Adaptive frequency islanding system for distributed generation energy districts

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Abstract. This paper presents the developed Adaptive frequency islanding system for distributed generation energy districts. The research is initiated due to the changes of power system structure, increasing the share of distributed generation. At the same time the existing islanding systems have a number of disadvantages, which leads to generation-shedding of distributed generation objects while allocating them for isolated operation. This is primarily due to the low speed of existing islanding systems. The solution to this problem can be an Adaptive frequency islanding system, which is high-speed and evens out the power balance in the distributed generation energy districts at the time of its allocation to isolated operation. The operating principle of this system is to determine the amount of control actions and their issuance at the substation of distributed generation energy districts based on the assessment of the electric power system mode and energy district real-time parameters.

1. Introduction

According to world practice, recently there has been a tendency of rapidly growing world energy consumption [1]. To solve this problem, in addition to large hydraulic and thermal power plants, distributed generation (DG) objects are actively used. In developed countries, among all types of distributed generation resources (DER) much attention is paid to renewable energy sources (such as solar, wind, geothermal, mini-hydro, etc.) due to the positive environmental impact [2]. However, in Russia the DG development is carried out mainly due to thermal power plants with efficient installations based on gas or diesel fuel. These include power plants with gas turbines and gas-piston engines.

There exist a number of features of parallel operation of the DER and the electric power system (EPS) that are not typical for such operation of large power plants and EPS [3]. These features have an impact on solving problems of ensuring the power supply systems' reliability, maintaining operating parameters within acceptable limits, as well as preventing and eliminating violations of the normal mode, both in energy districts with DER and in the adjacent EPS network.

The key indicator of power quality and the most important parameter of the power system mode is frequency. The electric current frequency regulation in the Russian power system is carried out in accordance with the requirements [4]. A significant reduction in frequency leads to emergency generation-shedding and mass disconnection of electrical energy consumers.

The under-frequency load-shedding (UFLS) is used in the power industry to rescue systems facing extreme disturbances to avoid system collapse. This system disconnects consumers to restore the balance of active power in the energy system [5]. This method of frequency control is quite effective, however, it can lead to a massive disconnection of consumers in distributed generation energy districts.

Another way to frequency control in distributed generation energy districts during system faults is to allocate such energy districts for isolated operation. This method allows to avoid mass disconnection of consumers by the action of UFLS, however, it quite often leads to shutdown of gas turbines and gas-piston power plants at isolating of DG energy districts with power unbalance. The reason for this is the low speed of frequency islanding system and slow load-shedding by UFLS, aimed at equalizing the power balance.

Studies have shown that the allocation of the distributed generation energy districts to the isolated operation can be an effective way to ensure uninterrupted energy supply in case of system fault, leading to decrease frequency, but it requires the development of a new high-speed frequency islanding system.

In this paper, we report a development Adaptive frequency islanding system (AFIS), which is high-speed and aligns the power balance in the distributed generation energy districts at the time of its allocation to isolated work.

2. Requirements to developing system

We have carried out the analysis of the effectiveness of existing islanding systems [6–8]. According to it, currently operated systems implement the allocation of DG energy districts only after the frequency changes in the EPS, without current monitoring the mode parameters in the distributed generation energy districts and not adapting to their change.

The solution of this problem can be an Adaptive frequency islanding system, which capable of carrying out the following:

- continuous measurement of real-time mode parameters of the EPS and DG energy districts;
- continuous calculation of the amount of control actions (CA);
- issuing commands for load-shedding (LS) and transmitting information about the volumes of CA to the power substation when it is allocated from the EPS with the subsequent control of their implementation through the Telemetry and SCADA system.

The AFIS development will allow solving the following tasks:

- allocation of DG energy districts for isolated operation in case of emergency frequency reductions in the power system while maintaining stable operation of generators;
- maintenance of the power supply of the motor load of the distributed generation energy districts while allocated to isolated work.

To solve the tasks posed, the AFIS must meet current requirements for speed and adaptability. The speed is achieved by the fact that the amount of CA is determined before the emergency mode and, accordingly, before the command of the network division (ND). In this case, the formation of control actions and the command to load disconnection is carried out at the same time as ND. Adaptability is provided by the function of automatic CA recalculation based on real-time measurements of parameters from the EPS and distributed generation energy districts and its processing in the pre-emergency mode. This eliminates the possibility of over-load-shedding.

3. Adaptive frequency islanding system

3.1. Main units

The developed Adaptive frequency islanding system is shown in Figure 1. The system consists of following elements: measuring unit (MU), transmitter/receiver of SCADA, starting unit (SU), computing unit (CU), control actions distribution unit (CADU), and operating unit (OU) implementing of CA.

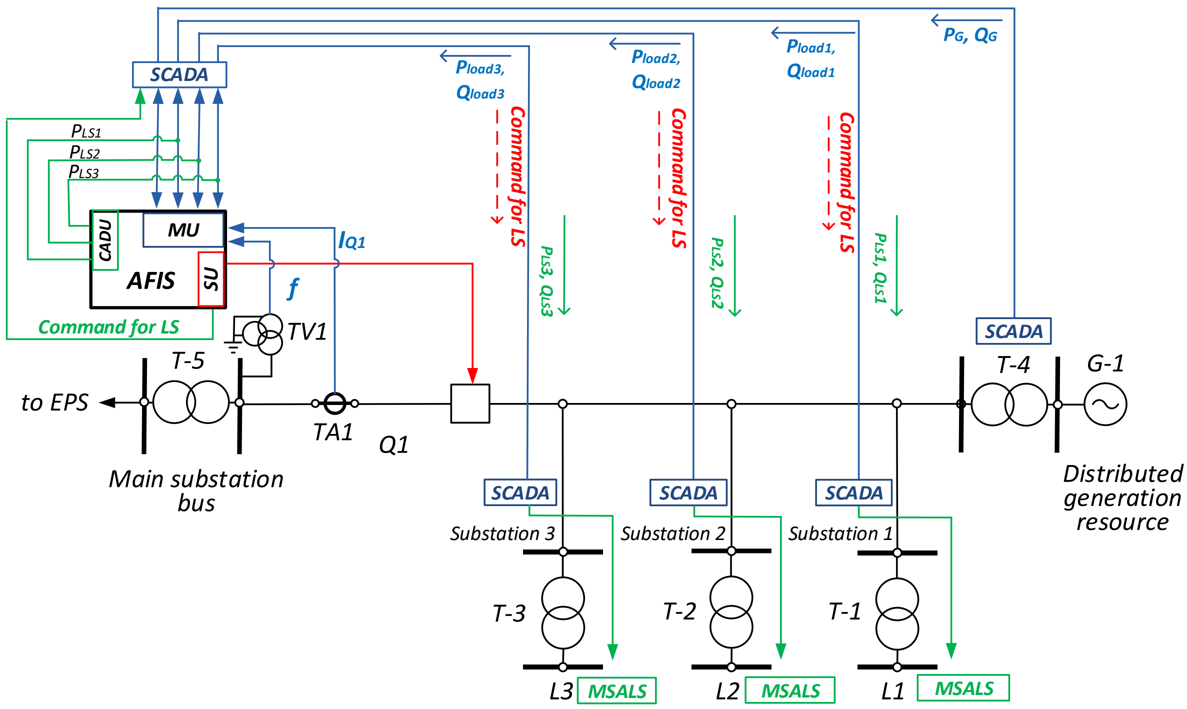

Figure 1. The schematic structure of the Adaptive frequency islanding system.

In case of abnormal frequency decreasing AFIS gives a signal to turn off the switch by the starting unit. The real-time values of frequency on the main substation bus, active and reactive power transferring from the EPS to the DG energy district, as well as the values of consumed and generated power at the stations and substations are measured in MU. For this, it is necessary to ensure the interaction of the ADIS with the SCADA.

A feature of the developed system is the presence of the computing unit. The CU task is to continuously calculate the amount of control actions according to real-time measurements of the mode parameters of the EPS and the DG energy district. The calculated amount of CA is sent to the CADU, and then redirected them to the SCADA, which issues a command to load-shedding of the corresponding substation by multifunctional system for automatic load-shedding (MSALS). The MSALS receives two signals from the SCADA: the first is the system actuation signal and the second is signal characterizing the amount of load shedding.

The use of Adaptive frequency islanding system with Multifunctional system for automatic load-shedding will allow to more effective load-shedding in cases of emergency reduction of the frequency in the EPS, and avoiding the excessive effect of load-shedding by emergency control system.

The MSALS can carry out disconnection of consumers on the fact of frequency and voltage reducing on low voltage buses of substation, as well as on the fact of receiving the actuation signal from the external emergency control system. The multifunctional system for automatic load-shedding can work both independently and as part of an emergency control system as an actuator. The MSALS is a separate complete actuator. The development of this system is a different issue and is not considered in this paper.

For more detailed description, Figure 2 shows the structural-functional scheme of AFIS.

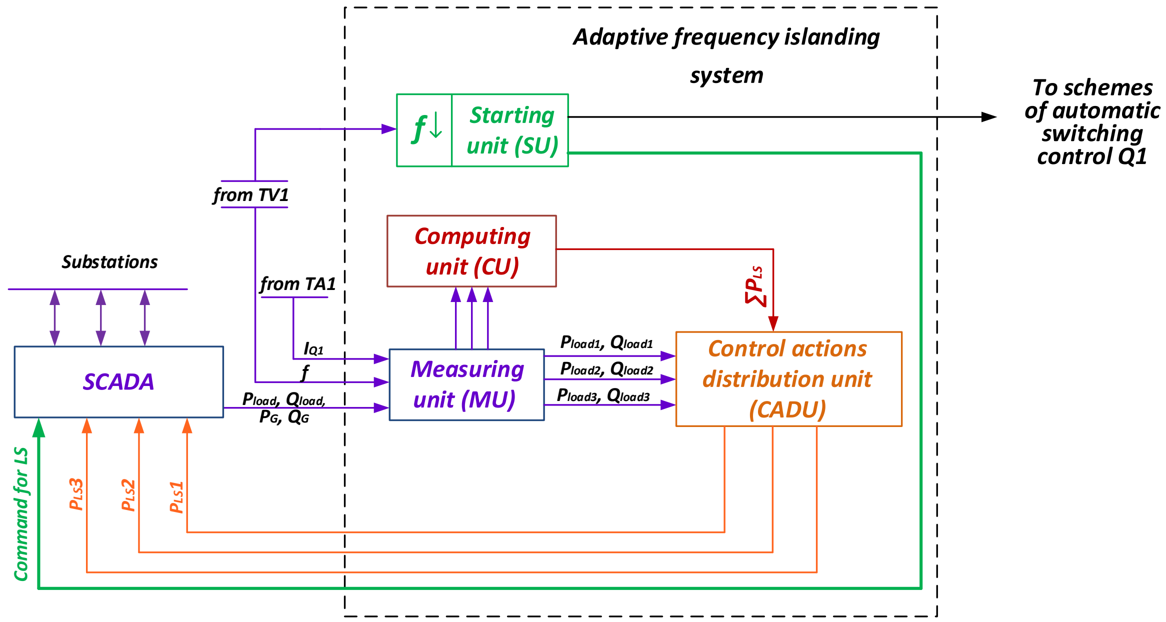

Figure 2. The structural-functional scheme of the Adaptive frequency islanding system.

3.2. Operating Principle

The developed Adaptive frequency islanding system works as follows:

1. A system fault occurs in the EPS.
2. The frequency decreases below rated level.
3. The SU on the main substation bus issues a command to allocate (split) the DG energy district for isolated work.
4. The command of power system splitting is issued to schemes of automatic switching control.
5. Simultaneously with the previous action, the amount of CA is calculated on the basis of the last measured parameters by the MU for load-shedding in the isolated DG energy district.
6. The distribution of total CA to the substations of the DG energy district is carried out by the CADU.

In general, the total active power, which is to be shut down, is calculated by the following equation:

$$\Delta P_{LS} = \frac{\Sigma P_G}{1,05} - \Sigma P_{load} \cdot (1 + \frac{(f_{rated} - f_{previous})}{f_{rated}} \cdot K_f) \ , \tag{1}$$

where $\sum P_G$ – is the total active power generated by sources of the DG energy district at the time preceding the isolation, MW;

$\sum P_{load}$ – is the total active load power at the time preceding the isolation, MW;

$f_{\text{previrated}}$ – is the rated voltage frequency, Hz;

f_{previous} – is the voltage frequency on the main substation bus at the time preceding the isolation, Hz;

K_f – is the self-regulation of the load in the interconnection, relative unit.

As mentioned before, the distribution of the total CA at the substations of the DG energy district is carried out by CADU. The distribution of the CA should occur in proportion to the measured values of consumers' power loads. For optimal distribution of the CA between substations, the coefficient of participation of the substation load in the total energy district consumption should be taken into account:

$$k_i = P_{load\ i} / P_{load\ \Sigma}, \tag{2}$$

where $P_{\text{load i}}$ – is the active power of *i*-substation, MW; $P_{\text{load }\Sigma}$ – is the total active power of energy district, MW.

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The obtained coefficients are multiplied by the value of the total amount of the CA ($\Delta P_{LS} \cdot k_i$) and, in the form of digital information, are distributed through the SCADA channels at the substations of the DG energy district.

As a result, load-shedding and restoring of the power balance in the isolated DG energy district is occurred at the time of the power system islanding. The DG energy district reliably stands out for isolated work.

4. Conclusion

Thus, this paper presents the developed Adaptive frequency islanding system, which meets the modern requirements of speed and adaptability. The implementation of the AFIS will significantly improve the efficiency of the allocation of the DG energy districts for isolated work, as well as increase the reliability of power supply to consumers of the DG energy districts in cases of unacceptable reduction in the frequency in the EPS. Due to the actions of the Adaptive frequency islanding system, it is possible to ensure stable generators operation and to preserve the power supply of the responsible motor loads while isolating the DG energy district.

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