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ANALYSIS OF MODERN APPROACHES TO THE FORMATION OF AUTOMATIC FREQUENCY LOAD SHEDDING IN POWER SYSTEMS

Analysis of the approaches to formation of the automatic frequency load shedding system is conducted, requirements of the current regulatory documents to the automatic frequency load shedding (AFLS) are considered. The paper also analyzes advantages and disadvantages of the approach, taking into account absolute frequency value and frequency reduction rate, of the approach with the application of AFLS system optimal adjustment algorithm, taking into account structure of generation and consumption, as well as of the current approach to AFLS formation.

Key words: *frequency, automatic frequency load shedding, integrated power system of Ukraine, modelling, load, transient processes.*

Introduction

At present, reliable operation of the integrated power system (IPS) of Ukraine is impossible without application of modern means for frequency and active power control. Such control can be implemented through generation control, using automatic frequency and active power control system that operates in normal and post-emergency modes, as well as through load volume control by automatic frequency load shedding (AFLS), which is actuated only under emergency conditions.

One of the main problems of power system operation is ensuring its reliability and stability under emergency conditions. As the analysis of other countries' experience has shown [1], the most severe accidents are usually caused by the loss of considerable volumes of generating capacities or the loss of a region connection with the high load. In such cases frequency reduction is observed in the regions, where generation is insufficient. To prevent development of emergencies, associated with the active power deficit and frequency reduction, AFLS devices are used.

Due to the extreme importance of AFLS operation for liquidation of emergency conditions, accompanied by frequency reduction, analysis of the approaches to AFLS queues formation in IPS of Ukraine becomes especially relevant.

In order to conduct a comprehensive analysis of the problem of AFLS organization in IPS of Ukraine, the paper considers a perspective approach, that takes into account the absolute frequency value and load reduction rate, a method with the application AFLS system optimal adjustment algorithm, taking into account generation and consumption structure, as well as current approach to AFLS formation.

Perspective approach to AFLS formation, taking into account absolute frequency value and frequency reduction rate

The approach, taking into account absolute frequency value and frequency reduction rate, is strongly recommended for implementation in IPS of Ukraine in [1, 2]. On the opinion of the authors, current AFLS system is artificially slowed due to big number of queues of uniform small volumes. Therefore, according to [1, 2], there is a danger of providing frequency levels, permissible for APS, in IPS of Ukraine and, consequently, of the possibility to use APS reactors for their own needs. The proposed approach is based on the following distribution of AFLS devices: under system active power deficits automatic frequency load shedding according to frequency reduction rate must be actuated, while under local active power deficits additional automatic shedding operation is provided.

Current regulatory document [3] contains the requirements to the application of automatic frequency load shedding according to frequency reduction rate under system active power deficits, which enables bringing the existing AFLS system to the maximally efficient condition. Regulatory

requirements, in particular, indicate frequency reduction rate limits and the necessity in a substantiated approach to introducing certain changes into the existing AFLS system. According to article 9.1 of document [3], ALFS (АЧР-1С) organization for IPS of Ukraine should be performed after elaboration of specialized programs for adjustment and choice of settings of AFLS (АЧР-1С) devices on the basis of calculated long-time transient processes with frequency reduction under insufficient active power conditions and gaining the necessary experience of implementing АЧР-1С devices in strongly deficient regions of IPS of Ukraine, where (if АЧР-1С are not available) at the moment of their allocation it is impossible, as a rule, to provide liquidation of severe frequency emergencies and full de-energizing of consumers with the existing frequency load shedding devices (АЧР-1). According to 9.3, frequency load shedding devices АЧР-1С must operate with settings at $f \leq 49{,}5$ Hz and frequency reduction rate $df/dt \geq 1{,}7$ Hz/s with minimal time delay $T = 0.15$ s for detuning from short-time frequency variations [3].

It is worth noting that increased lower settings of the frequency load-shedding automatics (from 47.2 Hz to 48 Hz), proposed in [1], can cause worsening of the conditions of power station unit allocation to the regions with balanced load under frequency reduction to 47.5 Hz as a result of ЧДА-2 operation [3]. If allocated unit generation is lower than the load of the region, there is a possibility of cutting off a part of the allocated region load by reducing lower settings in case of further frequency drop. Thus, the existing lower-priority queues of frequency load shedding automatics are necessary for additional provision of successful allocation of the power station units to the regions with a partially balanced load due to slow frequency reduction to 47.5 Hz.

Besides, calculations, to which references are made in [1], do not take into consideration new capabilities of generators as to their participation in frequency control, which are resulted from their modernization, performed at power stations of IPS of Ukraine. It also should be noted that enlargement of the queues could lead to cutting off large load volumes and, consequently, to considerable amplification of emergency mode in the power system.

AFLS formation method with the application of the AFLS system optimal adjustment algorithm, taking into account generation and consumption structure

Method with the application of AFLS system optimal adjustment algorithm, taking into account generation and consumption structure, is proposed in [4, 5]. AFLS system formation according to [5] is based on the analysis of emergency modes (for normal and repair schemes). Such computations should be performed with structural changes of the scheme, connection of other consumers or other changes requiring checking the sufficiency of AFLS volume. The list of emergencies, data about AFLS locations and their settings are used as initial data for such computations. At the initial stage a list of emergency modes is formed. First, according to the analysis of all emergency modes, relative influence of each AFLS device is evaluated. For further calculations an assumption is made, that AFLS volumes to be found take continuous values in the range from zero to their discrete value. According to the authors of [5], such assumption makes it possible to obtain not only optimal shedding volume of the entire power system, but also to determine the shedding volume required from each AFLS device, taking into account its location in the circuit topology. Then search of the regions, not having the necessary active power volumes for shedding, is conducted. Analysis of the regions with insufficient shedding is required for taking decision about additional shedding volume or ignoring such situations as unlikely. At the second stage a set of loads, required to cover the active power deficit for all emergencies, is determined so that minimum amount of volume will be involved. As a result of performing the entire complex of computations, the significance of each AFLS device for the deficit region is determined, i.e. the analysis shows participation of AFLS sets in the liquidation of local emergencies. If no local emergencies for AFLS unit actuation are found, a conclusion of its not being necessary is made. On the same principle, availability of the minimum required volume for covering active power deficit is

verified for each deficit region.

A disadvantage of such approach is statistical formation of the emergency list with the use of expert analysis. This reduces significantly the amount of computations but could lead to incorrect results as it does not cover the entire variety of possible emergencies. At the end of the first stage the list of emergencies is additionally limited by ignoring a part of emergencies as being unlikely, which reduces reliability of the results.

AFLS formation method, used in IPS of Ukraine

According to 6.1.1. [3], frequency load shedding automatics is designed for preventing dangerous frequency reduction in the case of active power deficit in IPS of Ukraine or in its separate parts by means of cutting off a part of the consumers' load. Cutting off the consumers should be performed by small queues with slow frequency reduction. At present frequency reduction rate of more than 1.7 Hz / s is adopted as critical, although it is recommended to determine critical frequency reduction rate using special procedure, based on large-scale computational experiments with the application of a qualitative mathematical model of the power system.

Plans of the Scientific technical center of the electric power industry include elaboration of the methods for determining critical frequency reduction rate as well as for the adjustment and selection of AFLS settings, which respond to the frequency reduction rate.

According to the "Instruction on preparation and application of the schedules of limiting and emergency cut-off of the consumers as well as of the electricity consumption emergency reduction systems" [6], AFLS is developed, used and updated in accordance with the "Rules of using system emergency control automatics for preventing and liquidation of dangerous frequency reduction or increase in the power systems" [3]. Tables 1, 2 present the existing AFLS structure with percentages and loads of the last year.

Table 1

Distribution of the load in IPS of Ukraine, which is disconnected using AFLS (АЧР-1 – САЧР, ЗАЧР and main queue of АЧР-1), depending on the setting and frequency

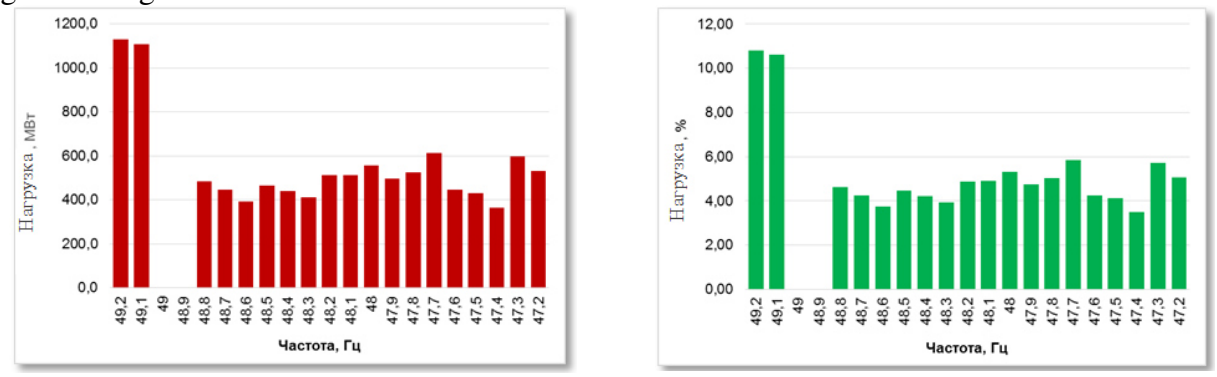
S No.	Actuation frequency	Load to be disconnected, MW	Percentage of the load to be disconnected, %
1.	49,2	1130,4	10,81
2.	49,1	1108,2	10,60
3.	48,6	482,8	4,62
4.	48,5	445,5	4,26
5.	48,4	391,4	3,74
6.	48,3	465,9	4,46
7.	48,2	440,1	4,21
8.	48,1	411,8	3,94
9.	48	510,8	4,89
10.	47,9	512,8	4,91
11.	47,8	554,6	5,31
12.	47,7	496,0	4,74
13.	47,6	524,5	5,02
14.	47,5	611,2	5,85
15.	47,4	445,1	4,26
16.	47,3	431,1	4,12
17.	47,2	365,2	3,49
In total:		10453,6	100

Table 2

Distribution of the load in IPS of Ukraine, which is disconnected with AFLS (АЧР-2, combined), depending on the frequency setting

S No.	Actuation frequency	Load to be disconnected, MW	Percentage of the disconnected load, %
1.	49	1643,4	21,1
2.	48,9	1696,0	21,8
3.	48,8	2426,5	31,2
4.	48,7	2012,4	25,9
In total:		7778,3	100

Graphical representation of the load, that is disconnected with AFLS (АЧР-1) in IPS of Ukraine, is given in Fig. 1.



a) b)

Fig. 1. Graphical representation of the load in IPS of Ukraine, disconnected with AFLS (АЧР-1): a) in absolute units; b) as a percentage

At present, according to the annual "Decision on AFLS system (АЧР-ЧАПВ) formation principles in IPS of Ukraine for autumn-winter maximum", AFLS settings are reviewed once in a year. In accordance with the Decision, for each power system a certain load volume, which must be allocated to AFLS action, is indicated for each queue as a percentage of the total consumption. Thus, load volumes to be allocated to AFLS are annually reviewed and corrected according to the requirements of current regulatory documents [3]. Such approach is considered to provide efficient AFLS operation, i.e. it prevents frequency reduction below a corresponding level during the period exceeding the permissible time, and enables automatic recovering of the power system adequate operation.

Conclusions

Each of AFLS formation methods, considered above, has certain advantages and disadvantages. Main disadvantage of the method, taking into account absolute frequency value and frequency reduction rate, is loss of flexibility due to enlargement of the queues as compared to the existing ones. Besides, increasing settings of the lower queue above ЧДА-2 level may cause worsening of the conditions of power station units allocation to the regions with partially balanced load. Method with the application of AFLS system optimal adjustment algorithm, taking into account generation and consumption structure, does not consider the entire variety of possible emergency conditions and can be useful only for studying small power regions.

The conducted analysis has shown that none of the proposed methods takes into account perspective and already performed replacements of the equipment at power stations, which is involved in frequency control and should be taken into consideration for computation of long transient processes.

For qualitative research on the expediency of introducing changes into existing system of AFLS formation it is necessary to conduct a large-scale computational study of long transient processes in

IPS of Ukraine, taking into account simulation of AFLS units as well as the equipment involved in frequency control. This requires application of a detailed and qualitative model as well as of the advanced software packages.

It is worth noting, that none of the discussed methods takes into consideration limitation of power leakage across the controlled cross-sections, existing in IPS of Ukraine, in the computations and, therefore, they do not assume the possibility of losing stability of the modes due to the changes of flow distribution during AFLS operation under frequency reduction. The latter could lead to the development of additional emergencies, caused by the loss of stability.

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