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Streszczenie rozprawy doktorskiej
Dziedzina nauk inżynieryjno-technicznych
Dyscyplina: automatyka, elektronika, elektrotechnika

Tytuł rozprawy doktorskiej

Zdecentralizowany system zarządzania zapotrzebowaniem na energię elektryczną do przesuwania obciążeń szczytowych oraz poprawy stabilności dynamicznej systemu elektroenergetycznego

Decentralized Demand Side Management System for peak load shifting and improvement of dynamic stability of power system

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Zielona Góra, 2020

Abstract

In planning and management of power flow in an Electrical Power System, maintaining stable and uninterrupted work is one of the main aims. The effect of couplings between the Electrical Power Systems of different countries is to make a larger system, with concomitant economic advantages resulting from better use of energy potential, production and transmission capacity. However, such a solution also carries the risk of losing dynamic stability, in particular frequency stability. It is well-known that system failures may occur as a result of exceptional weather conditions, such as lightning, but they may occur also during normal system operation. An analysis of the structure of the Polish Power System (85% are thermal power plants) shows there are significant problems with peak loads, which reduce the potential power reserve for primary regulation and, moreover, the peak power value is close to the maximum generation capacity of the whole Polish Power System. Due to heat, and thus difficulties in cooling the generating units, or the lack of water for pumped storage units, the power potential may be significantly reduced. An example of this was seen in the restrictions in Poland in August 2015, which naturally resulted in significant financial losses in industry. The construction of new generating units will not fully solve the discussed problems, moreover such a solution is a relatively expensive and time-consuming one. An additional limitation is found in transmission lines, which often operate at the limit of their load capacity. The efficiency of the Power System is also worth mentioning, because the large daily power fluctuations significantly affect the efficiency of energy production - in the night valley the efficiency of energy production decreases, and during the day and peak hours, transmission losses increase.

In relation to the issues described above, the key aspect which influences the continuity of the electricity power supply and the maintenance of the power balance in the power system is dynamic frequency stability. Power systems are equipped with regulators responsible for the so-called primary regulation. However, in situations where the range of regulation on the generating side is insufficient or too slow, the Automatic Load Shedding systems protect against large power imbalances, the operation of which can cause complete loss of power for consumers. The action of saving the power system in critical situations by load shedding is not the typical frequency and power regulation.

Considering the above, the author has formulated the following thesis: *Electricity demand management allows for the improvement of dynamic stability and the shifting of peak loads without adversely affecting the operation of the power system.* Testing this thesis is the main goal of the work.

A dedicated DADR (Decentralized Active Demand Response) system for electricity management on the consumer side was designed and made. The main aim

of the DADR system is to support the dynamic power frequency regulation of the power system. The DADR system consists of several AGP devices (active interconnection socket), i.e., intermediary elements between the 230 V power supply side and the controlled loads installed in a given area. The controlled loads can be, for example, a chosen type of household appliances. Each AGP independently calculates the frequency of the voltage at the point of connection. A given AGP is activated (most often it will be load disconnection during frequency decrease) in response to frequency changes, according to the programmed algorithm. The use of stochastic variables in the algorithm, allows the operation of the DADR system without communication between its components and without a superordinate controller. Hence, the operation of the DADR system is characterized by a rapid reaction speed (the reaction to a drop in frequency starts after about 1 second) and the lack of big step changes in the character of the regulation. At this point it should be noted that in the case of problems with maintaining frequency stability in the power system, in particular with the phenomenon of the so-called frequency avalanche, the speed of change of frequency is in single seconds and during this period a power balance should be achieved.

Checking whether the operation of the algorithm improved frequency stability was verified in a simulation using a single-generator model, where the frequency fluctuations were directly caused by an imbalance between the power generation and the load. Scenarios for different power potentials of the DADR system were simulated (with the power potential of the DADR system being lower or greater than the interference power). In all the considered cases, especially where the power potential of the DADR system was much greater than the power of the interference, there was an improvement in the control parameters (reduction of the adjustment time and reduction of the frequency error).

The algorithm used to reduce loads during peak hours has been simulated and compared with the algorithm's operation in a deterministic approach. In order to estimate the reduction capacity, an analysis was carried out concerning the selection of the target group of end-user which would have the main impact at evening peak hours. Dedicated loads were selected, taking into consideration the dissemination and nature of their work (cyclicality). It turns out that the most suitable loads are cooling devices, which is due to the inertia of the processes they carry out, while the group of end-users that contributed mainly to the evening peak are domestic users. Moreover, analyses carried out showed that disconnecting refrigeration devices for power system purposes will not degrade the stored food.

Experimental tests were carried out in a laboratory stand built for the purpose of the research. In the scope of the experiment, analyses were performed in which the basic assumptions of the DADR system were checked and confirmed. One of them was that there would be an equal number of activations of individual AGPs in the

DADR system during an extended period (this excludes situations in which one device will be activated much more often than another). Another assumption was that there would be an equal number of AGPs participating in each frequency error with the same duration and the same error value, which in turn would affect the predictability of the reduced power volume during frequency errors (studies conducted in an open system). Then the operation of the DADR system, consisting of 900 AGPs, was checked in a microgrid using an electromechanical set. Numerous frequency control tests were made for different power potentials of the DADR system (different numbers of AGPs participating in the regulation).

The results of the research confirmed the behavioural assumptions of the DADR system during the support of frequency regulation. The characteristic features are compiled and described at the end of the dissertation. The described issues were the subject of publications in international journals from the JCR list, among others ”Application of Stochastic Decentralized Active Demand Response (DADR) System for Load Frequency Control” (IEEE transaction on Smart Grid), ”Demand Side Management using DADR automation in the peak load reduction” (Renewable and Sustainable Energy Reviews, Elsevier) and ”Distributed active demand response system for peak power reduction through load shifting” (Polish Academy of Sciences Bulletin).