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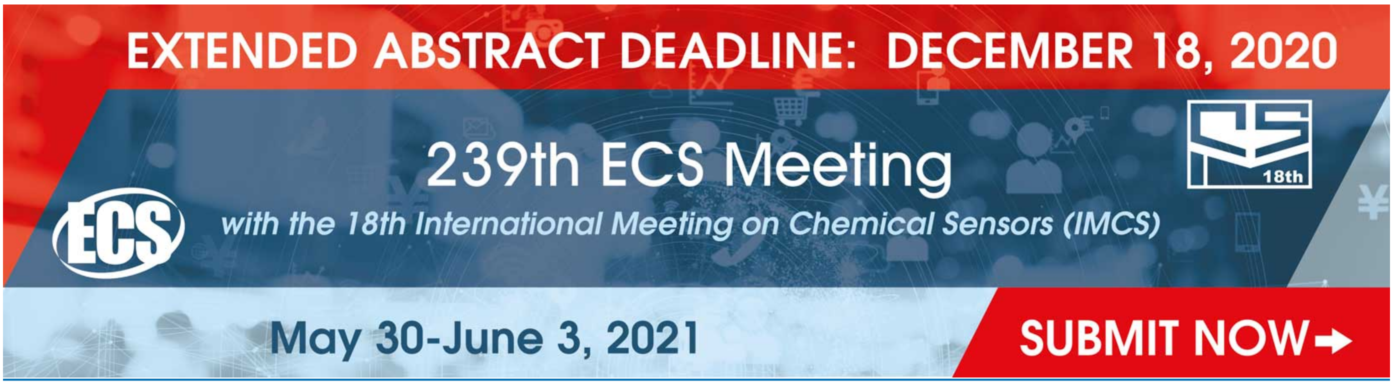

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Calculation the dynamic stability zone of the distribution grid with generating sources based on renewable energy

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Abstract. This study discusses the problems of ensuring the dynamic stability of distributed grids, including traditional generators, as well as renewable energy sources. Based on the energy distribution problem, an alternative regime model is formulated to calculate the steady-state in the distributed grid. Instead of using the state vector, it uses a calculated vector containing flows of active and reactive power for all branches of the grid's equivalent circuit and nodal voltages. Test circuits of the distribution grid are drawn up for the power node with the possible connection of a solar power station and a gas turbine. It is shown that the appearance of heavy perturbations on the lines connecting these parts leads to a loss of dynamic stability. This creates new scarce and redundant parts of electrical grids. The possibility of the appearance of such areas is reduced with small (up to 30%) and large fractions (more than 85%). Therefore, in this range, it is advisable to concentrate distributed generation facilities in individual nodes of the power system.

1. Introduction

Improving the reliability of power supply to individual consumers in recent years is achieved by installing affordable devices for generating and storing electricity. Such installations include mobile consumer gas piston, diesel generator and highly maneuverable gas turbine units, as well as generating sources operating on renewable energy [1]. These sources due to the big non-stationary nature of renewable sources (wind, sun, water resources, etc.) [2-7] lead to the emergence and development of energy storage systems. The term "distributed generation" [8] is applied to the listed facilities. In addition to increasing reliability, the emergence of distributed generators in grid is associated with the desire of consumers to reduce their energy supply costs. It is easiest to implement the elements of the Smart Grid concept and implement the developed control systems [9] in the grids of modern large enterprises with good technical equipment, as well as in relatively new sections of 10 kV grids [10, 11]. In addition to the scheme of the distributed grid, one can distinguish another feature related to the implementation of distributed generation installations. Their appearance among consumers as participants in energy exchange leads to a change in the flow of capacity and energy flows in the grid. Compared to the previous organization of power supply, in which capacity and electric energy flowed from the power centers to the consumer in only one direction, now the flows can be directed in the opposite direction - towards the buses of the central point and further to the high-voltage grids. Such change in flows may be chaotic and depends on the decisions made by the owners of generation plants and energy storage devices on the amount of power output to the common grid. From the point of view of the operation system problem using the classical regime model with equations of nodal voltages [12], it is practically impossible to take into account the change in the capacity and energy flows, as well as the grid diagram inside the measurement information collection interval T, which will be cause problems with the correct solution of the operational problem on this, but already in calculated time interval T [13].

Creating a complete computational model of the distributed grid’s section requires taking into account a large number of nodes and branches in the grid equivalent circuit [14]. Due to the significant total length of power lines and a considerable number of transformer and distribution points, the dimension of the problem to be solved, even within the same energy region, can be significantly larger than the dimensions of the same problem solved in high-voltage grids. Despite the fact that the computational capabilities of modern computers are quite large, the calculation of operational parameters in a distributed grid can take up to half a minute. A lot of work based on the use of parallel computing [15] is devoted to solving this problem in the distributed grid.

To solve some of these problems and take into account the features of distribute grid in some cases, within the framework of solving the problem of assessing the state, it becomes important to choose the mathematical model of the grid’s mode of operation.

2. Method

The main way to evaluate the current operation of power systems and their elements is the well-known procedure for calculating the steady regime according to the data of the node capacities. The result of calculating the steady regime is to obtain all operational parameters in the grid circuit according to the specified parameters of the node loads and generation. Calculation models that allow obtaining operating parameters are based on equations connecting them in the framework of the basic laws of electrical engineering, recorded through reference calculated values. These values are included in a single state vector of the X_{eq} regime model and the formed system of equations is solved with relation to them. The generation and load parameters of nodes for calculating the steady regime, forming a basis, are usually set in the form of nodal flows of active and reactive power, less often in the form of currents. This is in good correlation with the specifics of the information development of 6-35 kV grids, which consists in increasing the number of modern microprocessor meters electricity in the nodes of the grid [16]. Also, the use of various models for calculating steady regime implies a direct calculation or additional calculation of power flows or currents, which to some extent reflects their "streaming" nature.

The most common mathematical models for calculating steady regimes in ring and radial grid circuits are model algorithms [17] that use the equations of nodal voltages, written in the form of a power balance or in the form of a current balance [18]. To link regime parameters in these equations, the first Kirchhoff law and Ohm's law are used [19].

Despite the prevalence of regime models based on the equations of nodal voltages, they all have a number of significant drawbacks related to their use in a distributed grid. The first problem is related to the use of voltage modules and their angles in the state vector. Mathematical equivalentization of grid sections in such model is possible only by creating fictitious links, without reference to the original existing grid scheme. Such problem may arise when exclusion of unobserved grid sections, as well as sections that do not affect the result of calculating steady regimes. Grid sections with new virtual connections make it difficult to analyze the results of calculating steady regime. In addition, the inclusion in the equivalent circuit of simultaneously long lines with high resistance and short branches, the resistance of which tends to zero (the angles of voltages at the ends of such lines are almost equal to each other), leads to a significant deterioration in the conditionality of the system of equations being solved and significantly complicates the calculation of steady regime if its have small errors [20].

Both of the problems described are relevant when using the classical model of steady regime with nodal voltages equations for calculating the operation mode in grids with renewable energy sources, which have many unobservable sections that have branch resistances of different sizes in the grid circuit. This limits the use of models that use modules and voltage angles in the state vector to calculate operating parameters in the distributed grid.

To calculate the operating mode of 6-35 kV grids, a mode model is needed that takes into account their specifics and possible configurations of electrical circuits, trends in their information development, has the ability to algorithmize, and in which there are no described shortcomings of the classical model that uses classical equations nodal voltages. In this regard, on the basis of the energy distribution problem [21], an alternative mode model is formulated for calculating steady regime, using instead of the state vector a calculation vector containing flows of active and reactive capacities for all ***M*** branches of the grid equivalent circuit and nodal voltages (Eq. 1):

$$X_{eq}^{m}=\left[P_{b}^{n};Q_{b}^{n};U_{n}\right] \tag{1}$$

In contrast to the state vector, the dimension of which is always (Eq. 2):

$$2\cdot(N-1) \tag{2}$$

The calculated vector of the proposed model is wider and, like the state vector, it is possible to uniquely determine the remaining operational parameters in the grid [22]. The equations of state of such a model describe separately the balances of active and reactive capacities in all N - 1 nodes except for the balancing circuit and in all ***M*** branches of the grid equivalent circuit. Therefore, in the work, this regime model was called the “stream model”. It does not use angles when solving a system of equations and, unlike the classical regime model, does not have problems connected with them.

The system of equations of the steady regime of an electric system due to non-linearity with relation to the sought variables can formally have many solutions or not have any physically feasible solutions. Since in the general case the solution of nonlinear nodal equations for a complex electrical system can be obtained only iteratively, it is necessary to solve the problem of the relationship between the convergence of the process and the existence of a solution. Indeed, if the iterative process does not converge when calculating a certain mode, the solution can sometimes be obtained by improving the initial approximation, adjusting the course of the process (using accelerating coefficients, introducing an additional parameter, etc.) or using another method. The problem of stability of the obtained solution also arises [23, 24]. Thus, it is necessary to solve the problem of the relationship of the properties of nonlinear equations and real modes, i.e. the adequacy of the properties of the steady state real electro energy system and its accepted mathematical model.

The determination of the steady regime, the limit on any of its parameters (capacity or voltage module in individual nodes, capacity flow, etc.) is a frequently encountered problem in practice. In the general case, this problem can be solved through a series of calculations of steady-state regimes with their “weighting”. In this case, the options and trajectories of the regime’s weighting from the initial to the limit are determined by the nature of the problem being solved.

The idea of this distribution is the possibility of generating the energy necessary to meet the requirements of the load and the system, manage them and obtain the necessary power in the system while minimizing the cost of control. In the process of electric energy transmission, one of the main issues is the control of reactive power in the grid [25], which is associated with ensuring the necessary voltage levels in its nodes, since this minimizes active losses. There are many methods for optimizing reactive power control. The method proposed by the authors of [26] implements this using linear programming and is based on calculations of reactive capacity by the reactive current of the grid.

Calculations of reactive current in standard elements of the electric grid, necessary for planning purposes, are carried out according to the expression [26]:

$$P_i + j \cdot Q_i = U_i \cdot \sum_{k=1}^{n} \left(U_{ik} U_k \right), i = 1,2,...,n \tag{3}$$

which is solved with respect to U_i is the system voltage in steady regime. The distribution of reactive power in many cases is unknown, but the solution obtained is very close to it. In the event that several solutions are considered, then finding the answer is difficult. The solution of similar problems is achieved if part of the changing values is set in advance or changed automatically, by simple exhaustive search. Only in this way can a general solution or its criteria be obtained. This will be the optimal distribution of reactive power flows, which is one of the tasks of the general capacity distribution. The parameters of the optimal distribution of capacity flows with values characterizing the regime of the energy system are presented in table 1.

Table 1. Parameters of capacity flow distribution and mode

Controlled parameter	*Given values z*		*The sought quantities y*
	Fixed *c*	Controlled *x*	
Free (uncontolled)	δ_i	U_i	*Pi. Qi*
P, *U* (generator) 9/5000	P_i	U_i	δ_i, *Qi*
P, *Q* (reactive power source)	P_i	Q_i	δ_i, U_i
P, Q (load)	P_i. Q_i	-	δ_i, U_i
Elements of lines	Transformers, lines topology	t_1	Threads in branches (currents, power)

The optimization problem in this case is given as:

$$f(x, y, c) = \min \tag{4}$$

Relatively

$$e(x, y, c) = 0 \tag{5}$$

$$x_{min} \leq x \leq x_{max} \tag{6}$$

$$h(x, y, c) \leq 0 \tag{7}$$

Equation (5) corresponds to equation (3) and meets the balance requirement:

$$f_1(x, y, c) = \sum_{k=1}^{n} P_i \tag{8}$$

hear n_i—number of nodes.
Given real capacities

$$f_i = P_{\text{uc}},$$

$$f_2(x, y, c) = \frac{1}{m} \cdot \sum_{i=1}^{m} \left(\frac{1}{n_i} \cdot \sqrt{\sum_{k=1}^{n_i} \left(V_{ki} - V_i \right)^2} \right) \tag{9}$$

here:

$$V_i = \frac{1}{n_i} \sum_{k=1}^{n} V_{ki} \tag{10}$$

m - number of substations of the electrical system; n_i - the number of nodes of the i-th subsystem; P_{uc} - unbalance capacity.

It is important to know the optimal distribution of reactive power for both planning and control purposes. Knowing the reactive capacity during planning, it is possible to minimize energy losses during power transmission and to identify weak points in the energy system from this point of view. When reactive power is controlled, the best conditions for voltage regulation are determined, and the conditions for achieving a stable state of the system are provided.

The task of reactive capacity optimization is closely related to ensuring optimal voltage levels [26] by minimizing power losses in the electrical system. Therefore, when solving this problem, the issue of ensuring a power balance in the system, optimizing the upper and lower limits of voltage values, the position of transformer solders, and generating reactive power is simultaneously solved.

The problems of calculating capacity fluxes to solve the voltages in nodes, the values of reactive power, and the positions of transformer solders are described in [26]. The use of such linear models is possible together with the application of the methods of economic intervals and economic distribution of active power between generators of power plants. At the same time, problems of both minimizing losses and power distribution between generators of power plants are solved.

When forming a model of a generating system with parallel connection of elements, the generating element of the system can be represented in the form of some integral powers Y_i, corresponding to the probability$P_{G1}(Y_i)$ and frequency $F_{G1}(Y_i)$. When two generators from renewable energy sources are connected in parallel, the value of their combined power Y_k is equal to the sum of the respective capacities of each unit, taking into account the available access to solar, wind or other energy. Integral probabilities and frequencies for this compound can be found from the data of single generators without taking into account the transient process between them [26].

It is assumed that the integral probabilities and frequencies of the generators G_1 and G_2 are presented in the form:

$$p_{G_1}(Y_i), F_{G_1}(Y_i), i = 1,\dots,n_{G_1}$$

$$p_{G2}(Y_j), F_{G2}(Y_j), j = 1,\dots,n_{G2}$$

Here Y_i – rated power.

When the power lines are connected in series with the transmission capabilities Y_j of the generator power Y_i, the smaller Y_{jk} of the two transmitted power lines is taken as the capacity of this connection.

We take the integral probabilities and frequencies of the separate generator G and line T:

$$p_G(Y_i), F_G(Y_i), i = 1,\dots,n_{G_1}$$

$$p_T(Y_j), F_T(Y_j), j = 1,\dots,n_T$$

The equations for the integral probabilities and frequencies for the serial connection of the generator and the power line are as follows

$$p_{G-T}(Y_k) = p_G(Y_k) + p_T(Y_k) - p_G(Y_k)\cdot p_T(Y_k) \tag{11}$$

$$F_{G-T}(Y_k) = F_G(Y_k)[1 - p_T(Y_k)] + F_T(Y_k)[1 - p_G(Y_k)] \tag{12}$$

Additional generation. If the transmitting power of the line Y_j is less than the possible generating power Y_i, then in this case only a part of the generating power can be transmitted via overhead lines. The power difference Y_k should remain in the generating system. These power residues, due to the design features of overhead power lines, will be called additional generation of G_T. The formulas for integral probabilities and frequencies for additional generation are as follows:

$$p_{\overline{G}_T}(Y_k) = \sum_{j=1}^{n_T} p_G \cdot (Y_k + Y_j)\cdot\left[p_T(Y_j) - p_T(Y_{j+1})\right] \tag{13}$$

$$F_{\bar{G}_T}(Y_k)=\sum_{j=1}^{n_T}\left\{F_G\cdot(Y_k+Y_j)\cdot\left[p_T(Y_j)-p_T(Y_{j+1})\right]-p_G\cdot(Y_k+Y_j)\cdot\left[F_T(Y_j)-F_T(Y_{j+1})\right]\right\} \tag{14}$$

Addition to the transmission power of the line. If the transmission capacity of the line Y_j is greater than the transmitted generating power Y_i, then it is possible to transmit additional power from other generating sources. This remainder of the Y_k line transmittance used for other sources of generation is considered as a complement to the T_G line transmittance.

The expressions for determining the integral probabilities and frequencies of complementing the transmission power of the line are as follows:

$$p_{T_G}(Y_k)=\sum_{i=1}^{n_G}p_T\cdot(Y_k+Y_j)\cdot\left[p_G(Y_i)-p_G(Y_{i+1})\right] \tag{15}$$

$$F_{T_G}(Y_k)=\sum_{j=1}^{n_G}\left\{F_T\cdot(Y_k+Y_j)\cdot\left[p_G(Y_j)-p_G(Y_{j+1})\right]-p_T\cdot(Y_k+Y_j)\cdot\left[F_G(Y_j)-F_G(Y_{j+1})\right]\right\} \tag{16}$$

Options for using system reserves, restrictions for communication lines, and priority rules for transmissions will include in a conditional equivalent unit with “-” states used for closed systems.

3. Results and Discussions

Studies of the effect of distributed generation on the stability of the distribution grid and electro system are carried out on test circuits shown in Figure 1. Distribution grid consists of 11 nodes.

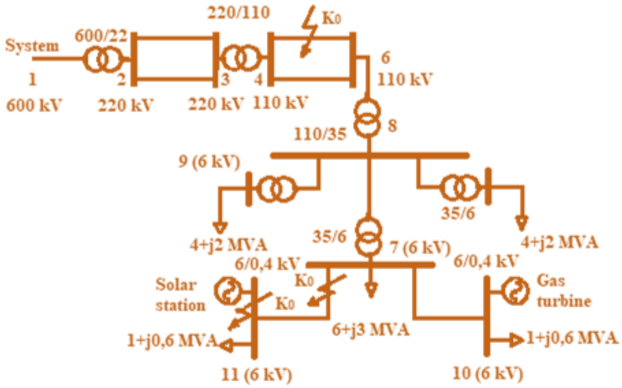

Figure 1. Test circuits for a distribution grid with a solar station and a gas turbine

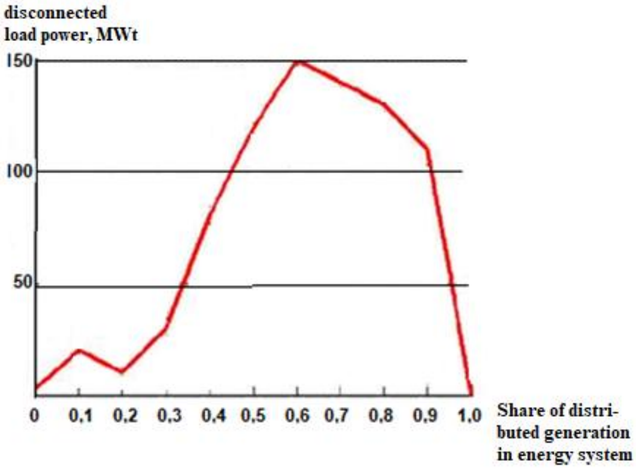

Figure 2. The dependence of the disconnected power on the share of the distributed grid

Studies of the effect of distributed generation on the dynamic stability of electro power system are carried out. According to the results of the analysis, it was determined that the most potentially dangerous range of the total share of distributed generation in the EPS is 30% -85% of the total power load of the electro power system (Figure 2). In this range of fractions, the greatest load disconnection and generation power is observed. This is due to the fact that in this range the most possible cases of concentration of distributed generation units in certain areas of electro power system are, thereby creating new scarce and excess parts of it. The appearance of heavy disturbances on the lines connecting these parts leads to a loss of dynamic stability. With small (up to 30%) and large fractions (more than 85%), the possibility of the appearance of such areas is reduced. The important role of the distribution of small generators in electro power system is also established. It is precisely determined that the uniform distribution of small generation over it has a positive effect on the dynamic stability.

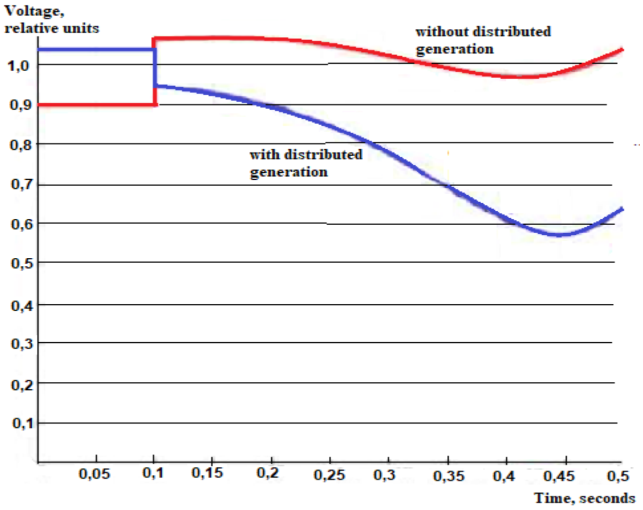

Figure 3. Time dependence of the operational parameters of an unstable line.

When analyzing the mechanism of loss of dynamic stability, it was found that a sign of loss of dynamic stability in the electro power system is an unlimited increase in the angle of transmission on unstable lines. At the same time, electric swing centers are formed on the lines, characterized by a deep decrease in voltage.

Figure 3 shows the time dependences of the operational parameters of an unstable line with a loss of dynamic stability for a distributed grid.

When analyzing the effect of distributed generation on the grid, it was found that an increase in the generation power can cause dangerous fluctuations in the transmission angles between nodes with and without distributed generation units (due to the inertia of the distributed generation units), which leads to deep voltage drops and loss of dynamic stability.

4. Conclusions

1. The load schedule can vary greatly over time, is the presence of distributed generation operating on renewable energy sources. Electro energy generation at such power plants is highly dependent on meteorological conditions. During hours of the greatest solar radiation and strong winds, its generation will be maximum, otherwise, generation of electro energy may be significantly reduced. Under such conditions, energy flows will quickly change their direction when flowing from the distributed grid to high-voltage grids and contra versa. All this, one way or another, can contribute to a sharp change in the load curve on the tires of the head power centers.

2. Limitations associated with fast dialing and load shedding in the grid make sense only if the grid has mobile and highly maneuverable generation units (gas turbines and microturbines).

3. Based on the results of the analysis, it was determined that the most potentially dangerous range of the total share of distributed generation in the electro power system is 30÷85% of the total load power of the electro power system.
4. The introduction of distributed generation in the electric grid can cause the appearance of redundant and scarce areas, which will negatively affect the dynamic stability of the power system. The loss of dynamic stability in the power system is characterized by an increase in transmission angles on unstable lines. The use of the operational regulator of the flow power, which allows for quick adjustment of the conductivity of the lines, makes it possible to regulate the flows of active power and ensure the dynamic stability of the generators in the power system.

References

[1] Adewuyi OB, Lotfy ME, Akinloye BO, Howlader HR, Narayanan K 2019 *Applied Energy* **2451** 16-30.
[2] Worighi I, Maach A, Hafid A, Hegazy O, Van Mierlo J 2019 *Sustainable Energy, Grids and Networks* **18** 100226.
[3] Anarbaev A, Tursunov O, Kodirov D, Muzafarov Sh, Babayev A, Sanbetova A, Batirova L, Mirzaev B 2019 *E3S Web of Conferences* **135** 01035.
[4] Tursunov O, Isa KM, Abduganiev N, Mirzaev B, Kodirov D, Isakov A, Sergiienko SA 2019 *Procedia Environmental Science, Engineering and Management* **6**(3) 365-374.
[5] Kodirov D, Tursunov O, Parpieva S, Toshpulatov N, Kubyashev K, Davirov A, Klichov O 2019 *E3S Web of Conferences* **135** 01036.
[6] Kodirov D, Tursunov O 2019 *E3S Web of Conferences* **97** 05042.
[7] Tursunov O, Zubek K, Dobrowolski J, Czerski G, Grzywacz P 2017 *Oil & Gas Science and Technology – Rev. IFP Energies Nouvelles* **72**(6) 37.
[8] Pazderin AV 2004 *Electricity* **12** 2-7.
[9] Eissa MM, Ali AA, Abdel-Latif KM, Al-Kady AF 2019 *Int J Electrical Power & Energy Systems* **108** 40-51.
[10] Dymshakov AV 2017 *International Conference and Exhibition "Relay Protection and Automation"*, St.Pteresburg, Russia 25-28 April.
[11] Mukhlynin ND 2015 *Bulletin of the Siberian Science Tomsk Polytechnic University* **15** 72-76.
[12] Mirakhorli A, Dong B 2018 *Applied Energy* **23015** 627-642.
[13] Krivorot AV, Efimov DN 2015 *Reliability of energy systems: achievements, problems, prospects,* **64** 344-350.
[14] Khushiev S, Ishnazarov O, Tursunov O, Khaliknazarov U, Safarov B 2020 *E3S Web of Conferences* **166** 04001.
[15] Zhang GR, Brameller A 1984 *In Proceedings: The 8th PSCC*, Helsinki, 369-400.
[16] Aboushal MA, Zakaria Moustafa MM 2019 *Alexandria Engineering Journal* **58** 1229-1245.
[17] Khokhlov MV 2004 *Management of Electric Power Systems - New Technologies and the Market*, Syktyvkar, 39-48.
[18] Adnan M, Tariq M, Zhou Zh, Poor HV 2019 *Int J Electrical Power & Energy Systems* **104** 744-771.
[19] Ilyushin PV 2015 *Energoekspert* **1** 58-62.
[20] Samoilenko VO 2014 *Industrial Energy* **11** 31-35.
[21] Chakraborty S, Simoes MG, Kramer WE 2013 *Power Electronics for Renewable and Distributed Energy Systems, Green Energy and Technology,* Springer-Verlag, London.
[22] Mongrain RS, Ayyanar R 2020 *Int J Electrical Power & Energy Systems* **119** 105890.
[23] Laudgvist A, Bubrnko JA, Sjelvgren D 1984 *In Proceedings: The 8th PSCC*, Helsinki, 418-424.
[24] Doi A, Takeda S, Vemura K 1984 *In Proceedings: The 8th PSCC*, Helsinki, 434-438.
[25] Li Y, Feng Yu, Zhang H, Cao Y, Rehtanz Ch 2018 *Int J Electrical Power & Energy Systems* **103** 652-659.
[26] Mishra MK, Lal VN 2020 *Solar Energy* **199** 230-245.