International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 23 (2017) pp. 13868-13873

The Parameter's and Configuration's Controlling of a 6-20 kV Distribution Network

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Abstract

The article describes the development and research of variants for possible solutions to the problems of controlling the parameters and configuration of a 6-20 kV distribution network with intelligent devices based on a Solid-State Voltage Regulator with PWM at the network frequency. The methods of automatic control of power supply recovery for distribution network consumers are explored. The analysis of existing methods of network reconfiguration is conducted; their advantages and disadvantages are revealed. The Balanced-Zone Algorithm for network reconfiguration was proposed. It allows to make a quick assessment of the state and to generate control actions to restore power supply to consumers in distribution networks with renewable energy sources. The method for the priority conservation of electrical loads is proposed. Simulation modeling of the functioning of the algorithm for low and medium voltage networks was carried out.

Keywords: algorithm, distribution networks, smart grids, active-adaptive networks, islanding, Solid-State Voltage Regulator, distributed generation, automatic control

INTRODUCTION

The transition to intelligent distribution networks of low and medium voltage is accompanied by the active introduction of sources of distributed generation (including renewable sources), the creation of new intelligent power devices (such as UPFC, Solid-State Voltage Regulator, etc.), the formation of clusters of power storage devices, and the widespread introduction of new information communications and protocols.

Intelligent networks open up new opportunities for management [1, 2, 22-24]: the process of production, transmission, consumption and related management becomes flexible and fully automatic. However, many management tasks remain unresolved, or require the development and implementation of new approaches to adapt to the rapid modernization process. In existing electric networks with single, territorially separated sources, the quality and reliability of electricity supply to consumers was maintained through the creation of the necessary reserves of generating capacities and a single parallel stable operation of large power plants. Historically, in most countries medium and low voltage distribution networks perform passive electricity distribution functions.

Russia has developed a concept [3], which defines the development of distribution networks as actively-adaptive, flexible networks. At the same time, the functioning of such networks assumes an active change in the configuration of the power supply scheme [4], with the possible allocation of balanced sections of the network with sources of distributed generation to isolated work.

Today city electric networks already have a lot of reserve connections, including from large sources.

The task of searching the chain for a power consumer at emergency shutdowns of energy sources and supply lines becomes particularly laborious

ANALYSIS OF EXISTING METHODS FOR RECOVERY OF CONSUMER ELECTRIC POWER SUPPLY

There are various methods for restoring power supply to the consumers of the distribution network [1, 5 - 15] after the accident and successful shutdown of the emergency area. Among them are the following: methods of graph theory and combinatorial mathematics [5-8]; methods using a database on the set of possible modes of the network and the optimal scheme advising them [9-12]; methods using the apparatus of artificial neural networks [13-14]; methods based on multi-agent systems [1, 12, 15]; combined methods combining algorithms of graph theory and artificial neural networks [1, 12, 15-17] et al. These methods are mostly oriented to backbone networks, or to distribution networks of radial configuration. A comparative analysis of the main methods is given in Table 1. In this case, depending on the method of solution, a different objective function of the problem being solved is chosen [1].

The existing methods [5-8, 10-12, 14] of the restoration of electricity supply are calculated taking into account the large inertia of traditional sources (diesel power plant (DPP), gas-turbine station (GTS), combined cycle gas turbine (CCGT), hydro power plant (HPP), thermal plant (TPP), nuclear plant (NPP), fuel cell (FC)) and, accordingly, the long time [18] of their deployment and the complexity of synchronization [19, 20] for the restoration of power supply (Figure 1).

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The total starting time of the backup source is determined by the (1).

$$t_{la\Sigma} = (t_{la} + t_n) \cdot k, \qquad (1)$$

where t_{la} - minimum time required to start a single generator set; t_n - minimum time required for the output of the work of a single generator to the rated power; k - number of single generator sets.

Table 1: Main methods of automated recovery of consumer electric supply in distribution networks

Name of methods[a]	Advantages	Disadvantages
Methods using the theory of graphs and combinatorial mathematics	Finding an adequate network configuration for any mode. Solution of the task of reconfiguring the network by a set of criteria	Long time of calculation and search for the optimal configuration. High requirements for computing power. The occurrence of errors with the assumption of constraints to speed up the calculations
Methods using a database on the set of possible modes of the network and its corresponding optimal scheme	Modeling possible modes outside real time. High speed of decision made	A very large database of possible modes and configurations. The need to conduct complex modeling in the modernization of the electricity supply network. High requirements for synchronization and measurement accuracy
Methods using the apparatus of artificial neural networks	Simplified way of teaching the network model to possible modes	High probability of incorrect topology and mode. Assumption of a state of uncertainty in the solution
Methods based on multi-agent systems	The possibility of functioning with centralized and decentralized control systems	The need to design new schemes of distribution substations
Combined methods, combining algorithms of graph theory and artificial neural networks[b]	Decrease in the total time of searching for the optimal scheme. Reducing the likelihood of incorrect modes	Complex algorithms for checking and adapting to the evolving electrical network. Complex system of forming priority load rules

[a] Only basic methods are considered

[b] Using the example of the method described in [1]

Distribution networks of low voltage and medium voltage with renewable sources of generation have the ability to almost instantly deliver a limited amount of power from existing accumulators (AB), installed in connection with the technological features of the operation of installations (wind generators (WG), solar power plants (SPP), mini hydropower plant (MHP), etc.). Also, most of the existing methods of reconfiguration presuppose the separate operation of small generation sources in distribution networks, although there is a tendency to include them in parallel operation within a specific network of 0,4 and 6-20 kV.

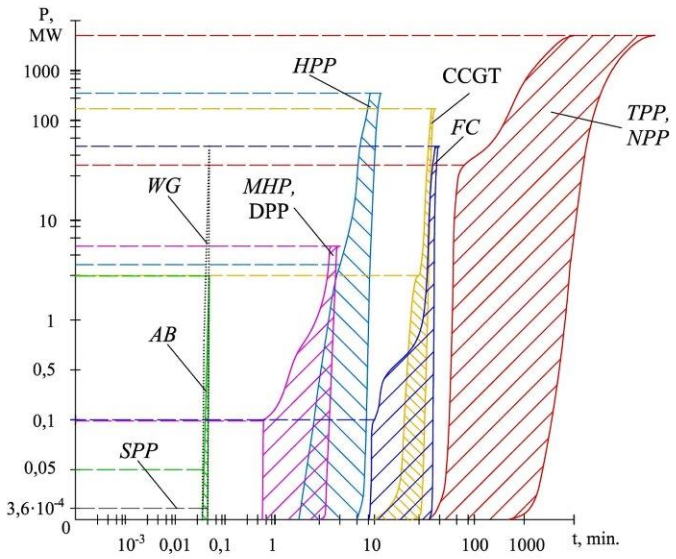

Figure 1: The minimum time required for the output of the work of single units of sources of different power and type to the nominal mode of generation (assuming that in the initial state of the installation were disconnected)

THE NETWORK RECONFIGURATION ALGORITHM ON THE BASIS OF THE BALANCE-ZONE MATRIX

The authors propose a way of changing the working configuration as a result of a post-accidental occurrence of a power shortage in a distribution network with renewable sources based on the balance-zone algorithm.

The balance-zone reconfiguration algorithm allows, after the loss of power supplies, to determine the scarce sections of the network (such us distribution substations, transformer substations) and to form in the minimum number of operations the network working scheme taking into account the priority of the loads.

The proposed method for restoring power to consumers in the distribution network is based on constant monitoring of network currents, load currents, the status of switches (with remote control), the current load of generating units and the availability of a power reserve for each type of source. To implement the algorithm, it is necessary to have a well-developed communication infrastructure, which is typical for intelligent distribution networks with renewable generation sources [21] using synchronous vector measurement devices [20]. According to the procedure of the proposed balance-zone network reconfiguration algorithm (BZNRA), the entire network is divided into zones. Each balanced zone is a main unit, namely the substation bus with feeders and the connected load (Figure 2).

The sum of the power flows in the balance zone in the normal mode is zero, which is the balance condition (2).

$$\sum S_i = 0, \tag{2}$$

where i - the number of connections to this network node bus (distribution bus); S_i - value of power flow through i-th connection

Network status is described by the incidence matrix (3).

$$A = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{pmatrix}, \tag{3}$$

where a_{mn} - state of the n-th switch in relation to the m-th balance zone. Thus, the entire network consists of m balance zones.

Each n-th switch in the network incidence matrix can take the following values:

1) "1" – the flow enters the balance zone through the n-th switch;

2) "-1" – the flow leaves the balance zone through the n-th switch;

3) "0" – the n-th switch is not located in the considered m-th balance zone.

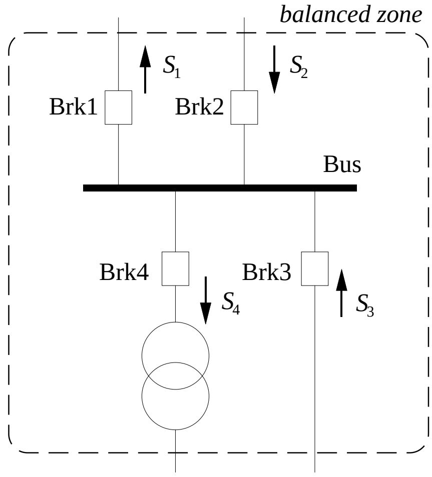

Figure 2: Typical image of the balanced zone of the distribution network

The numerical values of the power flux are determined by the instantaneous power matrix (4).

$$B_F = \begin{pmatrix} h_{11} & h_{12} & \dots & h_{1n} \end{pmatrix}, \tag{4}$$

where h_{11} - power flow through the n-th switch.

BALANCE ESTIMATION AND SEARCH OF UNBALANCED ZONES IN THE DISTRIBUTION NETWORK

The BZNRA procedure for estimating the instantaneous balance at the nodes of the distribution network is described by the balance expression (5), and implies that in normal mode in each balance zone of the distribution network, the sum of the power flows is zero and the mode exists.

$$Z_B = A \times \left[B_F \right]^T, \tag{5}$$

where Z_B - matrix (balance matrix), which determines the balance status of individual zones and the entire distribution network.

The balance matrix (5) has the structure (6):

$$Z_B = \begin{pmatrix} z_{11} & z_{12} & \dots & z_{1m} \end{pmatrix}, \tag{6}$$

where z_{1m} - quantity describing the state of balance or imbalance of m-th balanced zone. The condition of existence of balance: $z_{1m} = 0$. If $z_{1m} < 0$, then there is a power shortage; if $z_{1m} > 0$ then there is a power surplus (Typical for network nodes with a source of generation). If a failure occurs in the distribution network, an unbalanced zone occurs. Particularly critical are the situations associated with the failure of the main (most powerful) source from work or the failure of the main supply line.

BALANCE-ZONE NETWORK RECONFIGURATION ALGORITHM

The proposed BZNRA algorithm is a modification of the algorithms for restoring power supply to consumers in a distribution network based on graph theory. The principal structure of the algorithm is shown in Figure 3.

At the time of the occurrence of the accident BZNRA captures the parameters of the mode and network scheme corresponding to the pre-failure state in network. Further, these data are used as rigid initial conditions. A network model is formed. After the detection and deactivation of the damaged network section from relay protection and network automation [19], the algorithm procedure updates the switch status matrix and the balance matrix.

In the presence of unbalanced zones, the network is formed by step-by-step connection of the balance zones, starting from the remaining generation sources or power storage devices in accordance with the generated capacity matrix while maintaining the total estimated balance of each of the isolated islands. The procedure includes the following successive steps:

– determination of the switch (basic switch) of the working source of electric power (the basic source for a new section of the working network, called the island);

– determination of the balance zone, which includes the source switch;

– determination of the type of each switch, also included in the considered balance zone, different from the basic switch;

– detection of the feeder switch which parameters are specified by the line matrix, determination of the switch at the end of the line (end feeder switch);

– determination of the balance zone, which includes the end feeder switch;

– determination of the type of each switch entering the considered balance zone, other than the end feeder switch;

– determination of load switches, load estimation;

– the recalculation of the balance taking into account the generation capacities and the newly added load, etc..

Decisions on the inclusion of loads in the process of post-failure reconfiguration of the network after the evaluation is made in accordance with a matrix predetermined priority. The procedure of the algorithm for disabling loads is presented in a general form in the Figure 4.

The procedure includes:

– the allocation of the load block of each balance zone in accordance with the highest priority;

– evaluation and comparison of the value of the unit load of each balance zone with the power of the source, and its elimination from the calculation when the load exceeds the load above the generation;

– Evaluation and comparison of the unit load of each balance zone with the power of the source, and its exclusion from the calculation when the load is exceeded (the load of one connection with a switch) over generation.

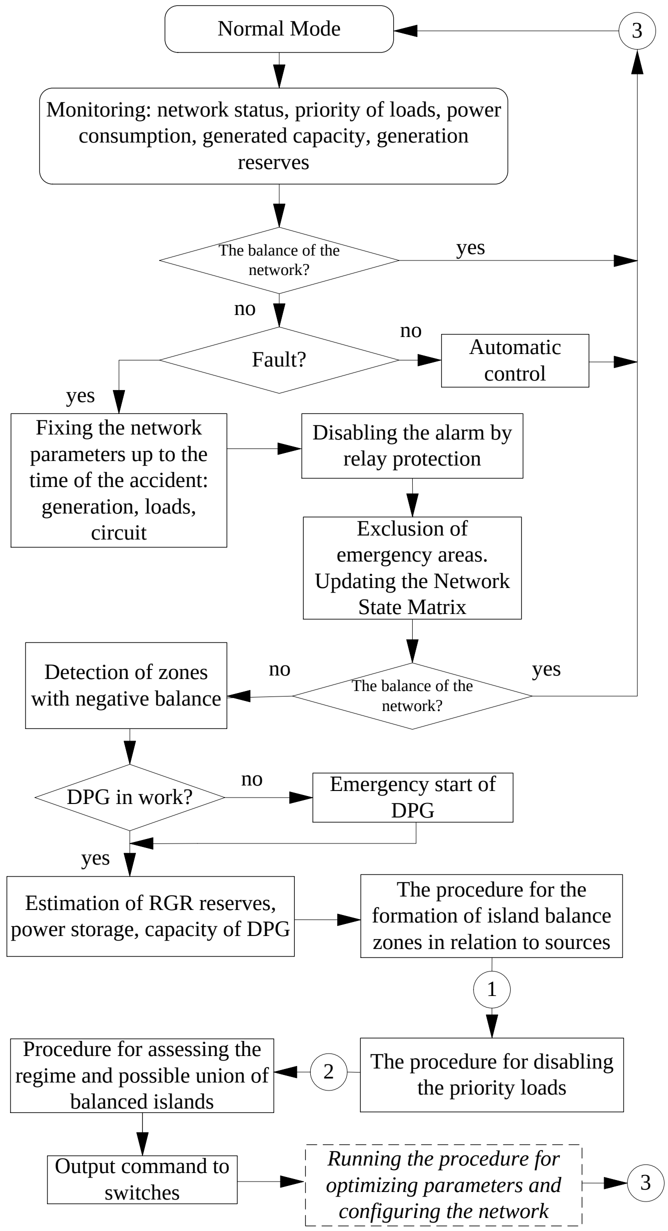

Figure 3: The basic structure of the BZNRA

The switch-type matrix specifies additional procedures for the BZNRA algorithm, such as the inclusion of sources for parallel operation, the verification of the permissible load of the distribution network lines, the recalculation of the loads.

CONCLUSION

The proposed algorithm is implemented in Matlab and has shown its efficiency on real-time simulation models in PSCAD both in tree networks with stand-by connections distribution network and in promising ring intelligent networks using the example of a 20 kV hexagonal distribution network.

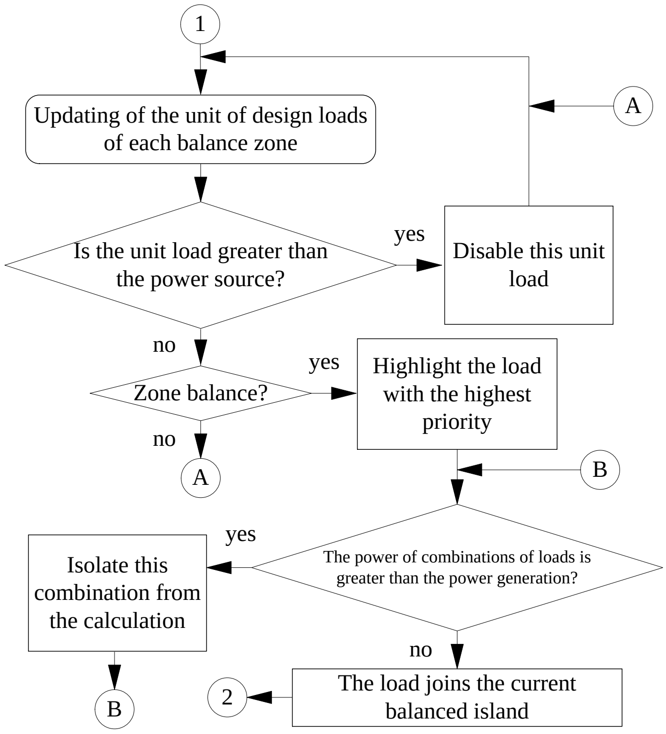

Figure 4: The principal structure of the algorithm procedure for priority preservation and disconnection of loads

After the operation of the BZARS algorithm, it is possible to refine the regime using the existing optimization methods. Regulating Mode possible using intelligent network parameter control devices based on a Solid-State Voltage Regulator with PWM at the network frequency. Application of the Solid-State Voltage Regulator in perspective will allow minimizing losses, reducing the levels of short-circuit currents, forming a more even distribution of loads, etc.

The procedure of post-fault operation of the algorithm in hexagonal networks has a speed of 2,7 times higher and with greater preservation of the users in operation in comparison with radial configuration networks, due to the unification of the network scheme, the substation scheme and the use of lines of the same section, which indicates the increased survivability of hexagonal Network structure.

ACKNOWLEDGEMENT

Research is carried out with the financial support of the state represented by the Ministry of Education and Science of the Russian Federation (agreement No. 14.574.21.0167 for provision of support of September 26, 2017. Unique project identifier RFMEFI57417X0167).

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