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Evaluation of the operational reliability of a smart electric grid

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Abstract
The paper considers the trends in the development of the modern electrical networks and their transformation into Smart grids. The possibilities for traditional networks functioning as Smart grids are described. The technical means by which a passive electrical network is converted into a Smart grid are considered. Analysis is made of the features, on the basis of which the selection of the indicators for evaluating the operational reliability of a Smart grid is carried out.

Keywords: smart grid, operational reliability

Introduction

Traditional electrical networks are designed and built according to the requirements to deliver the produced electricity from the energy sources to the consumers. In recent years, the question of their renewal has arisen for the following reasons:

- A large part of the existing electrical networks in our country are operated much longer than their period of operation by design.
- The demand for electricity is constantly increasing, which leads to high load and throughput problems of the elements in the electrical networks.
- In recent years, a large number of decentralized energy sources (DES) have been connected to the electricity grids, which has changed their structure and their modes of operation.

The global demand for electricity will increase in the future. This necessitates the need to improve the traditional electrical network and ensure its transition into a modern Smart grid.
The paper aims at making an analysis of the features, on the basis of which to select the indicators for evaluating the operational reliability of a Smart grid.

Trends in electrical networks development

Smart electrical grids are a new direction in the electricity sector development. Many technical means of digitization, computer technologies, communication systems and automation devices have been implemented in the modern electrical networks, which allows for realizing the rational use of the energy resources and achieving optimal operational conditions [1÷5].
The decentralization in the Smart grid allows allows for appearance of new independent electricity producers. These are the decentralized energy sources (DES), constructed on the basis of renewable resources: wind power plants, photovoltaic systems, small water power plants, etc. The incorporation of DES to the existing electrical networks requires coordinated functioning of both systems and matching the settings of the protective equipment and the means of automation [6÷10]. The operation of the DES within the Smart grids must take into account the amount of electricity demanded by the consumers and the operation of the storage devices.
Modernization of the traditional electrical networks, based on new principles and technologies, ensures increased reliability of the connections between the electricity producers and electricity consumers [11÷14].

The trends in the development of the modern Smart grids are:

- implementation of innovative technologies;
- digitization, anti-emergency automation, tele-mechanics and automated control systems;
- adaptation of the characteristics of the facilities depending on the operating modes;

active interaction between generation and consumption, which allows to create a system with implemented modern information and diagnostic systems, tools for automation control and self-diagnosis of all elements involved in the processes of electric power transmission, distribution and consumption (Fig. 1).

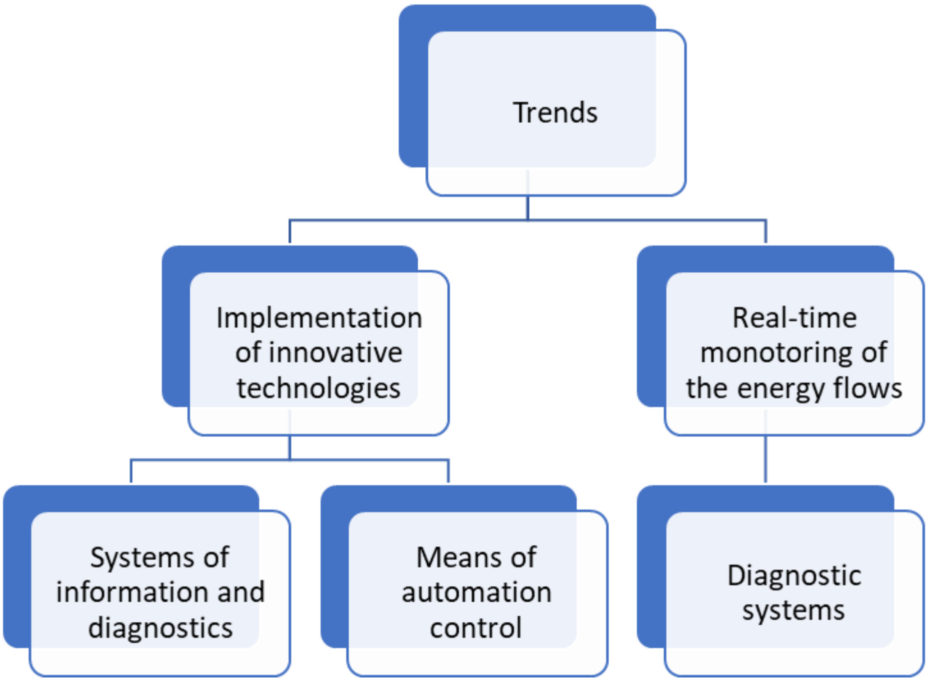

Fig.1: Trends in the development of the modern Smart grids

The built Smart grids result from transformation of passive devices for power transmission and distribution into active elements with parameters and characteristics, which vary depending on the operation modes of the electrical network.

Basically, the main tasks of the adaptive systems are:

• taking over the changes of mode nature;

• reacting to changes, which occur when new elements are added to the Smart grid or when the configuration of the electrical network is changed.

By monitoring the mode parameters in the Smart grid, optimization of the control over the balance between demand and supply of electricity is achieved.

With the construction of a communication network infrastructure, implemented in the Smart grid, the electricity supplier has more information about the consumers. With the two-way communication between the consumer and its supplier, the harmonization of the electricity management is possible. In traditional electricity grids with a centralized structure, the electricity flows are one-directional, from the producers to the consumers. In a Smart grid with DES, it is possible to integrate multiple producers with different capacities and new ways to store electricity, thereby achieving accumulation and increasing the reliable electricity supply of consumers.

Possibility to operate traditional networks as Smart grids

The question arises about the possibility of traditional networks to work as Smart grids. From this point of view, the traditional networks are divided into two groups:

- electric power transmission networks for high and extra-high voltage;
- electric power distribution networks for medium and low voltage.

The power transmission networks for high and extra-high voltage meet the requirements and have a high degree of readiness for operation as part of the Smart grid. They are equipped with digital relay protections, anti-emergency and technological automation, tele-mechanics and automated control systems. In addition, the power transmission networks have a ring structure and provide two-way power supply to the consumers, which is one of the requirements for building a Smart grid.

The distribution networks for medium and low voltage are not ready yet for direct transition to operation as part of the Smart grid. They do not meet the basic pre-conditions for a Smart grid: observability of the mode parameters, two-way power supply to the users, automated control and diagnostic systems. Usually, the distribution networks for medium and low voltage are open branched. The first stage of achieving two-way power supply to consumers is the provision of emergency connections, redundancy and reconfiguration of the power grid. The implementation of DES to power distribution networks creates conditions for bilateral power supply of the branch, to which the consumers are connected.

Electrical networks operation is based on the principle of balance between the produced and consumed electricity at any moment in time, regardless of their structure. There is no provision for accumulating the excess amount of electricity in traditional networks. The Smart grid envisages the introduction of powerful storage systems to be charged during the surplus of electric power and, accordingly, its consumption - in the event of a shortage of power during consumption increase. The creation of powerful electricity storage systems allows to stabilize the modes of operation of the generating sources within a day: in the hours of low consumption accumulation takes place, and in the hours of peak loads, consumption of the accumulated electricity begins. Combining the work of DES with the operation of the storage systems creates conditions for continuous electricity supply to hybrid users.

Evaluation of the operational reliability of a Smart grid

Basically, reliability is the property of the object to perform its functions, keeping the operational indicators within set limits during the operational period [15]. Reliability is a complex property, evaluated according to 4 indicators - infallibility, durability, repairability and storability or by a combination of these properties. Two more are added to these for electric power facilities: safety and continuity of power supply.

The choice of a reliability indicator to be investigated depends on the type of reliability evaluated: parametric, functional, a priori, operational, structural.

To evaluate the operational reliability, it is appropriate to study the infallibility indicator - this is the property of the object to preserve its operability continuously for a certain period of time.

In order to evaluate the operational reliability, it is necessary to consider the generating sources, electrical networks and storage systems as elements of the Smart grid system. From the infallibility indicators, the probability of failure-free operation is selected for evaluation.

Taking into account the described features, when evaluating the operational reliability of the Smart grid, the following states are considered (Fig. 2):

1 – state of failure-free operation of all elements of the Smart grid;

2 – state of unsustainable failure of a Smart grid element (which self-removes during the diagnostic process);

3 – state of sustainable failure of a Smart grid element with successful automatic switching and restoration of the power supply to the consumers;

4 – failure status of a Smart grid element.

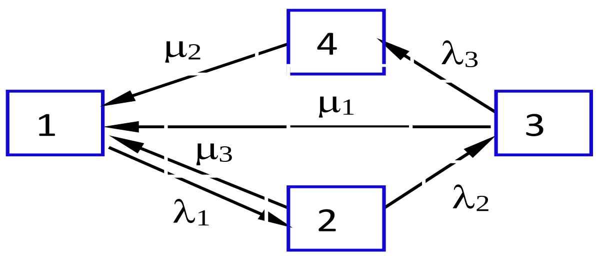

Fig.2: State diagram: l_i - failure intensity; m_i – recovery intensity

According to the state diagram of the Smart grid from Fig. 2, the calculation expressions for determining the probabilities P_i (i=1÷4) for the respective states are derived:

(1) $$P_1 = P_4 \frac{\mu_3}{\lambda_3} \cdot \frac{\lambda_3 + \mu_2}{\lambda_2} \cdot \frac{\lambda_2 + \mu_1}{\lambda_1}$$

(2) $$P_2 = P_4 \frac{\mu_3}{\lambda_3} \cdot \frac{\lambda_3 + \mu_2}{\lambda_2}$$

(3) $$P_1 = P_4 \frac{\mu_3}{\lambda_3};$$

(4) $$P_4 = \frac{1}{1 + \frac{\mu_3}{\lambda_3}\left[1 + \frac{\lambda_3 + \mu_2}{\lambda_2}\left(1 + \frac{\lambda_2 + \mu_1}{\lambda_1}\right)\right]}.$$

To estimate the probabilities P_i, data from the operation of the Smart grid are needed regarding the failure intensity l_i and the recovery intensity m_i. The more the probability P1 approaches to 1, the more the Smart grid becomes fully functional.

Conclusions

- Smart grid construction is the main trend in traditional electrical grids development. Modern technical means allow at any moment of time to control the generation of electricity according to the magnitude of the load, and to accumulate excess energy and use it if necessary.
- The implementation of innovative technologies allows for increasing the reliability and efficiency of power supplying the users.
- The proposed approach for evaluating the operational reliability of the Smart grid allows to estimate based on operational data the probability of failure-free operation, which, for a real smart grid should have a value close to 1.

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