METHODOLOGY FOR ASSESSING THE RELIABILITY OF AGS BASED ON RENEWABLE ENERGY SOURCES

N.S. Mammadov[1], K.M. Mukhtarova[2]

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Azerbaijan State Oil and Industry University, Baku, Azerbaijan
[1] nicat.memmedov.sa@asoiu.edu.az ; [2] kubra.muxtarova.m@asoiu.edu.az

Abstract

With the introduction of renewable energy sources, in particular wind power and photovoltaic installations, in the autonomous generation systems, the problem of reliability of the equipment used and the entire energy complex becomes one of the main ones. It is necessary to develop and improve methods for analyzing and calculating reliability, which will make it possible at the design stage to take into account the probabilistic characteristics of renewable energy resources, reliability indicators and operating experience of the equipment used. The article discusses the scheme of an autonomous energy complex based on renewable energy sources. A graph of the dependence of failure rate on recovery time is presented. This paper discusses various methods for assessing the reliability of autonomous generation systems based on renewable energy sources: analytical methods, state space method (Markov process theory), Monte Carlo method, fault tree method and state enumeration method. The advantages and disadvantages of these methods are considered.

Keywords: autonomous generation systems, renewable energy sources, energy complex, wind turbine, reliability.

I. Introduction

In recent decades, renewable energy sources (RES) have become a key element of sustainable development strategies. These sources, including solar, wind, hydropower and biomass, have significant potential to reduce dependence on fossil fuels and reduce environmental impacts. One of the most promising applications of renewable energy sources is autonomous generation systems that provide electricity to remote or isolated areas where connection to centralized power grids is not economically or technically feasible.

There are several main configuration options for constructing autonomous generation systems using wind turbines and/or solar panels, diesel generators and batteries:

– a wind turbine operating in conjunction with a diesel generator;

– a wind turbine operating in conjunction with a diesel generator and an energy storage system;

– photoelectric converter operating in conjunction with a diesel generator and battery;

– joint operation of a wind turbine, photoelectric converter and diesel generator;

– joint operation of a wind turbine, photoelectric converter, diesel generator and battery.

The composition of the equipment of autonomous generation systems based on renewable energy sources varies depending on the availability of local energy resources. Figure 1 shows a scheme of an autonomous energy complex using wind and solar energy. This complex includes:

1) generating equipment photoelectric converter, wind turbine, diesel generator and energy storage system;

2) elements of transformation (inverter, converter, rectifier), transmission (cable line) of electricity;
3) switching equipment (automatic switches).

Photoelectric converters generate constant voltage electricity, which depends on external conditions, unlike wind turbines and a diesel generator. To coordinate different voltage levels received from the panels, wind turbines and diesel generators, and to ensure the rated output voltage, when the solar cell operates in the maximum power output mode, a converter is used in the circuit. The batteries serves as a backup power source and helps smooth out possible power fluctuations caused by the variable nature of natural energy resources [1-5].

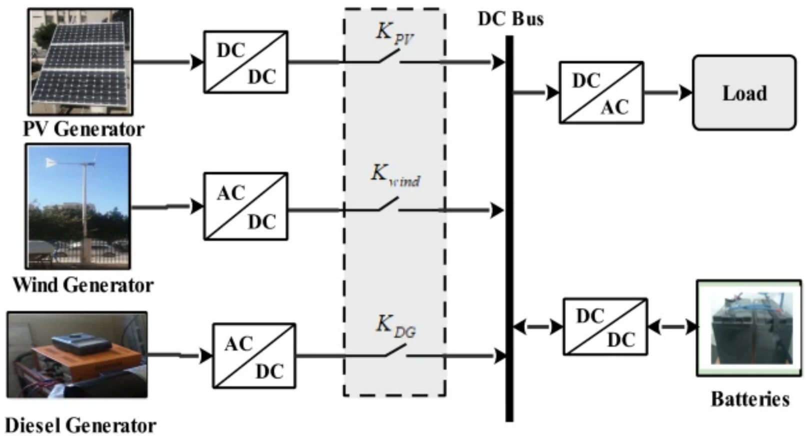

Figure 1: *Scheme of an autonomous energy complex based on renewable energy sources*

II. Formulation of the problem

The reliability of such off-grid generation systems is a critical factor in determining their efficiency and acceptability. Reliability refers to the ability of a system to perform its functions under specified operating conditions over a required period of time. For autonomous generation systems based on renewable energy sources, this means a stable and continuous supply of electricity, despite variable and often unpredictable natural conditions. The main challenges facing such systems include the variability of generated power due to natural factors, the need for efficient energy storage, the integration and management of different types of renewable energy sources, and the durability and wear resistance of system components. Given these challenges, the development of reliability assessment techniques is becoming a key element in the process of designing, operating and improving autonomous generation systems.

Over time, equipment in electrical power plants may fail. Failure is defined as an event in which the operational state of an object is disrupted. Most often, failed elements can be restored. The use of reserve elements allows you to restore equipment without interrupting its operation. The process of equipment restoration and prevention does not completely eliminate the possibility of failures, but significantly reduces their likelihood, which increases reliability. Any object and its properties can be described using various systems of reliability indicators. The choice of a system of indicators depends on the nature of the object, its purpose, general requirements for the process and the results of its operation, as well as the economic efficiency criteria used. In this work, the main indicators characterizing the reliability of electrical equipment of autonomous generation systems (AGS) based on RES are the failure rate $\lambda(t)$, 1/year, the average recovery time τ_{avg}, h, and the recovery rate μ, 1/year. Failure rate is the conditional probability density of a failure occurring at a given point in time, provided that a failure has not occurred before that point. The physical meaning of the failure probability density is the number of failures of an element over a sufficiently short time interval [6-9].

Figure 2 shows a failure rate vs. operating time curve that is typical for many pieces of electrical and electronic equipment. The figure shows that the entire time interval can be divided into three sections. The first section (run-in period) is characterized by increased values of the function $\lambda(t)$ due to equipment failure shortly after the start of operation, caused by hidden defects during production. The second section (the period of normal operation) is characterized by a constant value of the failure rate. The last section is the aging period.

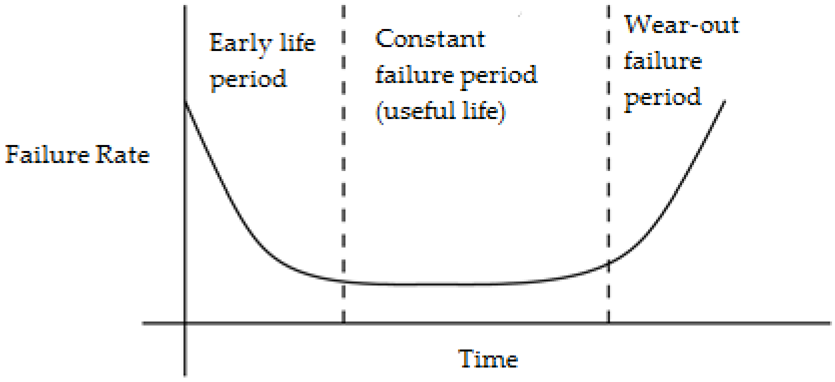

Figure 2: *Dependence of failure rate on recovery time*

In this work, we assume that $\lambda(t)=\lambda=const$, since for most elements in autonomous generation systems based on renewable energy sources, the failure rate remains almost constant for a long period of time. The run-in period can be ignored, assuming that normal operation begins immediately after its completion. Mean time to recovery is the time required to detect and eliminate one failure, during which the equipment is in forced downtime. The recovery time of wind turbines or photovoltaic panels depends on many factors, the main of which is the nature of the failure, the availability of technical diagnostics, as well as the level of qualifications of maintenance and repair personnel. Complex indicators characterizing the reliability of the operation of autonomous generation systems (AGS) based on renewable energy sources (RES) in this work include the forced (emergency) downtime coefficient (q_d) and the availability coefficient (K_a). The forced downtime coefficient is the probability that a system (or its element) will be inoperable at a randomly selected point in time between scheduled repairs. Forced downtime includes periods necessary to detect and eliminate failures, restart the system, as well as downtime caused by the lack of spare parts and maintenance. In this case, downtime associated with scheduled repairs and maintenance is not taken into account [10-12].

III. Problem solution

Analyzing the reliability of autonomous generation systems based on renewable energy sources is a complex practical problem, the solution of which has been the subject of a significant amount of research. Let's consider various methods for assessing the reliability of autonomous generation systems based on renewable energy sources: analytical methods, state space method (Markov process theory), Monte Carlo method, fault tree method and state enumeration method. Most studies have focused on assessing the reliability of generation systems based only on wind or solar energy, while significantly less work has been devoted to assessing the reliability of systems using renewable energy sources in combination with traditional energy sources such as diesel generators.

The analytical method provides information about the probability of failure of generation facilities to cover the predicted load. In most analytical methods, the generation model is presented in the form of a table of powers and associated outage probabilities. The load model is represented by a daily peak load curve or a constant load curve. Also, the analytical method makes it possible to determine the probability of load loss and the expected shortfall in energy supply from an autonomous system based on wind turbines, diesel generators and an energy storage system. An analytical method can also be proposed for assessing the reliability of an autonomous wind turbine, represented as series-connected elements. The overall failure rate is estimated based on statistical data on the reliability of wind turbine elements, taking into account planned repairs and weather conditions. Another analytical method is a method that takes into account the uncertainties associated with solar radiation, wind speed, electricity consumption and shutdown of various generators. Beta and Weibull distributions are used to model solar radiation and wind speed. The study period is divided into several time periods. In practice, there is also the use of an analytical method to determine the probability of failure-free operation of a system consisting of PV arrays with various converter connection schemes [13-16].

The Monte Carlo method involves simulating hourly data on natural energy resources (wind speed, solar radiation) for various locations using time series models created from historical data collected over several years. Figure 3 shows a model with wind data for the summer season. Hourly data on natural energy resources makes it possible to determine the power output of wind turbines and/or solar power plants. The method also includes modeling the state of the battery based on the generation and load time series of the analyzed system. The difficulty in applying the Monte Carlo method is the need to have accurate and detailed data on wind speed or solar radiation for a specific location. For many regions, meteorological data is either unavailable or available in compressed form.

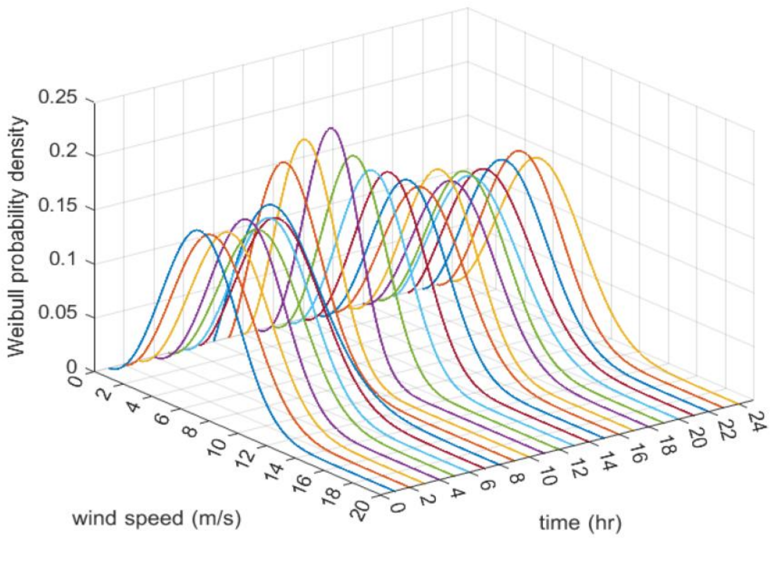

Figure 3: *Model with wind data for the summer season*

To analyze the reliability of renewable energy sources in autonomous generation systems, a state space method (Markov processes) is also proposed. An analysis of the reliability of an autonomous wind farm consisting of two wind turbines shows that all possible transitions in such a system are described by a Markov state graph. To analyze the reliability of an autonomous wind farm, taking into account the stochastic characteristics of wind speed, wind turbine failures and repairs, a model implemented using Markov chains can be proposed.

The main advantage of the state space method is the clear representation of all states of the system and the transitions between them. Assessing the reliability indicators of technical systems using Markov chains allows one to take into account many factors (partial failures, failures due to common causes, emergency and planned repairs, weather conditions, dependent failures, sequence of failures) affecting the system. However, the method has a number of disadvantages that limit its use: the lack of initial data (the intensity of the transition between states, the probability of states and the duration of stay in each state), the high dimension of the mathematical model when analyzing the reliability of generation systems with a large number of elements.

The fault tree method and state enumeration method are less common for assessing the reliability of autonomous generation systems based on renewable energy sources. The fault tree (FT) method is used to assess the reliability of an autonomous power supply system based on solar cells and batteries, taking into account failures of the inverter and control system. It is also used to assess the reliability of large-scale grid-tied PV systems by taking into account the presence of an energy storage system and a charge controller. The DL method is a powerful tool for assessing the reliability of real technical systems, as it allows you to predict potential failures and improve the reliability of the system at the design stage, visually representing the cause-and-effect relationships between failures and identifying weak points of the system. However, constructing a fault tree requires significant effort, which limits its use in assessing the reliability of autonomous power supply systems based on renewable energy sources.

The state enumeration method is used to quantify the reliability indicators of an autonomous power supply system based on solar cells. The method takes into account the impact of system component failure rates on output power, voltage level and power loss. Each component of a photovoltaic system can be in one of two states: operating or non-operating. The method of enumerating states allows one to take into account changes in the intensity of solar radiation, but is only suitable for systems with the same type of elements [17-20].

Despite the wide variety of methods for analyzing the reliability of AGS using RES, some issues remain unresolved or require more careful study. In particular, the following are not fully taken into account: the influence of weather conditions on the reliable operation of generation systems; emergency failures of generating and additional equipment (inverter, converter, busbars, cable lines), backup equipment and switching equipment. This creates a need and determines the relevance of carrying out research work on the development of scientifically based models and methods for analyzing the reliability of AGS based on RES.

IV. Conclusions

Analyzing the reliability of autonomous generation systems based on renewable energy sources is a complex task that requires taking into account many factors and the use of various methods. The methods discussed, such as analytical methods, state space method, Monte Carlo method, fault tree method and state enumeration method, offer different approaches to assessing the reliability of systems. Each method has its own advantages and disadvantages, which determines their use depending on the specifics of the system being analyzed.

Analytical and Markov process methods can provide accurate estimates when the necessary data are available, whereas the Monte Carlo method requires detailed meteorological data for specific locations. The fault tree method and the state enumeration method are powerful tools for analyzing real technical systems, but require significant effort in their implementation. In general, the use of combined approaches and the development of methods for assessing reliability makes it possible to increase the efficiency and sustainability of autonomous generation systems based on renewable energy sources.

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