Ministry of Industry and Trade

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DEUTSCHE ZUSAMMENARBEIT

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giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

EREA Electricity & Renewable Energy Authority

HAND-BOOK

Operation and maintenance of rooftop solar systems

IMPRINT

Published by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Registered offices Bonn and Eschborn, Germany

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As at December 2024

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On behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ)

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Foreword of the GIZ Energy Support Programme

Viet Nam's journey towards a sustainable energy future has gained significant momentum, with solar power emerging as a key player in the nation's energy mix. By the end of 2023, Viet Nam installed over 103,509 rooftop solar (RTS) systems, totalling 7,680 MW. The nation's ambitious target of "50% of office buildings and 50% of residential houses using rooftop solar power by 2030", as outlined in the 8th Power Development Plan (PDP8), underscores the potential for further growth and innovation and shows the Government's commitment to continue developing solar energy.

However, the rapid growth of RTS power, not only increases the country's renewable energy capacity but also comes with new challenges. To address these challenges and foster the sustainable growth of RTS, the Commercial and Industrial Rooftop Solar (CIRTS) Project, initiated by the GIZ Energy Support Programme (ESP), has been instrumental. By focusing on strengthening the national partners, Ministry of Industry and Trade (MOIT) and Viet Nam Electricity (EVN), the project has tackled technical, administrative, and regulatory hurdles.

The further development of rooftop solar power aims at providing clean electricity locally, helping to reduce the load on the power grid, reduce investment costs for the power industry and reduce power losses. To fully realise this potential, it is crucial to ensure the optimal operation and maintenance (O&M) of existing and future rooftop solar systems. This Handbook provides essential guidelines and best practices to maximise system performance, extend lifespan, and minimise downtime, while ensuring compliance with safety regulations.

As Viet Nam continues to embrace renewable energy, I hope that this Handbook, and the accompanying materials include performance ratio calculation, maintenance checklist and safe practices on operation and maintenance of rooftop solar system serve as valuable resources for policymakers, industry professionals, and investors, providing guidance on O&M strategies for the effective operation, monitoring, and maintenance of rooftop solar systems in Viet Nam.

Yours sincerely,

Sven Ernedal
Director
Commercial and Industrial Rooftop Solar Project (CIRTS)

Foreword of the Electricity and Renewable Energy Authority / Ministry of Industry and Trade

Amid the global challenges of climate change and energy security, renewable energy has emerged as an inevitable trend to ensure sustainable development. In Viet Nam, solar power has experienced significant growth, particularly rooftop solar power (RTS). By end 2023, installed capacity of RTS systems reached 7,680 MW, accounting for 9.5% of the country's total installed power capacity.

Under the National Power Development Plan for the 2021–2030 period, which includes a vision to 2050, the Government is aiming for 50% of public office buildings and 50% of residential homes to use self-consumption RTS systems by 2030. This ambitious target underscores Viet Nam's strong commitment to promoting renewable energy development, making a substantial contribution to a just energy transition. To achieve this goal, the Government issued Decree No. 135/2024/ND-CP on 22 October 2024, outlining mechanisms and policies to encourage the development of self-consumption RTS systems, primarily to meet the needs of individuals and organisations investing in them.

To ensure the efficiency of RTS systems, their management and operation must comply with state regulations, particularly regarding the safety of the distribution grid. Recognising this practical need, the Electricity and Renewable Energy Authority (Ministry of Industry and Trade), in collaboration with the "Commercial and Industrial Rooftop Solar" project, the GIZ Energy Support Programme, and Viet Nam Electricity (EVN), has developed the "Handbook for Operation & Maintenance of Rooftop Solar Systems". By providing comprehensive and accessible guidance on RTS system operation and maintenance, this handbook aims to help system owners to not only sustain efficient performance but also extend system lifespan and deliver sustainable benefits throughout its operational lifecycle.

We hope this handbook serves as a valuable resource for investors, contractors, project developers, and all stakeholders on their journey toward clean and sustainable energy sources.

Faithfully,

To Xuan Bao,
Director General
Electricity and Renewable Energy Authority
Ministry of Industry and Trade

Acknowledgments

"Handbook for Operation & Maintenance of Rooftop Solar Systems" was compiled by the technical staffs of the "Commercial and Industrial Rooftop Solar" (CIRTS) Project.

To complete this Handbook, we have received valuable comments from investors and contractors for the construction of rooftop solar systems, especially the cooperation and input of information related to practical experiences in the operation and maintenance of rooftop solar in Viet Nam of Vu Phong Energy Group Joint Stock Company.

We would like to express our sincere thanks to the Electricity and Renewable Energy Authority / Ministry of Industry and Trade, Vietnam Electricity and colleagues at GIZ for cooperating and supporting us in the process of developing and completing the Handbook.

Disclaimer

The “Commercial & Industrial Rooftop Solar” (CIRTS) Project is funded by the German Federal Ministry for Economic Cooperation and Development (BMZ). This handbook was compiled by the CIRTS Project. GIZ is the sole entity responsible for the content of this manual and it does not reflect the views of BMZ.

Readers should not use the contents of the Handbook as a substitute for legal, technical and/or financial advice. Therefore, the authors are not responsible for any losses in business, including but not limited to losses in profits, income, revenue, and production.

The GIZ Energy Support Programme would like to thank you for your comments and sharing from those who use the "Handbook for Operation and Maintenance of Rooftop Solar Systems” so that we can continue to update it in the future.

Abbreviations

AC	Alternating Current
ACB	Air Circuit Breaker
ACDB	AC distribution board
ASEAN	The Association of Southeast Asian Nations
BMZ	German Federal Ministry for Economic Cooperation and Development
CBM	Condition-Based Maintenance
CIRTS	Commercial and Industrial Rooftop Solar Project
DC	Direct Current
DC Optimizer	DC-DC power optimizer
DPPA	Direct Power Purchase Agreement
EPC	Engineering Procurement and Construction
ESP	GIZ Energy Support Programme
EVN	Viet Nam Electricity
GIZ	The Deutsche Gesellschaft Für Internationale Zusammenarbeit
IEC	International Electrotechnical Commission
KPI	Key Performance Indicator
MC4	Multi-Contact, 4 millimetres
MCCB	Mounted Case Circuit Breakers
MOIT	Ministry of Industry and Trade
MSB	Main Distribution Boad
O&M	Operation and Maintenance
PPC	Power Plant Controller

PR	Performance Ratio
SCADA	Supervisory Control and Data Acquisition
RTS	Rooftop Solar Power
TCVN	Vietnamese Standards

Symbol Conventions

Symbol	Description
	The symbol **DANGER** indicates a hazardous situation which, if not avoided, will result in death or serious equipment damage.
	The symbol **WARNING** indicates potentially hazardous situation which, if not avoided, will result in injury or partial equipment damage.
	The symbol **NOTE** provides additional information to emphasise or supplement important points.

Chapter 01

Introduction

Chapter 1: Introduction

1.1 Objectives and target readers

Objectives

The "Handbook for Operation & Maintenance of Rooftop Solar Systems" was developed to help investors, contractors and other stakeholders to have a general understanding of the processes and best practices in operating and maintaining rooftop solar (RTS) systems as well as creating maximum value from them.

The information in this Handbook helps investors and EPC/O&M contractors maintain the effective operation of an RTS system throughout its lifetime. In addition, the Handbook also provides basic information to other stakeholders, such as authorities, to support the process of monitoring and supervising the quality of operation and maintenance (O&M) of the RTS systems.

Targeted users

The targeted users of this O&M handbook are:

- EPC contractors, investors/ developers of RTS projects;
- The company or subcontractor to the EPC contractor, which provides installation and O&M services for RTS;
- Building owners;
- Government authorities in charge of the electricity sector;
- Lecturers and students of electrical engineering in universities, colleges and vocational training centers;
- Organizations and individuals interested in RTS.

1.2 Structure of the handbook

The handbook includes the following main contents:

- **Chapter 1: Introduction.**
- **Chapter 2: Overview of rooftop solar development -** provides basic information on the development of RTS in Viet Nam, the types and main components of the RTS system.
- **Chapter 3: Operation of rooftop solar system -** introduces the process of regular operation of the RTS system.
- **Chapter 4: Maintenance of rooftop solar system -** introduces preventive and corrective maintenance procedures, how to detect and diagnose, and the extent of intervention when dealing with problems.
- **Chapter 5: Safety in operation and maintenance -** introduces the requirements and safety measures in the RTS system.
- **Appendices**.

Chapter 02

Overview of Rooftop Solar Development

Chapter 2: Overview of RTS Development

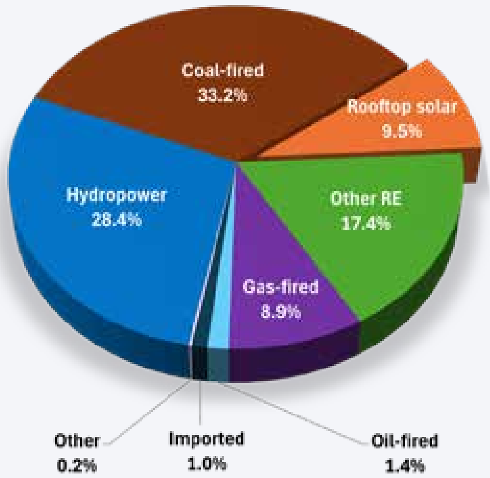
2.1 The development status of RTS in Viet Nam

By the end of 2023, Viet Nam's total installed power capacity reached approximately 80,555 MW. Of this, renewable energy sources (wind, solar, biomass) accounted for 21,664 MW (27%). Viet Nam's power system ranks first in the ASEAN region in terms of generation capacity.

This achievement is attributed to the incentives under the Government's solar power development policies, as outlined in the Vietnamese Prime Minister's Decision No. 11/2017/QD-TTg and Decision No. 13/2020/QD-TTg. As a result, installed capacity of solar power projects, including rooftop solar, has increased rapidly. As of 31 December 2023, 103,509 RTS systems had been installed nationwide, totalling 7,680 MW and accounting for 9.5% of the total power system capacity[1].

Table 1: Viet Nam's power generation mix and electricity generation in 2023[2]

Power generation mix



Electricity Generation and Imports

Resource	Electricity (mil. kWh)	Share (%)
Hydropower	80.904	28,8%
Coal-fired power	129.577	46,2%
Gas Turbine	26.315	9,4%
Oil-fired power	1.267	0,5%
Imports	4.191	1,5%
Wind power	11.367	4,1%
Utility-scale Solar	14.567	5,2%
Rooftop Solar	11.135	4,0%
Biomass	853	0,3%
Others	453	0,2%
SUM	**280.629**	**100%**

2.2 Relevant legal documents for RTS

To ensure efficient O&M of the RTS system throughout the project's life cycle, the investor must comply with State regulations and standards, as well as grid connection requirements.

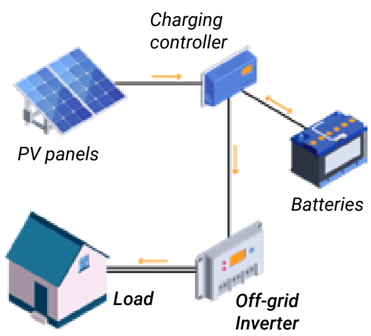
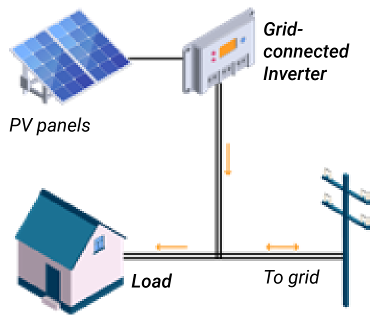
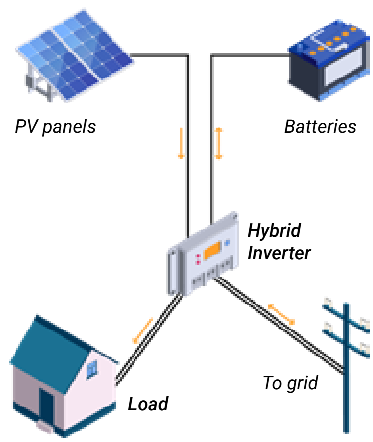
A list of relevant legal documents is attached in Appendix 1.

[1,2] Data presented by EVN at the Consultation Workshop on O&M Handbook for Rooftop Solar Systems on September 18, 2024. Rounded data.

2.3 Types of RTS systems

RTS systems are categorised into the following types:

Table 2: Types of RTS systems

Classification	Characteristics	Basic components
Off-grid RTS system	The system is not connected to the distribution grid and uses es a hybrid inverter and battery storage system to control generation and supply electricity directly to loads. Surplus solar energy is diverted to storage for use during periods of inadequate sunlight.	
Grid-connected RTS system	The system is connected to the distribution grid and uses a grid-tie inverter. The system can either export surplus electricity to the grid or, when equipped with a zero-export grid-tie inverter, exports can be prevented to help maintain grid stability.	
Hybrid RTS system (grid-connected with storage)	The system is connected to the distribution grid and equipped with battery energy storage. It functions as a grid-connected system when grid power is available. In the event of a grid outage, the system seamlessly transitions into off-grid mode, ensuring uninterrupted power supply to the loads. The battery storage can be charged from the grid or from solar energy when solar generation exceeds on-site load demand.	

Notes: Direct current (DC) Alternating current (AC) Current direction

2.4 Main components of a RTS system

The main components of a RTS system vary depending on the type installed, as illustrated in the figure below:

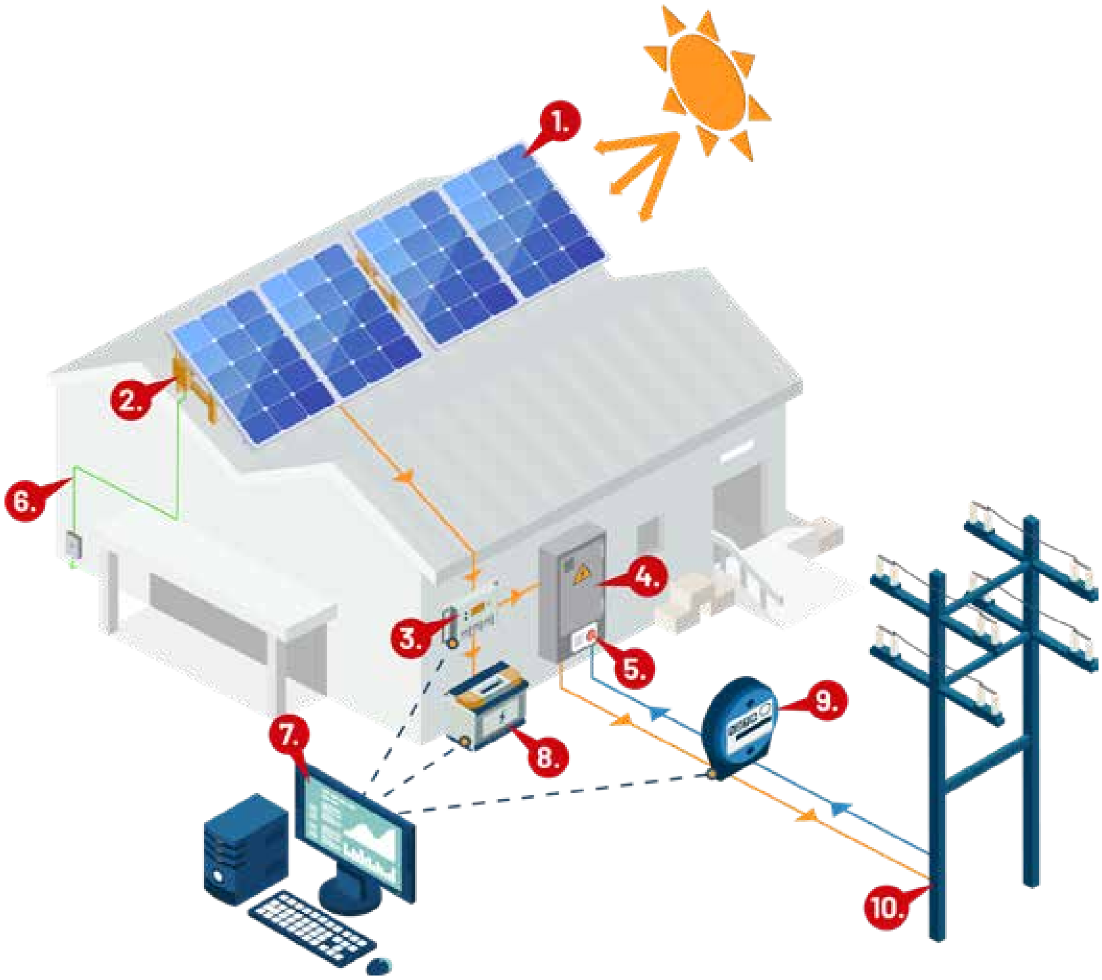


Figure 1: Main components of a RTS system

Where:

1. PV panels **2.** Mounting structure **3.** Inverter **4.** AC distribution board

5. Emergency stop button **6.** Grounding system

7. RTS monitoring and management system

8. Energy storage device (for off-grid or hybrid systems)

9. Metering system (for grid-connected or hybrid systems)

10. Grid (for grid-connected or hybrid systems)

2.4.1 PV panels

Solar photovoltaic (PV) panels are devices that convert sunlight (solar energy) into direct current (DC) electricity using what is known as the photovoltaic effect. PV panels are arranged in series, parallel, or a combination of both configurations to enhance the overall voltage or current output before being connected to an inverter.

PV panels are composed of interconnected photovoltaic cells, typically fabricated from silicon or other semiconductor materials. PV panels are categorised based on the type of photovoltaic cells used:

- Monocrystalline silicon
- Polycrystalline silicon
- Thin-film (amorphous silicon, CdTe or CIS).

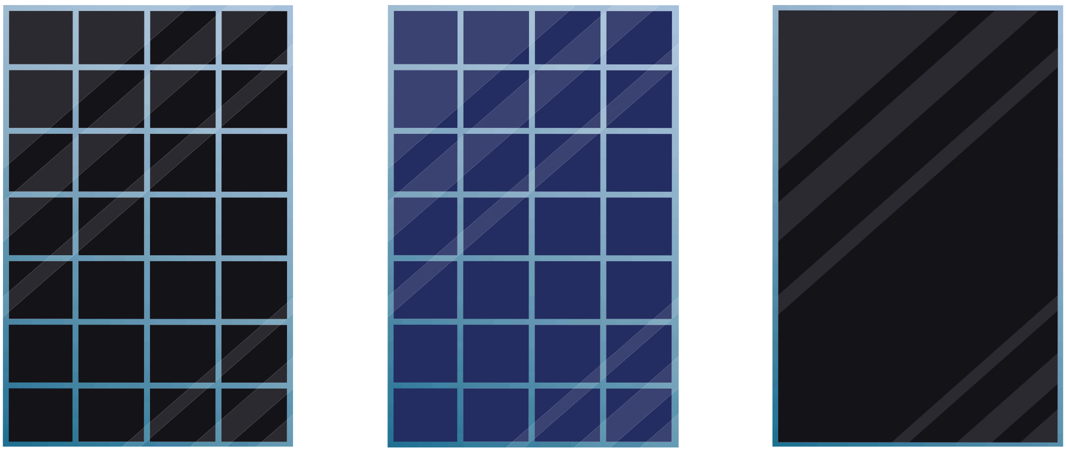


Figure 2: PV panels categorisation

In Viet Nam, PV panels primarily consist of monocrystalline and polycrystalline silicon. Thin-film PV panels, due to their lower efficiency, have not been widely adopted.

2.4.2 Mounting structures

Mounting structures serve as structural supports for securing PV panels at a specific angle, ensuring optimal solar energy absorption. Overall design considerations for mounting structures:

- RTS system load (weight);
- The load-bearing capacity of the roof where the RTS system is installed;
- Typical and maximum wind speeds at the installation site, considering mounting height;
- Potential threats from natural disasters, such as hurricanes, floods, and earthquakes;

- Environmental factors such as high salinity or corrosive environments.

Figure 3: PV panel mounting structures

Figure 4: RTS system mounting structures installed on a metal roof

For tile or sheet metal roofs, the mounting rail must be securely attached to the roof purlins. A minimum gap of 150mm between the solar panels and the roof surface (whether tile or metal) must be maintained to ensure proper ventilation for cooling.

For concrete roofs, a tilted mounting structure must be constructed to prevent water pooling on the solar panels, reduce dust accumulation, and improve efficiency. At the connection points between the base of the mounting structure and the concrete roof, columns can be cast for bolt anchoring. Direct drilling into the concrete roof should be minimised to avoid leaks.

Since Viet Nam is in the Northern Hemisphere, the south-facing direction receives the most solar radiation throughout the year. Therefore, the mounting structure should be positioned to orient the solar panels southward, particularly for roofs facing east-west. The tilt angle of the mounting structure must also be properly fixed to optimise sunlight capture. As Viet Nam is near the equator, the sun's high position requires a lower tilt angle to optimise sunlight exposure. The optimal tilt angle for solar panels is between 10-15 degrees, decreasing toward the south.

2.4.3 Inverter

Inverters play a pivotal role in RTS systems by converting DC electricity generated by PV panels into AC electricity. The selection of an inverter is tailored to the specific type of PV system: off-grid, grid-connected and hybrid.

Beyond their primary function, smart inverters offer several advanced features such as anti-islanding protection, over/under voltage/frequency ride through (smart inverter). The functions of the grid-connected inverter must meet the requirements for RTS resources connected to the national grid as prescribed in Circular 30/2019/TT-BCT and Circular 39/2022/TT-BCT.

Figure 5: Inverter and inverter placement

2.4.4 AC distribution board

An AC distribution board (ACDB) distributes AC power generated by PV panels and isolates the RTS system from the grid when necessary. Major components of an ACDB:

- **Air circuit breaker (ACB)**: The ACB serves as the main disconnect switch of an RTS system with multiple inverters. The input of the ACB connects to the output of Mounted Case Circuit Breakers (MCCB). The output of the ACB connects to the Main Distribution Board (MSB) to connect to the electrical system and supply power to the load. The main function of an ACB is to isolate the entire RTS system from the grid.
- **Mounted case circuit breakers (MCCB)**: These serve as the disconnect switch for each individual inverter. The input of the MCCB connects to the AC output of each inverter. The main function of the MCCB is to isolate individual inverters. For small RTS systems comprising just one inverter without an ACB, the MCCB can isolate the RTS system from the grid.
- **Protection devices**: Including over frequency, undervoltage, overvoltage, voltage surges, overcurrent, ground fault, short circuit, leakage current protection mechanisms, emergency stop, etc.
- **Automatic transfer switch (ATS)**: In the case of grid-connected RTS system with storage, a backup generator is installed to automatically transfer power between the grid and the generator.
- **Capacitor bank**: In case it is necessary to increase the power factor (cos φ) to avoid purchasing reactive power from the grid.

Figure 6: Outside and inside the AC distribution board

2.4.5 Emergency stop button

When a dangerous situation or incident occurs, to safely isolate the RTS system from the grid, the system operator must press the emergency stop button.

Inside the emergency stop button is a (normally closed) contact connected to the shunt trip of the ACB/MCCB. During normal operation, current from the RTS system will flow through the ACB/MCCB to generate electricity to the grid. When the emergency stop button is pressed, it activates the shunt trip to trigger the ACB/MCCB to immediately isolate the RTS system from the grid.

Figure 7: Emergency stop button

2.4.6 Grounding system

The grounding system is for safety and is used to protect operators and equipment such as PV panels, inverters, mounting structures, etc., from the impacts of dangerous phenomena like lightning, phase faults, and other electromagnetic phenomena.

In addition, if the RTS system is installed in areas with high lightning risk, lightning protection devices should be used for both DC and AC circuits.

Refer to TCVN 9385:2012 when designing, installing, testing and maintaining grounding and lightning protection systems.

Figure 8: Grounding wire connected to the mounting structure, grounding test box, and grounding field

2.4.7 RTS management and monitoring system

The management and monitoring system plays a crucial role in helping operators and system owners obtain useful parameters during operation and data on cumulative output during the operational lifetime of the RTS system. In addition, for grid-connected RTS systems with an installed capacity of 100 kWp or more, the investor is responsible for installing management and monitoring devices and ensuring they can be connected to the collection, monitoring, and control system of the power distribution company, ensuring compliance with the requirements outlined in Circular 39/2022/TT-BCT and

Figure 9: Illustration of the Main Interface of the RTS Management & Monitoring System

The management & monitoring system includes the following main components:

- **Host computer system:** uses a cloud computing system integrated with the inverter or a host computer system with monitoring software on dedicated infrastructure.
- **Datalogger:** collects and transmits data from inverters, multifunctional meters, weather monitoring stations, and other sensors (if any) to the host computer system using standard connection protocols. In addition to the above functions, some dataloggers also have power plant control functions (PPC).
- **Weather sensors:** solar irradiation sensors, ambient temperature sensors, wind speed, PV panel temperature sensors, etc.
- **Multifunctional meters:** In cases where the system requires anti-reverse power flow to the grid, meters supporting this function (zero export function) need to be installed.
- **Network and communication devices:** support LAN/WAN/Internet connections via fiber optic or 4G.

Figure 10: Monitoring of the RTS system via a dedicated host computer system

Figure 11: Solar irradiation measurement sensor

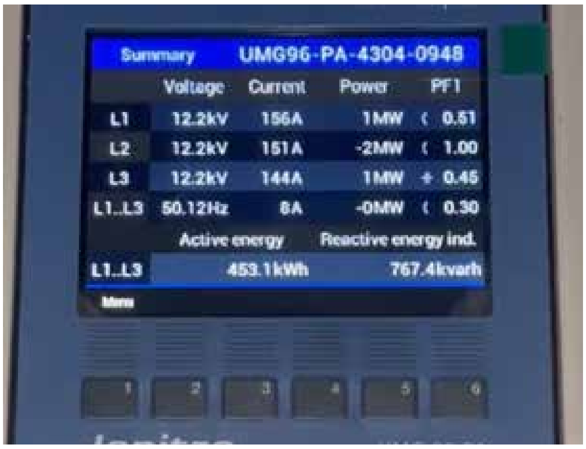


Figure 12. Zero export meter (anti-reverse power flow to the grid)

Figure 13: Datalogger (left) and 4G modem (right) installed in the communications cabinet

2.4.8 Energy storage devices

Energy storage devices are used for off-grid or hybrid systems.
Storage devices function to store surplus electrical energy generated by the RTS system and supply electricity back to the load when solar energy is insufficient or there is no grid connection.

The most common energy storage devices used currently are lead-acid batteries or lithium-ion batteries. Lead-acid batteries are heavy and, while they have good energy storage capacity, they have short lifespans (3-5 years). Lithium-ion batteries are lighter, have longer lifespans than lead-acid batteries and are maintenance-free.

The charging and discharging process of storage batteries and the charging voltage/current are controlled to protect against overcharging or discharging below the allowed threshold.

Figure 14: Lead-acid batteries and lithium-ion batteries

2.4.9 Energy metering system

For grid-connected RTS systems selling surplus electricity to the national grid, the seller (system owner) is responsible for installation of an energy metering system (including energy meter, current transformers, voltage transformers) connecting to the Automatic Meter Reading system of the buyer (power distribution company). This enables monitoring of the electricity output the RTS system feeds into the grid as well as electricity consumption from the grid, ensuring technical requirements comply with Circular 42/2015/TT-BCT, Circular 07/2019/TT-BKHCN, Decree 135/2024/ND-CP and current standards and regulations.

Figure 15: An electronic energy meter

2.4.10 DC and AC cables

DC cables

DC cables connect and transmit DC electricity from PV panels to inverters. The cross-sectional area of DC cables is selected to match the system's rated current, minimising voltage drops, power losses (due to resistance), and ensuring the necessary safety factor. DC cables feature specialised MC4 connectors, as depicted Figure 16.

Figure 16: DC cables with MC4 connectors

AC cables

AC cables are responsible for transporting AC electricity from the inverters to the point of connection within the PV system. AC cables can be either copper or aluminum conductors and feature an insulating layer.

Figure 17: AC cable

2.5 Technology trends

The rapid development of solar power in general, and rooftop solar in particular, around the world has driven swift changes in the adoption of new technologies for RTS systems. Some emerging trends include:

- **High-capacity solar panels (400+/500+ Wp and above) and bifacial panels:** The demand to optimise costs and maximise output (kWh/m²) in a limited roof space is increasing, especially in the commercial and industrial segments where roof space is constrained. High-capacity and bifacial panels enable investors to achieve these goals with only a minimal increase in investment costs. Electricity output from systems with bifacial panels can be up to 4–5% more than from conventional single-sided polycrystalline panel systems;

- **Micro inverters:** Micro inverters perform the same basic function as traditional string inverters, except they are installed directly underneath individual or small groups of solar panels rather than being connected to a string of panels. Micro inverters are an excellent choice for systems designed in complex areas with multiple roof planes or shaded roofs, helping to maximise system output.

- **Building-integrated micro PV systems:** Micro PV systems, consisting of one or a few solar panels mounted or hung on existing building structures like balconies, awnings, facades, or parking lots, are rapidly developing in many countries (e.g., Germany). These systems are affordable, quick to install, and simple (as they do not require complex mounting structures). This approach maximises use of existing infrastructure to develop solar power. It also means that as well as buildings or households with sufficient roof space, even office renters, household tenants, or buildings with insufficient roof conditions can adopt solar power.

- **Development of RTS systems with energy storage:** Continuous advancements in battery storage technology are expected to reduce the global average cost of lithium-ion batteries by 40% from 2023 to 2030[3]. This will transform the market for energy storage systems and create significant opportunities to integrate lithium-ion battery storage with RTS systems.

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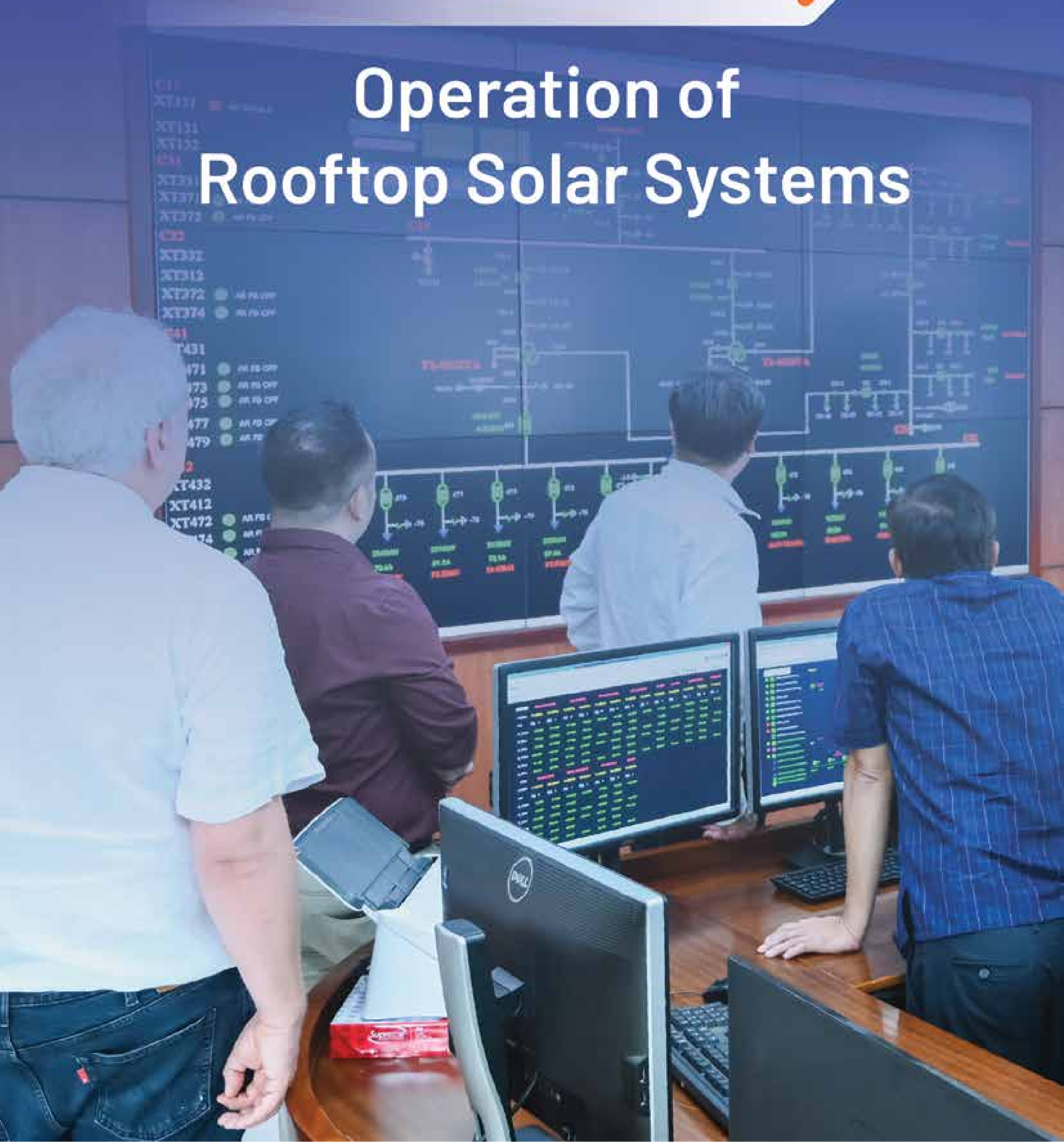
[3] Report of the International Energy Agency (IEA) https://www.iea.org/reports/batteries-and-secure-energy-transitions/executive-summary

Chapter 03

Operation of Rooftop Solar Systems



Chapter 3: Operation of RTS Systems

3.1 Overview

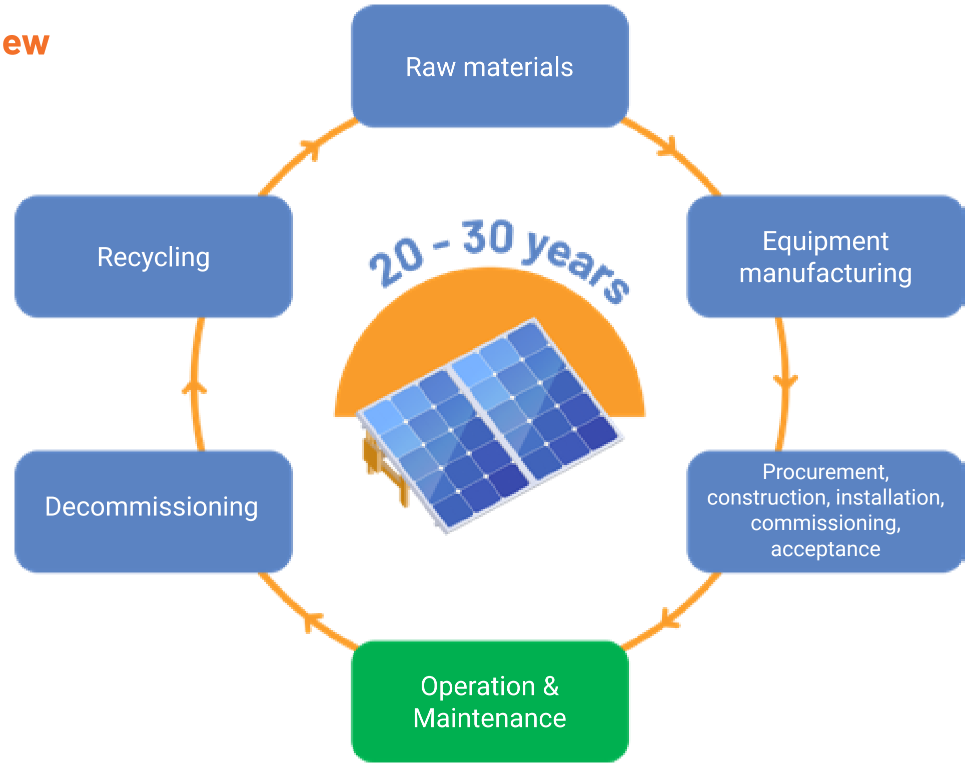


Figure 18: Life cycle of a Rooftop Solar System

The operation of a RTS typically involves remote monitoring, supervision and control to optimise the technical performance of the system, while also complying with the regulations on distribution grid operations specified by dispatch authorities.

To maintain the designed lifespan of the RTS system (20 to 30 years), operators must adhere to the following operational procedures to minimise potential risks throughout the system's life cycle.

The primary tasks involved in operating a RTS system include:

Routine Operation Procedures

- **Start-up and shutdown**
- **Monitoring and supervision of operational status**
- **Performance calculation**
- **Compliance with grid operation requirements**

Figure 19: Key tasks in operating a RTS System

3.2 Routine operation procedures

During normal operation, manual intervention is not required for a RTS system. Typically, a RTS system always remains in a "ready" state, with the power supply from the distribution grid to the main circuit breaker (ACB), branch circuit breakers (MCCB) of the AC system, and the inverter's DC switch all in the "ON" position. The RTS system will automatically switch between "running" and "standby" modes depending on the intensity of solar irradiation and the related feature of the used model.

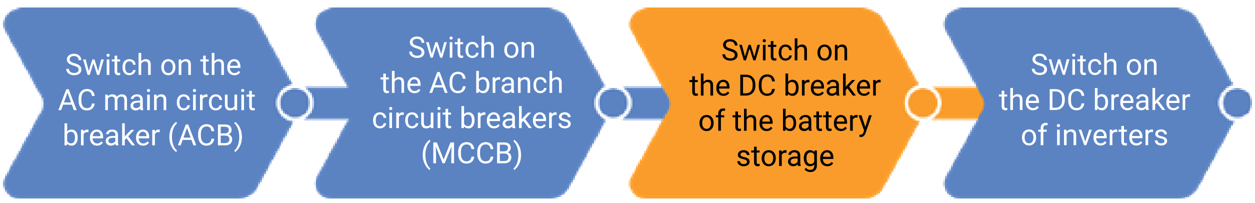
Operators must follow these operational guidelines:

3.2.1 Start-up / shutdown

Before starting up, the following checks must be performed:

- The inverters are installed correctly and securely;
- The DC and AC switches / breakers are turned OFF;
- The AC and DC cables are connected correctly and securely;
- Unused terminals and connection ports are locked with waterproof covers;
- The inverter cover is closed and screws are tightly fastened;
- The surrounding environment must be clean and tidy;
- The voltage on the AC side is within the allowable operating range (220V/380V + 10% & - 05%).

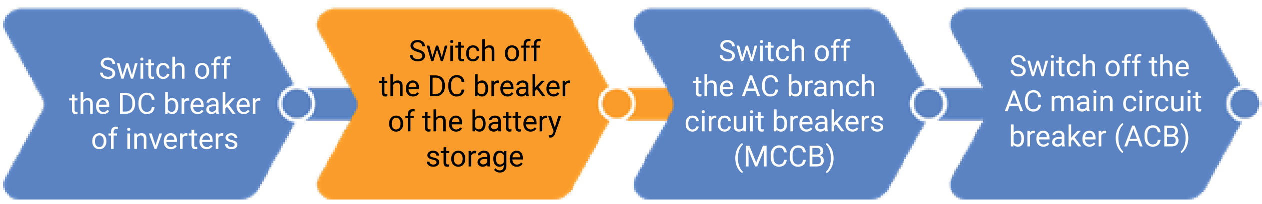
To start up the RTS system, follow these steps in order:



For RTS system installed with a Battery Storage System

When it is necessary to disconnect the RTS system from the national grid, follow the shut-down procedure in reverse order of the start-up procedure.

The steps are as follows:



For RTS system installed with a Battery Storage System

NOTE

Refer to the start-up / shutdown instructions of inverter manufacturer and actual operating conditions to adjust the system start-up / shutdown procedures accordingly.

After performing these steps, check the status and warning indicators on the inverter. Check for error messages. If the inverter does not operate at all, immediately contact the supplier.

3.2.3 Monitoring and supervision of operational status

Operators are responsible for continuously monitoring and supervising the operational status of a RTS system. This task is typically done remotely using a RTS management and monitoring system and / or centralised control centres in the case of monitoring multiple RTS systems simultaneously.

The management and monitoring system, typically in the form of a web-based portal, will connect with the inverters to collect all RTS data, enhancing real-time operational status awareness. This data is stored long-term in a dedicated database for various purposes.

Operators have access to the collected data for monitoring, reporting to the RTS owner, and proposing necessary solutions.

Key parameters to be monitored include instant power output, cumulative energy yield, weather data such as solar irradiation, ambient temperature, PV panel temperature (if available), etc

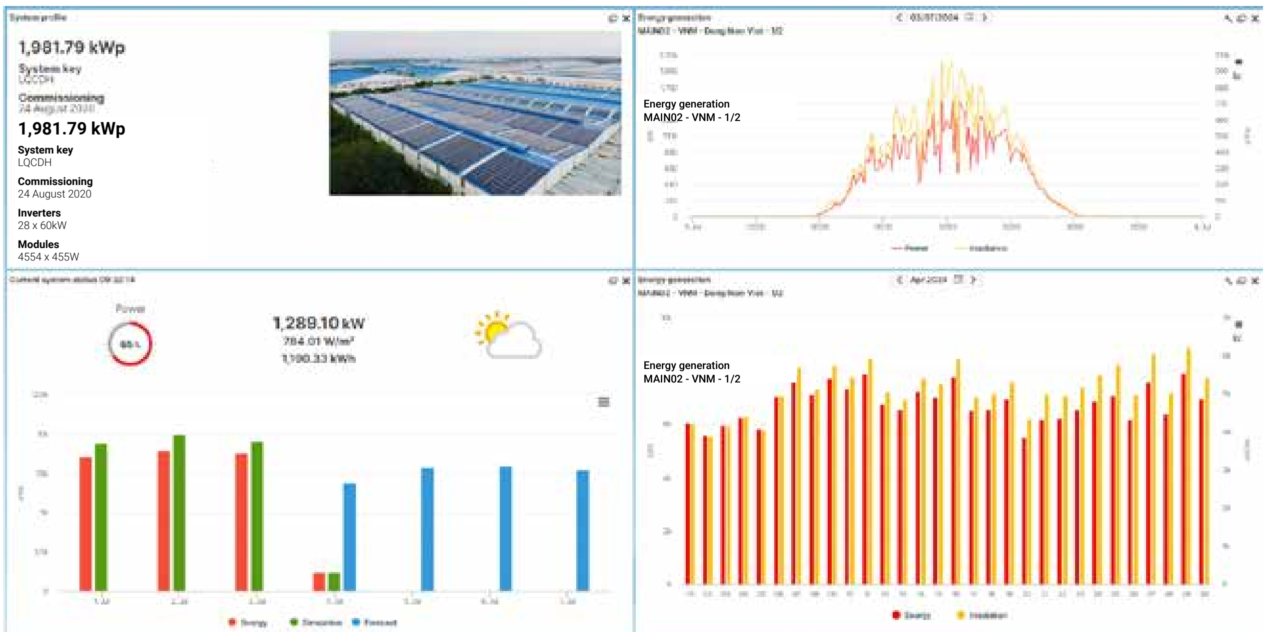


Figure 20: The power and output of a RTS system are tracked through the monitoring system

3.2.3 Performance calculation

3.2.3.1 Data collection

Key performance indicators (KPIs) must be calculated to ensure a RTS system is operated safely within allowable technical limits. To calculate these indicators, the following data must be collected:

- Solar irradiation intensity (W/m2);
- Temperature: Photovoltaic panels, ambient environment;
- AC Active power (kW);
- Reactive power (kVAR);
- Energy generated by the RTS system (kWh);
- Energy fed into the grid (kWh);
- Fault events and downtime;
- System unavailability events (shutdowns for maintenance, repairs, output curtailments due to dispatching authority requirements, etc.).

Depending on the information update requirements, the data collection frequency can be weekly, monthly, quarterly, or annually.

3.2.3.2 Performance indicators calculation

The KPIs of a RTS include:

- Actual energy yield (kWh);
- Performance ratio (%);
- Technical availability (%).

Actual energy yield is the electricity (kWh) produced per installed capacity (kWac/kWp), calculated over a certain period. This metric allows comparison of power generation performance between different RTS systems with the relevant DC/AC ratio z

Performance ratio (PR) is the ratio between actual energy yield and theoretical reference yield (yield obtained under standard conditions with consideration of the temperature and without losses). The PR indicates the overall impact of losses in a RTS when converting from DC power to AC power. The higher the PR, the more effectively the system operates.

Technical availability is the ratio of the time that a RTS system actually operates compared to the total time the system is able to operate (the time when the RTS system receives irradiation higher than the minimum irradiation threshold – MIT, so that the inverters can start generating electricity) without taking into account any exclusion factors (such as the system having to stop working due to an incident, downtime for maintenance, etc.). The technical availability reflects the operational readiness of the RTS system.

Refer to the IEC 61724 standard (TCVN-13083) for calculation method of KPIs.

Based on KPI calculation results and the technical limits, operators can monitor system performance and propose solutions to maintain the RTS performance as designed.

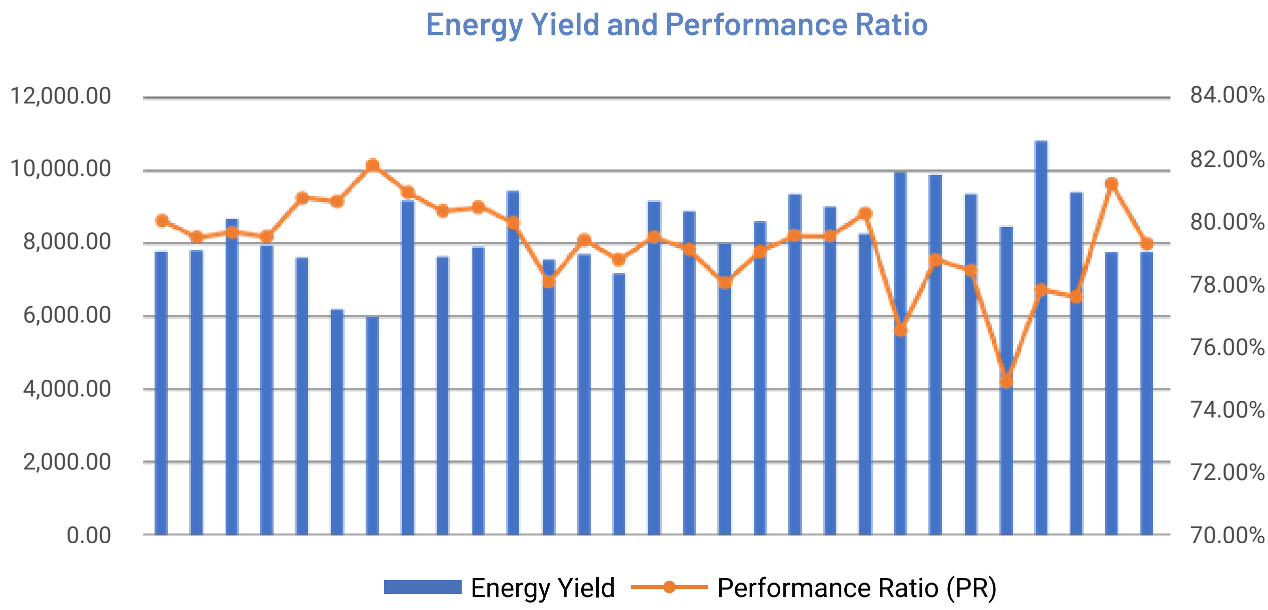


Figure 21: Monthly energy yield and PR report

NOTE

In cases where O&M services are outsourced, the O&M service provider and the system owner must agree on one of the KPI indicators mentioned above as a guaranteed commitment. PR serves as an effective commitment indicator between parties, particularly when the EPC contractor also acts as the O&M service provider. This is because PR comprehensively reflects both the overall quality of the system installation and the O&M performance of the RTS system. The PR calculation form is presented in Appendix 2.

3.2.4 Compliance with grid operation requirements

When a RTS system has a Supervisory Control and Data Acquisition (SCADA) connection, the dispatching authority will directly monitor the operational status and remotely control the RTS system (as stipulated in Circular 39/2015/TT-BCT dated November 18, 2015, regulating distribution systems and Circular 39/2022/TT-BCT dated December 30, 2022, amending and supplementing Circular 25/2016/TT-BCT, Circular No. 39/2015/TT-BCT and Circular No. 30/2019/TT-BCT by the Ministry of Industry and Trade).

In the absence of a SCADA connection, the operator will manually switch on/off the devices or control the RTS system according to the dispatching authority's instructions.

If the hosting capacity of the regional grid is insufficient, the dispatching authority will require a limitation on the maximum power output fed into the grid. There are three methods to control compliance with these limitations:

- **Option 1:** Set limits using parameters in each inverter.
- **Option 2:** Install a Power Plant Controller (PPC) for the RTS system to flexibly adjust parameters (active power, reactive power, power factor, ramp rates, etc.) of the inverters.
- **Option 3:** Manually adjust the power output of the RTS system, comply with the allocation of dispatching authority or isolate the RTS system from the grid according to the dispatch order.

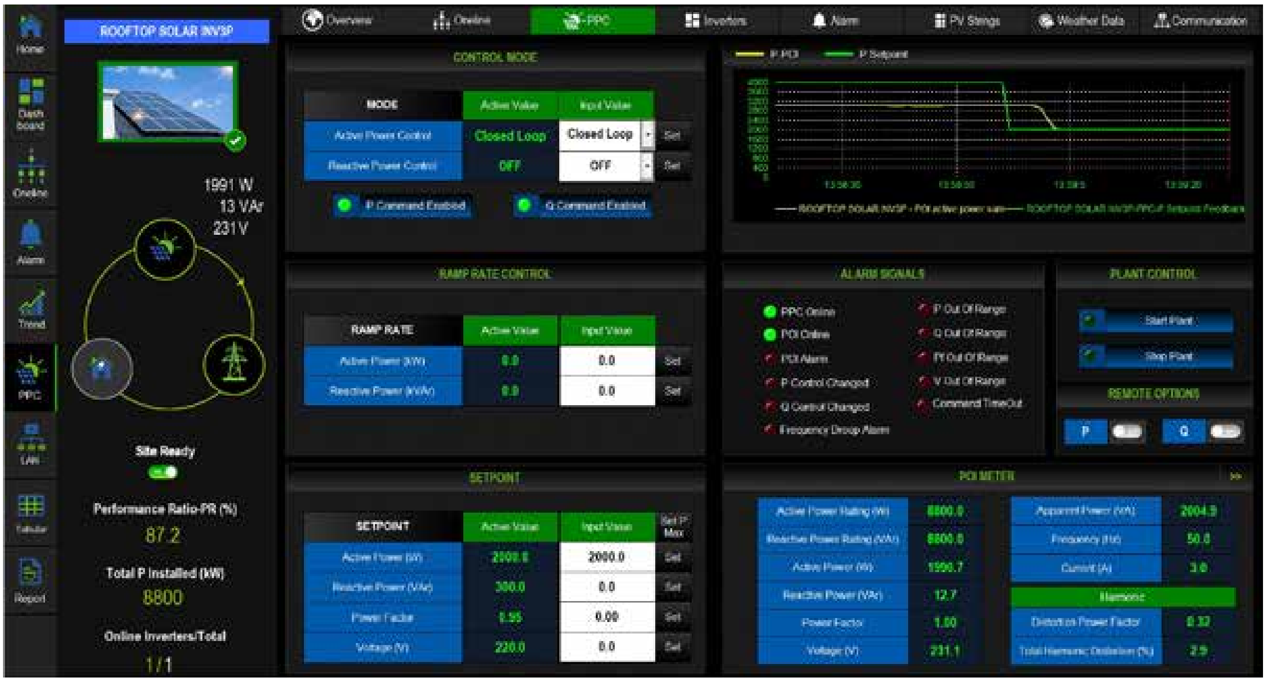
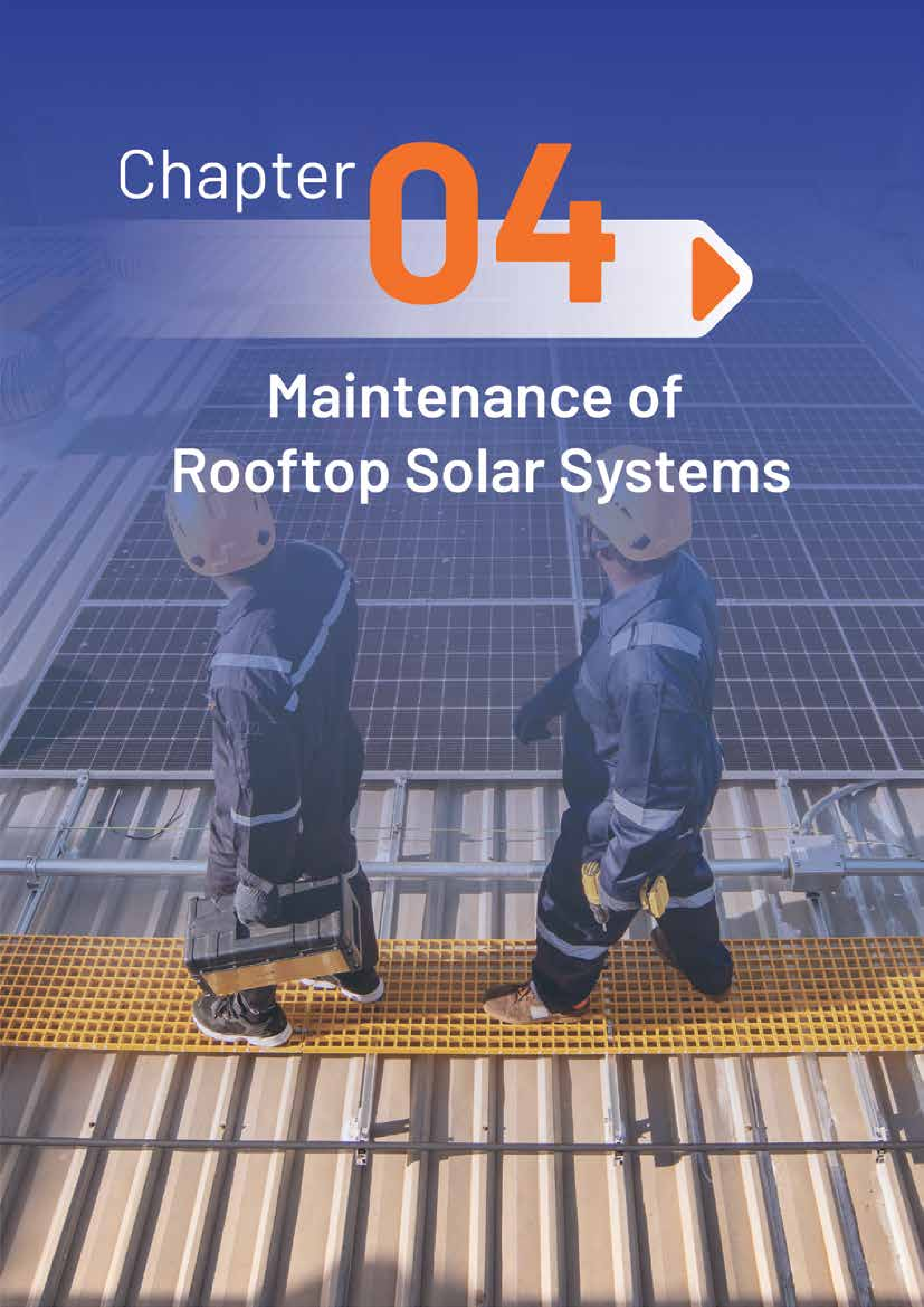


Figure 22: Controlling RTS operational parameters via PPC

Chapter 04

Maintenance of Rooftop Solar Systems



Chapter 4: Maintenance of RTS Systems

Maintenance is a combination of preventive and corrective actions throughout the lifetime of equipment.

The main objective of maintaining a RTS system is to preserve the efficiency and lifespan of the system to ensure continuous electricity production according to the designed technical specifications.

For small-scale RTS systems (under 100kW), system owners may perform maintenance themselves. In that case, if a problem occurs and cannot be resolved, the system owner should contact the supplier/distributor or a professional maintenance service.

For industrial and commercial RTS systems, maintenance is recommended as shown in the figure below:

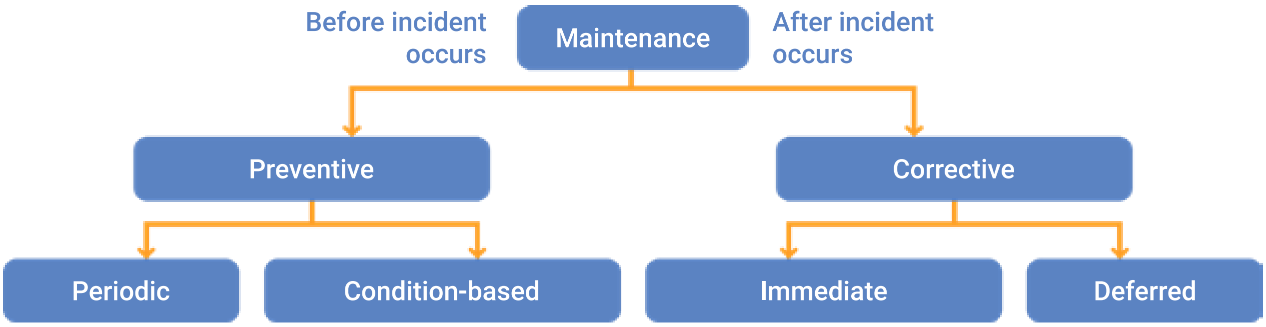


Figure 23: Overview of maintenance types

To ensure maintenance is carried out quickly, minimising downtime of all or part of the RTS system, it is necessary to stock up on essential tools and materials.

The following factors should be considered when stocking materials to bring the best economic benefits to the owner:

- Frequency and impact of failures on the system;
- Cost of replacement parts;
- Reliability and degradation rate of equipment;
- Procurement time for additional supplies;
- Possibility of consignment with manufacturers;
- Warehouse conditions (location, infrastructure, security, safety, environment).

A suggested list of spare parts to stock for a 1MW RTS system is described in Appendix 3.

To ensure effective and safe maintenance of a RTS system, it is advisable to begin with the tools and equipment outlined in Appendix 4.

4.1 Preventive maintenance

Preventive maintenance is a planned activity (periodic maintenance) or based on predetermined criteria (condition-based maintenance - CBM) to prevent and minimise potential incidents that may occur. The differences between these two maintenance methods are described in the following figure:

	Periodic maintenance	Condition-based maintenance
Purpose	Prevent damage through periodic inspection, maintenance, and repair	Promptly identify signs of deterioration and predict when equipment might require repairs
Time frame	According to pre-planned schedule	Proactive, condition-based
Implementation conditions	According to manufacturer's instructions, warranty terms	Equipment's actual condition
Improvement capability	Working efficiency and equipment lifespan	Maximising equipment utilisation by delaying premature replacement
Impact on operation	Has interruption time, extended according to maintenance schedule	The downtime is usually shorter due to a reduction in the number of unnecessary maintenance

Figure 24: Comparison between periodic maintenance and condition-based maintenance

NOTE

The most suitable time to perform preventive maintenance is during late afternoon or evening when the system's power output is low. Avoid maintenance during intense sunlight (9:00AM - 3:00PM) to minimise production losses. When performing maintenance, refer to the equipment operation manual provided by the manufacturer / distributor to understand the structure, methods, frequency of maintenance, and safety measures to be followed. Furthermore, if the EPC contractor left an O&M manual, follow it also.

Proper implementation of preventive maintenance procedures will bring many benefits to a RTS system owner:

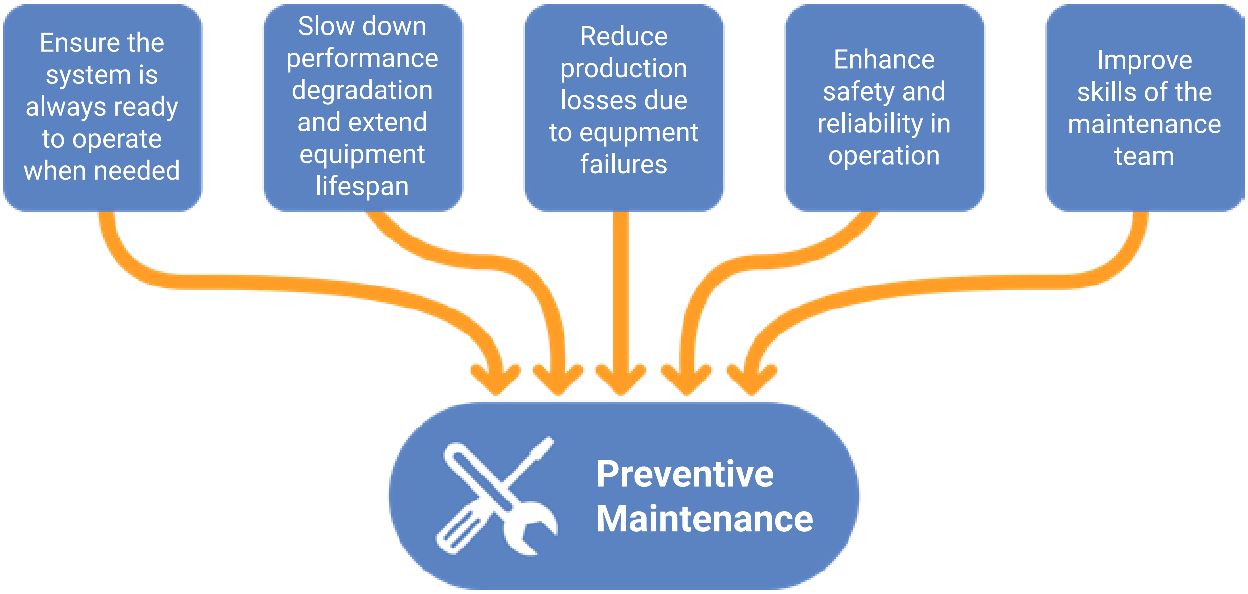


Figure 25: Benefits of preventive maintenance

4.1.1 Periodic maintenance

The recommended frequency for periodic equipment maintenance is presented in Appendix 5.

The periodic maintenance procedures for main equipment (PV panels, mounting structures, and inverters) are described in the sections below.

4.1.1.1 PV panels

The performance of a RTS system will be affected if the PV panels encounter the following issues:

- Dust accumulation on the surface;
- Hotspots;
- Mismatch;
- Physical damage.

4.1.1.1.1 Dust accumulation on the surface

Causes

After a period of operation, a layer of dust will adhere to the surface of a PV panel, leading to a partial reduction in the amount of sunlight contacting the PV cells. This causes performance degradation, reduced system output, and decreased lifespan of the PV panel.

Figure 26: PV panel with dust accumulation

Figure 27: Cleaning PV panels

Solutions

Regularly clean the surface of PV panels to increase light absorption, improve operational efficiency, and slow down the oxidation process of the surface, frame, wires, and connection points.

Depending on the level of dust in the air at the installation site, an appropriate cleaning frequency for the PV panels can be determined (from once every 3 to 6 months).

The manual cleaning steps are as follows:

- Prepare tools, equipment, and personal protective equipment: Use only specialised cleaning agents recommended by the PV panel manufacturer and soft brushes.
- Mix the cleaning agent: Mix the cleaning agent with clean water (not contaminated with alum or salt). Refer to the recommended mixing ratio on the cleaning agent packaging.
- Cleaning: Dip the soft brush into the prepared cleaning solution and gently wipe. If the bottom surface needs cleaning, use a dry cloth to avoid damaging wires or junction boxes.

NOTE

Refer to Appendix 7 for recommendation on cleaning difficult stains like bird droppings or oil stains, iron dust, cement dust, etc.

The current trend is to use automated equipment instead of human labour for O&M tasks. One of the highly beneficial tools recently applied is the use of robots for cleaning PV panels. These robots can result in superior efficiency and other benefits, such as:

- Ability to clean remote, hard-to-reach locations and move through gaps between PV panels;
- Energy and water savings during the cleaning process;
- Use of less manpower with higher productivity.

Figure 28: Using robots to clean PV panels

Recommendations	
Before cleaning	• Carefully inspect PV panels for cracks, damage, and loose clamps; • Check water temperature, pressure, and flow to ensure you do not use water that is too hot/cold or high-pressure and high-flow nozzles that could affect the durability of the PV panels.
During cleaning	• Do not walk, sit, stand, or step on the PV panels during cleaning; • Avoid rubbing hard or scraping dust stains on the top surface of the PV panels; • Do not clean cracked, broken, or damaged PV panels; • Do not clean during adverse weather conditions like storms or intense sunlight, as it can be dangerous for the person performing the task.
After cleaning	• Collect all tools, avoiding leaving any items on the surface of the PV panels.

Figure 29: Clean water storage tank and pump for cleaning PV panels

Figure 30: Do not clean damaged PV panels

Figure 31: Do not climb, sit, or stand on PV panels

4.1.1.1.2 Hotspots

Figure 32: PV panel shaded by trees and hotspot phenomenon

Causes

A hotspot is a phenomenon where a PV cell on a panel experiences a high temperature increase due to partial shading that is not addressed, leading to irreparable damage to the PV panel. By design, PV panels should not be shaded between 9:00 AM and 5:00 PM.

Additionally, shading affects the system's efficiency. The degree of shading depends on the size and position of the obstructing object, as well as the duration of shading. For instance, even 20-30% shading of the surface will result in 30-40% reduction in the power output[3].

Causes of shading include:

- Objects placed on the PV panels (agricultural products, leaves, etc.);
- Shadows from nearby trees, electric poles, and tall buildings, etc., falling on the PV panels;
- Improperly installed PV panels (panels overlapping each other, different mounting frame heights, etc.).

[3] https://ieeexplore.ieee.org/document/6924142.

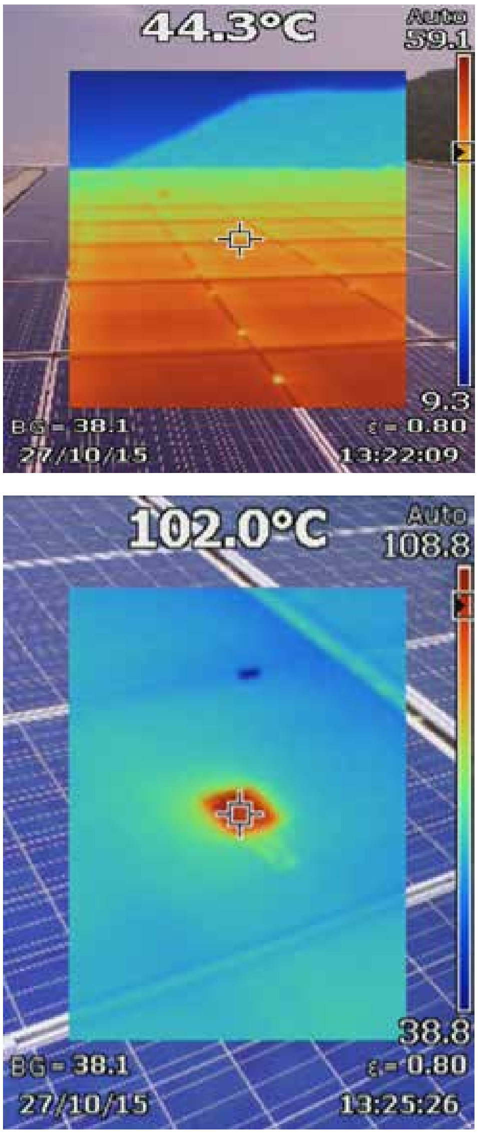


Figure 33: Thermal images of normal PV panels and when local hotspots appear[4]

Solutions

When shading is detected, the following solutions should be implemented:

- Remove objects/obstacles placed on the surface;
- Trim parts of trees creating shadows;
- Contact the installation company to address improperly installed PV panels or relocate panels or mounting frames away from shadows (if possible).

To detect local hotspots that are not visible to the naked eye, use a thermal imaging camera or specialised unmanned aerial vehicle (drone) with a camera and thermal sensor, then replace damaged PV panels.

Figure 34. Detecting faults in PV panels using drone with thermal sensors

Recommendations

Using different stringing arrangements (group PV panels that receive shade into strings and keep PV panels that are not shaded in separate, parallel strings), PV panels with bypass diodes, and DC Optimisers to minimise efficiency losses due to shading and local hotspot phenomena.

Figure 35: DC Optimiser installed under a PV panel

[4] Top image: The PV panel temperature is uniform at 40°C.
Bottom image: A cell in the PV panel is abnormally hot (temperature above 100°C).
The PV cell has been damaged and therefore this panel needs to be replaced.

4.1.1.1.3 Mismatch

Figure 36: System with both mono and polycrystalline PV panels

Causes

To achieve the designed efficiency, the technical parameters/specifications of PV panels (current, voltage, and power) need to be uniform.

However, during operation, the operating parameters of PV panels can become non-uniform due to dust accumulation, shading, damage, or differences in aging rates. This is the mismatch effect.

Additionally, when damaged panels are replaced with others, differences in technology, power, or quality can also cause mismatch.

Solutions

- Regularly remove accumulated dust and shading on the surface of PV panels;
- Replace damaged PV panels with new ones that have matching technical specifications.

Recommendations

- To ensure uniform equipment quality, purchase from reputable manufacturers / distributors;
- Keep a stock of spare PV panels with identical specifications for replacement when necessary.

4.1.1.1.4 Degradation, physical damage

Causes

PV panels can degrade over time due to environmental factors such as temperature, humidity, rainstorms, light-induced degradation (LID, LeTID) or by what is known as potential-induced degradation (PID).

Additionally, they may have physical damage caused by external impacts that can be visually identified, such as moisture, sea salt damage, cracks, or microcracks on the PV panels.

Moisture-damaged PV panel

Microcracks on PV panel

Corroded PV panel

Cracked PV panel

Figure 37: Examples of physical damage on PV panels

Solutions

Periodically measure the voltage (open circuit voltage, operating voltage) and current (operating current, short circuit current) of the PV strings, analyse the current-voltage characteristic curve (also known as the I-V curve) to identify PV panels with performance degradation exceeding the manufacturer's specifications and replace if necessary.

Regularly inspect and replace physically damaged PV panels.

Recommendations

Regularly clean dust off the PV panels to minimise physical damage.

4.1.1.2 Maintenance of mounting structures

Causes

During installation or over time, mounting structures may lose ability to securely hold PV panels for the following reasons:

- Installation in unstable positions on the roof;
- Bolts on the mounting structure not being tightened;
- Salt soiling and corrosion over time;
- Frequent operation in areas with storms and high winds.

Figure 38: Mounting structures installed inadequately

Figure 39: Loose bolts on mounting structures

Solutions

Periodic maintenance measures for mounting structures include:

- Reinforcing roof areas with weak support to ensure it can bear the weight of the RTS system;
- Tightening bolts to ensure all clamps are secure;
- Lubricating, replacing corroded or rusted components of mounting structures and accessories;
- Adjusting the tilt angle of mounting structures to ensure it meets the optimal angle as designed.

Recommendations

- Strictly adhere to safety regulations for occupational safety equipment when working on rooftops
- Do not access the roof during adverse weather conditions like storms or intense sunlight, as it can be dangerous for the person performing the task.

4.1.1.3 Inverters

Causes

After a period of operation, dust can accumulate on inverter components, some parts may oxidise, error warnings may appear on the inverter display, or the inverter may emit loud noises. Additionally, long-term operation in harsh environments with metal dust, chemicals, mist, etc., increases the risk of inverter failure or explosion.

Solutions

To extend the lifespan of inverters, implement the following measures:

- Clean the area around inverters;
- To ensure good ventilation conditions for the inverters, clean the cooling fan and if necessary, replace the filter;
- Tighten any loose or disconnected electrical cable ends, cover cable ends, conduits, ensure insulation, avoid overheating and corrosion;
- If an inverter continues to make loud noises or displays internal circuit or software errors, contact maintenance and repair personnel.

Figure 40: Normal (green) and abnormal (red) inverter status indicators

Figure 41: Burnt, damaged Inverter

Figure 42: Cable detached from inverter

Figure 43: Dust accumulation on inverter

Recommendations

- Before maintenance, turn off both AC and DC power to avoid electric shock;
- Wait at least 5-10 minutes for internal capacitors to fully discharge;
- Keep commonly used replacement components ready to minimise downtime due to component replacement (if applicable).

4.1.2 Condition-based maintenance

Condition-based maintenance (CBM) is not conducted on the basis of a fixed schedule but based on predictions derived from analysing and evaluating critical degradation parameters of the equipment.

The degradation of equipment is detected through sensor systems and analysis software. This allows operators to assess the condition and predict the necessary maintenance timing before failures occur.

Applying new technologies (big data, machine learning/artificial intelligence) for CBM enhances diagnostic capabilities and proposes accurate solutions to improve maintenance quality and operational efficiency.

Machine learning/artificial intelligence application software uses big data to analyse and accurately identify faults, It then suggests necessary actions. This data is continuously collected over long periods (one or several months) from the RTS system (current, voltage of PV strings, thermal images taken by drones, irradiance, etc.). This provides operators with accurate information to implement appropriate measures to effectively prevent failures.

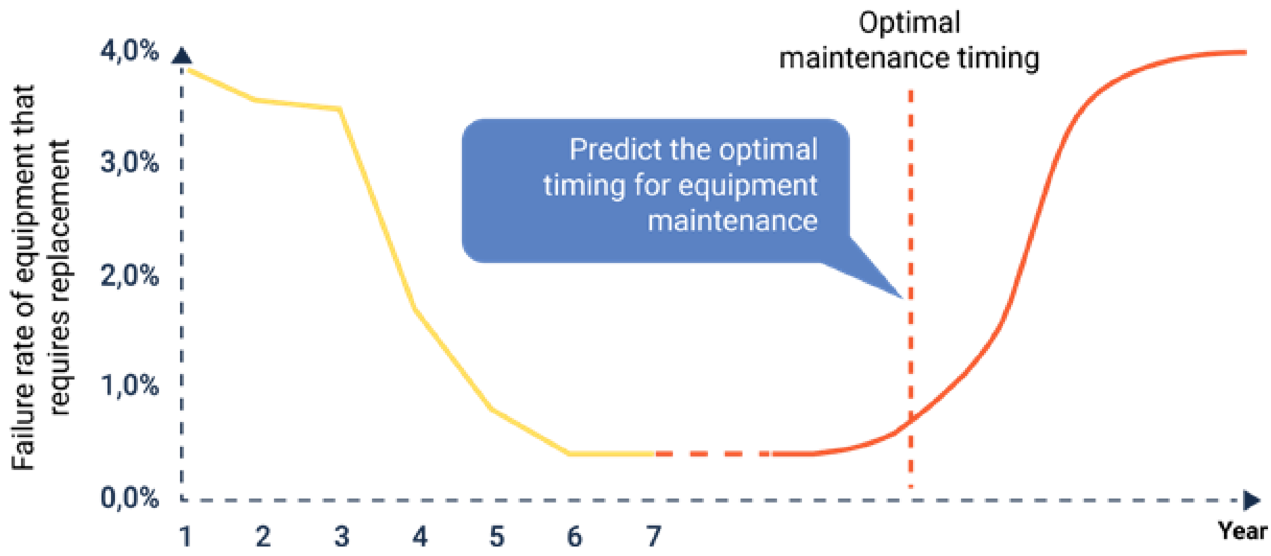


Figure 44: Condition-based maintenance predicts optimal maintenance timing

4.2 Corrective maintenance

Corrective maintenance is performed after a fault occurs to restore equipment or a RTS system to its original operating state, often involving repair or replacement of faulty equipment.

Preventive maintenance is proactive, while corrective maintenance is reactive.

The severity of faults is classified as follows:

- **Non-critical fault:** A few components in a system may be faulty but the system continues to operate and generate power.
- **Critical fault:** A fault that causes a system to stop operating and disconnect from the grid.

Corrective maintenance is typically divided into two main types:

- **Immediate Maintenance:** Involves repair actions taken immediately after the equipment experiences a fault. These faults are typically critical and directly affect the operation of a RTS system. They should be repaired in less than 24h.
- **Deferred Maintenance:** Involves necessary repair actions for non-critical faults that can be delayed due to budget, time, or personnel constraints. They should be repaired within one week to one month depending on whether replacement equipment is available and/or nature of the fault.

The process for selecting corrective maintenance is illustrated in the diagram below:

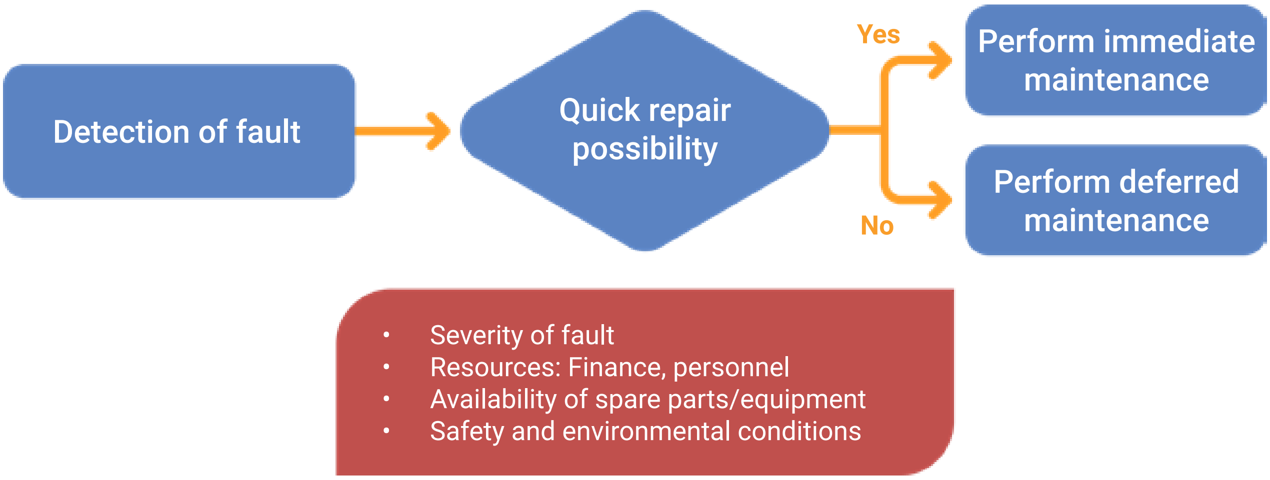


Figure 45: Corrective maintenance selection process

Performing corrective maintenance ensures existing faults are resolved without spreading, impacting operational time, or increasing costs unnecessarily.

In the short term, therefore, corrective maintenance helps save time and costs. However, in the long run, this form of maintenance may cost more than preventive maintenance because the same fault may recur frequently, leading to extended downtime and reduced power generation.

4.2.1 Fault detection and diagnosis

Most faults in a system are recorded and displayed on-site through fault indicator lights on the inverter or via a RTS management and monitoring system.

RTS monitoring systems consolidate, categorise, and provide initial handling instructions for these faults (if available).

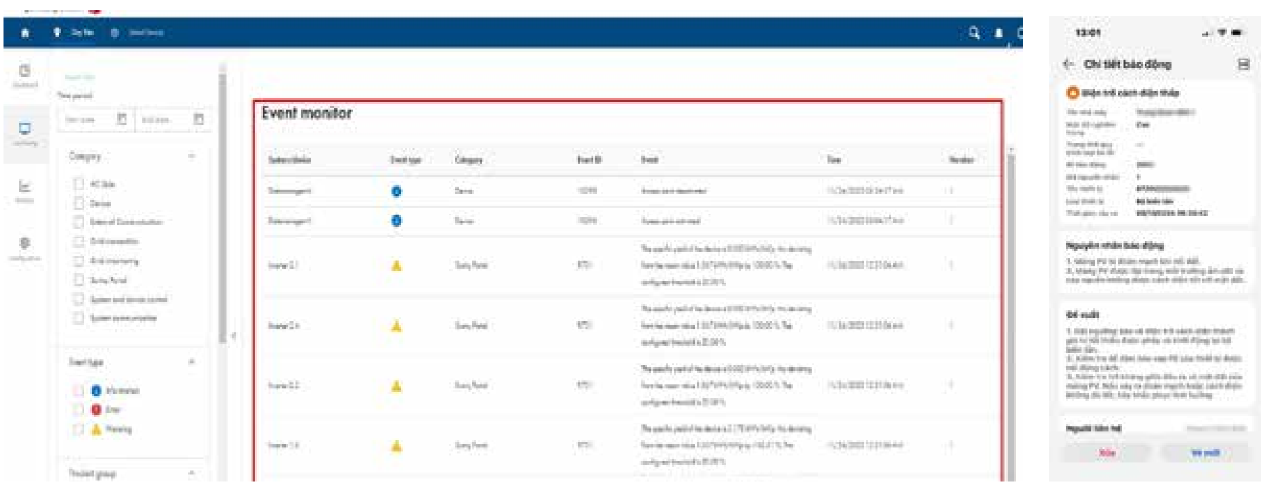


Figure 46: Management and monitoring system records faults and issues alerts and warnings

4.2.2 Levels of intervention in fault handling

Depending on the severity of a fault, O&M staff can apply levels of intervention in sequence as follows. If the fault is resolved at one stage of intervention, the next level will not need to be implemented.

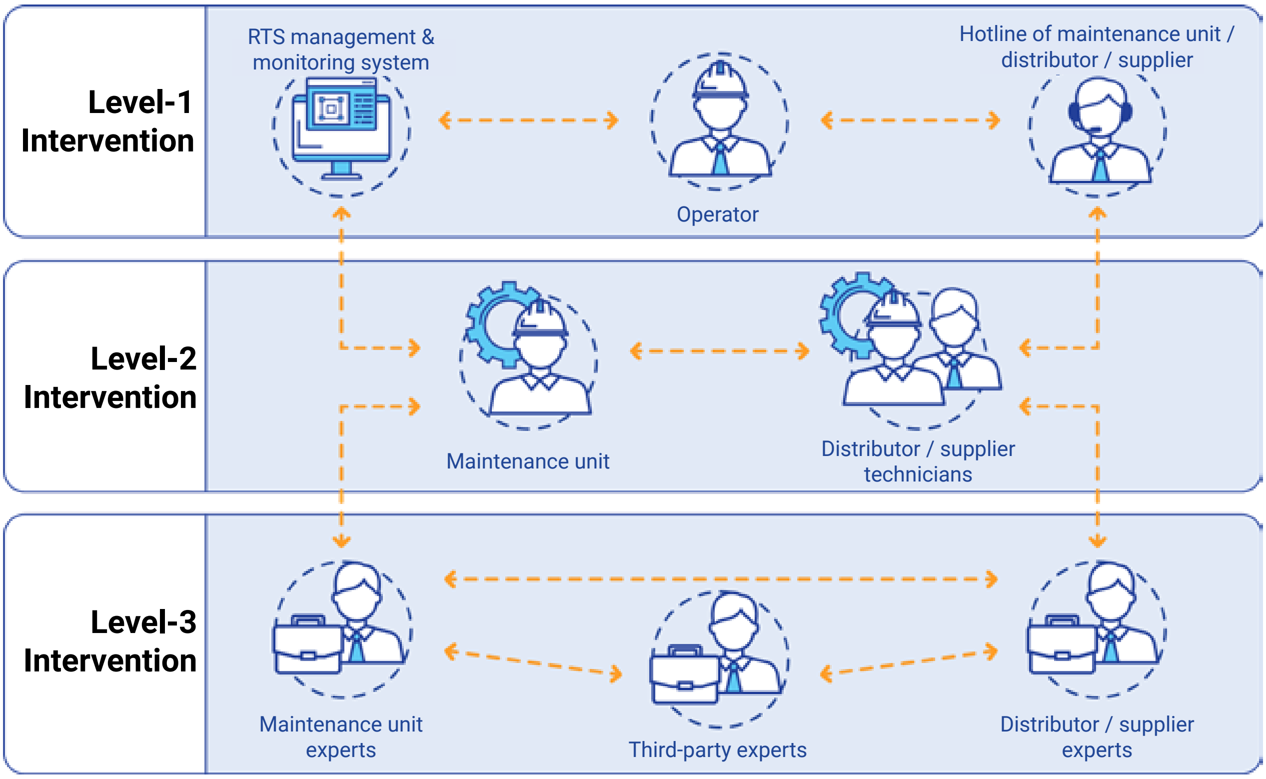


Figure 47: Levels of Intervention in fault management

- **Level-1 Intervention:** Based on the warning information from the RTS management and monitoring system, the operator performs simple actions to handle the fault (Section 4.2.3). If the fault cannot be resolved, the operator should contact the maintenance unit / equipment distributor / supplier for remote fault diagnosis and handling guidance.
- **Level-2 Intervention:** The operator contacts the maintenance unit/ equipment distributor / supplier to attend the site for fault handling. At this level, faults are primarily handled by repairing or replacing equipment (Section 4.2.4).
- **Level-3 Intervention:** This level is for faults that require extensive expertise, such as faults related to configuring operational parameters, inverter software system errors, or RTS management and monitoring system software errors, etc. The operator must contact experts from the maintenance unit / equipment distributor / supplier or third-party experts for handling.

4.2.3 Dealing with common issues

After a RTS system has been operating for a long time, some abnormal situations/faults may occur. Some common issues and possible solutions are as follows:

Table 3: Common faults and how to troubleshoot

Fault	Cause	Troubleshooting steps
Inverter stops working, grid voltage high/ low warning appears, or frequency high/ low warning appears	Grid voltage / frequency is higher / lower than the safe limits set in the inverter	• Check the inverter to ensure the protection parameters are set correctly. • Wait 5-10 minutes; if the grid voltage / frequency returns to the normal operating range, the inverter will reconnect to the grid automatically. • If the fault is unresolved, contact the maintenance unit/equipment distributor / supplier for guidance. • If the fault recurs, measure the current grid voltage / frequency and contact the power company to report the power quality and seek resolution.
Inverter stops working, overcurrent warning appears	AC output current exceeds the inverter's maximum allowable limit	• Wait 5-10 minutes until the AC output current is within the normal operating range; the inverter will reconnect to the grid automatically. • If the fault is unresolved, contact the maintenance unit/ equipment distributor / supplier for guidance.
Inverter stops working, grid power failure warning appears	Main circuit breaker (ACB) or branch circuit breaker (MCCB) is off, or disconnected from the grid supply	• Check the ACDB panel to ensure the main circuit breaker (ACB) and branch circuit breaker (MCCB) are connected and turned ON. • Check if the grid power is normal. • Wait for grid power restoration; the inverter will reconnect to the grid automatically. • If the fault is unresolved, contact the maintenance unit / equipment distributor / supplier for guidance.
Inverter stops working, device fault warning appears	A component of the inverter has a transient fault	• Restart the inverter. • If the fault is unresolved, contact the maintenance unit / equipment distributor / supplier for guidance.

NOTE

The operator should refer to the manufacturer’s / distributor’s/ supplier’s manuals to understand the detailed process for handling faults.

In some cases, the troubleshooting step is as simple as restart the inverter/ RTS system, especially for software / firmware-related issues. However, if the problem is still not resolved after restarting, it is necessary to shut down the inverter / RTS system to perform the next maintenance steps.

DANGER

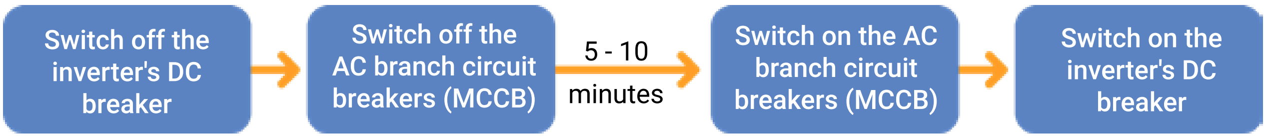
When restarting or shutting down an inverter / RTS system, operators must strictly follow the procedures outlined below. Failure to comply may result in electrical arcs, system damage, and potential fire hazards.

Refer to the user manual provided by the inverter manufacturer for specific sequences and precautions when restarting or shutting down the system

The procedure for restarting and shutting down the inverter / RTS system is as follows:

4.2.3.1 Inverter / RTS system restart

To safely restart an inverter, follow this sequence:



WARNING

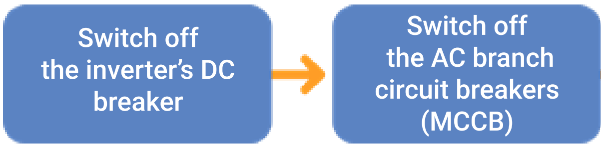
To safely restart the system, it is necessary to discharge all residual electrical energy, then wait 5-10 minutes before turning the inverter back on.

If the inverter has an LCD screen, check for status indicators or error messages (if any). Refer to the inverter manual to understand these messages.

Perform the above procedure for all inverters if restarting an entire RTS system.

4.2.3.2 Inverter / RTS system shutdown

To turn off an inverter, follow this sequence:



To shut down the RTS system, follow the sequence described in Section 3.2.1.

WARNING

Once the above steps are completed, the RTS is shut down. However, there may still be residual electricity and heat in the chassis, which can cause electric shocks or burns. Therefore, keep the system off for 5-10 minutes before performing any further actions.

Do not disconnect the MC4 connectors while the inverter is still connected to the power supply.

4.2.4 Repair and replacement procedure

At this level, repair and replacement of parts or entire pieces of equipment are usually carried out by specialised technicians on-site (either from the maintenance unit or the distributor / supplier).

DANGER

Turn OFF and ground the equipment safely, ensuring there is no voltage or current present before proceeding with repair or replacement to avoid the risk of electric shock.

Use complete personal protective equipment.

Avoid contact with system cables or exposed connectors.

NOTE

Refer to the manufacturer's / distributor's procedure manual before performing repairs or replacements.

The repair and replacement procedure for key components of a RTS system is as follows:

Figure 48: Process of repairing/replacing key components

Figure 49: Technician performing on-site repairs

Figure 50: Using a clamp meter to measure current

Chapter 05

Safety in Operation and Maintenance

Chapter 5: Safety in Operation and Maintenance

To ensure safety during O&M of a RTS system, workers must comply with all measures related to electrical safety, working at height safety, fire and explosion safety. A system of safety signs must also be displayed by all RTS system owners to warn O&M operators, people working under the roof where the system is installed, and firefighters of related dangers.

5.1 Electrical safety

Electrical safety regulations for RTS systems are stipulated in relevant legal documents, including: Decree 14/2014/ND-CP, Decree 51/2020/ND-CP; Circular 05/2021/TT-BCT, QCVN 01:2020/BCT.

Strictly adhere to electrical safety measures before performing maintenance by, among other things, taking the following actions:

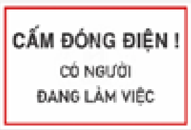
- Switch off the power and take measures to prevent it from being restored;
- Verify the absence of power to ensure safety;
- Perform grounding (earthing) to eliminate electrical hazards;
- Place barriers and hangi safety signs to secure the work area.

When performing maintenance of the solar power system, it is necessary to use personal protective equipment properly. This includes protective clothing, hat, gloves, boots, glass, mask, etc.

Figure 51: Using personal protective equipment when maintaining a RTS system

Pursuant to Circular 05/2021/TT-BCT, electrical safety signs are divided into three types: prohibition signs, warning signs, and instruction signs, as described in the following table:

Table 4: Electrical safety signs

Type	Content of sign		
Prohibition signs	 "Do not climb! Fatal high voltage"	 "Do not enter! Fatal high voltage"	 "Stay away! Fatal electricity"
	 "Do not energise! Workers are working"		
Warning signs	 "Stop! Fatal electricity"	 "Electrical cable"	
Instruction signs	 "Work here"	 "Enter this way"	 "Grounded"

In addition to the prescribed electrical safety signs, the system owner and O&M service provider can create signs with other content, for internal use, suitable to the nature of the work:

Figure 52: Some typical warning signs

5.2 Safety during working on the roof

RTS O&M workers must often work on roofs, facing many dangers and potential risks. To ensure workers' safety, compliance with safety regulations and principles when working at height is extremely important.

According to Circular 06/2020/TT-BLDTBXH, working at height is one of 32 especially dangerous occupations. Therefore, it is necessary to strictly comply with labour safety regulations. This specifically includes the following: Decree 44/2016/ND-CP; Circular 16/2021/TT-BXD (Section 2.7: Working at height), QCVN 23:2014/BLDTBXH (Section 3.4: Management of belts, equipment and components in personal fall protection systems during use), QCVN 18:2021/BXD (Section 2.19: Working at height and on roofs).

Figure 53: Workers are fully equipped with safety belts when working on a roof

5.3 Safety during battery storage usage

Batteries are especially dangerous due to the following characteristics:

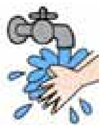
- Acid in lead-acid batteries is corrosive and can cause blindness;
- Lithium-ion batteries contain heavy metals that can cause poisoning;
- When a battery is short-circuited, it will emit a very large current that can cause fire or explosion.

Therefore, O&M operators must be very careful during work. When in direct contact with batteries, please note the following guidelines:

- Fully use labour protection equipment: masks, goggles, rubber gloves, etc.
- Wash hands immediately after any contact with batteries;
- Keep baking soda or bicarbonate of soda readily available to neutralise any acid spills (when using lead-acid batteries);
- Periodically check the condition of batteries when connected to a RTS system or to each other;
- Prior to performing any maintenance or repair tasks, disconnect batteries from the system;
- Utilise appropriate lifting equipment when moving or lifting batteries;
- Always follow the manufacturer's instructions for use;
- Check the temperature of batteries when using Lithium-ion batteries).

Below are some solutions for issues related to batteries:

Table 5: How to address some battery problems

Incidents	How to fix it
Fire or explosion caused by batteries	• Small fires: extinguish fires with fire extinguishers • Large fires: contact 114 immediately  
Spilling or leaking acid from lead-acid battery	• Pour large amounts of acid onto the floor: prevent acid from spilling into other areas with sand, scoop away the sand and put it into the treatment area • Leaking small amount of acid: dilute with water, clean acid area 
Acid and / or electrolyte solutions contact with eyes	Rinse eyes constantly with clean water and go to the nearest medical facility  
Acid and / or electrolyte solutions contact with skin	Wash the skin exposed to acid continuously with clean water and go to the nearest medical facility  
Ingestion of electrolyte solutions	Drink plenty of water to dilute the electrolyte solution and go to the nearest medical facility  

5.4 Fire and explosion safety

5.4.1 Preventive measures

Fires and explosions in RTS systems can stem from a variety of causes, including:

- PV panels are cracked or have localised hot spots, leading to issues in the DC circuit;
- Plugging the positive and negative poles of the DC circuit in reverse or connecting the AC circuit to the wrong phase when repairing causes a short circuit;
- Connections that are poorly contacted, or wires that are cracked or scratched during repair, leading to the appearance of an electrical arc;
- Ground fault, grounding system error.

To minimise the risk of fire and explosion incidents, it is crucial for owners and operators to strictly adhere to state regulations on fire prevention, such as: fire prevention and fighting law, Decree 136/2020/ND-CP, Decree 50/2024/ND-CP, Circular 149/2020/TT-BCA, Circular 32/2024/TT-BCA, QCVN 06:2022/BXD, TCVN 3890:2023, TCVN 5738:2021, TCVN 7336:2003, and other regulations of the current law on fire prevention and fighting in design, installation of rooftop solar systems (letter No. 3288/CP07- P4 dated 08th September 2020).

In a battery room, a "No Fire" sign should be installed at the entrance.

Figure 54: "No Fire" sign

NOTE

Here are some important points to consider for fire protection in RTS systems:

- PV panels and inverters should be installed in a spacious area, separate from other machinery and equipment;
- PV panels must not be installed on flammable objects (classified as fire and explosion hazard classes A and B);
- Allow the use of fire alarms integrated with remote control and monitoring systems (SCADA);
- All RTS systems must be equipped with an emergency stop device which should be located near the inverter and switchgear, along with emergency stop procedures clearly displayed;
- A layout diagram of the PV panels and a system connection diagram should be displayed in the roof area, as these will be useful for disconnecting PV panels in case of incidents and for fire prevention efforts.

Figure 55: PV panels, inverters and other equipment are burned or exploded

Figure 56: Location of access to the roof and ladder to the roof

5.4.2 Fire response procedure

In the event of a fire, immediately adhere to the following steps:

1. Upon detecting a fire, sound the alarm and alert nearby individuals to evacuate to a safe location;
2. Disconnect the RTS system to prevent the fire from spreading. This can be done by pressing the emergency stop button located at the ACDB cabinet and inverter, or by turning off the ACB main circuit breaker;
3. Use a Class C fire extinguisher or a carbon dioxide (CO2) fire extinguisher to put out the fire;
4. If the fire cannot be controlled, contact the Fire Department by dialing 114.

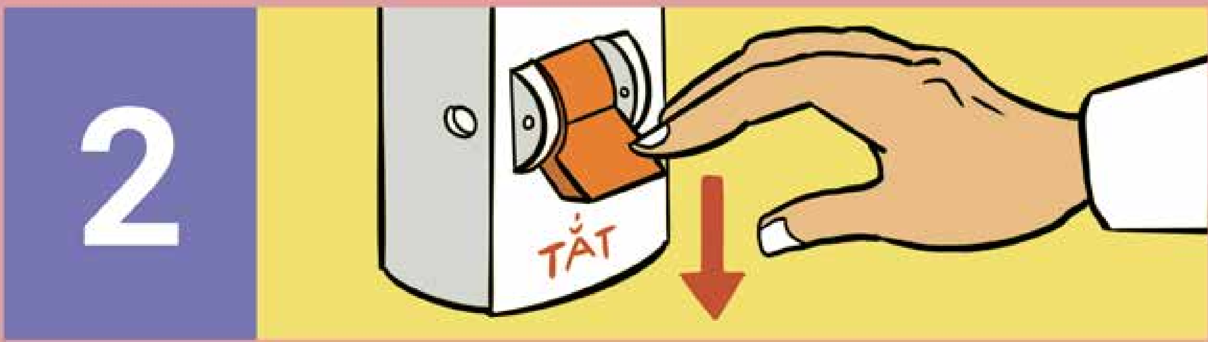
WARNING

DO NOT use a water-based fire extinguisher as it may lead to electric shock.

Figure 57: Instructions for using a portable fire extinguisher

Fire Actions

- **Alarm:** Alert others by shouting, activating the fire alarm, etc.



- **Turn of the power**

- **Use initial fire-fighting equipment:** buckets, blankets, fire extinguishers, wall fire hydrants, etc.

- **Call 141 for report on fire**

Figure 58: Procedures when discovering a fire

5.5 Measures for responding to natural disasters

As a country heavily impacted by climate change, Viet Nam experiences various types of natural disasters annually (such as storms, floods, landslides, strong winds, etc.) with increasing intensity, frequency, and severity, causing significant damage to people and property. These can seriously affect the outdoor equipment of RTS systems. Therefore, implementing measures to mitigate weather-related damages and ensure safe, efficient operation and extended equipment lifespan is essential.


Figure 59: PV panels were cracked and clamps were broken after a storm

5.5.1 Design and installation for disaster resistance

- **Selecting quality equipment and materials**: To ensure RTS systems can withstand harsh weather, selecting standard-compliant materials is crucial. PV panels should have high durability, particularly against impact from flying debris during strong winds or storms.
- **Sturdy mounting structures**: Mounting structures for PV panels must be robustly designed to withstand strong winds. Aluminum alloy frames with anodized finishes are recommended to minimise corrosion in humid or saline environments.
- **Safe installation**: Ensure PV panels are securely attached to the roof. For sheet metal or tile roofs, PV panels should be fixed to the purlins. Bolts must be tightened with sufficient torque (16–20 N·m) to prevent PV panels and structures from shifting.


Figure 60: Torque test

5.5.2 Equipment and material preparedness

- Store flashlights, backup generators, and basic repair tools to respond to power outages
- Prepare materials like tarps, ropes, and weights to reinforce areas when necessary
- Maintain spare parts in storage for quick replacement after disasters
- Stockpile essential items such as drinking water, medicine, and emergency supplies to prepare for disruptions in transportation or power outages caused by natural disasters.

5.5.3 Preventive measures

1. **Weather monitoring:** Regularly update weather information and disaster warnings to develop preventive plans that minimise risks to assets and operations.
2. **Inspection and reinforcement before disasters:**
    - ***For mounting structures:*** Additional guy wires can be installed to secure the system further and straps can be used to stabilise mounting structures, walkways, and cable trays, especially in areas prone to strong winds.
    - ***For solar panels:*** Check the connections and cables to ensure they are not loose or damaged.
    - ***For inverter stations:*** Check ventilation systems and areas vulnerable to rainwater penetration and, if necessary, use waterproofing materials such as tarps. In cases of heavy rain or flooding warnings, relocate critical electronic equipment (e.g., computers, control cabinets, electrical devices, and important documents) to higher, dry areas. Inspect the roof of the inverter station and take necessary measures based on the situation.
    - ***For electrical system:*** To ensure safety, shut down the entire RTS system (both DC and AC sides) before a storm or upon receiving disaster warnings. Inspect ACDB cabinets and connection systems. Ensure all outdoor elec-trical cabinets are well-sealed and properly shielded.
3. **Safety notifications:** Notify all staff within the system operation area before a storm to implement appropriate response measures.

[6] Follow the notifications on the website of the National Center for Hydro-Meteorological Forecasting: https://kttv.gov.vn/Kttvsite/vi-VN/1/index.html

Figure 61: Reinforced with additional end clamps and MC4 connector tie-downs

5.5.4 Measures during natural disasters

- Do not perform any repairs or adjustments during storms or floods
- Keep doors and windows securely closed. Reinforce with weights if necessary. Operational personnel must remain in safe areas and avoid standing near solar panels or inverter stations during storms to prevent accidents caused by strong winds or heavy rain.
- Be prepared for evacuation if ordered by authorities or if conditions become dangerous.

5.5.5 Post-disaster recovery measures

1. **System inspection:**
    - As soon as site conditions allow, conduct a comprehensive inspection of all ma-terials and equipment in the RTS system;
    - If any PV panels are displaced or damaged, or if electrical equipment is affected, inspect and create a list to plan for repairs or replacements.
2. **Clean up and remediate the consequences:**
    - Remove debris, fallen trees, and wind-blown objects that may affect the opera-tion of PV panels and inverters;
    - Repair or replace damaged materials and equipment.
3. **Restoration of operation:**
    - Inspect the condition of inverters and electrical systems. Ensure no water has infiltrated the inverters or electrical cabinets. If water or moisture is detected, thoroughly dry the affected areas before restarting;
    - Check the air conditioning or ventilation systems in the inverter station to ensure they are functioning properly;
    - Once electrical cabinets are confirmed to be safe, with no signs of short circuits or damage, restore power to the entire system. Restart the RTS system only af-ter completing all inspections, following the standard startup-shutdown procedures.

Chapter 06

APPENDICES

Appendices

Appendix 1: Legal documents, applicable standards and regulations

Table 6: Legal documents

No.	Document	Issued by	Date of issue	Content
1	Decree 44/2016/NĐ-CP	Government	15/May/2016	Details some articles of the law on occupational safety and sanitation, technical inspection of occupational safety, training of occupational safety and sanitation and monitoring of occupational envir
2	Decree 140/2018/NĐ-CP	Government	08/Oct/2018	Amends and supplements the decree 44/2016/NĐ-CP
3	Decree 136/2020/NĐ-CP	Government	24/Nov/2020	Details some articles and measures to implement the Law on Fire Prevention and Fighting and the Law Amending and Supplementing a Number of Articles of the Law on Fire Prevention and Fighting
4	Decree 50/2024/NĐ-CP	Government	10/May/2024	Amend the decree 136/2020/NĐ-CP
5	Decree 135/2024/NĐ-CP	Government	22/Oct/2024	Regulating mechanisms and policies to encourage the development of self-production and self-consumption rooftop solar power
6	Decision 19/2006/QĐ-BCN	Ministry of Industry	11/Jul/2006	Code on Electric Facility
7	Circular 04/2011/TT-BCT	Ministry of Industry and Trade	16/Feb/2011	Regulating national technical standards on electrical engineering
8	Circular 23/2013/TT-BKHCN	Ministry of Science and Technology	26/Sept/2013	Group 2 measuring instruments

No.	Document	Issued by	Date of issue	Content
9	Circular 28/2014/TT-BCT	Ministry of Industry and Trade	15/Sept/2014	Regulating the process of troubleshooting in the national power system
10	Circular 44/2014/TT-BCT	Ministry of Industry and Trade	28/Nov/2014	Regulating operating procedures for the national electricity system
11	Circular 33/2015/TT-BCT	Ministry of Industry and Trade	27/Oct/2015	Regulating technical safety inspection for electrical appliances and tools
12	Circular 39/2015/TT-BCT	Ministry of Industry and Trade	18/Nov/2015	Regulating electricity distribution system
13	Circular 42/2015/TT-BCT	Ministry of Industry and Trade	01/Dec/2015	Regulating electrical measurement in electricity system
14	Circular 07/2019/TT-BKHCN	Ministry of Science and Technology	26/Jul/2019	Amends and supplements circular 23/2013/TT-BKHCN on measurement of group 2 measuring instrument
15	Circular 30/2019/TT-BCT	Ministry of Industry and Trade	18/Nov/2019	Amends and supplements some articles of Circular 25/2016/TT-BCT and Circular 39/2015/TT-BCT
16	Circular 39/2020/TT-BCT	Ministry of Industry and Trade	30/Nov/2020	Promulgating the National technical regulations on electrical safety
17	Circular 06/2020/TT-BLĐTBXH	Ministry of Labor, War Invalids and Social Affairs	20/Aug/2020	Promulgation of list of occupations bound by strict requirements for occupational safety and health
18	Circular 149/2020/TT-BCA	Ministry of Public Security	31/Dec/2020	Details some articles guidelines for Law on Fire Prevention and Fighting and Law amending and adding a number of articles of the Law on Fire Prevention and Fighting and Decree 136/2020/NĐ-CP

No.	Document	Issued by	Date of issue	Content
19	Circular 05/2021/TT-BCT	Ministry of Industry and Trade	02/08/2021	Elaborating some content on electrical safety
20	Circular 16/2021/TT-BXD	Ministry of Construction	20/12/2021	QCVN 18:2021/BXD National technical regulation on safety in construction
21	Circular 06/2022/TT-BXD	Ministry of Construction	30/11/2022	QCVN 06:2022/BXD National technical regulation on fire safety of buildings and constructions
22	Circular 39/2022/TT-BCT	Ministry of Industry and Trade	30/12/2022	Amending and supplementing a number of articles of Circular 25/2016/TT-BCT, Circular 39/2015/TT-BCT and Circular 30/2019/TT-BCT
23	Circular 09/2023/TT-BXD	Ministry of Construction	16/10/2023	Amendment 1:2023 of QCVN 06:2022/BXD on national technical regulation on fire safety of buildings and construction
24	Circular 32/2024/TT-BCA	Ministry of Public Security	10/07/2024	Amending Circular 149/2020/TT-BCA and Circular 08/2018/TT-BCA
25	Circular 12/2024/TT-BCT	Ministry of Industry and Trade	01/08/2024	Amending and supplementing a number of Circulars of the Minister of Industry and Trade concerning the load dispatch and operation of the national power system and the electricity market
26	Letter 2075/C07-P4	Police Department of Fire Prevention and Fighting and Rescue	09/08/2022	Guidance on design appraisal and testing of fire prevention and fighting
27	Letter 98/C07-P4	Police Department of Fire Prevention and Fighting and Rescue	12/01/2023	Guidance on some contents of applying QCVN 06:2022/BXD

Table 7: Standards and regulations

No.	Viet Nam Standard	Equivalent International Standard	Content
1	QCVN 23:2014/ BLĐTBXH	-	National code on personal fall protection systems
2	QCVN 01:2020/BCT	-	National code on electrical safety
3	QCVN 18:2021/BXD	-	National code on safety in construction
4	TCVN 6783:2000	-	Cells and batteries for photovoltaic energy systems - General requirements and testing methods
5	TCVN 9358:2012	-	Installation of equipment grounding system for industrial projects - General requirements
6	TCVN 9358:2012	-	Lightning protection for construction works - Guide to design, inspection and maintenance of systems
7	TCVN 10896:2015	IEC 61646:2008	Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval
8	TCVN 6781-1:2017	IEC 61215-1:2016	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements
9	TCVN 6781-1-1:2017	IEC 61215-1-1:2016	TTerrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules
10	TCVN 6781-2:2017	IEC 61215-2:2016	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures
11	TCVN 11855-1:2017	IEC 62446-1 (2016-01)	Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection
12	TCVN 12230:2019	IEC TS 62910:2015	Utility-interconnected photovoltaic inverters - Test procedure for low voltage ride-through measurements

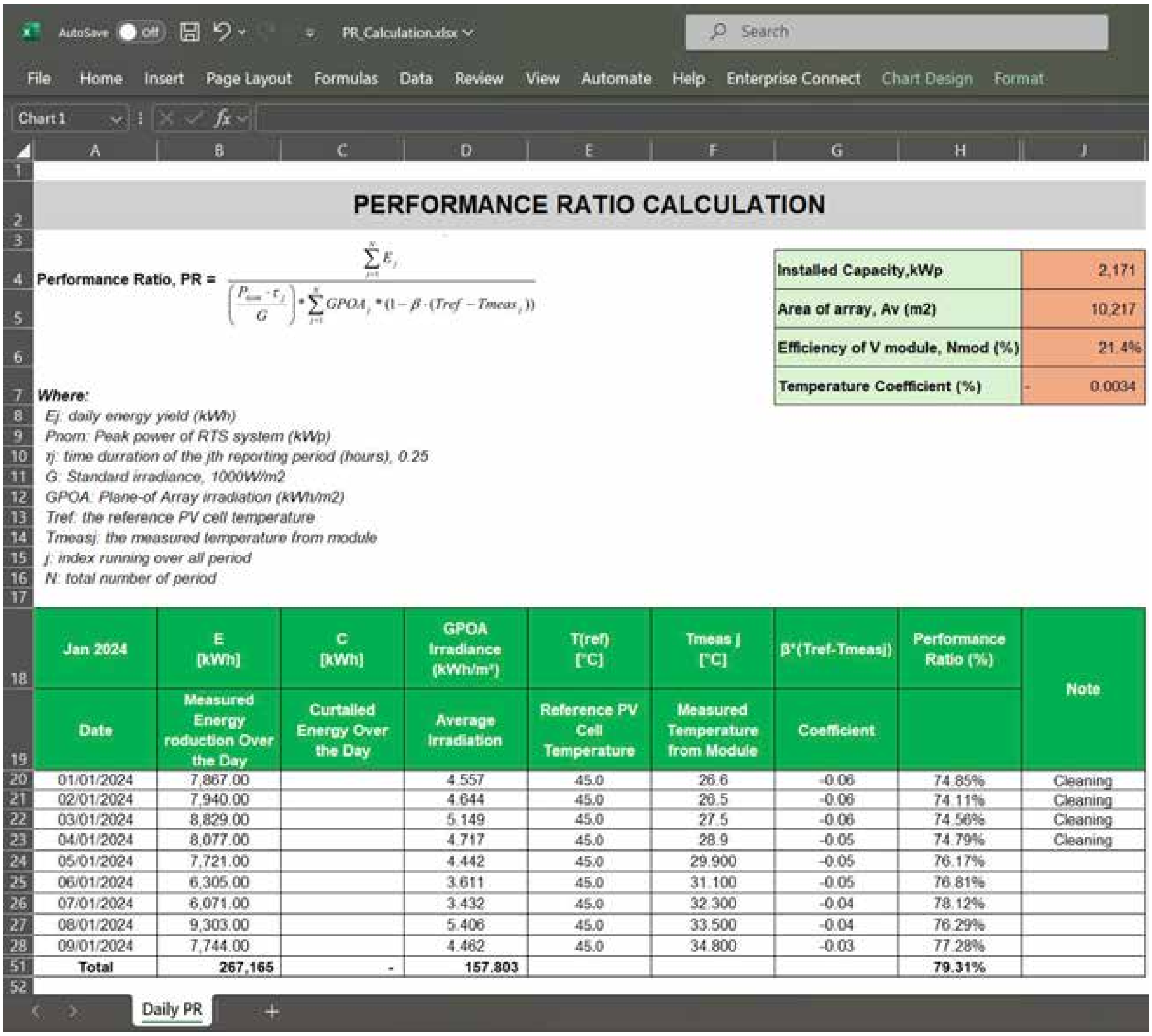
No.	Viet Nam Standard	Equivalent International Standard	Content
13	TCVN 12231-1:2019	IEC 62109-1:2010	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements
14	TCVN 12231-2:2019	IEC 62109-2:2011	Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters
15	TCVN 12232-1:2019	IEC 61730-1:2016	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction
16	TCVN 12232-2:2019	IEC 61730-2:2016	Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing
17	TCVN 7447-7-712:2019	IEC 60364-7-712:2017	Low voltage electrical installations - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems
18	TCVN 12718:2019	IEC 62852:2014	Connectors for DC-application in photovoltaic systems - Safety requirements and tests
19	TCVN 12672:2019	IEC 62930:2017	Electric cables for photovoltaic systems with a voltage rating of 1,5 kV DC
20	TCVN 12673:2020	IEC 62894:2016	Photovoltaic inverters - Data sheet and name plate
21	TCVN 12674:2020	IEC 61683:1999	Photovoltaic systems - Power conditioners - Procedure for measuring efficiency
22	TCVN 12675:2020	IEC 62790:2014	Junction boxes for photovoltaic modules - Safety requirements and tests
23	TCVN 12676:2020	IEC 62548:2016	Photovoltaic (PV) arrays - Design requirements
24	TCVN 12677:2020	IEC 61829:2015	Photovoltaic (PV) array - On-site measurement of current-voltage characteristics
25	TCVN 12678-1:2020	IEC 60904-1:2006	Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics

No.	Viet Nam Standard	Equivalent international standards	Content
26	TCVN 12678-1-1:2020	IEC 60904-1-1:2017	Photovoltaic devices - Part 1-1: Measurement of current-voltage characteristics of multi-junction photovoltaic (PV) devices
27	TCVN 12678-2:2020	IEC 60904-2:2015	Photovoltaic devices - Part 2: Requirements for photovoltaic reference devices
28	TCVN 12678-3:2020	IEC 60904-3:2016	Photovoltaic devices - Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data
29	TCVN 12678-4:2020	IEC 60904-4:2009	Photovoltaic devices - Part 4: Reference solar devices - Procedures for establishing calibration traceability
30	TCVN 12678-5:2020	IEC 60904-5:2011	Photovoltaic devices - Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method
31	TCVN 12678-7:2020	IEC 60904-7:2008	Photovoltaic devices - Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices
32	TCVN 12678-8:2020	IEC 60904-8:2014	Photovoltaic devices - Part 8: Measurement of spectral responsivity of a photovoltaic (PV) device
33	TCVN 12678-8-1:2020	IEC 60904-8-1:2017	Photovoltaic devices - Part 8-1: Measurement of spectral responsivity of multi-junction photovoltaic (PV) devices
34	TCVN 12678-9:2020	IEC 60904-9:2007	Photovoltaic devices - Part 9: Solar simulator performance requirements
35	TCVN 12678-10:2020	IEC 60904-10:2009	Photovoltaic devices - Part 10: Methods of linearity measurement
36	TCVN 13083-1:2020	IEC 61724-1:2017	Photovoltaic system performance - Part 1: Monitoring
37	TCVN 13083-2:2020	IEC TS 61724-2:2016	Photovoltaic system performance - Part 2: Capacity evaluation method

No.	Viet Nam Standard	Equivalent international standards	Content
38	TCVN 13083-3:2020	IEC TS 61724-3:2016	Photovoltaic system performance - Part 3: Energy evaluation method
39	TCVN 6781-1-2:2020	IEC 61215-1-2:2016	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules
40	TCVN 6781-1-3:2020	IEC 61215-1-3:2016	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules
41	TCVN 6781-1-4:2020	IEC 61215-1-4:2016	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu(In,GA)(S,Se)2 based photovoltaic (PV) modules
42	TCVN 13084-1:2020	IEC 62805-1:2017	Method for measuring photovoltaic (PV) glass - Part 1: Measurement of total haze and spectral distribution of haze
43	TCVN 13084-2:2020	IEC 62805-2:2017	Method for measuring photovoltaic (PV) glass - Part 2: Measurement of transmittance and reflectance
44	TCVN 8251:2021	-	Solar Water Heating equipment – Technical Requirements and Testing Methods
45	TCVN 5738: 2021	-	Fire prevention and fighting - Fire prevention and fighting equipment for houses and works - Equipment, arrangement
46	TCVN 7336 : 2021	-	Fire prevention and fighting – Fire Alarm System – Technical Requirements
47	TCVN 3890:2023	-	Fire prevention and fighting– Automatic fire extinguishing system with water and foam

Appendix 2: Performance ratio calculation

Refer to the MS Excel file for performance ratio (PR) calculation.



PERFORMANCE RATIO CALCULATION

Performance Ratio, PR = $$\frac{\sum_{j=1}^{N} E_j}{\left(\frac{P_{nom} \cdot \tau_j}{G}\right) * \sum_{j=1}^{N} GPOA_j * (1 - \beta \cdot (Tref - Tmeas_j))}$$

Installed Capacity,kWp	2,171
Area of array, Av (m2)	10,217
Efficiency of V module, Nmod (%)	21.4%
Temperature Coefficient (%)	- 0.0034

Where:

Ej: daily energy yield (kWh)

Pnom: Peak power of RTS system (kWp)

τj: time durration of the jth reporting period (hours), 0.25

G: Standard irradiance, 1000W/m2

GPOA: Plane-of Array irradiation (kWh/m2)

Tref: the reference PV cell temperature

Tmeasj: the measured temperature from module

j: index running over all period

N: total number of period

Jan 2024	E [kWh]	C [kWh]	GPOA Irradiance (kWh/m²)	T(ref) [°C]	Tmeas j [°C]	β*(Tref-Tmeasj)	Performance Ratio (%)	Note
Date	Measured Energy roduction Over the Day	Curtailed Energy Over the Day	Average Irradiation	Reference PV Cell Temperature	Measured Temperature from Module	Coefficient		
01/01/2024	7,867.00		4.557	45.0	26.6	-0.06	74.85%	Cleaning
02/01/2024	7,940.00		4.644	45.0	26.5	-0.06	74.11%	Cleaning
03/01/2024	8,829.00		5.149	45.0	27.5	-0.06	74.56%	Cleaning
04/01/2024	8,077.00		4.717	45.0	28.9	-0.05	74.79%	Cleaning
05/01/2024	7,721.00		4.442	45.0	29.900	-0.05	76.17%	
06/01/2024	6,305.00		3.611	45.0	31.100	-0.05	76.81%	
07/01/2024	6,071.00		3.432	45.0	32.300	-0.04	78.12%	
08/01/2024	9,303.00		5.406	45.0	33.500	-0.04	76.29%	
09/01/2024	7,744.00		4.462	45.0	34.800	-0.03	77.28%	
Total	**267,165**	**-**	**157.803**				**79.31%**	

Figure 62: PR calculation tool on Excel

Appendix 3: Spare part management

Due to the varying scale, configuration, and operating conditions of RTS systems, the quantity of spare parts to keep in inventory differs for each system. However, for commercial and industrial RTS systems (above 100 kW), it is generally recommended to maintain a spare parts inventory of 1% of the quantity of installed equipment (with a minimum of one unit per type of equipment). For smaller RTS systems (below 100 kW), maintaining a spare parts inventory is not necessary.

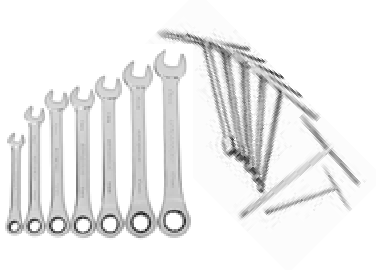
The table below suggests a list of spare parts to stock for a typical 1MW RTS system:

Table 8: Recommended spare parts list for 1MW system

No.	Category	Amount	Unit
1	Inverter	1	Piece
2	PV panel	10	Piece
3	L-bracket	10	Piece
4	End clamp	30	Piece
5	Middle clamp	30	Piece
6	Grounding plate	30	Piece
7	4/6 mm^2 DC cable (black)	100	m
8	4/6 mm^2 DC cable (red)	100	m
9	35 mm^2 DC cable (black)	200	m
10	50 mm^2 DC cable (red)	300	m
11	MC4 male connector	10	Piece
12	MC4 female connector	10	Piece

Appendix 4: Common tools and equipment for maintenance

 Protective boots	 Protective helmet	 Insulated gloves
 Safety belt and reflective vest	 Clamp meter	 Insulation resistance meter
 Thermal drone	 Thermal scanning camera	 Contact resistance meter
 Electric tester	 Electric pliers	 Lifeline
 Bake screwdriver	 Electric cutting pliers	 Hexagon set

 Cleaning brush	 Multi-purpose solar tool kit	 Industrial rags
 Wrench	 Pressure pump	 Pressure pump line
 Electric roller	 Rotating mop	 Robot mop

Appendix 5: Preventive maintenance frequency

Table 9: Preventive maintenance frequency[5]

Category	Activity	Description	Frequency	Note
PV panels	Inspection	Determine dust level, new obstructions (like tree growth), or leaves covering the surface	Monthly	
		Inspect junction boxes, check for any signs of wear or damage, such as loose connections or moisture ingress.	Semi- annually	
		Perform thermal imaging to check local hotspots (for systems > 100 kW)	Semi-annually	Use an infrared thermal imaging camera/drone
		Inspect the PV panels for any damage	Annually	Record the location and serial number of the damaged PV panels
	Cleaning	Clean bird nests, bird droppings, leaves, etc.	Every 3-6 months or according to on-site conditions	Do not use brushes or any solvents, abrasives, or harsh detergents
		Clean surface dust with clean water or water with a mild detergent		
Mounting structures	Inspection	Visually check stability and hardness, ensure their integrity	Quarterly	Fix and tighten mounting rails, bolts, and clamps between the PV panel and the bracket frame
		Verify Alignment: Ensure all bracket frames and mounts are properly aligned to avoid stress on the panels	Semi-annually	

[5] Depending on the actual operation of the RTS system, this list can be adjusted and supplemented

Category	Activity	Description	Frequency	Note
Mounting structures	Inspection	Corrosion Testing	Every two years	
Inverters	Inspection	Observe the instantaneous operating indicators on the face of the inverter to ensure there are no abnormalities in the display parameters as well as the generated power output	Quarterly	
		Perform thermal imaging to check the electrical connection	Quarterly	Use an infrared thermal imaging camera
		Check for insect infestation	Weekly	
		Check the area where the inverter is located	Weekly	
	Update firmware	Ensure the inverter's firmware is up to date for optimal performance and security	Monthly	
	Cleaning	Clean the air filter	Monthly	Replace the air filter if necessary
Storage device (if applicable)	Inspection	Check if carbon buildup is detected on the battery terminals	Monthly	If found, clean the terminals
	Track	Ensure the BMS is functioning correctly and update if necessary	Monthly	
		Measure the voltage of different types of batteries according to their thresholds	Monthly	
		Record and store battery state of charge (SoC) parameters	Annually	

Category	Activity	Description	Frequency	Note
AC distribution board	Inspection	Check the cabinet for corrosion, water infiltration or insect infestation	Quarterly	
		Regularly check switches and circuit breakers for tripping or wear	Quarterly	
		Measurement of input and output voltage/current	Quarterly	
		Check if there are any loose connections	Quarterly	
	Protective equipment inspection	Verify that surge protectors are functioning correctly and replace if needed	Semi- annually	
		Check whether the fuse is intact and working well	Quarterly	
		Operation of the leakage current protection device (RCD) (if applicable)	Quarterly	
		Operation of isolators of PV strings and emergency stop devices (if applicable)	Quarterly	
Grounding system	Inspection	Check the safety grounding system, lightning protection grounding is working properly	Annually	
		Check the tightness of the joints	Annually	
		Check for corrosion of ground wire	Annually	
	Measuring	Measure ground resistance	Annually	Record and confirm the value is within acceptable limits

Category	Activity	Description	Frequency	Note
AC/DC cable	Inspection	Inspect the cable for signs of cracks, damage, loose connections, hot, arcs, short circuits, or open circuits, and ground faults	Semi-annually	
		Perform thermal imaging to check electrical connections	Semi-annually	Use an Infrared Camera
Metering system	Inspection and Confirmation	Monitori and check on-site metering data, confirmmeter readings with the power company	Monthly or at the request of the power company	Ensure the meter is in operation and records output equivalent to the output recorded through the management system.
Management and monitoring system	Supervision	Monitor daily performance and operations	Daily	
	Update software	Ensure the management system software is up to date	Semi-annually	
Spare parts	Management	Component inventory management	As needed	
Operation log	Taking notes	Record all O&M activities in an operation logbook	Ongoing, as activities take place	
General system	Check for wildlife issues	Inspect the system for any signs of wildlife interference or damage.	Monthly	
	Inspect site conditions	Regularly assess the site for changes in conditions that could affect system performance, such as new shading or debris buildup	Monthly	

Appendix 6: Troubleshooting common issues

Table 10: Troubleshooting common issues

No.	Issue	Cause	How to handle
I	**Inverters**		
1	The inverter is not turned ON	Faulty power switch?	Take it to a service centre for repair
		Inverter disconnected?	Close the DC switch
2	Inverter shuts down intermittently	Overvoltage or undervoltage conditions	Check the input voltage and current, ensure the inverter is configured to handle local voltage conditions, and update firmware if necessary
3	Inverter displays fault codes	Communication issues with sensors	Verify connections to sensors and modules, consult the inverter's manual to interpret fault codes, and perform recommended troubleshooting steps
4	Power output is very different from the previous periodic inspection	Low solar irradiation for a long time	If the system has a weather monitor, record all system output and irradiance data to calculate and compare performance
		Fuse blown, switch jumped or wire broken	Use a voltmeter and multimeter to test and record the inverter's operating input voltage and current level on the DC side and check the voltage and current level on the AC side
5	Non-stop alarm sounds	Overload error	Disconnect the load
		Cooling fan stuck	Clean the cooling fan and, if the problem persists, disconnect the inverter for maintenance and repair.
6	Inverters make noise	The sound of the wind	This is normal - no action is required
		Humming noise produced by harmonics	This is normal - no action required
		Too much noise from the fan	Clean the fan Vacuum the inverter cleaner Check for defective fans If the problem persists, disconnect the inverter for maintenance and repair

No.	Issue	Cause	How to handle
7	Inconsistent data from monitoring system	Communication issues with monitoring equipment	Check connections and configurations of monitoring equipment and ensure firmware and software are up-to-date
II	**PV panels**		
1	The RTS system does not work (no current and output voltage)	The connection point is loose and rusty, causing disconnect	Reconnect Replace the connection equipment
		PV panels are damaged and cracked	Replace PV panels but also find the root cause of the PV panel damage/failure and solve the problem
		Improper installation, connection	Check the installation diagram and connection method and then reinstall and/or reconnect.
2	PV panels have a voltage difference, but no current	The PV panel is defective due to its manufacture	Replace the PV panel with a new one
3	Delamination or bubbling on panels	Poor quality materials or manufacturing defects	Inspect panels for physical damage If delamination is observed, contact the manufacturer for warranty claims or replacement options.
4	Hot spots on panels	Dust or debris causing localised heating	Clean the panels to remove dust and debris Inspect for damaged or defective cells and replace affected panels
5	Water ingress in panels	Poor sealing or damage to panel housing	Inspect panels for damage or poor sealing Ensure proper installation to prevent water ingress Replace any damaged panels
6	PV strings operate with unusually low efficiency	PV panels are dirty due to dust or the impact of animals, or the panel surface is obscured by plants, etc.	Clean PV panels and/or clear the surrounding bushes and trees

No.	Issue	Cause	How to handle
7	The RTS system always operates with low efficiency	The PV panel is defective due to its manufacture	Replace the PV panel with a new one
		Improper installation	Adjust the installation orientation so the PV panels receive the most irradiation from the sun.
8	Electrified aluminum frame	The PV cells are separated and the circuit is exposed to create a path to the edges of the PV panel	Replace the PV panel with a new one
9	Fire in the junction box	Poor connection	Replace the junction box or PV panel with a new one

Appendix 7: Effective cleaning of PV panels

The most common method of cleaning PV panels is to use clean water. However, in the areas with a lot of dust or heavily polluted areas such as at chemical, steel, or cement factories and construction areas, using water is not enough to ensure cleanliness.

PV panels are coated with an anti-reflective coating on the surface of the glass, which reduces reflection and increases the ability of sunlight to pass through the glass. However, the anti-reflective coating material used is a nano-material with a size of only about 10-30 nm, so it can be easily damaged if the surface of PV panels is not treated and cleaned properly.

Therefore, for PV panels with dust which is difficult to clean such as oil, iron dust, cement dust, etc., it essential to use special, biodegradable cleaning chemicals. These will increase cleaning effectiveness and ensure the electrical output efficiency of the panels is maintained.

However, other core components of PV panels, such as aluminum frames and rubber edges, are materials that are sensitive to acids or alkalis, which can cause corrosion over time or irreversible degradation if used. Therefore, if chemical cleaners and/or cleaning additives with acidic or alkaline properties are used, it is likely to cause damage to PV panels.

Detergents such as soaps are also not recommended due to their alkaline nature. They can leave a thin film on the surface if not washed off properly, affecting the ability of PV panels to absorb sunlight and speeding up dust accumulation.
Experiments have also shown that many chemical cleaners on the market, even when used at the recommended application concentrations, also damage PV panel components, notably the anti-reflective coating on the surface[6].

In addition, without a plan to collect wastewater after cleaning, the use of cleaning chemicals that are harmful to the environment risks polluting water and soil in the area.

Figure 63: Wastewater from the PV panel cleaning process

[6] According to a study by the Fraunhofer Institute on the microstructure of materials and IMWS systems (How cleaning agents can damage photovoltaic modules - Fraunhofer IMWS)

Therefore, to clean PV panels that are dirty and difficult to clean, it is necessary to use appropriate biodegradable chemical cleaners. These will ensure the safety and endurance of PV panel components as well as protecti the environment. Accordingly, material-friendly, highly efficient and biodegradable cleaners can be used or mixed with clean water (at the right ratio) to clean PV panel surfaces.

Figure 64: PV panels being cleaned with a biodegradable cleaning chemical[7]

Figure 65: Dust accumulation rates reduce significantly when the PV panels are cleaned with a biodegradable cleaning chemical

[7] Results from the use of Rivolta P.H.C. biodetergent | https://www.bremer-leguil.de/en/branche/photovoltaic

Appendix 8: Maintenance checklist

Table 11: Maintenance checklist

No.	Maintenance checklist	Requirements	Result		Notes
			Pass	Fail	
I	**Environmental condition inspection**				
1	Check the waterproofing at the sites of mounting structures linked to the roof/floor	Make sure the roof is not leaking			
2	Check the shade surrounding the system	Make sure PV panels are unshaded or shaded strings have been connected separately			
3	Check the irradiation sensor and environmental sensor (if applicable)	Make sure the sensors are installed securely and are not shaded and or covered by dust			
II	**Measurement of operation parameters**				
1	Measurement of insulation resistance, open-circuit voltage (Voc), maximum power point voltage (Vmpp), maximum power point current (Impp) and short-circuit current (Isc) of PV strings	Record and make notes Analysis of I-V characteristics of PV panels.			
2	Measure phase voltage (Up), wire voltage (Ud), working current (Ib), power of inverters	Record and make notes			
III	**PV panels inspection**				
1	Inspect PV panels both visually and with an infrared thermal imaging camera	Ensure that no PV panels are defective (hotspots, layer separation, cracks, breakage, discoloration, etc.)			
2	Inspect the connections of PV panels	No burning of MC4 connectors between PV panels			
3	Remove leaves, trash.... on the surface of PV panels	Make sure there are no leaves or trash on the surface of PV panel			
4	Inspect the connection between the PV strings and the inverter with an infrared thermal imaging camera	Ensure good contact			

No.	Maintenance checklist	Requirements	Result		Notes
			Pass	Fail	
5	Inspect the dust level and foreign objects on the surface of PV panels	Record information			
6	Inspect PV panel frames	Ensure no rust and corrosion			
7	Inspect the condition of cable trays and racks	Make sure the cable tray is not rusted and the lid is in place			
8	Inspect DC wiring	Make sure the DC wiring is secure and not laying on a roof surface or hanging loosely, and that the wires are not kinked, excessively bent, or stretched over sharp surfaces			
9	Inspect for new obstructions that may affect the system	Record information			
10	Inspect the electrical hose including accessories	Make sure it is secured and not exposed, broken or rusting			
IV	**Mechanical structure inspection**				
1	Inspect the condition of PV mounting structures and inverter support frame	Make sure there is no rust, sagging, deformation, missing or damaged bolts			
2	Inspect the links of PV panels with mounting structures	Make sure the bolts on clamps are tightened and that the clamps are not deformed or rusting			
3	Check roof access, lifeline, protective fence and ladder (if any)	Ensure sturdiness, no rust, no unraveling, no deformation			
V	**Inverter inspection**				
1	Cleaning inverters	Make sure the inverters are not dented/distorted and not subject to dust or dirt			
2	Inspect the appearance of the inverter visually	Make sure the inverter is securely fixed on the wall or ground			
3	Inspect the DC/AC jack	Ensure good contact, no burning			
4	Test shutdown operation on DC side	Make sure the DC switch rotates smoothly			

No.	Maintenance checklist	Requirements	Result		Notes
			Pass	Fail	
5	Inspect the fuses inside inverters (if applicable)	Make sure fuses are not blown			
6	Inspect the grounding of inverters	Ensure grounding is in good connection, not loose			
7	Inspect Surge Protective Devices (SPDs) on DC and AC of inverters	Make sure the SPDs are in good working condition (the indicator color is blue)			
8	Inspect the temperature of inverters	Make sure the temperature is ≤ 60°C			
9	Inspect the cooling fan	Make sure the fan is in good working condition and clean			
10	Check and record the last inverter fault that occurred	Record information			
11	Check the inverter's settings	Make sure the settings are correct and does not reduce the power output of the inverters			
VI	**ACDB inspection**				
1	Inspect the external condition	Ensure that it is not scratched, damaged, or deformed			
2	Clean the ACDB	Make sure the inside and outside are free of dust, cobwebs, etc.			
3	Check for deformation and check the switching operation of ACB/MCCB, protective devices	Ensure the contacts of CBs are not burnt or deformed and that protective devices are working properly			
4	Inspect electric wires and cable quality	Make sure the surface of electric wires and cables are not peeling or burning			
5	Inspect busbar condition	Ensure the busbar is fixed and not burnt, and ensure the integrity of heat shrink			
6	Check the temperature inside the cabinet with an infrared thermal imaging camera	Make sure the temperature ≤ 40°C			
7	Check the wiring connections	Ensure the wiring connections are tight and in good contact			

No.	Maintenance checklist	Requirements	Result		Notes
			Pass	Fail	
8	Check the cosse connectors	Make sure the cosse connectors are pressed tightly and in good contact with the CB terminals			
9	Inspect Surge Protective Devices (SPDs) on DC and AC sides	Make sure the SPDs are in good working condition (the indicator color is blue)			
10	Inspect other devices (phase indicators, power meters, ammeters, voltmeters, etc.)	Make sure the devices are in good working condition			
VII	**Grounding system inspection**				
1	Measure grounding resistance	Make sure the grounding resistance is ≤ 4 Ohm			
2	Inspect the connection of conductors to the grounding yard	Make sure the grounding conductors are securely connected to the main grounding rod of the grounding yard			
3	Check the connections of grounding conductor with the mounting structures, PV panels, and inverters	Make sure the connections are in good electrical contact			
4	Check the cosse connectors	Make sure the cosse connectors are not rusted or loose			
VIII	**Inspection of management and monitoring system**				
1	Inspect the datalogger	Make sure the device connects with all inverters and other measurement devices			
2	Test management and monitoring system	Ensure the system fully displays the information of inverters, other parameters and is stable			
3	Check the network status (wifi, internet, etc.)	Ensure a stable, flicker-free network