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DISTRIBUTION OF AVAILABLE CAPACITY IN POWER NETWORK

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Abstract- The issue of the available capacity distribution of power plants as a part of the power system in the branches of the electric network is formulated. The formation of the potential capabilities of the active power of the generating units affords to determine the capacity volume of power plants and the power system, the flows of apparent power and current for the selection of the power through the grid equipment, the cross-section of wires and other current-carrying parts. To implement a variety of required electrical quantities for practical purposes is proposed the simulation of the artificial operating mode modeled in the database of available capacities in each of the power consumption nodes as part of the active power of the operating mode and the power of the existing emergency reserve of the power system, distributed in proportion to the active power consumption load nodes in operating mode. The balancing of artificial mode, the associated reactive powers are connected to the database of available capacities, formed in each load node according to the available power of the artificial mode database and the power factor of the operating mode, and the voltage level in the generating units should be maintained close to the operating mode.

Keywords: Active Power, Available Capacity, Reactive Power, Apparent Power, Operating Mode, Artificial Mode, Existing Reserve, Emergency, Overload.

1. INTRODUCTION

The huge amount of scientific papers and technical materials [1-7] devoted to the balance of available and active power demand in various divisions of power systems that ensure the operation, research and development of the electric power industry. However, the concept of available power is used only for power plants as a resource of active power generated at power plants. It is not defined for the elements and circuits of the network. Quantitative observations and analysis of these capacities are possible for power plants and this circumstance is widely used in balance calculations of power systems [8-10]. For each of the components of the power grid networks, these operations are not available.

At the same time, available capacity from the point of view of power demand is an infinitely divisible electrical resource, i.e., a natural parameter of the capabilities of both the entire power system, its power plants, and in all its networks: in branches (lines, generator, transformer, converter and load circuits) and nodes (substation buses).

Therefore, the assessment of the energy resource parameter of available capacity for each branch is expedient and important regulated through nominal currents and equipment capacities, conductor cross-sections in the operating conditions:

- for the largest outputs from the buses of power plants and transmission along the main lines of high-voltage networks,
- for the smallest - power consumption through radial feeders and distribution network structures.

Problems with flows in the branches and circuits of the network can be set and solved if the principle and method of distributing available power across the elements of electrical networks are known. Such means are currently unknown, but their development is necessary for assessing the resource of these branches of the network, which is currently estimated by the maximum flows of power demand. This approach is justified due to the unknown network available flows, which always exceed the demand flows.

It should be noted the difference between physical power demand flows and virtual flows of available capacity. The formers are found according to the rules of electrical engineering, and the latter can be modeled the same approach as with the formers. To do this, it is necessary to have a power system in which the available capacities of power plants and power consumption nodes are distributed in the network according to the rules of electrical engineering.

The model of the power system and the flows of available capacities in the network can serve as professional software for balancing operating modes with databases of available capacities of power plants and available power consumption capacities, i.e., instead of actual generation and loads in the nodes of the network modeled in the software, there should typically be available capacities in the form of an equivalent scheme. When balancing the artificial mode of available capacities, requirements for voltage levels in the network nodes are set close to the operating mode voltages. This means that it is necessary to have databases of available capacities of power plants, available capacities of loads, and a list of conditions for voltages in network nodes that are close to the values when calculating power demand in operating modes.

The formation of databases of available capacities of power plants and power systems is practically carried out by summing up the nominal active capacities of units minus repair and other special types of reserves. Similarly, the active capacities of the load nodes are summed up. The difference in these total capacities is determined by the existing emergency reserve, which is distributed proportionally to the active capacities of the load nodes of the operating mode network. The distributed reserve is added to the active load capacities of the operating mode nodes. As a result, a database of available capacities of power consumption nodes is formed, which is used to calculate the artificial mode for the distribution of available capacities in the network branches of the operating power system with the existing emergency reserve.

2. AVAILABLE CAPACITY

The available capacity of each power plant provides the active power at load nodes of consumers required from it, and some reserve as a source of electricity, which covers the actual active power demanded from the power plant and there is some reserve for unforeseen needs due to emergency and planned repairs of power equipment or a rapid increase in the load. The available capacity, together with the accompanying permissible reactive power, is used to determine the total current and total power transmitted from the power plant to the grid. In power station networks and adjacent areas of the power system, the concept of available capacity is usually more and more lost as having less and less relation to each specific power plant by this indicator, the active power in the power flows of the network and consumers is formed from the capacities of different power plants. In other words, the formation of available capacity in the branches and consumers of the network from many or all power plants of the power system is more complex and meaningless from the point of view of the initial determination of this power from a specific power plant.

However, another approach is also possible to consider the available capacity, which is formed in the branches and nodes of the network from the available capacity of many power plants. This approach is based on a more extended concept of available capacity, summed up in the branches and nodes of the network from a number or all power plants of the power system. This extended concept is new with respect to the available capacity of each power plant, but essentially the same for the components of the network in terms of the resource relative to the usual widely used current or actual power demand of operating modes.

The available capacities of power plants summed up in the branches and nodes of the network, if necessary, together with the associated reactive capacities, are practically a resource for power flows in the elements and nodes of the network, therefore it is very important and necessary to determine the cross-sections of overhead transmission lines, cable cores, capacities of transformers and autotransformers at substations, to clarify and substantiate the available capacities of power plants, i.e. it allows engineering selection of the named parameters and materials are used, equipment, the structure of power plants. Moreover, the distribution of the available capacities of power plants along the branches of the network in the form of summable parts from each power plant is quite possible.

The distribution model according to the rules of electrical engineering with the required excess of the active capacity content of the initial data, as is the case when calculating the flows of power demand in operating modes, successfully balanced with another excess of the total active generation of the total load by some simply achievable amount. In the case of an artificial mode of available capacity, the load of network nodes, according to the logic of the power balance, should include an emergency reserve both in the whole power system and in each load node.

A procedure is possible when the initial load data must be specified in a natural form, i.e., how to calculate the operating steady-state conditions that is called dynamic process. It is implemented in the operating mode, when in an unforeseen, for example, an emergency, local and system controls provide the required additional flows of active power from the provided reserves of power plants in the network elements and pass them to the place of increased consumption. In such a situation, in the mode with the available capacities in the generating units and the actual active powers in the load units, the switching in the network, causing an emergency situation, must additionally be taken into account.

Each network element in the operating modes generates, transmits, or receives the desired active power which, in any part of the network in accordance with the rules covered electrical generation sources forming part of the active (the available) power in the grid. In accordance with these rules, the process of distribution of the actual active power as part of the available power of power plants is accompanied by flows of reactive power and voltages in the space of branches and in the nodes of the network. In an unforeseen emergency, for example, local and system controls provide the required additional flows of active power from the provided reserves of power plants in the network elements and pass them to the place of increased consumption.

At the same time, the processes take place with more intensive involvement of regulatory funds, but also according to the rules of electrical engineering, which means with reactive power flows and voltage values on the network elements, and both the actual and the reserve active power of the units are distributed over the network, which together forms the available power of the plants.

Consequently, both additional and in general the available capacity of power plants is basically distributed among the network elements in almost the same way as the actual capacity of operating modes. The voltages on the network elements may be different within the permissible limits, but for the specificity and unambiguity of the correspondence of the modes with the actual and available capacities, it is advisable to set the voltages on the branches the same as they were in the calculations of the operating modes. In order to normally ensure the distribution function of available capacities without overloading, along with an increase in reserve capacities at power plants, when designing and building a network, they provide for increased cross-sections of line wires and throughput capacities of transformers and autotransformers - the costs of related activities in the surrounding network. In general, the available flux power in each circuit (branch) must exceed the actual or current active flux power. But how much should be provided for strengthening the circuit and increasing the reserve capacity of power plants, as power flows under operating conditions are constantly changing.

A simple and logical answer in the case of a deterministic solution to the issue may be to consider several options and find the maximum-limiting value of working, available and emergency power flows in order to choose an option to avoid overload. But not only power plant units, but most likely the cross-sections of the wires of the lines and the throughput capacities of the transformer branches of the network area, covered by the process of increased power flows.

This decision could be final, but ineffective, since the maximum limit value may be rare. Consequently, to prevent a possible excess of the value of the maximum-limiting mode, large, poorly used, unnecessary funds will be required, spent on strengthening the electrical circuit (branch) and other measures in the network surrounding each circuit of interest. To some extent, the solution of the above and similar issues can fundamentally be facilitated by the use of modern energy software computational complexes for the parameters of electrical networks modes, which make it possible to quickly perform the required numerous calculations of both operating modes and modes with available capacities, as well as practical expert analyzes and conclusions based on the calculations.

Professional software can be used to calculate both the actual power flows of the operating modes for which they are intended, and for the available or resource quantities with the features of the initial data, consisting, as a rule, in the increased values of the powers of the load and generator units in comparison with the operating modes. Due to this, the calculation results should be considered as resource or disposable values in comparison with the results of the previous operating mode. If in a particular circuit there is an excess of the available power over the actual one, then this information is evidence of the correct balance of power in ensuring electricity consumption, at least in this operating mode and the corresponding mode of available capacities. In this case, expert recommendations are applied to the possibility analysis of using the obtained ratio of the available and actual active power in this circuit. Otherwise, expert recommendations should be adopted on changing the initial data of available capacities at network nodes and calculating new modes of available capacities in the network branches, including the circuit required to be analyzed.

3. PRACTICAL IMPLEMENTATION

In the calculations, the available power refers to the resource active power of units, power plants, and power systems, which would manifest itself in conditions of electrical voltages in the nodes that took place in the actual operating mode of each unit, but when its active available power was issued. From the point of view of each linear circuit (branch), the resource is determined by the cross-section of the wires, which in its turn is determined by the economic current density and the total current due to the flows of active and reactive power at the given resource (available) active powers and voltages of the load and generator nodes of the network. The throughput power resource of each branch of the transformer and autotransformer is formed by the total power flows through the branch also at the given resource (available) active powers and voltages of the load and generator nodes of the network and at the regulated (actual) voltage of each output of the transformer (autotransformer). The resource available power of each power plant is formed by the flow of the limiting active power through its buses at the given resource (available) active powers and voltages of the load and generator units of all other power plants in the initial operating mode.

Thus, three problems of operation and future development of power systems and power supply systems are formed and solved:

- the required determination of the total throughput of transformers and autotransformers of substations,
- the required total current and cross-section of wires and cores of cables of lines and network feeders,
- the required available capacity of power plants.

It should be noted that the interaction of the actual and available capacities in their pure form takes place only as part of the third task of determining the coverage of the available power of power plants of their actual active load at voltages at the outputs of the units in operating mode. For transformers and autotransformers of substations, the interaction of complete information of the actual and available capacities are required, which are determined, respectively, by the actual and available flows of active and reactive powers falling on the branches of selected transformers and autotransformers.

As for the wires cross-sections of lines and feeders, it is not required that the capacities correspond, but the calculated (actual) and received (available) cross-sections, which interact through the total actual and available currents, which in turn are associated with the total actual and available powers flowing through the wire's branches. Wire cross-sections are determined by dividing the available total current by the economic current density for the accepted wire material.

The functional dependences of the total powers for transformers (autotransformers) and currents for wire cross-sections are determined by additional calculations through the flows of actual and available active and reactive powers in the transformer (auto-transformer) branches of the network. Reactive quantities are the initial part of apparent powers and currents naturally accompany electrical modes.

Therefore, the determination of the parameters of modes with available capacities is also accompanied by reactive quantities, which in a number of cases may be appropriate to assign the name available.

Thus, the required content of the initial data of the artificial mode of available capacities should ensure an increase in the active capacities of the load nodes of the operating mode by the amount of the existing reserve that decreases on each load node - to form a database of available capacities for load nodes. This is done by a sequence of operations:

1) the operating mode is calculated with the specified active powers of the load nodes and the sum of these specified capacities is the total active load capacity of the power system,
2) the available capacity of the power system is calculated as the sum of the nominal capacities of the units,
3) the existing total reserve is determined as the difference between the available power and the total active power of the load of the power system in the operating mode,
4) the existing total emergency reserve of the power system is found as the difference between the total existing reserve of the power system and repair and other special types of reserve normalized by the available power of the power system, which is distributed according to the specific weights of the active power of the load nodes (proportional to the active capacity of the load nodes) in the operating mode, forming a system of emergency reserves in the load nodes,
5) in case of distributed generation and there is a reasonable need to take it into account, the total value of its available capacity in the power system is distributed according to the specific weights of the active power of the load nodes in the operating condition and is added accordingly to the emergency reserve of each load node, forming a complete emergency reserve of this node, similarly, the reserve power provided by neighboring power systems can be taken into account,
6) the received capacities of the full emergency reserve in the load nodes are summed up with the active capacities, which determines the formation of a database of available capacities of the load nodes.

According to the received database of available capacities of load nodes, databases of associated reactive powers of load nodes, or voltages of load and generating nodes can be formed. It is advisable to leave the ratio of the associated reactive and available active power in each load node the same as it is in the operating mode.

The generated database of available capacities of load nodes together with the database of associated reactive powers allows to calculate the artificial mode of available capacities with the existing reserve in the power system and thus obtain the flows of available capacities of power plants in all branches of the power system. Since the flows of available capacities in the branches are accompanied by flows of reactive powers and voltages in the nodes, the flows of total available currents and capacities necessary to solve the problems of choosing the cross sections of the transmission lines wires and the capacities of transformers and autotransformers can be determined. The total flows of generating branches of the artificial mode of available capacities are also useful for adjusting the composition of generating units and capacities of power plants.

The analysis showed that for the processes that ensure the production and distribution of available capacity for consumers, different models can be proposed. However, the most logical and adequate model is similar to the one considered for the actual operating steady-state modes, which is based on the physical representation, similar to the actual power flows in the network components according to the laws of electrical engineering, taking into account the limitations inherent in the operation regulations and the characteristics of the dynamic elements of the power system. This model has no obstacles to its implementation according to the steady-state algorithm using the same industrial software for calculating the parameters of the actual steady-state modes.

The initial data required for this purpose are the active available powers in the form of constant magnitudes and voltages in the load nodes close to the operating mode voltages, similar active available powers and voltages of the generating units, i.e., power plants with the capacity of the units, varying within the permissible limits according to the conditions for exceeding the available capacity in the branch of the network of interest. Natural functional dependencies in these calculations, issued by the software package, are the flows of available active and associated reactive powers, and their derived total powers and currents in the circuits (branches) of the network by the named tasks of determining the power of transformers (autotransformers) and wire cross-sections of the lines are calculated according to the rules of electrical engineering.

If the available parameters exceed the actual ones, the first ones can be considered as satisfying the requirement with a margin in the operating steady-state mode for choosing the rated power of transformers (autotransformers), the cross-section of the wires of the lines, but to what extent it is impossible to answer unambiguously without an expert opinion. To simplify such an assessment, it is possible to set the numerical value of the margin of the available parameters values relative to the actual ones, for example, not less than 20%. But the set numerical value is unlikely to provide an objective assessment, since it is intuitively and logically clear that the numerical value of the excess depends on the structure, volume and complexity of the electrical network, the characteristics of the equipment and many other factors, so the margin cannot remain unchanged in any way.

Depending on the specific combination of all or some of the factors listed, the value of the excess of the available parameter of interest over the actual one will be different. However, each of the options for exceeding the available parameter of interest over the actual one by 20% or more, as indicated above, can be considered acceptable and only with a reduced value of the available parameter compared to the actual one by 20% or less, it is expedient to vary primarily the values of the available capacities of power plants and the network structure for delivering available power to the branch under consideration.

Thus, a very natural method of choosing equipment and wire and cable connections in the structure of power systems was designed by comparing the actual and resource (available) parameters as separate units (units, transformers, autotransformers, converters, wire, cable, bus connections, switching devices), so and complexes of these units (power plants, substations, distribution and conversion devices).

The described mode process of setting and forming available capacities in network elements has been tested for one of the power systems without taking into account connections with neighboring power systems and the absence of distributed generation when using energy calculation by the next software as Mustang, Dakar, and Microsoft Office modules. The balancing of operational and artificial mode was conducted in DAKAR software for Tyumen region power system (Figure 1). The Tyumen region is located in Siberia, Russia. Tyumen power system consists of five power plants with a total installed capacity of 13856 MW; the main industrial consumers are oil and gas companies with a power demand of about 87% of the power generated.

Figure 1. Map of Tyumen region, Russia [11]

The procedure of available capacities distribution may be described in the next steps:

1. Preparing the data depends on the digital arrangement of operational control units with professional software.
2. Initial data: power system nodes ≈ 1200, load nodes ≈ 1100, network branches ≈ 2000.
3. Database of <u>operational condition</u> active and reactive powers of load nodes, expected result - active and reactive powers of network branches.
4. Database of <u>artificial condition</u> ≈ 1100 available capacities and reactive powers in load nodes, expected result - available capacity was distributed in approximately 2000 branches of the power system.
5. The difference of power magnitudes in operational and artificial modes was from 2% up to 27%.

The distribution of available capacity is necessary with an optimal emergency reserve, because at the same time, the flows of available capacity in the branches of the network, as a rule, are greater than with the existing emergency reserve, and the design and operational development of power systems tend to bring them to the natural status of the optimal emergency reserve, based on the reliability index (probability of any shortage).

The costs of maintaining and operating the capacity reserve are very huge. Therefore, the optimal reliability index of power systems should set based on the minimum amount of costs for the maintenance and operation of the emergency power reserve and damage from emergency under-supply of electricity. It is obvious, that the greater the reserve capacity in the power system, the higher its reliability and the lower the probability of a power shortage or a reliability index. Given the optimal reliability index and the existing emergency reserve, it becomes possible to approximately determine the optimal emergency reserve.

5. CONCLUSION

The proposed approach to separate consideration of the actual power and available capacity of power plants with distribution in the power system network according to the laws of electrical engineering by means of modern software makes it possible to practically ensure the formation of their actual and available active and apparent powers and currents in each element and network subdivisions of a specified chosen area. It is shown that the available capacities can be calculated and distributed over the network according to the same methods as the actual ones, but the initial data must be replaced by those available or located in the generating units and the actual ones in the load units.

Based on the available values in the branches and nodes of the network of the system mode with the available capacities, it is possible to represent, evaluate or calculate the maximum:

- available capacities of power plants - according to the flows of active available capacities of the generator nodes of the network;
- cross-sections of wires of lines and cable cores, rated currents of switching devices - according to available total currents of network branches;
- throughput capacities of transformers and autotransformers - according to the flows of the available apparent capacities of the transformer branches of the network.

Half of the sums of the actual and available values in each branch and each node of the network, respectively, of the operating mode and the mode with available (potential) capacities or the mode with available (potential) capacities in the generating units and actual capacities in the load units and with possible emergency switching, fix the ranges, in where values are placed with minimal risk of overload.

These halves, in the absence of a calculation of overload risks, can be considered the best values (as if corresponding to the minimum risk of overload) for making engineering decisions (cross-sections of wires and cores, total throughput capacities for transformers and autotransformers, total currents for switching devices). Therefore, the values to be taken for the implementation of the design concept and it is advisable to use them as design operational value for the selection of current ratings and power equipment, switching devices, cross-sections of current-carrying circuits, and other indicators, close to the minimum the risk of overload. In the presence of practical methods for determining the risks of overload, the exact values of the distributed parameter can be used as a refinement of the previously adopted design decisions [12].

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BIOGRAPHIES

Lyudmila V. Krivova was born in Voroshilovgrad, Russia, 1974. She graduated from Tomsk Polytechnic University, Russia as engineer in 1997 and received the Ph.D. degree from Novosibirsk State Technical University, Russia in 2003. Currently, she is an Associate Professor of Power Engineering Department at Tomsk Polytechnic University and visiting Professor at Saint Petersburg Polytechnic University, Russia. She also received the ING-PAED-IGIP diploma in 2006. Her research interests are in the area of power engineering, structural and functional reliability of power plants, pedagogics and some aspects of linguistics. In spring semester 2005, she worked as a visiting Professor in University of Ulsan, South Korea. Currently, she is involved in international Master's degree students training at Saint Petersburg Polytechnic University.

Anatoly V. Shmoilov was born in USSR, Karaganda, 1939. She graduated from the Tomsk Polytechnic University as engineer in 1962 and received the Ph.D. degree at Tomsk Polytechnic University in 1967. Up to 2019 took possession as Associate Professor of Power Engineering Department at the Tomsk Polytechnic University. Now he is Scientific Advisor of post graduate students. His research interests are in the area of Power Engineering, Structural and Functional Reliability of Power Systems, some aspects of Protective Relaying. From 1974 up to 1990 worked as Scientific Advisor on development of control system for military ships and air planes. From 1989 up to 1999 was responsible for mathematical modelling and practical application of Tyumen region power system.