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Miguel A. Sanz-Bobi *Editor*

Use, Operation and Maintenance of Renewable Energy Systems

Experiences and Future Approaches

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Preface

The aim of this book is to put the reader in contact with real experiences, current and future trends in the context of the use, exploitation and maintenance of renewable energy systems around the world. Today the constant increase of production plants of renewable energy is guided by important social, economical, environmental and technical considerations. The substitution of traditional methods of energy production is a challenge in the current context. New strategies of exploitation, new uses of energy and new maintenance procedures are emerging naturally as isolated actions for solving the integration of these new aspects in the current systems of energy production. This book puts together different experiences in order to be a valuable instrument of reference to take into account when a system of renewable energy production is in operation.

Part I of the book is focused on different aspects about the operation and maintenance of renewable energy systems, and in particular, attention is paid to systems that produce electrical energy by wind, sun and biogas because these are the most extended types of plants using a renewable source of energy. Current practices of operation and maintenance at these plants will be described in order to know strategies for a better use of their life cycle.

"Condition Monitoring and Maintenance Methods in Wind Turbines" presents a review of the main principles supporting different strategies of maintenance. Later, a framework is presented which is able to integrate different aspects related to the life of a wind turbine. In particular, a method is proposed for the detection of abnormal behaviour with respect to the normal behaviour expected and a procedure to obtain failure mode risk indicators that can help apply maintenance in wind turbines precisely when it is needed. This will contribute to a better use of the life cycle of the wind turbines in a wind farm.

"Operation and Maintenance Methods in Solar Power Plants" describes the fundamentals about the operation and maintenance in solar power plants. In these plants, Operation and Maintenance (O&M) is becoming more and more important for improving the performance of the plant. Most of the solar power plants are located in remote places with unreliable communication infrastructure. This makes it very difficult to diagnose and rectify problems in a timely manner. System operations and maintenance (O&M) is a broad area, and it is the continuing focus of several industry/government/national laboratory working groups. This chapter will review their main results.

"Biological Biogas" will review briefly the most significant part of the history of biogas. Here an overview of the microbial process will be provided covering some of the different types of digesters and looking at building, starting and operating a simple type of digester, including fault finding.

"Development, Operation, and Future Prospects for Implementing Biogas Plants: The Case of Denmark" describes different concepts of biogas technology as understood in a Danish context. It emphasises how energy from production of biogas is distributed, either as biogas to regional combined heat and power plants (CHP) or as district heating (DH) to small-scale local networks. The chapter provides an overview of the political situation and a historical outline of the development of the Danish biogas sector, and it presents the biogas process and operational aspects. The chapter ends with a discussion of biogas in both global and European contexts.

"Operation and Maintenance Contracts for Wind Turbines" addresses the fundamental negotiating issues of wind turbine O&M contracts. It includes a conceptual mathematical framework to support the analysis and design of O&M contracts. This will make it possible to investigate mechanisms through which incentives perceived by O&M contractors can be aligned with the objectives of wind farm owners over both the short and the long terms.

Part II of the book addresses how new renewable energy systems can be integrated with traditional methods of energy production, and also, with a new smart environmental use of energy. Within this perspective the hybridation of systems must be considered.

"Grid Integration of Wind Power Generation" discusses how generator technology affects grid integration of wind generation. Wind generators based on squirrel cage and doubly fed induction machines and multi-pole synchronous machines will be reviewed. The performance with respect to stability, load frequency and reactive power–voltage control is discussed.

"Control Methods Applied in Renewable Energy Systems" introduces the control methods used in renewable energy sources. The control methods of power electronics used in renewable energy sources such as solar, wind, and fuel cells are comprehensively explained through the different sections of the chapter. The required circuit topologies of current control methods are explained with grid-connected and island-mode operations of a solar energy system. The rest of the chapter consists of a discussion concerning renewable energy systems based on wind turbines and fuel cells.

"Low-Cost Hybrid Systems of Renewable Energy" is focused on research and development of low cost technologies for attending small and medium energetic demands. The results of such development are related to the use of hybrid systems combining different sources of renewable energy. To obtain the lowest cost of a system it is necessary to obtain the smallest cost in each one of their parts and a better control strategy that integrates the operation of these parts. In this chapter the constituent elements of a hybrid system will be presented along with different technological alternatives. Also control strategies will be presented in order to obtain the maximum efficiency of these elements and connection arrangements.

"Design for Reliability of Power Electronics in Renewable Energy Systems" is focused on the design of reliability of power electronics in renewable energy systems. Typically power electronics are designed for 20–25 years of operation and in order to do this it is crucial to know about mission profile of the power electronics technology as well as how the technology is loaded in terms of temperature and other stressors relevant for lifetime prediction. Hence, this chapter will show the basic power electronics technology for renewable energy systems, describe the mission profile of the technology and demonstrate how the power electronics is loaded for different stressors. Further, some systematic methods to design the power electronics technology for reliability will be given and demonstrated with two cases—one is a wind turbine and another one is a photovoltaic application.

Part III of the book is oriented to describing some experiences about the use of energy coming from renewable energy sources in different fields of industry and society. This is a point of increasing interest that is constantly changing and which future trends show will play a main role in how society uses energy.

"Use of Renewable Energy Systems in Smart Cities" addresses the use of renewable energy systems on a small scale, oriented to distributed generation for households or districts, integrated in a smart city. In this context, the main renewable energies and companion technologies are reviewed, and their profitability investigated to highlight their current economic feasibility. A simplified architecture for the development of a smart city is presented, consisting of three interconnected layers: the intelligence layer, the communication layer and the infrastructure layer.

"Analysis of the Impact of Increasing Shares of Electric Vehicles on the Integration of RES Generation" analyses the medium-term operation of a power system in several future scenarios that differ according to the level of use of electric vehicles and how renewable energy sources can be safely integrated into them. The analysis is performed using different vehicle charging strategies (namely dumb, multi-tariff and smart).

The analysis is based on results produced by an operation model of the electric power system where the charging of electric vehicles is being considered. Vehicles are regarded as additional loads whose features depend on a mobility pattern. The operation model employed is a combination of an optimisation-based planning problem used to determine the optimal day-ahead system operation and a Monte Carlo simulation to consider the stochastic events that may happen after the initial planning step.

Contents

Part I
Operation and Maintenance

Condition Monitoring and Maintenance Methods in Wind Turbines

Rodrigo J. A. Vieira and Miguel A. Sanz-Bobi

Abstract Wind is an attractive source of renewable energy, and its use has become increasingly important over the last decades all around the world. After this explosion of installations of wind farms, an important concern has arisen concerning several topics in which the goals are to keep the value of the assets of the wind farms and to guarantee long life cycles. The continuous monitoring of the life of the wind turbines and a correct application of maintenance plan contribute to achieving these goals. This chapter first reviews the main principles supporting different strategies of maintenance, later a framework is presented integrating different aspects of the lives of the wind turbine, and finally some methods for the detection of abnormal behavior in wind turbines and for failure risk evaluation are presented applied to some real cases.

1 Introduction

Wind is an attractive source of energy, as can be seen by the growing number of installed wind farms all over the world and the future trends of new installations over the coming years [35, 41]. Furthermore, asset management is gaining attention from different perspectives in industry, including wind energy, due to the competitive context where current businesses are being developed. Of increasing interest in industry is the integration of information coming from different departments of a company, such as operation and maintenance, during the application of reliability-centered maintenance (RCM) techniques, the application of prediction techniques, and other new emerging proposals, to better reach objectives in asset management [134, 149, 169].

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The cost-effective and efficient use of available assets is crucial in the current context, due to the competitive framework where current businesses are being developed. Asset management techniques are being extended to all segments of the power industry: generation, transmission, and distribution. All these strategies require information about the life of the assets in order to make decisions for future use. In the context of power systems, many approaches have been developed throughout the last decades to analyze different aspects of the life of the equipment or assets used in the operation. Maximizing the life span of the asset is one of the measures currently being analyzed and applied in this field. Maintaining the asset when required helps to guarantee that this maximization is achieved.

New engineering systems are becoming increasingly complex and subject to more severe working conditions to reach the new operation demand and to respond to the required quality levels.

The need for having systems with higher levels of quality and low costs causes the development of equipment with new technologies and new maintenance strategies that enable the operation of these increasingly complex systems to address this growing demand.

These systems are composed of various components that work together in order to accomplish the mission of the system. This mission must be fulfilled in the best possible way, i.e., with high levels of efficiency, so as to ensure the "proper functioning" of the system. Much of this responsibility is attributed to the maintenance.

Maintaining a good efficiency and system conditions over a long period of time, in good health and with a minimal risk of failure, is a challenge. This involves having a system capable of detecting incipient failures, assessing the current health of the system, predicting its remaining useful life (RUL), and being suitable for launching maintenance actions when they are actually necessary.

Many maintenances methodologies have been developed over the past several years with the primary objective of maintaining the proper functioning of a system and/or component. Each has its merits, but in general, they focus primarily on internal features of the system or component under study, i.e., only directly related to their work environment factors.

The wind energy industry has long been adopting maintenance methods which typically focus on corrective maintenance, i.e., when a fault occurs, repairs, and preventive maintenance to be performed at fixed time intervals. More recently, predictive maintenance, that is, using data from monitoring or inspections to determine the best moment to perform maintenance actions, is being incorporated into the maintenance plans.

Preventive maintenance actions have a direct impact on the availability and reliability of equipment or components (e.g., gearboxes and generators) by improving their health condition or prolonging their life. All maintenance involves a cost and a benefit to consider. Maintenance is profitable when the cost outweighs the potential cost associated with the occurrence of a fault that it attempts to prevent.

For maintenance planning over short and medium terms, the vast majority do not consider working conditions to which the component was subjected throughout its life, but rather plan their actions based on the occurrence of faults and repair actions made in the past.

Furthermore, it should also be noted that in recent years, the increasing application of continuous monitoring systems prompted the development of various diagnostic techniques. These techniques try to verify certain parameters and then analyze the possibility of a component failure in its current condition or with an estimated evolution. For that reason, there must be a history of failures with enough information to apply some statistical and probabilistic techniques that enable the diagnosis and identification of such unavailability.

For systems that do not have adequate and sufficient historical failure, physical models capable of simulating the behavior of an industrial process or component may be used. Such models can collect various effects and analyze the possible response of a component or manufacturing process to a solicitation or an event of a different nature. Physical models are very useful both in the design phase and the production phase, once failures have occurred and there is a need to investigate how they occurred.

At present, physical models are not being used continuously, and nor are they automatically embedded into a process of industrial diagnosis, but only when it is necessary to analyze specific aspects of behavior. One reason for this may be first noted by the absence of a methodology of failure diagnosis and evaluation of health condition using these physical models in an integrated way. Another reason is that these models have to be able to get results in a short enough time to make decisions before the situation has already changed and/or cannot be avoided or the impact of a failure reduced.

On the other hand, there are effective models to detect anomalies in real time. These models require prior knowledge of normal behavior situations or the absence of failure modes. These models are very useful to anticipate possible failure modes, diagnose the causes of anomalies, and even adjust the maintenance plan to the actual needs of the equipment or industrial processes according to its real life during process operation.

However, these models would be even more useful in addition to detecting the anomaly, if they could make a forecast of the effect over the short and medium terms that an anomaly would have in a component or industrial process. If this forecast could be made in real (or near real) time, processes recommendations could be made more efficient for the people in charge of production.

In this sense, observing the currently existing standards related to the topic, it can be concluded that areas such as data acquisition, signal processing, condition monitoring, and diagnostics are sufficiently developed [100]. In contrast, it is now time to concentrate research in the areas of forecasting and decision-making [9]. To achieve the objective of increasing investments in predictive intelligence techniques, maps are designed from relationships between variations in product quality and equipment degradation processes [77]. Furthermore, analysis of degradation should consider the work environment in which the equipment is inserted along their life cycle to make appropriate predictions [142].

On the other hand, it would be appropriate that maintenance methodologies were integrated with an asset management system to help in the decision-making process and thus perform maintenance actions more efficiently not only from the maintenance engineering point of view, but also from the "general system management" point of view, i.e., assessing associated risks, reducing costs, prolonging the life of the assets, and in the end providing a high-quality service and reliability [12, 134, 145]. However, strategies for the integration of all of this information are being developed, and the existing ones are being improved.

2 The Maintenance: A Review

This section presents a summarized review of the main maintenance concepts and applications in the field of wind turbines.

2.1 Asset Management in the Maintenance Context

"Maintenance" is defined as the combination of all technical, administrative, and managerial actions during the life cycle of an asset in order to "keep" or "to restore" the status that allows it to run the function for which it was designed [38]. Thus, it is very important that maintenance is integrated into the overall system management (asset management), i.e., to consider the impact of their decisions on the operational and financial management of the asset.

An asset can be defined as a unique and identifiable element or a group of elements that has a financial value and against which maintenance actions are performed. Asset management is the ability to model and compare operational, maintenance, and financing alternatives in order to find a global solution for the system. This solution must meet the required conditions of the system and look for the best trade-off between costs and benefits [59, 110].

In Fig. 1, the "asset life management wheel" is shown, where it can be observed the different areas (operation, maintenance, financial, quality, etc.) of an industrial asset with its different levels (execution and decision-making). From an input (system resources), the industrial asset generates or produces a product or service (system function output) plus some residues, e.g., in a thermo-electric power plant from the fuel (gas, oil, etc.), is expected to generate electrical energy and some residues such as smoke.

"Asset efficiency" is directly related to the well-being of the system function and the right balance between the resources inputs and outputs. All the different asset areas work (sometimes independently and sometimes together) to achieve the maximum system efficiency, centered on the asset needs.

Furthermore, in Fig. 1, two "data or communication rings" are highlighted. One ring is accessible by all (system data ring), and the other (general system data

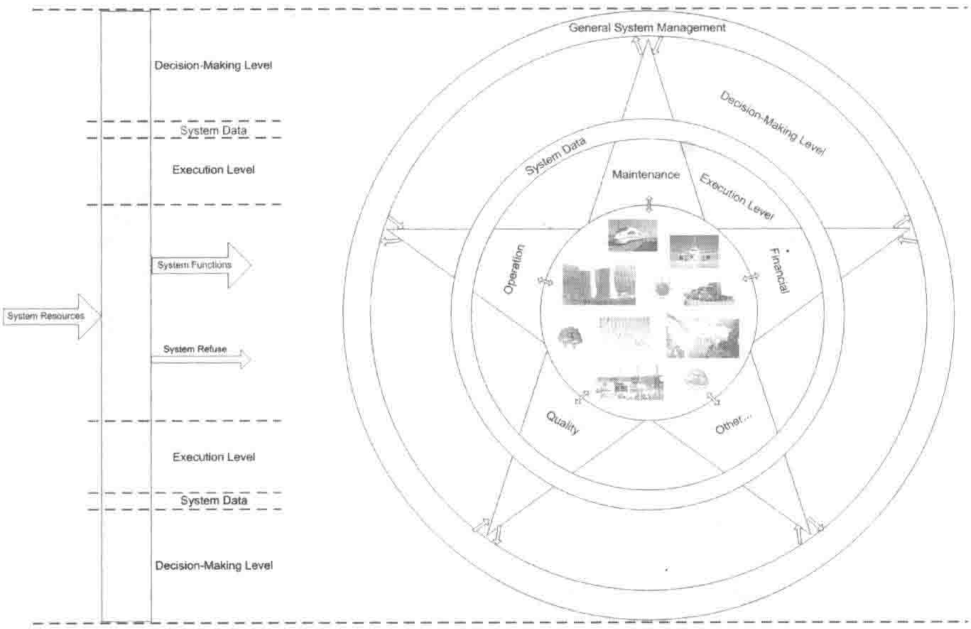

Fig. 1 Asset life management wheel

management ring) is only accessible by the senior managers of each area. In the ring are available storage system information and data. In the second ring, there is only shared strategic information related to the system/asset management within the environment in which it is inserted and where it acts.

Asset management and maintenance management represent a complex business area, including and requiring different processes and the integration of a wide range of knowledge (from technical and management to information and communication technologies, philosophies, management strategies, etc.) to provide an effective and satisfactory service to its customers. Over the last years, this integration is becoming more complex by increasing the amount of information to be processed [29].

The field of asset management is becoming increasingly professional. Knowledge related to the "practical application" of asset management exists in literature. However, this knowledge is less developed when compared to other areas [150]. Moreover, some models could be found in literature to formalize the knowledge and asset management practices, but sparingly and with only partial coverage of the very extensive and deep topic of asset management [56].

Asset management is nowadays a new and growing part of industry [128]. One of the facts that contributes to its growth is that asset management is witnessing the proliferation of various software [148], but each one is an independent solution within their expertise area (strategic planning, evaluation of the asset condition, inventory, etc.). Furthermore, not many software packages have been found with the potential ability to integrate data throughout the asset management cycle [57, 81, 114].

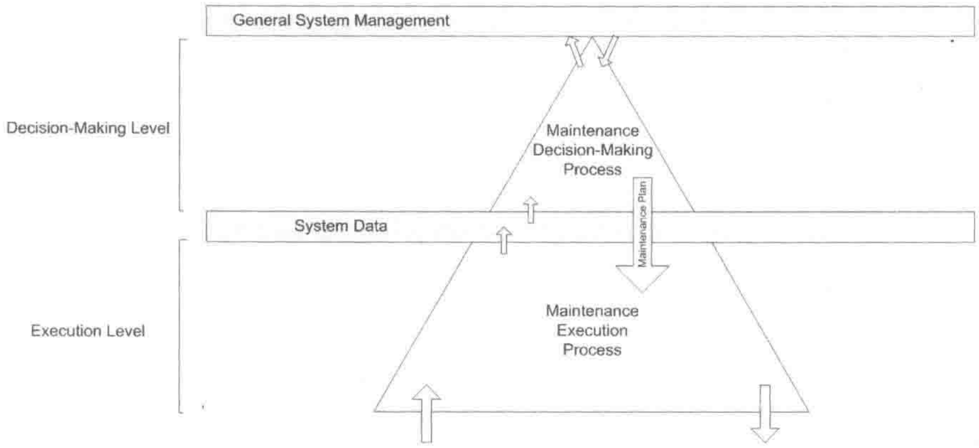

Fig. 2 General maintenance process

2.2 Maintenance Decision-Making Process Classification

Literature and maintenance-related knowledge can be found in the state of the art, according to different classifications proposed in some references such as [34, 48, 116, 146, 157]. These classifications are generally very long and complex; however, they are limited because in the end they cannot be easily applied to all literature related to maintenance.

In this section, a new maintenance process classification is proposed, supported by concepts related to asset management, i.e., according to the decision level that each method aims to address or contribute. Thus, the maintenance process is divided into two distinct parts (see Fig. 2), being one related to the execution process and the other related to the decision-making process in the same way as presented in other areas of the asset (system) in Fig. 1.

The "execution of maintenance" has the function to carry out the maintenance plan defined for the asset, i.e., it is the "physical" part referred to as the maintenance infrastructure (people, parts, working tools, etc.).

The other part is the maintenance decision-making process where three participation levels will be considered (described in detail in Sects. 2.3, 2.4, and 2.5): Maintenance Preprocessing, Maintenance Strategies, and Maintenance Management (Fig. 3).

This figure highlights the different levels of abstraction and interpretation of knowledge needed in the maintenance decision-making process, where the data represent the lowest level of interpretation or meaning in these levels. After the beginning of the interpretation process, the data are considered to be "information" and therefore knowledge.

The first level of the maintenance process in this classification is defined as maintenance pre-processing. The overall objective of this level is the conversion

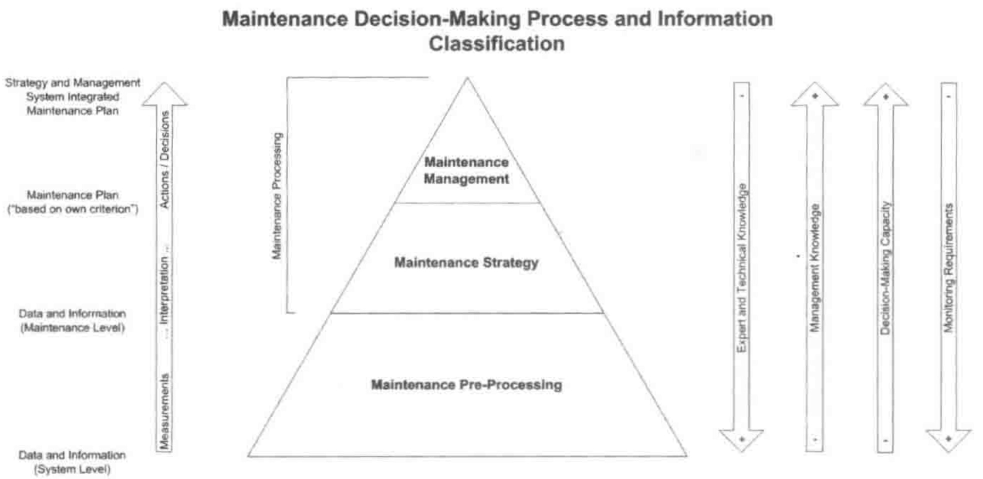

Fig. 3 Maintenance decision-making process

of the information or data available in the system to "treated" information to be used for the second level of this classification (maintenance strategies). In general, the methods are based on standard models or "expert" techniques supporting the maintenance strategies without the objective of making decisions with regard to the maintenance plan.

The other proposed classification level is called maintenance strategies, which are methodologies able to create and/or optimize a maintenance plan for the overall system using as input the information from the maintenance pre-processing level. At this level, the maintenance actions are planned and prioritized according to the criteria of each strategy.

The last classification level is formed by the support structures and methodologies in maintenance management that are responsible for integrating the proposed decisions from the maintenance strategies within them and with the restrictions and guidelines of the system. The final result of this level will be a maintenance plan set to the general interests of the system (operational, maintenance, financial, etc.) giving decision-making support within the asset management philosophy.

In Fig. 4, the three levels are presented in detail within the system structure. Thus, it is clear that the maintenance process of decision-making shall be as "final product" a maintenance plan integrated with the guidelines and strategies of the overall system. This maintenance plan, obtained from all available information in the system, will be executed by the other part of the maintenance process (execution level) shown in Fig. 2 and responsible for its implementation.

The following Sects. 2.3, 2.4, and 2.5 are three maintenance decision-making levels with the aim of defining the frontiers of knowledge as presented in the related literature and thus clarifying the main weaknesses, limitations, and future development trends.