines:**

**(a) Scheduled Detailed Inspections and Minor Maintenance (Performed at 3-year Intervals):**

- (i) Detailed inspections of poles with the intent to identify the following common deficiencies:
- Out of plumb, cracked or broken poles
  - Excessive surface wear or scaling on steel poles
  - Loose, cracked or broken cross arms and brackets
  - Woodpecker or insect damage, bird nests
  - Loose or unattached guy wires or stubs
  - Guy strain insulators pulled apart or broken
  - Guy guards out of position or missing
  - Grading changes, or washouts
  - Indications of burning
- (ii) Detailed inspections of pole mounted distribution transformers with the intent to identify the following common deficiencies:
- Degree of transformer tank corrosion / rust and the need for repaint
  - Phase indicators and unit numbers match operating map (where used)
  - Oil leaks
  - Flashed or cracked insulators
  - Contamination/discolouration of bushings
  - Ground lead attachments
  - Damaged disconnect switches or lightning arresters
  - Ground wire on arresters unattached
- (iii) Detailed inspections of pole mounted disconnect switches with the intent to identify the following common deficiencies:
- Bent, broken bushings and cutouts
  - Damaged lightning arresters
  - Ground wire on arresters unattached
- (iv) Detailed inspections of pole hardware with the intent to identify the following common deficiencies:
- Loose, rusted, or missing hardware
  - Insulators unattached from pins
  - Conductor unattached from insulators
  - Insulators flashed over or obviously contaminated (difficult to see)
  - Tie wires unravelled
  - Ground wire broken or removed
  - Ground wire guards removed or broken

(v) Detailed inspections of pole mounted cables and conductors with the intent to identify the following common deficiencies:

- Low conductor clearance
- Broken/frayed conductors or tie wires
- Exposed broken ground conductors
- Broken strands, bird caging, and excessive or inadequate sag
- Insulation fraying on secondary

(vi) Detailed inspections of vegetation growth near the lines with the intent to identify the following common deficiencies:

- Leaning or broken “danger” trees
- Growth into line of “climbing” trees
- Accessibility compromised
- Vines or brush growth interference (line clearance)
- Bird or animal nests

#### **12.4. Pad-mounted Distribution Transformers and RMUs:**

All active electrical components in a distribution transformer and SF6 insulated RMU are sealed inside the tank. In case of transformers, as long as the corrosion has not resulted in an oil leak from the tank through welds or gaskets, transformer does not require any maintenance of internal parts. In case of RMUs, as long as SF6 pressure gauge indicates correct pressure, no maintenance is required.

Maintenance activities for distribution transformers and RMU’s include:

- a) Reactive maintenance** – site specific repairs of external parts or replacement of the faulty unit with a spare one to meet immediate needs.
- b) Planned minor maintenance** – performed once a year – involves completion of the following tasks:
  - (i) Performing visual inspections to confirm safe condition of power equipment,
  - (ii) Clearing the equipment from dirt or debris, if required
  - (iii) Trimming shrubs near the equipment and
  - (iv) Painting rusted surfaces, to avoid more serious damage to equipment.
- c) Planned condition assessment of equipment** – performed once every five years –

Condition assessment of transformer should include:

- (i) testing of oil samples to assess condition of internal insulation;
- (ii) measuring insulation resistance with a megger; and
- (iii) Checking turns ratio to detect shorted coils

Condition assessment of SF-6 insulated RMUs include:

- (i) Inspecting for seals and gaskets of SF6 tanks,

- (ii) Checking gas pressure and identifying sources of leak, and
  - (iii) Measuring insulation resistance.
- d) Planned replacement – There are no major repairs recommended for transformers and RMUs, when the condition assessment results indicate poor or very condition, the equipment will need to be replaced.

## **12.5. Medium Voltage and Low Voltage Cables:**

34.5 and 13.8 kV or low voltage cables require no maintenance, other than replacement of cable upon failure. Some electric utilities conduct in-site tests to verify the remaining life of cables, but no reliable tests are available at this time, which could be performed cost effectively at site.

For condition assessment of the cables, the following tasks are required;

- (i) For all medium voltage and low voltage circuits, keep records of cable failures, indicating the type of failure, location of failure and cause of failure.
- (ii) Plan to replace the cables when the number of repeated failures on a circuit becomes excessively large.

## **12.6. Revenue Meters:**

Maintenance activities for revenue meters include:

- a) Reactive maintenance – which involve replacing non-working meters and resealing broken seals, when identified by meter readers.
- b) Removing and resending the revenue meters for calibration, after the current calibration period has expired.

## 13. Water Supply Systems:

### 13.1. Rain Water Harvesting System:

For rain water harvesting system, the following maintenance activities are required:

**(a) Planned minor maintenance** of rain water harvesting system should be performed twice a year and it should include the following steps:

- (i) Clean and clear all gutters of vegetation and leaves;
- (ii) Inspect joints in pipes for leaks;
- (iii) Re-attach and repair any gutters and downpipes, where rain water is leaking; and
- (iv) Cleaning of the coarse filter, when a filter is used;
- (v) Identify damaged/cracked roofs of below grade water cisterns, through which contaminated ground water could leak into the water cistern and make repairs.

**(b) Reactive maintenance** –involves repairs and reattachment of gutters and downpipes whenever leaks are noticed.

**(c) Planned major maintenance** – performed annually – The recommended tasks are included below:

- i. It is recommended the tank be partially drained, leaving about 1000 liters of water in the tank. About ½ bottle (125 ml) of plain household grade unscented and un-colored bleach (with 4% active chlorine) should be added to the water. The tank bottom and sides should be thoroughly scrubbed with this solution using a brush. The remaining water and bleach solution should then be drained out of the tank and the tank refilled with water left to settle overnight before use. Proper hand and eye protection should be worn when handling chlorine bleach solutions.
- ii. Water quality in tanks should be tested by the Ministry of Health and results compared against WHO water quality guidelines. Testing of water quality can guide when tanks need to be cleaned or disinfected. During water quality tests, the main focus should be on microbiological testing using tests such as thermos-tolerant coliform count Escherichia coli (E. coli) count, or the simple H<sub>2</sub>S test.

**(d) Planned condition assessment** should be performed once every five years – and it should include comprehensive condition assessment of the water tanks and water storage cisterns.

## 13.2. Water Desalination Plant:

Maintenance of water desalination should be carried out strictly in accordance with manufacturer recommendations indicated in the manual. Maintenance activities typically involve:

- (a) **Reactive maintenance** – day-to-day monitoring of the system operations including the following tasks:
  - (i) pump adjustment,
  - (ii) chemical feed inspection and adjustment,
  - (iii) leak detection and repair
  
- (b) **Planned minor maintenance** – including the following activities:
  - (i) Replacement of cartridge filter elements - once every two months;
  - (ii) Backwashing of the clogged membrane once every four months;
  - (iii) Instrument calibration, and structural repair of the system on a planned schedule per manufacturer's recommendations.
  
- (c) **Planned condition assessment** - should be performed once every five years – and it should include comprehensive condition assessment of the membrane and its replacement.

## 14. Maintenance Cost Estimates

As described in the previous sections, the scope of maintenance activities varies significantly for different asset types, to achieve the desired objectives of: (a) preventing premature asset impairment; (b) reducing the risk of in-service asset failures; and (c) providing economically efficient asset operations, throughout assets' life cycle. The level of optimal maintenance required by an asset depends on a number of factors. Generally speaking, those assets that employ a large number of moving parts for their operation, experience a higher degree of wear and tear and therefore, require more frequent and more extensive maintenance. Similarly, those assets that are routinely exposed to corrosive environment, experience accelerated degradation of metal surfaces due to oxidation and therefore, require more extensive maintenance to restore the condition of corroded surfaces. The maintenance effort required for an asset also increases with asset's service age. As assets age and approach the end of their typical useful life, they require significantly greater maintenance effort, in relation to brand new assets.

Based on the scope of maintenance activities required for different assets classes, the annual maintenance budget requirements should be calculated as % of gross replacement cost of the assets, as indicated in the Table below. The indicated costs are for routine maintenance, inspections and minor emergency repairs and do not cover the cost of major component renewal.

Asset Class	Avg annual mtc Cost as % of Replacement Cost
Residential Building	1.0%
office / Institution Building	1.0%
Sealed Roads - Surface maintenance	1.5%
Runway - Surface maintenance	1.5%
Motor Vehicle Light Duty	3.0%
Motor Vehicle Heavy Duty and Machinery	3.0%
Motor Boats	5.0%
Disel Generators	4.0%
PV Solar	2.0%
Electricity Distribution Assets	2.0%
Telecom Assets	2.0%
Coastal Protection Assets	2.0%
Miscellaneous Assets	2.0%

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