International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

March 2024	Issue 58	Volume 16	Number 1	Pages 233-238

PROBABILISTIC DISTRIBUTION OF AVAILABLE CAPACITY FOR UNIT RECOURCE ASSESSMENT

L.V. Krivova [1] A.V. Shmoilov [2]

1. Higher School of High Voltage Engineering, Peter the Great Saint Petersburg Polytechnic University, Saint Petersburg, Russia, krivova.milla@gmail.com
2. School of Power and Power Engineering, Tomsk Polytechnic University, Tomsk, Russia shm_av@rambler.ru

Abstract- An approach to the distribution of available power sources and loads for determining the capacity of power transformers and the cross-section of current-carrying parts of electrical installations is proposed. The use of available power will allow to choose the components of electrical installations, taking into account the necessary level of reliability, also in accordance with existing technical and economic requirements. Having used available capacity as a justification criterion, it becomes possible to assess equipment overload due to exceeding the capacity of power system elements.

Keywords: Probabilistic Characteristic, Available Capacity, Power Balance, Reliability, Load, Overload.

1. INTRODUCTION

The issue of equity between power being generated and being consumed at different nodes of power systems is represented in a huge amount of manufacturing, scientific, and technical materials that guarantees the normal operation and improvement of the electric industry in the whole [1, 2, 3, 4].

Nowadays in Russia the available capacity conception is applied generally for power plants as a starting or initial point of active power being produced by stations as a intrinsic part of power systems. Consequently, for any single unit or device in the electric installation this capacity has never been discussed or applied. For the forecast of the power system balance, the retrospective statistics and analysis of generating unit available capacities are used, not including network components unfortunately [5, 6, 7]. The expediency of numerical observations and scientific-engineering analysis of the presence of available capacities in each of the components of electrical installations is undeniable.

There is no obstacles for the available power being the load demand feature to be considered as resource capability in all power system elements and their connections:
- transmission lines,
- generators,
- power transformers,
- load circuits,
- nodes (at the substation buses).

Consequently, the estimation of available capacity as the energy resource parameter of for each power demand flow is opportunate and decisive:
- for the forceful bay connections at the switchgears of power plants and energy delivering along the trunk lines of high-voltage system communication,
- for the unforceful as a loads connected by radial lines and distribution subsystem.

For large flows primarily the named resource parameters are important for satisfying the appropriate level of reliability and reserve, in addition, for small flows the nominal currents, capacities, cross-sections (as nameplate parameters) and normal regimes are of greater importance.

Compliance with regulated values is also relevant for large flows. But all kinds of network tasks can be determined in case of approach for distributing the available capacity over the each component of the nets is exist. Despite the indisputability of such method nesessity, a tool is presently undiscovered.

Straightaway, the accumulated experience of forming the active reserve capacity of power plants and power systems in the form of a percentage relative to the winter maximum demand for active capacity is widely used, based on optimal reliability with guaranteed value of minimum costs for installation and maintenance by achieving additional reserve capacity [8]. Therefore, it seems very natural to consider the distribution of the power plant available capacities in accordance with the available capacity of loads. The last should be formed by the principle of exceeding the nominal load capacity by the actual active capacity of the loads in the same percentage (proportionally) as the reserve capacity of the power plant and the maximum demand of the load.

2. AVAILABLE CAPACITY STATISTICS

Table 1 illustrates the generation sutiation for the last year. Noticable that Siberian power system restrictions to nominal parameters execution are estimated as more than 25%.

Registered: 230730 Article Info: 1726 Accepted: 240223
Reserved: 240116 Available: 240331

Aging of some units is the obvious explanation for the reduced magnitude of available capacity. In addition, big territory with extreme weather conditions are the main constrains to fast renovation.

Table 1. UPS data for 2022 [9]

Power Systems	Apparent Power, MW	Available Capacity, MW	Operational Capacity, MW
Central PS	50527	48337	37699
Mid Volga PS	27974	24644	20003
Ural PS	53448	50825	39314
North West PS	24870	22831	19476
South PS	27283	23056	19556
Siberia PS	52323	38123	30643
East PS	11242	10612	7212
Russia UPS, in total	247667	218390	173499

Analysis of retro statistics and planned generation in Russia [9] has shown the growth of apparent capacity in all divisions of Unified Power System (UPS) across country. The comparison of installed active capacity and power demand as a forecast for period from 2022 to 2028 years, it is obvious that growth of power demand will slightly outpace the growth of installed active power (Figure 1).

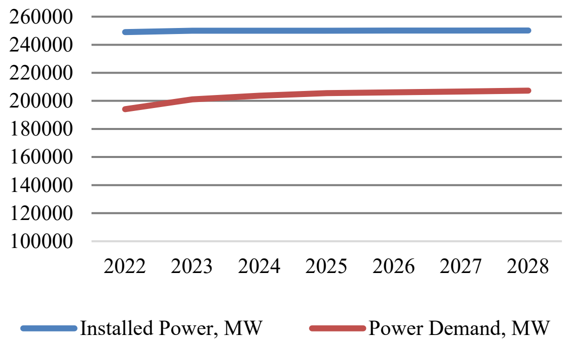

Figure 2. Power demand forecast in Russia

In 2022 the quantity of obsolete equipment in Russia unified power system was remarkable and limitations to generation were appreciable:
- power equipment in repair - 46%,
- installed capacity restrictments - 32%,
- unreleased power reserves - 7.7%,
- power decrease due to planned modes (repair of auxiliary system and general usage equipment, omitting winter-summer mode changes) - 4.1%,
- power in forced outage - 3.6%,
- power in reconstruction - 3%.

Taking into account data from Table 1 and forecast for power demand in Figure 1, where Siberia is one of the most powerful region of generation, but with the most significant difference between apparent and available capacities, it is possible to conclude that increase in consumption may be crucial. So, renovation of equipment is required. But, at the same time, the biggest part of power plants in Siberia are fossil fuel and world trend to carbon neutrality may negatively influence to old plants' perspective especially, the modernisation of equipment will be considered uneconomical.

The difference between apparent and available capacities in 2030 estimated to be minimized by modernization of some power industry objects (Figure 2).

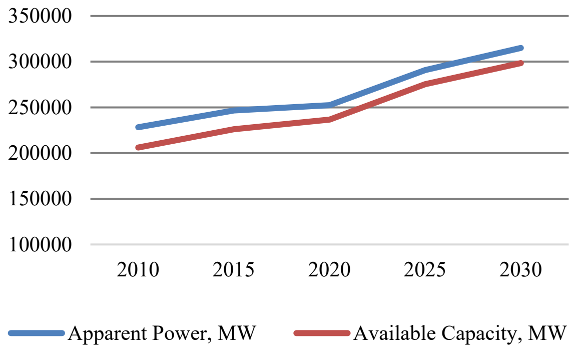

Figure 2. Power generation growth in Russia [9]

3. DETERMINISTIC APPROACH

It is also advisable to propose a variant of a deterministic solution, which consists in calculating the parameters of the expert-recommended operating mode and the mode with available capacities, and for the branches and nodes of interest, half of the sums of active, apparent capacities, apparetn l currents (cross sections) of the normal regime as well as regime with available capacities are determined. The data of half of the amounts are the boundary, the excess of which causes overload due to an increase in the working flow through the branch (node), as well as overload due to a decrease in the potential (available capacity, cross section, number of operating units, etc.) of the branch or node.

Variation of this boundary in the range of the defining parameter of each branch of the network leads to a change in losses due to the two named overloads, and in total they constitute the risk of overload, which also varies. Moreover, according to the rigid logic, the minimum of this risk can be when the boundary is located between the values of the indicator (power, current, cross-section, etc.) of the operating mode and the potential mode with available capacities.

Half of the sums of the determining parameter (power, current, cross section, etc.) of the operating and potential modes may accidentally correspond to the minimum risk, but they will always reliably be closer to the value of the determining parameter corresponding to the minimum risk than the values of this parameter in the operating and potential modes, i.e. in one or the other half of the range. Therefore, these halves or boundaries are hereinafter referred to as design and operational boundaries. They should be taken as optimal cross-sections of overhead lines and cables, through-pass power flow of transformers and autotransformers, available power of power plants, nominal parameters of switching devices, etc. This method was completely represented in details before [10].

4. NONDETERMINISTIC APPROACH

The available capacity of each electric plant supplies the active load capacity of consumers required from it and some spare power, which satisfies the actual mode active capacity demanded from the power plant and some proficit for unpredictable purposes due to abnormal conditions, maintenances and repairs of electric facility. The available active and reactive capacities together are utilized to complete the total current and power flow transported from the electrical plant to the network.

In power plant nets and in sections connected to the power system, the perception of available power is traditionally increasingly lost by reduction its affiliation to any station by this mark, because the active power flows of the transmited and distributed areas are formed by various generating units. Specifically, achieving the required capacity in various sections and customers of the power system using different energy sources is more difficult and inefficient if is proceeded from the original definition of the capacity associated with a specific power plant.

Non-deterministic calculations, i.e. setting the initial data as nonrandom argument (NA) and obtaining the results as the actual results (AR) in the form of probability distribution laws (PDL), i.e. probability distribution densities (PDD) or probability distribution functions (PDF) are not currently performed in the general case due to the huge amount of processing of the identical statistical information. At the same time, reducing the calculations is almost impossible. The only way to reduce this is the discretization of continuous processing and receiving the random variables, which provides an effect with sufficiently smooth changes in these quantities and functional dependencies between these quantities.

These capabilities are used to solve practical electric power problems including the above mentioned. To solving these tasks, as in cases of deterministic calculations, it is necessary:
- to structure the process on the initial data,
- the required functional transformations of this data in accordance with the content of the issues,
- the final result of all transformations being done.

A distinctive feature of probabilistic approach in comparison with deterministic calculations is the arrangement of not specific input data, but the PDL of all input data with their processing by deterministic or non-deterministic manipulations (random changes in transformation parameters) and obtaining not a specific random result, but a one-dimensional PDL of all specific transformations being performed.

Since data processing is currently performed only in a deterministic way (by means of professional software), non-deterministic calculations can be carried out only with the help of repeated numerous similar deterministic transformations that can be achieved due to the discretization of continuous random variables.

The issues of discretization, interconnection, preparation of initial data, selection of the basic type of PDL (PDD or PDF) for transformations and formations of the output PDL are the actual and main task that is being solved in this work. It allows to determine the PDL of each specific parameter in the modes of the power system by the PDL of the input data or random argument (RA). Another task is to obtain virtual flows of available capacities in the connections of the electric grid is based on the available capacities of power plants and load nodes.

Known PDL of mode parameters or current electrical units in the power network and PDL of available or resource capacities and currents allow to develop modifications of methods for determining the optimal magnitudes of design and operational values of available capacity of power plants and every specific component of the electrical installation based on the minimum risk. Finally the third urgent task of the electric power industry for the substantiated selection and verification of equipment, switching devices and current-carrying parts is implementing.

As a result, differences of the identical available and operational values or unbalances and their PDL can be formed on the basis of which the probabilities of negative unbalances or deficits can be determined, which can be interpreted as indicators of functional reliability or overload.

5. PROBABILISTIC ALGORITHM

The algorithm for determining the PDD of the specified functional dependancies is performed likewise as receiving the PDD of regime characteristics. The difference is the setting for the industrial software of the active available capacities in the load nodes as the constants, and in the generator nodes in the form of PDL [11]. The value of the voltage in the nodes in the form of PDL is used as the second parameter. During the operation of the professional software, power flows are formed in the sections, the first are considered as active available capacities of power plants distributed over the network.

These flows can be assigned the status of available, since they are obtained according to the same industrial software for calculating steady-state modes with modified (available) input data. The flows of reactive power in the branches in accordance with the electrical engineering have no differences from the reactive power that was obtained by balancing the steady state condition. Therefore, these reactive sflows in the branches can also be assigned the status of available. The remaining parameters of the modes for calculations with available input data should also be called available. Thus, the flows of available active and reactive capacities in the circuitry can be used to form functional dependencies (FD) such as available apparent capacities, total available currents in the branches, FD in the form of flows of available reactive power at the outputs of power plants.

Plenty of digital software systems are designed for deterministic calculations, in which the initial data or arguments that are processed by the function. The output result or the value of the FD on the arguments is given to the user. In power industry software for calculating the parameters of modes with the same initial data, a set of values of different FD relating to each object of the power system is issued, for example, required capacities in each branch, the magnitude and angle of voltage in each node of the network.

Since the initial data or arguments of functional transformations, as a rule, are random, the FD of all these energy tasks are also random, then the use of digital software systems is possible only for specific deterministic calculations. For the tasks of overload risks and optimal parameters of objects in the electric networks they should be used en masse. The latter is due to the enumeration of discrete value combinations of input data or random arguments (RA) that determine the discrete values of the FD that model the tasks.

Partially, the FD are provided in software complexes and they are used primarily, the missing FD are formed by users in accordance with the capabilities of softwares and the needs of the tasks being solved. The sampling of the RA can be arbitrary, and the discrete values of the FD depend on the accepted sampling of the RA. Since the values of random variables are ordered in the form of PDL, the arbitrariness of the RA sampling is always limited by the conditions of the PDL, which associate the values of each RA with its PDL as quantiles of setted orders, i.e. the values of each RA with the values of its PDL in the form of a PDF.

For each variant of the values (quantiles of different orders) of all the input data or RA of the process of sorting through the combinations of these quantiles and obtaining in each variant the value of each FD (that is embeded in the industrial program for processing the indicators of steady-state conditions, as well as available capacities under the same voltage restrictions) the additional FD should be calculated, that are of great practical importance:

- apparent actual and available capacity flows in circuits (branches) of transformer (autotransformer) connections,
- apparent actual and available currents or cross sections in branches of network conjunctions. The ineffectiveness of deterministic methods for selecting the potential capabilities of the last is stipulated by the regular unplanned transfer of electrical varieties through such circuits. The engineering methods and calculations are required that allow to analize fully the random nature of the initial data or the RA and the results or the FD determined by practical tasks. The tasks that arise in this case are diverse, including the electric power challenges set here.

Actual scheme quantities (capacities, currents, etc.) and consequently the resource equivalents transcending the actual ones are used in a deterministic form for the exploitating and design practice of power systems and industry in the whole (in addition to future engineer training at colleges and universities). Received practical results are appleable to solving some problems but incompleteness of output data caused by randomization of scheme quantities.

The most complete and adequate characteristics of random variables are the laws of probability distribution PDL, compacting all values in the form of probabilities and therefore taking into account all the features of such quantities in design optimization, control and management tasks. Undoubdetly it is possible because probabilities represent the significance of each value of random variables and give a complete picture of the interaction of these values. However, the widespread integration of problem solving in a probabilistic form is hindered by the inability to accurately set and obtain the PDL of random variables.

In the energy industry, as in many other enterprises, when carrying out probabilistic calculations, there are recommendations for approximating probabilistic distributions of loads (capacities and voltages, for instance) by normal PDL and the identification of the named PDL parameters. This enables to set the PDL of substation loads and actual loads of electrical plant units as RA for the tasks of obtaining regime parameters.

At present, the problem of obtaining PDL of random FD of the regime parameters and electrical quantities in case of damage using industrial programs has been solved in almost accurately. Therefore, the issue of using functional dependencies in the form of PDD for electric power tasks of calculating risks from exceeding the actual electrical value is especially acute. For example, exceeding by the flow of apparent power through a transformer element of the resource (nominal) capacity of this element and from a decrease in the resource (available) capacity of generating point as the integral part of power system relative to the resource (nominal) capacity of the transformer element, which can be delivered to this transformer element via the network from power plants. The total risk defined by the summation of various resource (nominal) capacities of the transformer has different values. With the minimum value of the total risk, it is advisable to accept the rated power of the transformer element.

The total capacity of the transformer circuit must exceed the ultimate actual capacity and do not surpass the minimum resource apparent capacity of the power plants as a part of the electrical system provided over the transformer circuit. Obvious, that in this case the named range of capacities for selection is practically unlimited. Therefore, one of the values of the possible resource capacity of the transformer element is selected and the risks may be optimized from the conditions:

- eclipsing the actual capacity through the power circuit of the selected one,
- reducing the resource (available) power of power plants delivered to the transformer element relative to the selected power of this element, where the minimum is the potential magnitude of the resource capacity delivered to the transformer element from generating point and the ultimate is the possible magnitude of the actual power over the transforming unit,
- scrutinizing the resultant risk .

The calculated value of the total risk corresponds to the resource capacity of the transformer element. Having vary the resource capacity of transformer it is possible to get different values of the total risk. The power is optimal from the point of view of the total risk (minimal value of risk) of overload of the transformer element circuit.

Correspondingly, the issue of the excellent cross-section of the transmission lines connecting power stations and substations of the network can be clarified. This resource problem can be applied to any transporting and network facilities, and not only to flows in branches, but also flows through nodes, for example, switchyard busbars at stations and substations for purpose of the economically and technically best option for buses cross sections selection.

6. CONCLUSIONS

The developed algorithm for determining the PDL of FD by the PDL of RA can be directly applied to such a commonly used value as unbalance in all parts of power system, i.e. the difference of the identical parameters of resource and actual current or power flows. The named difference or unbalance can be positive (reserve) and negative (deficit) – random variables, but very important fundamental values for all points of the network. Knowing the unbalance, it is possible to receive and analyze all the indicators required for operation, design, management with further improvement in the design or exploitation aspects of power system components [12-17].

The unknown conditional PDD of the resource or actual component will be required in the algorithm for determining the PDL of the unbalance to sum up the values of the joint PDD of the resource and actual elements. Accordingly, the PDL of such FD as unbalance is prescribed to be formed together with the PDL of all FD parameters of modes and resource quantities.

The proposed method may be applied to all types of power plants – fossil fuel, nuclear, hydroelectric and renewables as well, which is extremely important in time of power industry transformation from tradtional approach to eco-friendly way of power generation.

NOMENCLATURES

Acronyms

PS	Power System
UPS	Unified Power System
NA	Nonrandom Argument
RA	Random Argument
AR	Actual Result
PDL	Probability Distribution Law
PDD	Probability Distribution Density
PDF	Probability Distribution Function
FD	Functional Dependencies

REFERENCES

[1] L. Hirth, I. Ziegenhagen, "Balancing power and variable renewables: Three links", Renewable and Sustainable Energy Reviews, Vol. 50, pp. 1035-1051, 2015.
[2] file:///Users/sergej/Downloads/energies-13-01920-v2.pdf.
[3] http://www.journal.ftn.kg.ac.rs/Vol_9-2/04-Skokljev-Sosic.pdf.
[4] https://core.ac.uk/download/pdf/323986585.pdf.
[5] S.A. Gusev, O.M. Kotov, V.P. Oboskalov, "Meshed power system reliability estimation techniques", Energy Production and Management in the 21st Century, Vol. 1, pp. 235-247, 2014.
[6] G. Benysek, M. Pasko, "Power Theories for Improved Power Quality", Springer-Verlag London, pp. 1-11, 2012.
[7] https://arxiv.org/pdf/1601.08207.pdf.
[8] M. Kalantar-Neyestanaki, M. Bozorg, F. Sossan and R. Cherkaoui, "Allocation of Active Power Reserve from Active Distribution Networks Using a Cost-Benefit Approach: Application to Swissgrid Network", IEEE Milan PowerTech, Milan, Italy, 2019, pp. 1-6, June 2019.
[9] https://www.so-ups.ru/fileadmin/files/company/reports/disclosure/2023/ups_rep2022.pdf.
[10] L.V. Krivova, A.V. Shmoilov, "Distribution of available capacity in power network", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 49, Vol. 13, No. 4, pp. 207-212, December 2021.
[11] L.V. Krivova, A.V. Shmoilov, "Application of the Probabilistic Technologies to Power Plant Design", IOP Conference Series: Material Science and Engineering, Vol. 1019: The 14th International Forum on Strategic Technology (IFOST 2019), 012090, p. 5, 2021.
[12] N.R. Rahmanov, N.M. Tabatabaei, R.E. Kerimov, A.Z. Mahmudova, "Hybrid Distribution Generation Systems Construction with Renewable Energy Sources for Remote Consumers Power Supply", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 50, Vol. 14, No. 1, pp. 149-155, March 2022.
[13] T. Lazimov, E. Saafan, "Numerical Simulation of Capacitive and Small Inductive Currents Switching-off in High-Voltage Systems", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 51, Vol. 14, No. 2, pp. 136-152, June 2022.
[14] K.N. Taghizadegan, H.M. Ahangari, A. Mirzaei, "Optimal Design of Electrical Energy Storage Systems in the Presence of Intelligent Distribution Network to Improve Technical, Economic, and Performance Criterions", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 53, Vol. 14, No. 4, pp. 163-169, December 2022.
[15] J. Ma, Y. Liu, S. Zhang, L. Wu, Z. Yang, "Comprehensive Probabilistic Assessment on Capacity Adequacy and Flexibility of Generation Resources", International Journal of Electrical Power and Energy Systems, Issue 2, Vol. 145, February 2023.
[16] W. Zhou, M. Guo, C. Wang, H. Gao, T. Liu, J. Liu, "Power System Flexibility Assessment Based on Stochastic Production Simulation", Panda Forum on Power Energy, Chengdu, China, pp. 215-219, 27-30 April 2023.
[17] G. Zheyu, Y. Zheng, G. Li, "Power system Flexibility Quantitative Evaluation Based on Improved Universal Generating Function Method: A Case Study of Zhangjiakou", Energy, Vol. 205, 117963, August 2020.

BIOGRAPHIES

Name: **Lyudmila**
Middle Name: **Vladimirovna**
Surname: **Krivova**
Birthday: 12.08.1974
Birthplace: Voroshilovgrad, USSR
Master: Power Plants, Department of Power Plants, Faculty of Automation and Electrical Engineering, Tomsk Polytechnic University, Tomsk, Russia, 1997
Doctorate: Ph.D., Power Plants and Power Systems, Faculty of Power Systems, Novosibirsk State Technical University, Novosibirsk, Russia, 2003
The Last Scientific Position: Assoc. Prof., Higher School of High Voltage Engineering, Institute of Energy, Peter the Great Saint Petersburg Polytechnic University, Saint Petersburg, Russia, Since 2021
Research Interests: Power Plant Design, Structural and Functional Reliability of Power Plants, Pedagogy, Linguistics
Scientific Publications: 14 Papers, 1 Book, 1 Monograph, 33 Theses
Scientific Membership: ING-PAED-IGIP Register

Name: **Anatoly**
Middle Name: **Vasilievitch**
Surname: **Shmoilov**
Birthday: 29.04.1939
Birthplace: Karaganda, USSR
Master: Automation of Power Systems, Department of Power Plants, Faculty of Automation and Electrical Engineering, Tomsk Polytechnic Institute, Tomsk, Russia, 1962
Doctorate: Ph.D., Power Plants and Power Systems, Department of Power Plants, Tomsk Polytechnic University Tomsk, Russia, 1967
The Last Scientific Position: Assoc. Prof., Power Plants Department, Institute of Power Engineering, Tomsk Polytechnic University, up to 2019
Research Interests: Power Engineering, Structural and Functional Reliability of Power Systems, Protective Relaying
Scientific Publications: 64 Papers, 4 Patents, 10 Books, 2 Monographs
Scientific Membership: Scientific Manufacturing Organization "Energy", Russia