

----- RENEWABLE ENERGY TECHNOLOGIES -----

MAINTENANCE IN GES

**Preparation of Training Documents for Installation, Repair and
Storage Systems of Solar Energy Systems Supported by Artificial
Intelligence and Increasing Energy Efficiency**

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It is intended to guide vocational education trainers. It is free for users, cannot be sold. It cannot be duplicated. It will be published as an e-book on the Project Website (<https://ai-solarpower.com/>)

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EXPLANATIONS

AREA	Energy and sustainable energy sources
BRANCH/PROFESSION	
THE NAME OF THE MODULE	MAINTENANCE IN GES
DESCRIPTION OF THE MODULE	The module provides general information on maintenance in GES, which is crucial for ensuring the long-term and efficient operation of solar systems. This module content will cover various aspects of maintenance, including theoretical and practical knowledge, with the aim of familiarizing participants with effective management and maintenance of solar panels. The module will be organized into several main sections.
DURATION	40/32
PRECONDITION	This module does not have any prerequisites.
COMPETENCY	Introduces the basic concepts and facts related to the subject.
PURPOSE OF THE MODULE	<p>General Purpose This module provides general information on maintenance in GES, which is crucial for ensuring the long-term and efficient operation. The module will cover various aspects of maintenance in the GES system, including the components of the GES system, types of maintenance, and maintenance processes within the system.</p> <p>Objectives</p> <ol style="list-style-type: none"> 1. Maintenance in the GES system <ol style="list-style-type: none"> 1.1. Introduction 1.2. Components of the GES system



	<p>1.3. Types of maintenance in the GES system</p> <p>1.4. Maintenance processes in the GES system</p> <p>1.5. Challenges in maintaining the GES system</p> <p>1.6. The role of artificial intelligence in maintaining the GES system</p> <p>1.7. Application of best practices in GES system maintenance</p> <p>1.8. Conclusion</p>
<p>EDUCATIONAL ENVIRONMENTS AND EQUIPMENT</p>	<p>Environment: Renewable energy technologies area, renewable energy systems workshop</p> <p>Equipment: Basic electrical knowledge, basic electronic knowledge</p>
<p>MEASUREMENT AND EVALUATION</p>	<p>At the end of the module, the teacher will evaluate the knowledge and skills acquired in the module applications by using an assessment tool (multiple choice test, true/false test, gap filling, matching etc.).</p>



INTRODUCTION

Dear students,

In the fight against climate change, the reduction of greenhouse gas emissions and pollution, and ensuring a sustainable future for our planet, renewable energy sources are becoming increasingly prevalent. We are currently on the brink of a green revolution.

Through this module, it is important to familiarize yourself with maintenance in the GES system. It is essential to understand the concepts of the GES system in electricity production, as well as the goals and purpose of maintaining the GES system. In this module, you will learn about the components of the GES system, types of maintenance, maintenance processes, challenges in maintaining the GES system, the role of artificial intelligence in the GES system, and practical examples of GES system maintenance.



LEARNING ACTIVITY-5

PURPOSE

Installation, repair and energy supply of artificial intelligence-supported solar energy systems
This module on storage systems will provide participants with innovative energy solutions
aims to gain knowledge and skills in the subject.

RESEARCH

- Artificial Intelligence and Object Tracking Fundamentals
- Object Tracking Algorithms and AI Models
- Real Time Object Tracking Systems
- Challenges Encountered in AI Supported Object Tracking Projects

1 Maintenance in GES

1.1 Introduction

In the last decade, solar energy has become an increasingly important source of renewable energy worldwide. The global demand for clean energy sources has led to the rapid development of solar power plants, including electricity generation systems (GES). Maintaining these systems is crucial for their efficiency, longevity, and economic viability.

1.1.1 What is the GES system

The GES system refers to a system that enables the connection of solar energy to the electrical grid. This includes converting energy from solar panels through inverters, as well as optimizing the production and consumption of electricity.



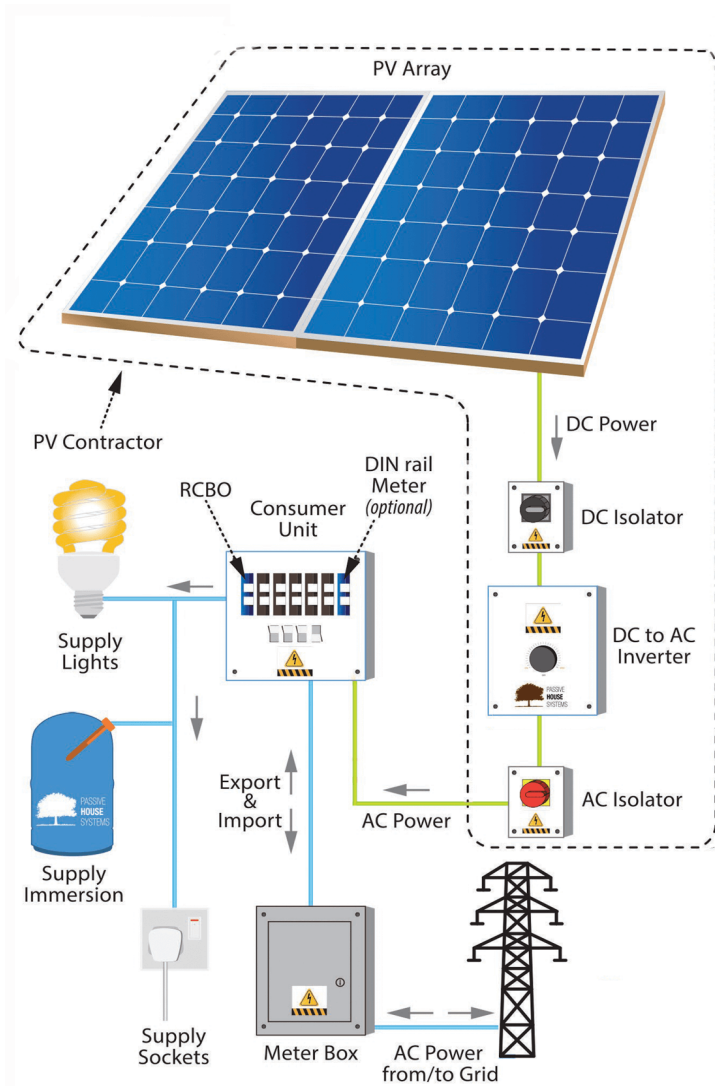


Figure 1: Pv System Schematic Diagram (<https://tinyurl.com/299q8jh4>)

Monitoring and managing the power plant's operation through software solutions, with the possibility of storing excess energy in batteries or sending it to the grid.

1.1.2 The importance of the GES system in electricity production

GES systems, or systems for utilizing renewable energy sources (RES), play a key role in electricity production due to their ability to reduce environmental impact and ensure sustainability. One of the most important advantages of the GES system is its ability to integrate renewable sources such as solar and wind power plants. These sources are essential for reducing greenhouse gas emissions and combating climate change. However, their production often varies depending on weather conditions, which can lead to stability issues in electricity supply and reduce the need for fossil fuels.



The use of GES systems also contributes to the reduction of CO₂ emissions and other pollutants. Electricity production from renewable sources through GES reduces dependency on fossil fuels, thereby contributing to environmental preservation. Furthermore, the infrastructure used for the transmission and storage of renewable energy already exists, which further facilitates the transition to more sustainable sources.

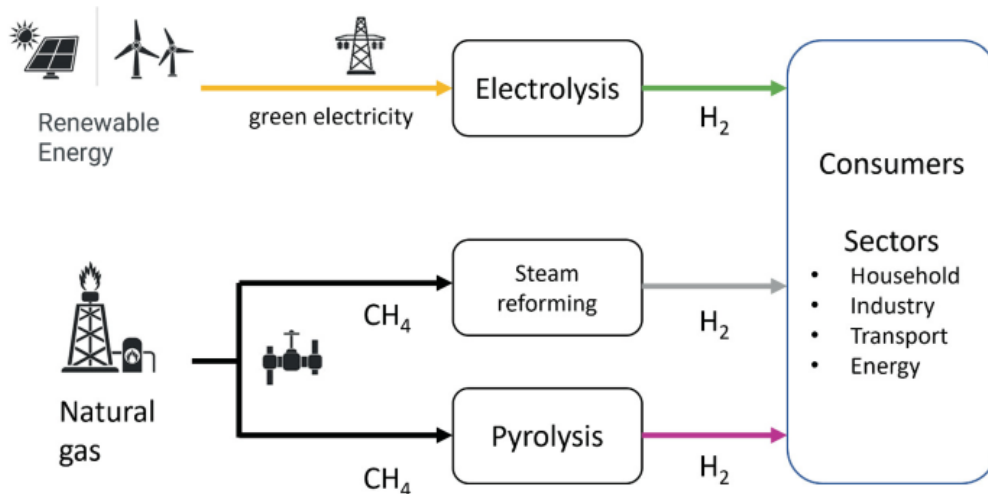


Figure 2: General Energy System (<https://tinyurl.com/2yjxfiza>)

The importance of GES systems in electricity production cannot be underestimated. They not only enable a reliable energy supply but also play a key role in integrating renewable sources, reducing harmful gas emissions, and stimulating economic growth. Given the global challenges related to climate change and energy security, strengthening and modernizing GES systems is becoming increasingly important

1.1.3 The goal and purpose of the GES system

One of the main goals of maintaining GES systems is to ensure the reliability and safety of the electricity supply. Regular maintenance allows for the timely detection and resolution of potential faults, thereby reducing the risk of supply interruptions and increasing the operational safety of the plant. Maintenance includes preventive, corrective, and scheduled activities that ensure the system operates within the specified parameters.

1. Increasing Efficiency

Maintenance of GES systems also aims to increase energy efficiency. Through regular inspections and servicing of equipment, it is possible to optimize system performance, reduce energy losses, and ensure that all parts of the system operate in line with the latest standards. This includes measurements, inspections, and adjustments that can enhance the overall efficiency of the power generation



system.

2. **Extending Equipment Lifespan**

Planned maintenance helps extend the lifespan of equipment within the GES. Through preventive maintenance, parts are replaced or serviced before a failure occurs, thereby reducing the need for costly corrective actions and prolonging the equipment's operational life. This approach not only lowers maintenance costs but also ensures more stable electricity production.

3. **Cost Reduction**

One of the key goals of maintaining GES systems is to reduce overall costs throughout the system's lifecycle. Effective planning and execution of maintenance activities can significantly reduce operational costs, including labor, materials, and equipment replacement costs. Investing in regular maintenance often pays off by reducing unexpected failures and downtimes.

4. **Compliance with Regulations**

Maintenance of GES systems is also crucial for compliance with technical regulations and standards. Regulations regarding technical requirements for power plants specify certain maintenance procedures to ensure safety and the quality of the electricity supply. Adhering to these standards helps avoid legal issues and potential fines.

The goal and purpose of maintaining GES systems include ensuring reliability, increasing efficiency, extending the equipment's lifespan, reducing costs, and complying with regulations. Through a combination of different types of maintenance, such as preventive, corrective, and scheduled maintenance, the optimal functionality of the power generation system is achieved, which is essential for stable electricity supply.

1.2 **Components of the GES system**

The main power generation system consists of several key components that work together to enable the production, transmission, distribution, and consumption of electricity.

1.2.1 **Basic components**

Energy Source

The energy source includes various types of power plants that generate electricity.

- **Thermal energy:** Uses fossil fuels (coal, gas, oil) to produce electricity.
- **Wind power plants:** Convert wind energy into electricity using wind turbines.
- **Solar power plants:** Use solar energy, either through photovoltaic panels or solar thermal systems.
- **Hydropower plants:** Generate energy by utilizing the potential energy of water.

1. **Transmission Network**

The transmission network is a system of power lines and substations that transmit



electricity from the source to end users. This network includes:

- **Power lines:** High-voltage lines that enable the transmission of large amounts of electricity.
- **Substations:** Devices that transform high voltage into lower voltage for safer distribution.

2. Distribution Network

The distribution network ensures that electricity reaches the end users. This network includes:

- **Low-voltage lines:** Lines that carry electricity from substations to homes and businesses.
- **Transformers:** Devices that reduce the voltage for safe use in households.

3. Consumers

Consumers are the end users of electricity.

Households: Use electricity for lighting, heating, cooling, and household appliances.

Industrial users: Use energy to operate machinery and production processes.

4. Control Systems

Control systems are critical for the efficient operation of the GES. They include:

Monitoring and control systems: Technologies that track the operation of the power system and enable quick responses to changes in demand or faults.

Automatic control systems: Systems that optimize the operation of the power system in real-time.

5. Protection Devices

Protection devices safeguard the system from faults and overloads. They include:

Protective relays: Devices that detect abnormalities in the system's operation and disconnect parts of the network to prevent damage.

Fuses and circuit breakers: Devices that break the current circuit in the event of an overload or short circuit.

These components together form a complex and integrated system that ensures a reliable electricity supply, adapting to changes in demand and operating conditions.

1.2.2 The function of each component

Each component of the main power system (GES) has a specific function that contributes to the overall operation of the system.

1. Generation Facilities



- Thermal power plants: Use fossil fuels to generate heat, which is converted into electricity.
- Hydropower plants: Utilize the potential energy of water to generate electricity.
- Wind power plants: Convert the kinetic energy of wind into electricity using wind turbines.
- Solar power plants: Use solar energy to generate electricity through photovoltaic panels or solar thermal systems.
- Nuclear power plants: Use nuclear fission to generate large amounts of energy.

2. Transmission Network

- Transmission lines: Transport electrical energy over long distances, enabling the connection between generation facilities and consumers.
- Substations: Convert high voltage into lower voltage to ensure safer energy distribution.

3. Distribution Network

- Low-voltage power lines: Deliver electricity from substations to end users, including households and businesses.
- Distribution transformer stations: Reduce voltage to match consumer requirements.

4. Consumers

- Households: Use electricity for daily needs such as lighting, heating, and household appliances.
- Industrial users: Utilize energy to power machines and production processes, contributing to the economy.

5. Control Systems

- Monitoring and control systems: Supervise the operation of the power system, enabling timely responses to demand changes or faults.
- Automated management systems: Optimize system operation in real-time, enhancing efficiency and reliability.

6. Protective Devices

- Protection relays: Detect system abnormalities and disconnect parts of the network to prevent damage.
 - Fuses and circuit breakers: Interrupt the electrical circuit in case of overload or short circuit, protecting equipment and infrastructure.
- These components collectively ensure that the GES system operates efficiently and safely, providing a stable electricity supply to all users.

1.2.3 The impact of components on the overall system

Each component of the main power system (GES) plays a crucial role in its overall functioning. The impact of these components can be analysed through various



aspects, including reliability, efficiency, safety, and costs.

1. Power Generation Facility

Impact on Energy Supply: Different types of power plants (thermal, hydro, wind) contribute to energy source diversity and a stable supply. For example, hydroelectric plants can provide rapid responses to changes in demand, while wind farms depend on weather conditions.

Environmental Impact: The use of renewable energy sources reduces greenhouse gas emissions and promotes sustainability.

2. Transmission Network

Impact on Energy Losses: The transmission network is responsible for transporting electricity over long distances, and losses during transmission can significantly affect the overall system efficiency. High voltage reduces losses but requires high-quality transformer stations.

System Stability: Proper sizing and maintenance of the transmission network ensure stability and reliability of the power supply.

3. Distribution Network

Impact on Users: The distribution network directly affects end users. The quality of distribution (e.g., voltage, frequency) can influence the performance of electrical devices.

Flexibility: Modernizing distribution systems allows for better adaptation to demand changes and the integration of renewable energy sources.

4. Consumers

Impact on Demand: Consumers shape the demand for energy, which affects the operation of the entire system. Changes in consumption (e.g., seasonal or daily variations) may require adjustments in production.

Role in Energy Efficiency: Educating consumers about energy efficiency can reduce overall consumption and ease the burden on the system.

5. Control Systems

Impact on Operational Efficiency: Control systems enable monitoring and optimization of GES operations, improving efficiency and reducing costs.

Response to Failures: A quick response from control systems can prevent the spread of failures and ensure system stability.

6. Protection Devices

Impact on Safety: Protection devices safeguard the system from overloads and short circuits, reducing the risk of major failures and ensuring operational safety.

Reducing Downtime: Efficient protection mechanisms reduce system downtime caused by faults.

The impact of GES components on the overall system is multifaceted and complex. Each component contributes to the system's reliability, efficiency, safety, and cost-effectiveness. Therefore, it is crucial to properly design, maintain, and manage all parts of the GES to ensure stable electricity supply and meet user demands.



1.3 Types of maintenance of GES systems

Maintenance of the main power system (GES) can be classified into several basic types, each with different objectives and methods. These types of maintenance ensure that the system operates efficiently, safely, and reliably.

1. Corrective Maintenance

This type of maintenance involves activities that are carried out after a failure or problem occurs in the system. The goal is to quickly address the fault and return the system to a functional state.

Example: Repairing a generator after a technical fault has caused an operational interruption.

2. Preventive Maintenance

Preventive maintenance refers to planned activities carried out regularly, even when the system does not show signs of malfunction. The goal is to prevent the occurrence of failures and extend the equipment's lifespan.

Example: Regular inspections and oil replacement in transformers based on predefined time intervals.

3. Predictive (Condition-Based) Maintenance

This type of maintenance uses technologies to monitor the condition of equipment in order to predict potential failures. Activities are performed based on the actual condition of parts and systems.

Example: Measuring vibration or temperature of motors to determine when maintenance is needed.

4. Scheduled Maintenance

Maintenance that is pre-planned for each system or device, based on time intervals or operational hours.

Example: Replacing parts based on a predefined schedule, such as changing filters or belts after a set number of operating hours.

5. Technical Maintenance

Technical maintenance includes activities such as cleaning, lubrication, oil checks, and inspections that ensure the equipment operates within the defined parameters.

Example: Regular lubrication of moving parts in electrical motors.

Different types of maintenance in a GES system play a key role in ensuring the efficiency, safety, and reliability of the power system. A combination of these maintenance types allows for optimal resource management and reduces costs associated with unplanned downtime and failures.

1.3.1 Preventive maintenance

Preventive maintenance is crucial for ensuring the longevity and reliability of the main electrical power system (GES). This type of maintenance involves a series of planned activities carried out to prevent failures and ensure the optimal functioning of the system.

Preventive maintenance is defined as maintenance performed at predetermined



intervals or according to specified criteria, with the goal of reducing the likelihood of failure or degradation of equipment functionality. Its main objectives include:

- **Reducing the risk of failures:** Regular inspections and servicing of equipment reduce the chances of unexpected failures that could cause disruptions in the power supply.
- **Increasing reliability:** Keeping equipment in optimal condition enhances its reliability during operation, which is crucial for the stability of the power system.
- **Cost planning:** It enables the prediction of maintenance costs, making financial planning and control easier.

Methods of Preventive Maintenance

Preventive maintenance can be performed in several ways:

- **Time-based:** Maintenance is carried out according to predefined intervals (e.g., every 100 hours of operation or once a year).
- **Usage-based:** Maintenance is based on the number of operating hours or cycles of the equipment, allowing the maintenance schedule to be adapted to specific operating conditions.

Advantages

Preventive maintenance offers numerous advantages, including:

- **Extending equipment lifespan:** Regular inspections and the replacement of worn-out parts help preserve the system's functionality and extend its operational life.
- **Cost reduction:** Although the initial costs of preventive maintenance may be higher, over the long term, it saves money by reducing the need for expensive corrective repairs and replacements.
- **Increased safety:** Regular maintenance reduces the risk of accidents caused by equipment failures, ensuring the safety of employees and users.

Disadvantages

Despite its advantages, preventive maintenance also has some drawbacks:

- **Implementation costs:** Introducing a preventive maintenance system may require significant investment in staff training and the acquisition of necessary equipment.
- **Possible inefficiencies:** If activities are not properly planned, there may be excessive or unnecessary maintenance that does not add value.

Preventive maintenance is an essential part of managing the main power system. Through regular inspections, servicing, and timely replacement of parts, it ensures the stability, safety, and efficiency of the system. Although it requires initial investments, the long-term benefits in the form of reduced costs and extended equipment lifespan make it a key element of the maintenance strategy.



1.3.2 Corrective maintenance

Corrective maintenance is a key aspect of managing the main power system (GES). This type of maintenance is performed after a fault or problem occurs in the system, with the aim of restoring the system to full operational capacity.

Corrective maintenance is defined as a set of activities carried out after the system experiences a failure or is not performing its intended function. Its main purpose is to restore the functionality of the equipment and the system to its previous operational level. This type of maintenance can be unpredictable, meaning it often cannot be planned in advance and is therefore considered an emergency intervention.

Corrective Maintenance Process

The corrective maintenance process typically involves several key steps:

1. **Failure Identification:** The first step is to recognize the problem or failure in the system. This may involve visual inspections, diagnostic tools, or user reports.
2. **Cause Analysis:** After identification, it's important to analyse the cause of the failure to prevent its recurrence. This may include reviewing the equipment's operational history and previous interventions.
3. **Repair Execution:** Depending on the nature of the failure, necessary repairs or part replacements are carried out to restore the system to a functional state.
4. **Testing and Verification:** After restoration, the system is tested to ensure it is operating correctly and that all issues have been resolved.
5. **Documentation:** It is crucial to document all steps and results of the corrective maintenance for future reference and analysis.

Advantages of Corrective Maintenance

- **Cost Efficiency:** Corrective maintenance may seem like the cheapest option since costs only arise when a failure occurs. In some cases, this can lead to maintenance cost savings.
- **Resource Utilization:** This method allows for maximum use of equipment as long as it is functioning properly, which can be beneficial for smaller installations or devices.

Disadvantages of Corrective Maintenance

- **Unplanned Interruptions:** The main drawback of corrective maintenance is the unpredictability of failures, which can lead to significant operational interruptions and decreased productivity.
- **Higher Costs in Case of Severe Failures:** Although initial costs may be lower, serious failures can result in higher costs due to the need for emergency repairs, equipment replacements, or even production losses.
- **Lower Quality Control:** Relying on corrective maintenance carries the risk of reduced service quality due to the urgency of addressing failures.



Corrective maintenance plays an important role in managing the GES, but relying solely on this strategy can be risky due to the unpredictability of failures and the potential for high costs in the case of serious issues. While it offers certain advantages, such as lower initial costs and maximum resource utilization, it is recommended to combine it with preventive approaches to ensure greater reliability and stability of the power system.

1.3.3 Predictive maintenance

Predictive maintenance is an advanced approach that uses technologies to monitor the condition of equipment and predict potential failures before they occur. This type of maintenance is based on continuous monitoring of physical parameters such as vibration, temperature, energy consumption, and other relevant indicators.

Predictive maintenance aims to prevent unexpected downtime by initiating maintenance activities only when clear indicators suggest that a failure is imminent. This approach reduces costs associated with unnecessary servicing, increases equipment efficiency, and optimizes spare parts management.

Methods of Predictive Maintenance

1. **Real-time monitoring:** Using sensors to measure various parameters (vibrations, temperature), the system continuously monitors the condition of the equipment.
2. **Data analysis:** The collected data is analysed to identify trends or anomalies that may indicate an impending failure.
3. **Digital twins:** In some cases, digital twins—virtual replicas of real-world objects—are used to simulate the behaviour of equipment under different conditions.
4. **IoT technology:** Industrial Internet of Things (IIoT) allows the transfer of data to platforms where it can be processed and analysed.

Advantages of Predictive Maintenance:

- **Reduced costs:** By avoiding unnecessary servicing or part replacements, companies can significantly lower expenses.
- **Increased reliability:** Reduces the number of unexpected production stoppages due to technical issues.
- **Resource optimization:** Better planning of maintenance activities allows for more efficient use of human resources and materials.

Disadvantages of Predictive Maintenance:

- **High initial costs:** Implementing advanced technology requires significant initial investments in hardware and software.
- **Dependence on data quality:** The accuracy of analysis depends on the quality of collected data; poor or inaccurate data can lead to incorrect conclusions.

Predictive maintenance is a revolutionary improvement over traditional strategies



as it enables proactive control over the condition of GES system equipment. The combination of advanced technology with expert knowledge ensures optimal efficiency of power facilities with minimal operational disruptions. Although it requires high initial investments, the long-term benefits in the form of reduced repair costs and increased reliability make it an extremely valuable investment for modern energy companies.

1.4 Maintenance process in the GES system

The maintenance process in the main power system (GES) encompasses a series of activities designed to ensure the reliability, safety, and efficiency of the electrical power system. This process can be divided into several key phases:

1. Maintenance Planning

Planned maintenance is the foundation for the proper functioning of the GES. It is based on predefined time intervals or the number of operating hours of equipment. This includes planning preventive interventions, procuring spare parts and consumables, and organizing human resources.

2. Equipment Condition Monitoring

Monitoring the condition of equipment is a crucial part of the process that uses sensors and other technologies to track device performance in real time. This includes measuring vibrations, temperature, and other parameters to predict potential failures.

3. Preventive Interventions

Preventive interventions are activities carried out to prevent equipment failures. These include servicing, cleaning, and replacing parts based on prescribed interventions or criteria.

4. Corrective Maintenance

Corrective maintenance involves repairs after a failure or problem occurs with the equipment.

The goal is to quickly restore the system to operational condition by performing necessary repairs or part replacements.

5. Documentation and Analysis

Documenting all maintenance activities enables tracking the operational history of devices and analysing the effectiveness of performed interventions. This helps in planning future maintenance and improving the GES management strategy.

The maintenance process in the GES must follow a systematic approach that combines various types of activities to ensure the optimal functionality of power systems. Through continuous monitoring, preventive actions, and emergency interventions, it is possible to achieve high operational reliability of the facilities while minimizing downtime costs.



1.4.1 System inspection and diagnostics

Inspection and diagnostics are key elements of maintaining the main power system (GES). These activities enable the early detection of potential issues, which can prevent unexpected downtime and improve the overall reliability of the system.

Inspection is a process that includes visual checks, measurements, or data analysis to assess the condition of equipment or the system. The goal of the inspection is to identify potential issues before a failure occurs.

Diagnostics is a process that uses advanced technologies for a detailed analysis of collected data. It helps identify the causes of issues or failures and suggests the best way to resolve them.

Methods of Inspection and Diagnostics:

1. **Visual Inspection:** Regular equipment inspections to detect visible signs of wear or damage.
2. **Measurement:** Using sensors to monitor parameters such as temperature, vibrations, voltage, etc.
3. **Data Analysis:** Utilizing software to process large amounts of data to identify trends or abnormalities.
4. **Advanced Diagnostic Equipment:** Includes the use of specialized tools such as thermal cameras for detecting thermal anomalies or ultrasonic devices for detecting gas leaks.

Benefits of Inspection and Diagnostics:

Early Detection of Issues – Enables quick response to potential failures before they cause serious consequences.

Reduced Repair Costs – Early intervention helps avoid more expensive repairs that arise from neglecting minor problems.

Increased Operational Safety – Regular inspections reduce the risk of accidents that may occur due to poorly maintained equipment.

Inspections and diagnostics play a crucial role in managing the GES as they allow for a proactive approach to problems, reducing the risk of unexpected downtime and improving the overall efficiency of the electrical power system.

1.4.2 Calibration and adjustment of devices

Calibration and adjustment of devices are key components of maintaining the main power system (GES). These activities ensure that measuring instruments provide accurate measurements, which is essential for the reliability and safety of power plants.

Calibration is a process that involves comparing the readings of a measuring instrument with a reference standard to verify its accuracy. The goal of calibration is to ensure that the instrument provides reliable results, which is critical for decisions based on that data.



Types of Calibration:

1. **Factory Calibration** – Performed in the factory or by authorized service partners. This is the most accurate type of calibration as it is conducted using high-quality reference standards.
2. **Field Calibration** – Carried out on-site by trained technicians. It is less accurate than factory calibration but more practical as it does not require transporting equipment to the factory.
3. **Automatic Calibration** – Utilizes specialized tools that automatically adjust the parameters of measuring instruments to ensure their accuracy.

Device adjustment involves modifying settings or configuring equipment to ensure optimal operation within the prescribed parameters. This may include:

- **Error correction:** If inaccuracies are detected during calibration, they need to be corrected to ensure the instrument provides accurate results.
- **Performance optimization:** Adjusting parameters such as voltage or frequency can improve system operation or reduce energy consumption.

Advantages of Calibration and Adjustment

Measurement Accuracy – Calibrated instruments ensure reliable data, which is crucial for the effective management of the power system (GES).

Operational Safety – Inaccurate measurements can lead to incorrect conclusions about equipment status, potentially causing accidents or system failures.

Compliance with Standards – Calibrated equipment allows comparison with standards set by regulatory agencies, ensuring compliance with legal requirements.

Calibration and device adjustment play a crucial role in the functioning of the GES by ensuring precise system operation through reliable measurements and optimal equipment settings. Regular verification of measurement accuracy enables better system monitoring and prevents potential issues in the early stages of problem development.

1.4.3 Repairs and replacement of parts

Repairs and part replacement are key aspects of maintaining the main power system (GES). These activities ensure that equipment remains in optimal condition, which is essential for the reliability and efficiency of the power system.

Types of Repairs:

1. **Corrective Repairs** – Performed after a failure or issue occurs with the equipment. The goal is to quickly restore the system to operational condition by carrying out necessary repairs or replacing parts.
2. **Preventive Repairs** – Conducted regularly to prevent failures. These include servicing, cleaning, and part replacements according to prescribed intervals or criteria.



3. **Predictive Repairs** – Based on monitoring the condition of equipment to predict potential failures before they occur.

Part replacement is an important aspect of GES maintenance as it ensures that worn-out or faulty components are replaced with new ones, thereby extending the equipment's lifespan:

- **Spare parts** – It is important to have a sufficient stock of spare parts to ensure a quick response to potential failures.
- **Quality documentation** – Detailed documentation of all activities related to replacements is necessary to facilitate planning for future maintenance.

Commitment to Timely Repairs and Replacements

- **Operational reliability:** Regular servicing reduces the risk of unexpected plant shutdowns.
- **Cost efficiency:** Early intervention can prevent more expensive overhauls caused by neglecting smaller issues.
- **Workplace safety:** Well-maintained equipment reduces the risk of accidents.

Repairs and parts replacements are essential for the functioning of the GES as they ensure the optimal functionality of power generation facilities, with minimal downtime costs. By combining various types of activities, such as preventive, predictive, and corrective maintenance, companies can improve system reliability and reduce the financial burden associated with unexpected issues.

1.5 **Challenges in maintaining the GES system**

The maintenance of the main power grid (GES) faces numerous challenges that impact its reliability, efficiency, and safety. These challenges can be of a technical, financial, or environmental nature.



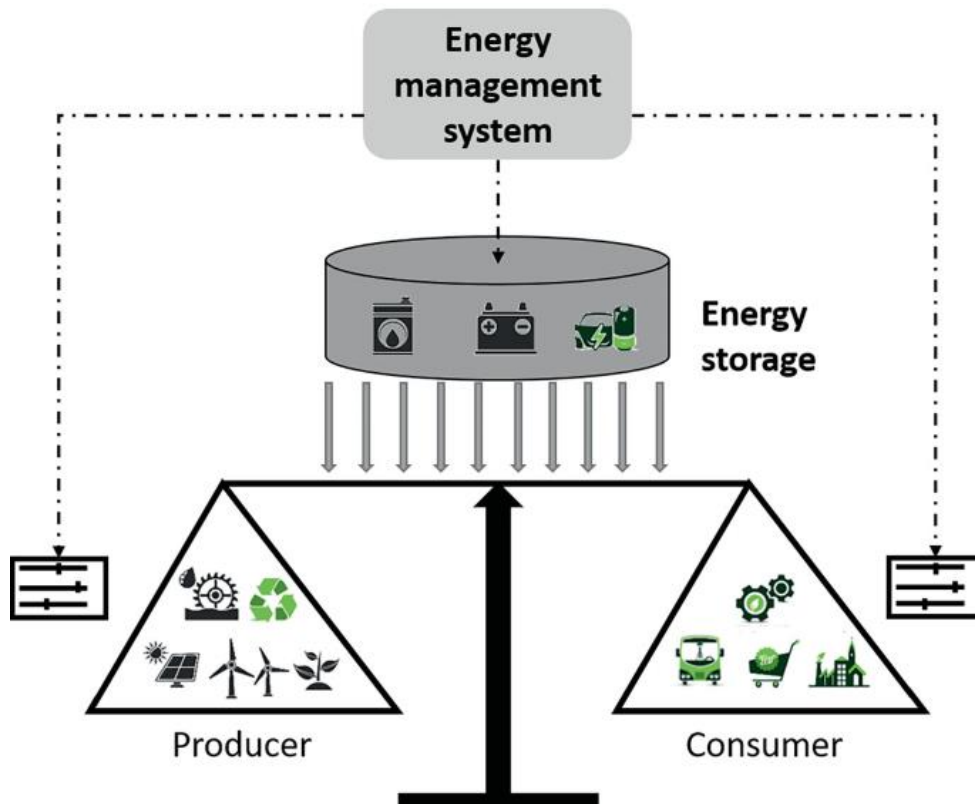


Figure 3: GES (<https://tinyurl.com/2yixftza>)

1. Technical challenges

System complexity: GES is a complex system that includes various components such as power plants, transmission networks, and distribution systems. This complexity can make it difficult to detect and resolve issues.

Rapid technological advancements require constant updating of knowledge and skills for maintenance experts to take advantage of new opportunities to improve efficiency.

2. Financial challenges

Maintenance costs: High costs of regular and predictive maintenance can be a limiting factor for companies with limited financial resources.

Investment in new equipment: Modernizing existing infrastructure or purchasing new equipment can be expensive, often limiting companies' ability to invest in advanced technologies.

3. Environmental challenges

Energy consumption – The maintenance process itself can consume additional energy, increasing the overall environmental impact.

Waste disposal – Replacing parts during repairs generates waste that must be properly handled to prevent negative effects on the environment.

Risk of accidents – Inadequate or poorly executed maintenance can increase the risk of accidents among workers or electricity consumers.

As digital technology is increasingly used in managing the GES system, there is

a risk of cyberattacks that could cause disruptions or compromise the security of the system.

The challenges in maintaining the GES are diverse and complex. A rational combination of preventive measures with predictive procedures enables better monitoring of complex electrical energy systems while simultaneously minimizing repair costs and maximizing the reliability of plant operations.

1.5.1 Technical issues and malfunctions

Technical problems and faults in the main power system (GES) can have significant consequences on the reliability, safety, and efficiency of the power system. These issues can arise due to various factors such as technical failures, outdated equipment, or unforeseen events.

Types of technical faults:

1. Mechanical faults – failures in mechanical components such as turbines or generators can cause system interruptions.
2. Electrical faults – issues with electrical components such as transformers or power cables can lead to system instability.
3. Software problems – errors in the software controlling the GES can cause malfunctioning of automated control or monitoring systems.
4. Communication problems – communication breakdowns between different parts of the system can prevent timely responses to changes in demand or faults.

Causes of technical problems:

1. Equipment age – outdated equipment is more prone to mechanical and electrical failures due to material wear and tear.
2. Insufficient maintenance – lack of regular inspections and servicing can lead to unexpected system breakdowns.
3. Environmental impacts – extreme weather conditions (floods, storms) can damage GES infrastructure.
4. Cyberattacks – security incidents targeting the computer systems managing the GES also pose a significant risk.

Consequences of technical problems:

1. Power supply interruption – Failures often manifest as unexpected outages in facilities, which can cause economic harm to users and businesses that rely on a constant supply of electricity.
2. Safety risks – Accidents resulting from technical problems can significantly increase the risk of injury to personnel or environmental damage.
3. Financial burdens – Repairs after severe failures often require large financial investments to restore the functionality of the facility to its previous level.



Technical problems and failures present a significant challenge for the operation of the main power system as they directly affect its performance and the economic efficiency of the companies that use it as the core infrastructure for electricity production.

1.5.2 Costs and resources

Maintaining the main power system (GES) requires significant investments in costs and resources. These costs can vary depending on the type of activity, the technology used, and the management strategy.

Types of costs:

1. Routine maintenance costs – include preventive actions such as servicing, cleaning equipment, and replacing parts at prescribed intervals.
2. Investment costs – related to the acquisition of new or replacement of existing equipment to improve system efficiency or safety.
3. Repair costs – arise after a failure or unexpected issue with the equipment, covering emergency interventions to restore the system to a functional state.
4. Administrative costs – include salaries for maintenance experts, accounting, and other support needed for managing maintenance processes.

Advantages of Optimal Cost Management

- Reduced Total Cost of Ownership – Planned investment in preventive and predictive maintenance can lower the overall cost of plant downtime.
- Increased Operational Reliability – Regular monitoring of equipment conditions can prevent a higher number of failures, resulting in improved system reliability.
- Better Cost-to-Performance Ratio – Efficient financial allocation can achieve a better balance between invested resources and achieved results.

Managing all types of costs, along with the efficient allocation of human, material, and financial resources, enables the optimal operation of the GES while minimizing unnecessary downtime. This, in turn, enhances the economic efficiency of companies that rely on it as the primary infrastructure for electricity production.



1.5.3 Introduction of new technologies

The introduction of new technologies in the main power system (GES) is essential for improving the efficiency, reliability, and safety of power plants. Technological advancements bring numerous opportunities for system modernization, cost reduction, and increased sustainability.

Areas of Technological Advancement

1. **Artificial Intelligence (AI)** – AI can be used for predictive maintenance, resource optimization, and automation of monitoring processes.
2. **Internet of Things (IoT)** – IoT devices enable real-time data collection, which is crucial for monitoring equipment conditions and responding to issues promptly.
3. **Computerized Maintenance Management Systems (CMMS)** – CMMS is software that enables efficient management of all maintenance-related activities, including planning, inventory tracking, and work order management. It applies to multiple industry sectors, as long as they involve equipment or infrastructure maintenance. The energy sector uses CMMS to monitor its infrastructure.
4. **Sensors and Monitoring** – Advanced sensors allow for more precise tracking of physical parameters such as vibrations and temperature.

Advantages of Implementing New Technologies

Improved Efficiency – New technologies enable the optimization of plant operations and the reduction of energy losses.

Reduced Costs – Automation of processes and predictive maintenance can significantly lower repair and downtime costs.

Increased reliability – Regular monitoring of equipment condition and timely response to issues ensure a more stable electricity supply.

Improved safety – AI-based systems can quickly detect potential hazards and alert workers or control systems.

The introduction of new technologies in the GES system brings numerous advantages, including improved efficiency, reduced costs, increased reliability, and enhanced safety. CMMS is essential for coordinating all activities related to availability, productivity, and the maintenance capability of complex systems.

1.6 The role of artificial intelligence in maintaining the GES system

The introduction of artificial intelligence (AI) in the maintenance of the main power system (GES) represents a significant step toward improving the efficiency and reliability of power plants. AI technologies can be applied in various ways to optimize maintenance and reduce costs.

Advantages of AI in GES Maintenance:

1. **Predictive Maintenance:** AI algorithms can analyse large amounts of data from sensors monitoring equipment conditions, enabling early detection of potential failures before they occur.



2. **Automation:** AI-based systems can automate monitoring processes and make autonomous decisions without human intervention, thereby increasing operational efficiency.
3. **Resource Optimization:** By using advanced analytical tools, companies can better allocate resources for repairs and parts replacements, thereby reducing overall plant downtime costs.
4. **Workplace Safety:** The implementation of AI can enhance safety protocols by quickly identifying potential hazards and alerting workers or control systems.

Challenges in Implementing AI:

1. **Data Quality:** The success of AI-based applications heavily depends on the quality of input data; poor or inaccurate data can lead to incorrect conclusions.
2. **Investment Costs:** Introducing advanced technologies requires significant initial investments in hardware and software, as well as staff training to use them effectively.
3. **Security Risks:** There is a risk of cyberattacks targeting the computer systems that manage the GES, so it is crucial to implement adequate protection to prevent system compromise.

The introduction of artificial intelligence into the maintenance processes of the GES system can lead to significant progress in predictive repairs, automation of activities, and resource optimization for equipment servicing. However, it is important to pay attention to the quality of input data as well as security aspects to fully leverage the benefits offered by this technological approach.

1.6.1 Automated monitoring and diagnostics

Automated monitoring and diagnostics in the main power grid system (GES) using artificial intelligence (AI) enables a range of improvements over traditional methods. AI systems can analyse large amounts of real-time data, recognize patterns and anomalies, and predict potential issues before a failure occurs.

Advantages of automated monitoring and diagnostics with AI:

1. **Early detection of issues** – AI can identify patterns that indicate potential safety breaches before they occur.
2. **Automated surveillance** – Automated monitoring systems using AI can quickly recognize dangerous situations and alert employees before an accident happens.
3. **Predictive maintenance** – AI is used to monitor equipment performance and predict failures before they cause accidents, reducing costs and improving production efficiency.
4. **Resource optimization** – AI can assist in better resource allocation by directing personnel and equipment to critical areas.

1.6.2 Predicting failures through AI models

AI models can be used to predict failures in GES systems of solar panels by analysing large amounts of real-time data, recognizing patterns and anomalies. This technology enables early detection of issues, automated monitoring, resource optimization, and improved work safety. Predictive maintenance reduces costs and increases production



efficiency.

AI systems can analyse data collected from monitoring equipment performance and predict failures before they cause accidents, which can improve safety and efficiency. The importance of recognizing patterns in failure data is emphasized for predicting and preventing future problems.

1.6.3 Maintenance optimization and cost reduction

The use of AI applications in solar tracking systems also presents some challenges:

Data Processing Cost: AI-based techniques such as neural networks and image processing algorithms require high processing power.

Weather-Dependent Performance: When the sun is less visible on cloudy or stormy days, the performance of image processing algorithms may degrade.

Power Consumption: Constantly processing environmental data and analysing the sun's position can increase energy consumption.

In the future, AI applications in solar tracking systems will become more autonomous and will develop with IoT (Internet of Things) integration. In particular, solar panels in different regions can be connected to each other over the network and efficiency optimisation can be achieved in the light of information such as weather conditions. In addition, storage and management of solar energy will also be improved with AI-supported energy forecasting algorithms.

Artificial intelligence is a powerful tool to increase efficiency and optimise energy production in solar tracking systems. By combining AI techniques such as neural networks, genetic algorithms, fuzzy logic and image processing, both the accuracy and adaptability of solar tracking systems are improved. This leads to more sustainable and cost-effective energy solutions in the long term.

Solar tracking systems have an important place in the renewable energy sector and increase the energy production capacity by enabling the efficient use of solar energy. The success of these systems relies on the positioning of solar panels at the most favourable angle to the movement of the sun. The integration of artificial intelligence (AI) techniques into solar tracking systems has made it possible to make these processes more precise, flexible and efficient. In this concluding chapter, the role of AI in solar tracking systems, its advantages, challenges and potential future developments will be discussed.

1.7 Examples of best practices in maintaining GES systems

Artificial intelligence plays a critical role in the optimisation of solar tracking systems. While traditional control methods are usually based on fixed algorithms, AI-based algorithms have the ability to dynamically adapt to environmental variations. This adaptation ensures that energy production is maximised. AI



techniques such as neural networks, genetic algorithms, fuzzy logic and support vector machines (SVM) are used to accurately predict the position of the sun and optimise the angle of the panels.

1.7.1 Examples from the industry

The role of Artificial Intelligence (AI) in GES systems, particularly in the context of solar energy (solar AI), is transformative, enabling more efficient, reliable, and sustainable operations. AI is integrated into solar systems in various ways, leading to significant improvements in energy production and management.

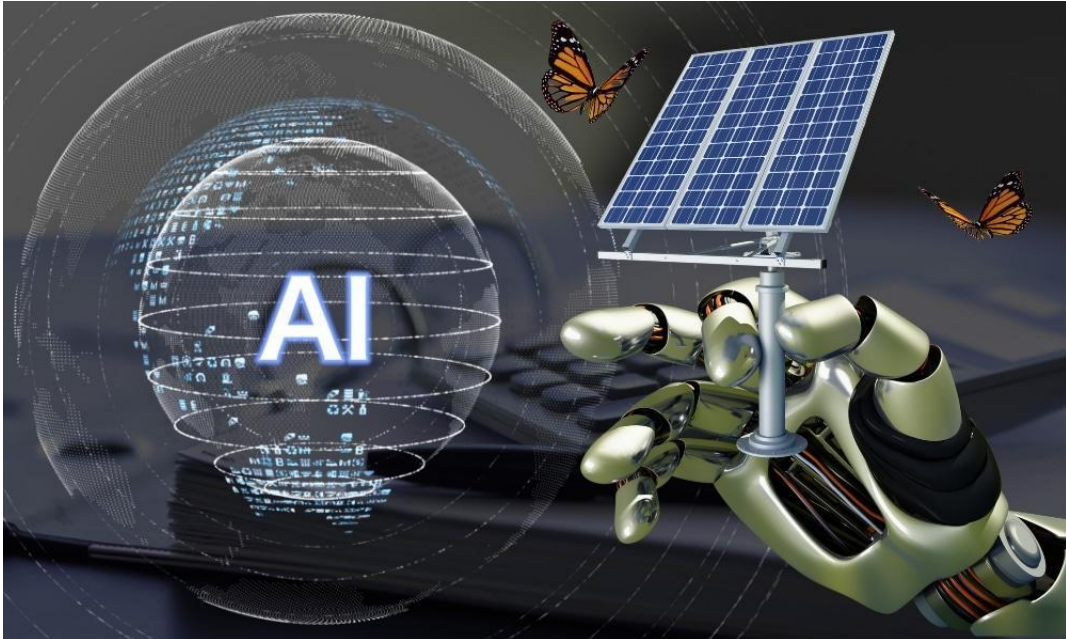


Figure 4: The Role of AI and Smart Technology in Solar Energy (<https://tinyurl.com/2ye4mu4h>)

Key roles of AI in solar GES systems:

- **Predictive Maintenance** – AI algorithms analyse real-time data from IoT devices integrated into solar panels, enabling the prediction of failures and optimization of maintenance. This reduces costs and increases energy production efficiency.
- **Increasing Solar Panel Efficiency** – AI can help develop more efficient solar panels. By analysing data, AI helps understand how to adjust production for higher efficiency.
- **Optimization of Grid Integration Production** – AI allows for better management of the fluctuating nature of renewable energy sources like solar, improving their reliability and efficiency.
- **Real-time Energy Monitoring and Improved Grid Management** – Smart solar systems with AI and IoT enable real-time energy monitoring and enhanced grid management. These systems are expected to increase the efficiency of solar plants by up to 20%.

It is expected that the global IoT in the energy market will significantly increase



by 2030, with a major contribution from smart solar applications. AI contributes to the development of renewable energy sources by optimizing their production and integration into energy grids.

1.8 Conclusion

The maintenance of GES systems is crucial for ensuring the reliability, and longevity of the power system. Proper and timely maintenance ensures a stable electricity supply, reduces costs and extends the lifespan of the equipment.

1.8.1 Key aspects of effective maintenance

Reliability and Safety – Regular maintenance ensures the reliability of electricity supply and reduces the risk of failures and outages.

Efficiency – Optimizing system performance through regular inspections and servicing increases energy efficiency and reduces energy losses.

Equipment Lifecycle – Preventive maintenance extends the lifespan of equipment, reducing the need for costly repairs and replacements.

Cost Reduction – Efficient planning and execution of maintenance activities lower operational costs, labor costs, material expenses, and equipment replacement costs.

Regulatory Compliance – Maintenance in accordance with technical regulations and standards ensures the safety and quality of electricity supply, preventing legal issues and penalties.

1.8.2 The future of maintaining GES systems

The future of GES system maintenance lies in the integration of advanced technologies and data to improve efficiency.

Increased adoption is expected in:

Predictive Maintenance – Utilizing sensors and data analysis to predict potential failures and plan maintenance activities based on the actual condition of equipment.

Automation – Implementing automated monitoring and management systems, enabling rapid responses to changes and real-time optimization of system performance.

Digitalization – Using digital platforms for tracking and managing maintenance activities, improving coordination, and reducing administrative costs.

Renewable Energy Integration – Developing systems for the integration of renewable energy sources, ensuring stability and reliability in electricity supply.



1.8.3 Recommendations for further development

Investment in Technology – Continuous investment in advanced technologies for monitoring and analysing equipment conditions, enabling predictive maintenance and cost reduction.

Education and Training – Ensuring continuous education and training for personnel to work with new technologies and maintenance methods.

Development of Standards – Establishing and implementing maintenance standards for GES systems, ensuring the quality and safety of electricity supply.

Collaboration and Information Exchange – Promoting cooperation among various stakeholders in the energy sector, facilitating the exchange of information and best practices in GES system maintenance.

Integration with Smart Grids – Developing and implementing smart grids that enable two-way communication between producers and consumers, improving efficiency and reliability in electricity supply.

By implementing these recommendations, power systems can become more efficient, reliable, and sustainable, ensuring a stable electricity supply for future generations.



MEASUREMENT AND EVALUATION 5

Read the questions carefully and choose the correct answer.

1. What is the main purpose of maintaining the GES system?

- A) Increasing electricity production without additional costs
- B) Ensuring the long-term and efficient operation of the system
- C) Full automation without human intervention
- D) Reducing the number of solar panels

2. What is one of the main advantages of using artificial intelligence in the maintenance of the GES system?

- A) Increasing dependence on fossil fuels
- B) Reducing costs and optimizing resources
- C) Eliminating the need for preventive maintenance
- D) Preventing remote monitoring of the system

3. What is the main function of the inverter in the GES system?

- A) Reducing voltage in the electrical grid
- B) Converting direct current from solar panels to alternating current
- C) Storing excess energy in batteries
- D) Monitoring the position of the Sun

4. Which type of maintenance uses artificial intelligence to predict failures?

- A) Preventive maintenance
- B) Corrective maintenance
- C) Predictive maintenance
- D) Manual maintenance

5. What is one of the biggest challenges in maintaining the GES system?

- A) Lack of sunlight during the night
- B) High maintenance costs and resources
- C) Inability to upgrade the system
- D) Complete independence from the power grid



MODULE EVALUATION

Write the appropriate words in the empty spaces in the sentences below.

1. _____, the type of maintenance that is carried out before a failure occurs to ensure the smooth operation of the system is called preventive maintenance.

2. _____; it enables automatic monitoring of the GES system's operation and performance optimization through real-time data analysis.

3. _____, it is a component of the GES system that enables the storage of excess energy generated by solar panels.

4. _____; it is the process of adjusting and correcting measuring devices to ensure their accuracy.

5. _____ These are technical challenges that can affect the operation of the GES system, including electrical failures and communication issues.

Write the letters 'T' if true and 'F' if false opposite the information given below.

1.() Predictive maintenance uses sensors and algorithms to analyse data and prevent failures before they occur.

2.() Preventive maintenance includes repairs after a system failure occurs.

3.() Artificial intelligence can improve the energy efficiency of solar systems by analysing data and automatically adjusting parameters.

4.() GES systems have no ecological advantages as they still produce greenhouse gas emissions.

5.() Corrective maintenance is the most expensive form of maintenance as it requires repairs and part replacements after a failure.



1. What are the main advantages of preventive maintenance in the GES system?

2. How does artificial intelligence contribute to the efficiency of solar systems?

3. What are the main challenges in maintaining the GES system?

4. What components form the basis of the GES system?

5. What are the key factors for increasing energy efficiency in GES systems?

EVALUATION

Please compare your answers with the answer key. If you have incorrect answers, you need to revise the Learning Activity. If you answer all the questions correctly, please contact your teacher and move on to the next learning activity.



ANSWER KEYS

Measurement and Evaluation-1:

1	B
2	B
3	B
4	C
5	B

Module EVALUATION:

Gap Filling:

1	PREVENTIVE MAINTENECE
2	ARTIFICIAL INTELLIGENCE (AI)
3	BATTERIES
4	CALIBRATION
5	TEHKNICAL PROBLEMS AND FAILURES

True(T) - False(F)

1	T
2	F
3	T
4	F
5	T



1. What are the main advantages of preventive maintenance in the GES system?

Artificial intelligence applications in solar tracking systems play an important role in improving energy efficiency and providing sustainable energy solutions. The integration of artificial intelligence algorithms has made it possible for systems to adapt to environmental changes, optimise energy production and reduce costs. However, there are also challenges such as high computational costs, data requirements and performance degradation due to environmental conditions.

2. How does artificial intelligence contribute to the efficiency of solar systems?

The advantages provided in solar tracking systems thanks to AI applications are as follows:

- 1. Increased Energy Efficiency:** Thanks to AI algorithms, more energy is generated by positioning solar panels at the most efficient angle.
- 2. Real-Time Adaptation:** Artificial intelligence follows the position of the sun by adapting to instant environmental changes and makes the system more flexible.
- 3. Less Maintenance Need:** Thanks to adaptive algorithms, the system requires less human intervention as it optimises itself according to environmental factors.
- 4. Low Cost:** As energy efficiency increases, energy production costs decrease, thus ensuring cost effectiveness in the long term.



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These references provide information on the applications of different methods and algorithms to improve the effectiveness of artificial intelligence in solar tracking systems.

