MANAGEMENT OF MAINTENANCE FOR PHOTOVOLTAIC SYSTEMS

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ABSTRACT: Energy efficiency is a major objective for the future of Romania and the European Union. In October 2012, the European Union adopted a new renewable energy policy and set a target of achieving at least 20% of the EU's renewable energy needs by 2020. The use of electrical energy generated from solar energy is being studied more and more. Maintenance activity of a photovoltaic system is important to ensure the continuity of energy supply and cost reduction. This paper proposed a type of approach to maintenance activity at photovoltaic systems. A good management of maintenance activity is very important to lower production costs.

KEY WORDS: maintenance, photovoltaic system, renewable energy, management

1. INTRODUCTION

According to new renewable energy policy adopted to the European Union, 20% of energy produced by 2020 must be from renewable resources. The renewable energy resources are: wind energy, solar energy, waves energy, geothermal heat and biomass.

Renewable electricity generation in 2011-2017 from European Union [1] is presented in figure 1.

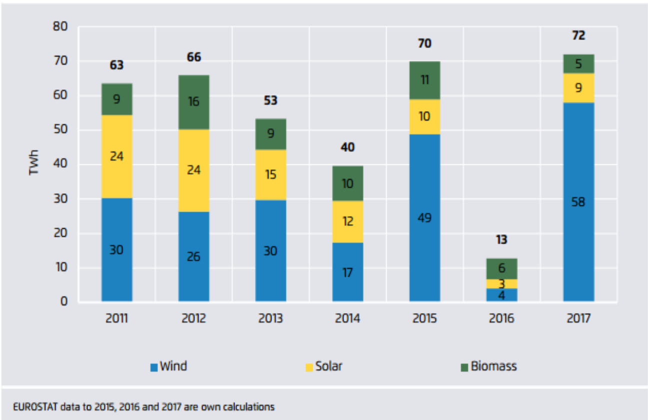

Figure 1. Renewable electricity generation 2017 [1]

Figure 2 shows how wind, solar and biomass has increased in every EU country in the last 7 years [1]. Renewable electricity generation increased its share of electricity production in every country, but at very different rates. The countries with the biggest increase is Denmark, the UK and Germany. Many countries had a little renewables growth like Slovenia, Bulgaria, France, Slovakia, the Czech Republic and Hungary; other countries had good growth at the start of the decade, but then gave up on renewables with almost no growth in the last three years like Spain, Italy, Portugal, Belgium and Greece. There are some countries that still have less than 10% of their electricity production from renewable resources.

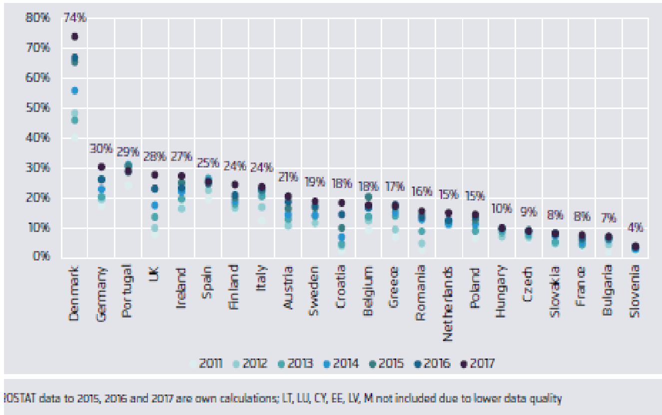

Figure 2. Wind, solar and biomass as percentage of national electricity production [1]

In this paper the authors propose to optimize maintenance management for photovoltaic systems.

Analyzing the map of the distribution of solar radiation in Romania [2] we can identify five areas of special interest for solar power applications:

- The first area, which includes the areas with the highest potential
- The second area, with good potential
- The third area, with moderate potential

The solar map [2] was made using and processing the data provided by: NMA as well as NASA, JRC, Meteotest. The data is expressed in kWh/m2/year, horizontally, this value being the one commonly used in photovoltaic solar energy applications. The map includes the distribution of annual average annual flows of solar energy incidents on the horizontal surface on the territory of Romania. In figure 3 is shows the solar potential of Romania, (sources: ICPE, ANM, ICEMENERG, 2006)

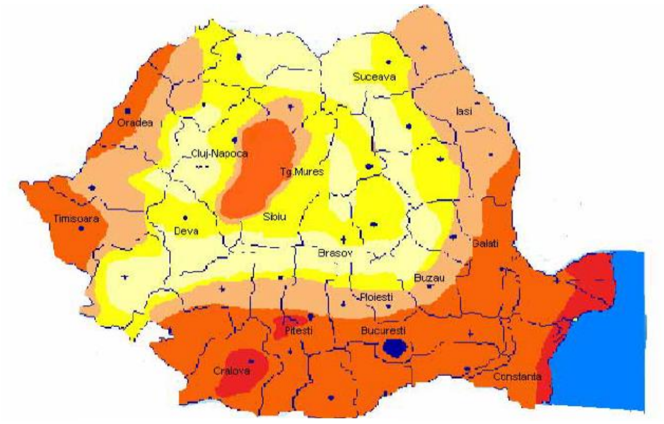

Figure 3. The solar map of Romania [2]

2. PHOTOVOLTAIC SYSTEMS

Photovoltaic panels [3] are devices that convert solar energy into electricity. When solar radiation passes through the atmosphere is subject to the phenomenon of absorption, diffusion and transmission. At Earth level, solar radiation can be classified into:

- direct radiation - the parallel component, coming from the solar disk and measured from the direction of normal to the surface.
- diffuse radiation - the radiation received by a flat surface derived from all the hemisphere seen from that surface except the solar disk.
- reflected radiation - is the result of the reflection of the rays by the surfaces reflective; this component depends on the surface albedo concerned.
- global radiation - direct radiation and diffuse radiation.

For PV panel operation [3], direct radiation is the most important. In the case of a clear sky, it has the highest intensity when the sun is finds its maximum point to the South in the northern hemisphere and to the North in southern hemisphere. Because of Earth's revolution, the position of the sun is different from the area and season.

A complete photovoltaic system includes different components that should be selected taking into consideration your individual needs, site location, climate and expectations. Major components of a photovoltaic system are:

- PV Modules - convert sunlight instantly into DC electric power
- Inverter - converts DC power into standard AC power for use in the home, synchronizing with utility power whenever the electrical grid is distributing electricity
- Battery - stores energy when there is an excess coming in and distribute it back out when there is a demand. Solar PV panels continues to re-charge batteries each day to maintain battery charge
- Charge Controller - prevents battery overcharging and prolongs the battery life of your PV system
- Utility Meter - utility power is automatically provided at night and during the day when the demand exceeds your solar electric power production

Photovoltaic systems are generally classified according to their functional and operational requirements, their component configuration, and how the equipment is connected to the other power sources and electrical loads (appliances). The two principle classifications are Grid-Connected and Stand Alone Systems

2.1 Grid Connected

Grid-connected PV systems are designed to operate in parallel with and interconnected with the electric utility grid. The primary component is the inverter, or power conditioning unit (PCU). The inverter converts the DC power produced by the PV array into AC power consistent with the voltage and power quality required by the utility grid. The inverter automatically stops supplying power to the grid when the utility grid is not energized. A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at an on-site grid-connected distribution panel. This allows the power produced by the PV system to either supply on-site electrical loads, or to back feed the grid when the PV system output is greater than the on-site load demand. During periods when the electrical demand is greater than the PV system output (night-time), the balance of power required is received from the electric utility This safety feature is required in all grid-connected PV systems, it also ensures that the PV system will not continue to operate and feed back onto the utility grid when the grid is down for service or repair. In figure 4 is represented a PV system grid-connected.

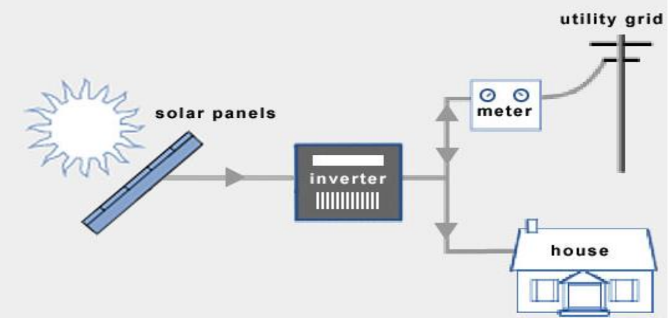

Figure 4. PV system grid-connected

2.2 Stand Alone System

Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads. Stand-alone systems may be powered by a PV array only, or may use wind, an engine-generator or utility power as a backup power source in what is called a PV-hybrid system. The simplest type of stand-alone PV system is a direct-coupled system, where the DC output of a PV module or array is directly connected to a DC load.

In figure 5 is represented a PV stand alone system.

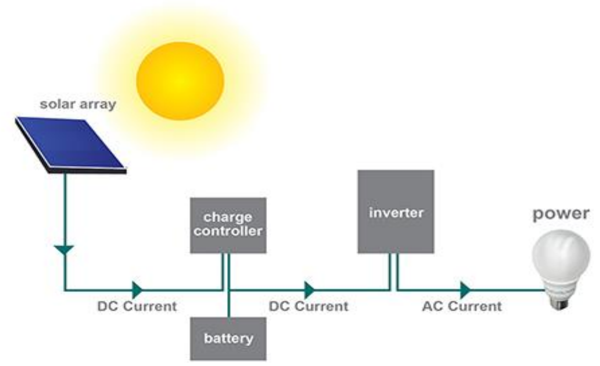

Figure 5. PV stand alone system

3. MAINTENANCE MANAGEMENT

3.1 Maintenance. General considerations

Maintenance is the set of technical, administrative and management measures taken during the lifecycle of a machine, intended to maintain or restore it to a state in which it can perform the function necessary to ensure that the system functions as efficiently as possible. The most important task of maintenance is to ensure the availability of long-term equipment.

According to UCECOM, "Maintenance Safety" [4], maintenance activity includes several professions and targets all sectors of activity. Maintenance workers are at risk of a whole series of accidents. It is estimated that about 15-20% of all accidents and 10-15% of total fatal accidents are related to maintenance operations.

In the "Industrial Systems Maintenance Course" [5] from Technical University of Cluj Napoca, the types of maintenance are: reactive, corrective, preventive and predictive. The best results are obtained by applying predictive maintenance, but this involves additional investment in measurement equipment and training courses for the training of staff using them.

The cost lifecycle of a piece of equipment includes all the resources needed to develop the product, produce, distribute, use, recycle, and remove it. Maintenance activities are managed over time.

Figure 6 shows the rate of occurrence of a fault depending on the operating time.

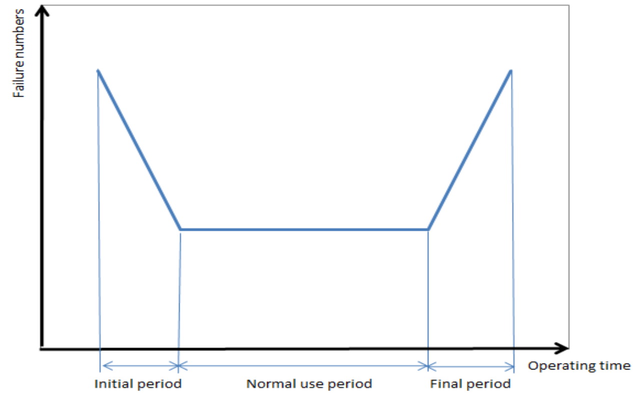

Figure 6. The operating time of a device

A new equipment is likely to fail in the first week since commissioning due to installation issues. After this period, the probability of a defect is relatively reduced over a long period of time. After this period, called the life cycle, the probability of failure increases rapidly with the elapsed time. Maintenance management should take this statistic into account when planning work.

3.2 Maintenance strategy

All equipment or installations requiring maintenance must be related to the amount of revenue or its importance (supply to vital consumers, customer satisfaction etc.). As long as the equipment are different importance, the type of maintenance chosen for them should not be the same.

The maintenance strategy determines the position of equipment (value and importance) to achieve a minimum lifetime cost, with maximum reliability and maximum availability. The efficiency of maintenance work depends on the type of maintenance and the strategy for doing this.

Figure 7 shows an algorithm that can be used to optimally select the type of maintenance for a specific equipment.

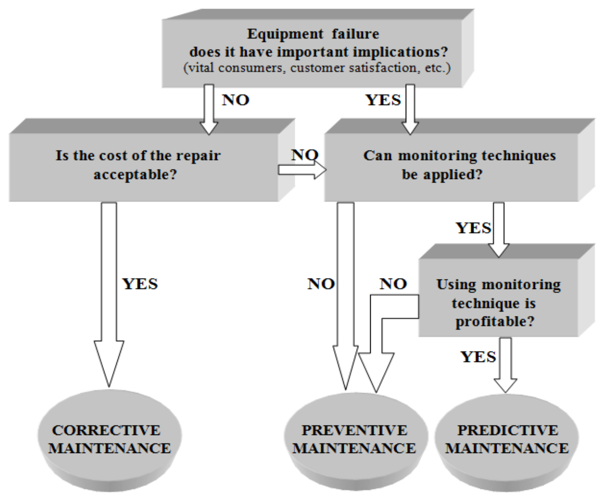

Figure 7. Algorithm for optimal selection of maintenance type

Optimal maintenance activities contribute to the efficiency of production systems by optimally using human, material, financial, and other resources. This can only be done if maintenance activities are planned and organized to the same extent as production activity, which involves building up and maintaining spare parts stocks, setting quality standards, applying maintenance training programs.

The role of the maintenance strategy [5] is to achieve and maintain the following:

- optimal availability of production / auxiliary equipment/systems to maintain the production capacity of the company at the established performance level;
- optimal operating conditions for production / ancillary equipment / systems;
- efficient use and maximum capacity of maintenance resources;
- extending the life of equipment / systems;
- fast response in the event of a fault

Different types of approach to maintenance strategy is shows in figure 8.

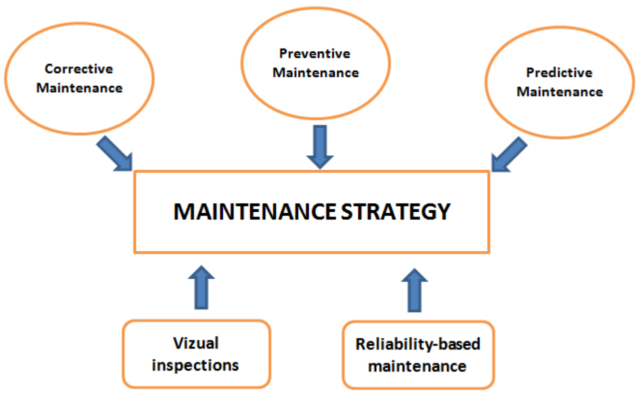

Figure 8. Types of approach to maintenance strategy

3.3 Efficiency indicators

In article "Efficiency indicators for maintenance activity" [6] are presented these indicators and they role. The role of efficiency indicators is to "quantifying the quality of the service provided by the maintenance team". The values of the efficiency indicators may be different, but they can be useful in:

- making the optimal decision;
- comparing the performances obtained in the respective year with those of the previous years;
- testing the benefit of a maintenance strategy;
- knowing the effect of liberalization of energy markets on maintenance service;
- assessing the effectiveness of any improvement and budget required for maintenance work for the coming year.

Indicators that express the efficiency of maintenance activity are numerous, but in practice can be selected less or only one.

- Technical indicators
  - number of interventions
  - the use of the equipment over its lifetime
  - availability of equipment
  - stock of spare parts
- Economic indicators
  - the specific cost of maintenance
  - the specific cost of using spare parts stocks
  - share of repair cost in total cost
  - productivity indicators
- Time indicators
  - average response time
  - average repair time
  - planned maintenance time

3.4 Maintenance management

The Maintenance Framework [7] describing the maintenance management as the leadership and organization, planning and scheduling, preventive maintenance, condition monitoring, execution of maintenance repairs, root cause failure analysis and spare parts management.

Maintenance management [7] can be used to achieve improvements in safety and reliability, improvements to operating procedures and strategies and the establishment of capital and operating regimes. Successful implementation of a maintenance management system can lead to improvements in cost effectiveness, asset reliability and availability complemented by a comprehensive understanding and management of risk.

The maintenance activity must be managed to pass from corrective maintenance to reliability-based maintenance. It must prevent malfunctions, not repair the failure.

When failures can't be prevented by maintenance actions should be developed strategies to minimize effects.

The predictive maintenance is the first step to implement an efficient maintenance management.

Figure 9 shows the diagram of the occurrence of a defect [8]. It is possible to observe the moment of occurrence of a fault - O, the moment when it can be detected - P and the moment of damage - F.

The P-F interval is the interval between the point at which a potential failure becomes detectable and the point at which it evolves into a functional failure. The fault detection and diagnosis process requires access to certain significant system size / parameters that give information on its status at all times.

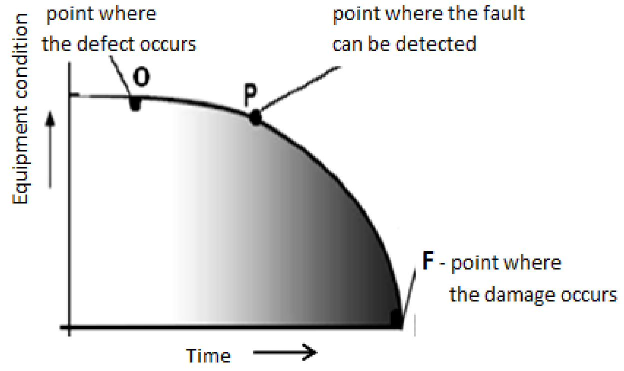

Figure 9. Early identification of a defect

To extend the life of a equipment, point P must be eliminate from P-F curve. This can be made by training maintenance personnel, effective work procedures, etc.

Tackling maintenance issues, establishing procedures and maintenance strategy for a system should therefore take into account both the monitoring and diagnosis of each component, but also the influence of the variables. The most well-known monitoring and diagnosis techniques are: vibration monitoring, thermography, lubricant fluid analysis and electrical system specific methods (Impedance Measurement, Insulation Resistance Measurement, Phase Harmonic Range Analysis).

Reliability-based maintenance: A set of actions and measures designed to establish the program and contents of preventive maintenance work to be carried out to maintain and eventually restore, when necessary, the technical state of the system, using fail- Safety analyzes, functional analyzes, critical analysis, etc. Reliability-based maintenance is a concept of using the informational feed-back of plant maintenance in the field of maintenance, based on the principles of reliability calculations. Reliability-based maintenance bases its planning on future actions on the technical state of the system, assessed on the basis of the estimated reliability of the system at planning time.

4. THERMOGRAPHY

Thermography is a technique of analyzing the thermal characteristics of an object from its infrared image, captured through non contact thermal imaging device. The following defects can be observed with the thermografic cameras:

- Loose connections / terminations
- Oxidation at the cable termination points
- Dust deposition at terminations
- Defective lug crimping, overloaded or imbalanced circuits
- Faulty breakers, damaged switches, faulty fuses and other hazardous electrical conditions.

Infrared thermography is a science dedicated to the acquisition and processing of thermal information from non-contact measurement devices [9]. The infrared radiation is form of electromagnetic radiation with longer wavelengths than those of visible light. Any object emits infrared radiation that can not be detected by the human eye. Infrared measuring devices are required to acquire and process this information.

Use of a thermography camera is essential to ensure predictive maintenance for a photovoltaic systems. Using this method can find:

- defects at photovoltaic modules
    - Diodes and connections defects
    - Hot spots in cells or between connectors
    - Hot cells due to shading
    - Short-circuit cell strings
- defects at distribution installations (c.a./c.c.)
    - Weakened terminals
    - Characteristic shine
    - Under-dimensioned fuses

Figure 10 shows some examples of defects in photovoltaic modules and figure 11 shows examples of defects in distribution system.

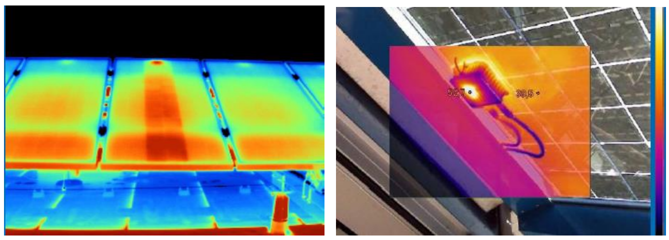

Figure 10. Defects in photovoltaic modules

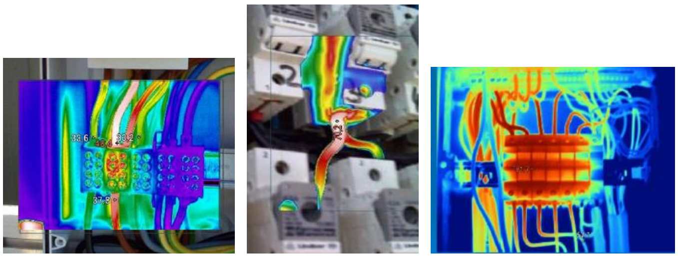

Figure 11. Defects in distribution systems

For a good quality of measurements, they must be carried out by a certified inspector according to DIN 54191 (Thermographic Testing of Electrical Installations). The inspector must have adequate knowledge of:

- Electrical systems,
- Thermography,
- The way of evaluating thermographic results for electrical installations

Factors that may affect measurement:

- Wind speeds greater than 1 meter per second
- Rain
- Cold / heat
- Reflection from the object to be tested
- Transmissions
- Too much distance
- Too little irradiation

The test object must be framed in the target field. In figure 12 is shown an example of the possibilities of framing.

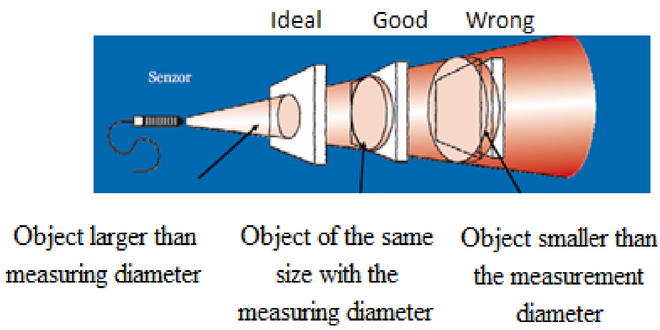

Figure 12. Framing of target field

The advantage of infrared thermography:

- allows the measurement of temperatures from a distance (centimeters to hundreds of meters) and without direct contact;
- it is a non-destructive method of investigation, because it does not interfere with and in no way influences the material, object or process investigated;
- It is an ultrasensitive measurement technique, highlighting temperature variations of tenths of degrees, both spatially and temporally.

5. CONCLUSIONS

The implementation of the Maintenance Management concept aims to improve productivity, efficiency by reducing the number of accidental equipment drops and customer satisfaction by implementing a culture of continuous improvement. To achieve this goal, it is necessary to use practical and modern tools for optimizing the activities, and it is necessary to inform the process.

Infrared cameras play an important role in locating the sources of defects at the photovoltaic modules and distribution systems. They contribute to the improvement of predictive maintenance at the photovoltaic systems for a correct maintenance management.

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