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Trends of changes in the power generation system structure and their impact on the system reliability

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ABSTRACT

The reliability of the electrical power system depends primarily on the reliability of the power generation sector and the subsystem of power transmission. In recent years there has been a dynamic rise in the amount of power obtained from renewable energy sources in the Polish power sector, including power generated in wind power plants in the first place. The efficiency of wind power plants strongly depends on the wind velocity. This paper presents a reliability analysis of the Polish power generation system. The results are compared to the reliability of North American systems given in NERC (North American Electric Reliability Corporation) reports. The analysis takes electricity generation on wind farms into consideration. A forecast of the reliability of the Polish system of power generation is also presented taking account of planned investments and investment projects which are now in progress. The impact of the increased amount of wind energy on the reliability of the bulk system is discussed. It is shown that, from the point of view of the system reliability, there is a limit to the volume of the share of wind energy in the total amount of electricity generated in the system. Increasing the amount of energy generated by wind farms involves the need to store it, e.g. in pumped hydroelectric storage power plants.

1. Introduction

The system reliability is characterized by its capability to satisfy the requirements, i.e. to provide the necessary supplies of energy – electricity in the first place – to customers. Naturally, this energy has to meet the appropriate quality criterion. Two aspects are named in the context of the power system reliability: adequacy and safety. Adequacy is defined by the system ability to fully satisfy the demand for energy in a given period, and it depends, among other factors, on the capacity for electricity generation and its correct distribution. Adequacy is strongly affected by the system failure rate and the management of routine repairs.

The other aspect of the system reliability is safety understood as the whole system resistance to sudden disturbances and failures of its components. Both these aspects are closely interrelated and can exert an influence on each other. The effect of the hierarchical structure of the electrical power system is that the system reliability is dependent on the reliability of its subsystems, down to the elements of the power engineering machinery and equipment. A failure may occur at any of the levels mentioned above and the failure consequences may affect higher levels. On the other hand, the failure and the consequences thereof may have no impact on the operation of more complex subsystems. The system capability to control such local failures or instances of damage to the system elements proves that the level of the electrical power system safety is adequate.

Planning the development of power systems, including an increase in the share of electricity generated by wind power plants, different factors need to be considered, be it technical, economic or such as the present structure of a given system and the availability of different types of fuel. Ensuring an appropriate level of reliability of power systems is an essential criterion for their development. Therefore, optimization of this process should be customized to suit the needs of different countries.

In recent years the structure of generation systems has been changing significantly. This is the result of the aging of the currently operated power units which have to be replaced with new plants. Another cause is the dramatic development of renewable energy sources which supplement or often replace decommissioned coal-fired power units.

Western European countries, such as Germany or Denmark, have solved the problem of the increasing share of electricity

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obtained from renewable sources by implementing the “smart grid” [1,2]. This type of network favours distributed electricity generation and helps the system to remain stable. It departs, however, from the stereotypical producer-transmission grid-consumer division and the unilateral energy transmission. However, it has to be remembered that the structure of energy sources of these countries is much more varied and it is easier for them to satisfy the changeable demand for power taking account of variations in generation of energy from renewable sources.

Another solution is the storage of energy produced from RES to use it in hours of peak demand. New highly efficient methods of energy storage are now being searched for all over the world. A lot of hope is put in hydrogen technologies but these are still at the stage of research and development. It is currently possible to store renewable energy on an industrial scale in CAES (compressed air energy storage) installations or use it to power pumped-storage units [3].

This paper investigates the reliability of systems with a dominating share of coal-fired plants such as the Polish electrical power system, where worn-out coal-fired power stations are being partially replaced by supercritical power units [4]. At the same time and according to the EU requirements, the share of RES – wind farms mainly – is growing rapidly. On the other hand, the appearance of such energy sources creates new difficulties as well – especially the problem of keeping an appropriate level of the entire power system reliability.

Further on, this paper presents the age structure and the reliability indices of the Polish power system, comparing them to available indices of the North American systems [5]. The Polish investment projects scheduled for the next few years in coal-fired power plants and in wind farms are presented. The impact of these projects on the reliability of the bulk system is discussed. An analysis is made of the possibilities of improving the reliability of a system based on a large share of RES by energy storage in pumped-storage power plants.

2. Age structure of the polish power units

Failure of the power unit basic components such as the turbine, boiler or generator is a direct cause of failure of power units which, in themselves and in terms of reliability, constitute a complex system whose elements are closely interrelated. At the same time, power units are elements of entire electrical power systems. There are many factors that may potentially damage an element, but the most significant are the load and the environment. Acting in time, both of them contribute to the development of various degradation processes leading to the material weakening and, in consequence, to damage. Therefore, analysing the power unit reliability, its age has to be taken into consideration. In order to illustrate this issue more closely, a comparison between the age structure of Polish power plants and the American (NERC) units is presented in Fig. 1. The comparison concerns hard coal-fired power units in 6 power output capacity ranges: from 100 to 199 MW, from 200 to 299 MW, from 300 to 399 MW, from 400 to 499 MW, from 500 to 599 MW and higher than 600 MW [5,6]. The first group comprises mainly power units installed about 40 (Poland) and 50 (NERC) years ago. In the other groups, the power unit average age is smaller, but the average for all groups under analysis is 34 years in Poland and 43 years in North America.

Detailed data on the operation time of Polish power units are shown in Fig. 2. This kind of the age structure means that the majority of power units, especially those with a lower power capacity, both in Poland and in North America, belong to a group with a long service life, which may contribute to their higher

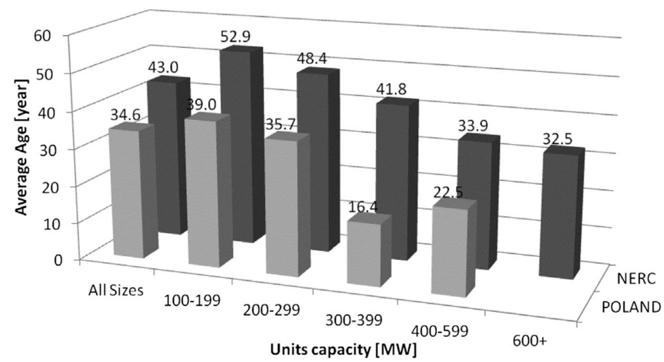

Fig. 1. Age of power units at the end of 2011.

failure rate. This is confirmed by the statistics concerning failures which are presented in Fig. 3. The share of failures caused by the material wear keeps rising and it now exceeds 70% of the total number of failures. At the same time, it is the boiler which is the most failure-prone component of the power unit. The share of the boiler in the total number of failures of the power unit main components is also rising (Fig. 4). The factors mentioned above will have an adverse effect on the reliability of individual power units as well as on the performance of entire systems. Data presented on Figs. 2–4 are calculated for lignite-fired and hard coal-fired power units.

3. Indices of reliability

The assessment of the operation reliability of power units can be based on two basic indices, i.e. the FOR (forced outage

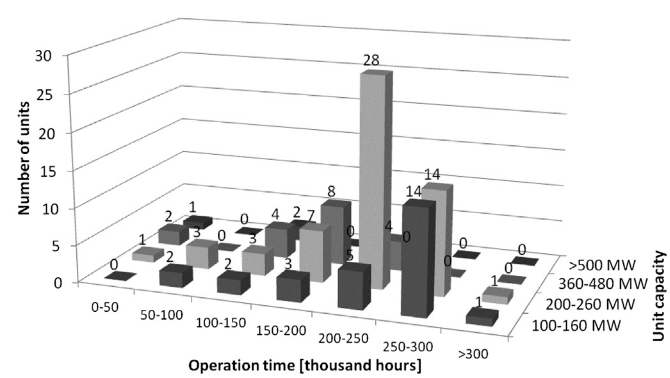

Fig. 2. Operation time of Polish power units at the end of 2013.

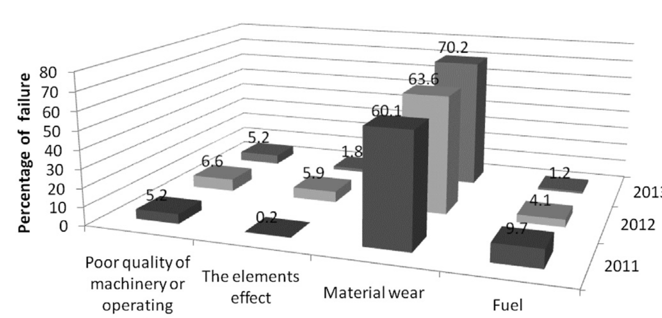

Fig. 3. Main causes of the power unit failure.