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

September 2020 Issue 44 Volume 12 Number 3 Pages 1-9

EVALUATION OF THE ELECTRIC POWER SYSTEM STATE USING MODELS OF PROBABILITY-FUZZY SYSTEMS

H.B. Guliyev

Azerbaijan Scientific-Research and Designed-Prospecting Institute of Energetics, Baku, Azerbaijan,
huseyngulu@mail.ru

Abstract- Probabilistic-fuzzy models are proposed that describe the variability of the power system state caused by the stochasticity of load and generation. The proposed models allow, based on the simultaneous consideration of the stochasticity and uncertainty of the power system state variability, for more accurate simulation of its state. The calculations of the probabilistic power flow show that at fuzzy-stochastic change of the load power and generation, with the increase of the maximum load, the probabilistic estimate of the voltages in the network can significantly change. The installation of a regulating compensating device significantly improves the voltage value and allows for getting its evaluation with a higher probability.

Keywords: Power System, Probability-Fuzzy Model, Membership Function, Voltage Probability Distribution Curve, Probability Density Functions.

1. INTRODUCTION

Currently, new approaches are widely used for the analysis and control of power system, that makes it possible to represent real processes with high accuracy, taking into account the probabilistic nature and the uncertainty of the initial information. The state of uncertainty, the random variability of the system mode parameters depend on many factors, as well as on the degree of their consideration in task models, such as load prediction, distribution of power flows, load distribution, etc.

In many practical applications the stochastic and deterministic methods of fuzzy modeling are used independently and separately, regardless of each other. Only one type of uncertainty is currently considered in the traditional theory of fuzzy mathematics and probabilistic models. There are studies in technical publications, in which an attempt is made to integrate methods of probability theories and fuzzy mathematics [1,2]. Some approaches and methods were proposed in the list of these studies, for example, methods for probabilistic measurements of fuzzy events in [3], fuzzy random sets [4,5], fuzzy random variables [6-9], non-stationary fuzzy sets and fuzzy model with probabilistic weight rules [10].

These methods are based on two integration rules. In one of them a fuzzy description is given in statistical form, in the other one the stochastic uncertainty is given in a fuzzy system. In this method a probabilistic fuzzy set is described in the coordinates of stochastic variables represented by a binary probability density function containing stochastic and non-stochastic uncertainties. The development of the proposed approach for solving the problems of regulation of reactive power and voltage in the electrical system is given in the paper.

In the general case the probabilistic nature of fuzzy-defined states of the power system is determined by the stochastic variability of the total electric power consumption, therefore, models of Gaussian type fuzzy sets with randomized center variability are considered in the paper. For the first time for fuzzy modeling of the state of electric power systems (EPS), random fuzzy set with a randomized Gaussian width is proposed in the thesis. The methodology for the combined use of probabilistic methods and fuzzy logic methods regarding the solving of EPS problems is considered.

2. THE ESSENCE OF THE FUZZY MODEL PROBABILISTIC REPRESENTATION PROBLEM

At present two forms of fuzzy system representation are theoretically developed and widely used. The first form is presented in the form of a fuzzy mathematical model in which the uncertainty is specified by state parameter clustering. The second form of the fuzzy model is based on a sequence of fuzzy rules, the adoption of which makes it possible to support fuzzy decisions.

Probabilistic fuzzy set (PFS) is a set that has stochastic and fuzzy properties. These properties can be represented in the form of probabilistic fuzzy system model, which can be represented in the form of the variability of the center and the width of Gaussian fuzzy set expansion [11,12]. Thus, in a probabilistic fuzzy set, for example, for an input variable x, there is one value or several values of the membership function. The parameters of membership function become a random variable that can be described by the secondary function of the probability density distribution. The membership functions of random variability load by hours and its membership function are given in Figure 1.

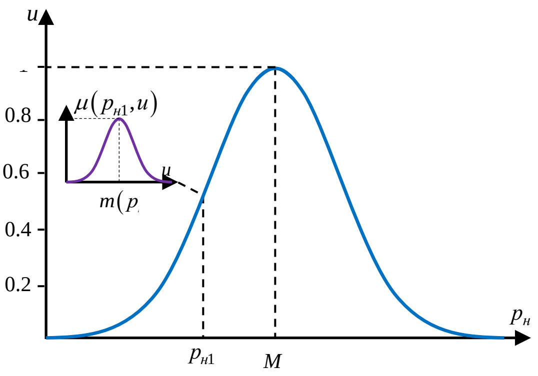


Figure 1. Probabilistic fuzzy set (primary and secondary MFs)

Like an ordinary fuzzy logical system, a probabilistic fuzzy logical system (PFLS) also has a fuzzification operation, has a logical inference and defuzzification mechanism. The difference also lies in the fact that PFLS uses a fuzzy set, expressed in a probabilistic form, and modeled by a multivariate membership function.

In the fuzzification process, real inputs are converted into PFS compiled on basis of membership functions with probabilistic parameters. You can meet many situations in which membership functions in fuzzy understandings can be interpreted in the form of a distribution of their parameters for variables, and the fuzzy control corresponds to the greatest realism. Regarding the electric power system or to its objects, fuzzy control methods are one of the successful practical implementations of fuzzy methodology in industrial conditions [13, 14].

Let's consider a generalized model of the power system state, in which the vector of variables at the output $X=(x_1,......,x_d)$ accepts the values within the area $x\subseteq\left\{R^{g,н}\right\}$, and the vector of variables at the output Y is set by the values $Y\subseteq\left\{R^{u,p}\right\}$, where $x_{gj},x_{нi}$ are current measured values of active and reactive power of generators in nodes j and load powers in the nodes i, respectively; and $x_{u_i},x_{p_{ij}}$ are current measured values of voltage profile and active power in electric network, respectively.

Based on fuzzy linguistic rules, implemented in the form "if ..., then ...", we compose rules using a verbal language modeled by a fuzzy set in following form:

$$R_j:\text{if } x_1 \text{ is } A_{j1},...,x_d \text{ is } A_{jd} \text{ then } y \text{ is } B_j,\ j=1,...,k \tag{1}$$

where, A_{ji},B_j are terms-subsets of $x_{gj},x_{нi}$ input and y_u,y_p output variables respectively.

The purpose of the fuzzy control is a derivation of rule of control $y=f(x)$ from R. Now, considering

$$A_j=\prod\nolimits_{i=1}^{d}A_{ji} \tag{2}$$

or

$$A_j(x_1,...,x_d)=t\left(A_{ji}(x_1),...,A_{jd}(x_d)\right) \tag{3}$$

where, t is accepted norm, one can see that R is a data set of type $\left(A_j,B_j\right)$, $j=1,...,k$ fuzzy pairs. If the couple $\left(A_j,B_j\right)$, summarizing the numerical data, represents relationship between x and y, it is more preferable than caused by causal relationship. In the context of control the B_j is a suggestions for realization, when input A_j is more preferable than A_j determined by a causal connection with B_j. Reasoning differently, it should be noted that the form of each R_j mapping of fuzzy relation on $X\times Y$ is more natural than the interpretation of "if ..., then ...." as an implied operator.

Sharpening or defuzzification is performed by calculating the mean of the center of the output controllable parameter. Traditionally, the values of the output parameter y_c according to the values of membership functions

$$y_c=\frac{\sum\limits_{j=1}^{\bar{j}}y_j\mu_R\left(x,y_j\right)}{\sum\limits_{j=1}^{\bar{j}}\mu_R\left(x,y_j\right)} \tag{4}$$

$$\mu_R=\max\left(\mu_{\bar{R}_1},...,\mu_{\bar{R}_j},...,\mu_{\bar{R}_{\bar{1}}}\right) \tag{5}$$

where, y_j is crisp input sequence; y_c, $\mu_{\bar{R}_j}$ are random output variables - center and membership functions. The clear conclusion of PFLS is the expected value of the output after traditional defuzzification [15]:

$$y=M\left[x\left(y_c\right)\right] \tag{6}$$

3. PROBABILISTIC POWER FLOW MODELING

Integration of renewable sources into the power system, especially their significant portion from wind and solar energy sources, creates the effect of random and intermittent variability of the total generating capacity in the power system, which leads to the corresponding random variability of voltage at network nodes and power flows in lines. The nature of random variability of the values of voltages and flows in the lines also depends on many other factors - weather conditions, time, electrical system circuit state, which lead to uncertainties of total generation in the system.

In order to represent in the system model the random nature of power generation from renewable sources (P_{WS}), as well as power consumption at load nodes P_L, the description of the variability of these powers in the form of distribution density functions $f(P_G)$, $f(P_L)$ is given in the paper. Representation of P_{WS} and P_L by relationships of their probability density $f(P_{G,WS})$ and $f(P_L)$ makes it possible to take into account:

- stochastic variability of load power of both individual nodes and the system on the whole;

- the portion of the effect of stochastic variability of the load power and generation in each node on the system mode and state relative to stability.

For modeling the probabilistic power flow, it is assumed that the distribution densities of power generation are set at the system circuit nodes with the included wind and solar stations, as well as the power consumption distribution density at load nodes.

Probability density function curves of wind turbine, PV solar plant and load consumption power are given in Figure 2.

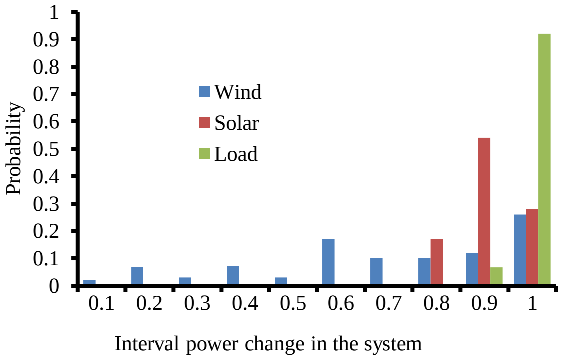
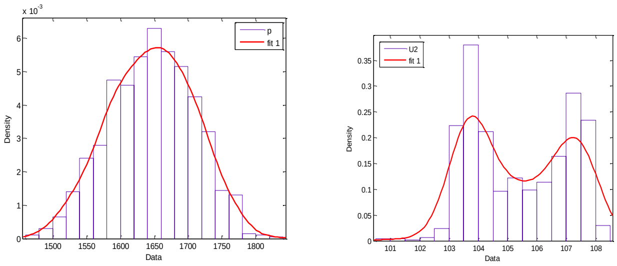


Figure 2. Graphs of probability density functions of wind turbine, PV solar plant and load consumption power

The resulting curve of the probability density of the coverage power in the node is investigated depending on the shared variability of the power values of wind and solar PV stations and the load power.

Having information about the value of the initial data, given as a function of probability density, power generation (the data are considered as powers of generating nodes), as well as probability density functions for load nodes (initial data of load nodes), a series of repeated power flow calculations can be performed, according to their results it is possible to construct a distribution density for nodal voltages and power flows in PTLs of distributed generation system. Such characteristics can be constructed for any hour of the daily curve, with their help it is possible to evaluate the current system state, considering the stochasticity of generation and load. As an example, Figure 3 shows the probability density curves of the distribution of voltage and power flows in one of the distributed generation systems of the Azerbaijani energy system.



(a) (b)

Figure 3. Voltage and load power distribution probability density curves a-active load; b-voltages

4. PROBABILISTIC MODELING AND ANALYSIS OF POWER SYSTEM MODES WITH STOCHASTICALLY CHANGING GENERATION AND LOAD

A characteristic feature of the development trend of modern power systems is the growth of the share of nonconventional energy sources - these are alternative energy sources such as wind generators, solar PV stations, geothermal, converters, fuel cell and other types of renewable sources. The difference between nonconventional and conventional sources is as follows:

- conventional sources are usually implemented in the form of powerful power plants that transmit generated power through high voltage networks, while nonconventional sources are sources of small and medium power, usually working with the power system through distributed generation networks or directly to the consumer's power supply network;
- ability to control power generation according to the dispatcher program: the operation of conventional sources is planned and controlled by system operator; nonconventional sources, such as wind farms, solar PV systems, do not have the ability to attract them to control the power generation in the required volume - their generation varies depending on the parameters of the wind and solar radiation;
- synchronous generators are used in all conventional power plants, and other generation technologies are used in nonconventional sources.

The power generation of such nonconventional sources as wind and solar power plants is stochastically changing, and the system operator for this reason cannot control their generation. Classification of nonconventional sources, taking into account the possibility or impossibility of controlling their power, is given in Table 1.

The system steady state model with integrated nonconventional sources with stochastic power generation is identified by the probabilistic characteristics of input data. To analyze the system state according to these data, a large number of calculations will be required. For example, for a power system diagram with N load nodes and stochastic sources, each production value, which is specified from the corresponding set of its sample (K of various measurements), K^N deterministic calculations of power flow are performed.

Table 1. Classification of nonconventional stations considering the production control capability

Generation technology	Regulated by the system operator	Stochastically changing
Biomass sources	+	
Geothermal station	+	
Combined heat- and power generating plants	+	
Small HPPs		+
Wind farm		+
PV solar sources		+
Tidal power plant		+
Wave power plant		+

Thus, it is possible to obtain quantitative information about the probabilistic assessment of the mode. This approach of stochastic system modeling includes the following three steps:

- information collection - input data of measurements of load and generation powers;
- quantitative determination of probabilistic changes in controlled parameters - nodal voltages and power flows in lines based on deterministic model, describing the system state;
- quantitative determination of probability characteristics for each random input parameter (representation of each input as probability density function).

In accordance with the above, probabilistic analysis can be implemented using analytical methods and stochastic modeling (Monte Carlo method).

Analytical methods. Application of these methods in real conditions is associated with the adoption of several the following assumptions:

- linearization of the system model assumes the representation of the output parameters of the steady-state model in the form of linear dependence from the inputs. Such approximation is allowable in cases where the dispersion for the inputs (stochastic measurements of the generation and load power) is limited by changes relative to the average value of this input;
- statistical independence of the system's input parameters. This assumption makes it possible to calculate system inputs using convolution or other decomposition methods;
- system inputs have a normal distribution. This assumption allows for using the linear correlation to represent the relationship between random variables. In this case, the linear dependence of random values can be used in analysis procedure; as a result input distribution can be obtained analytically by means of convolution.

Stochastic modeling (Monte-Carlo method) is based on the use of random numbers generated by a stochastic system model with a basic probability distribution function giving samples (test measurements) passing through a deterministic model, forming samples of values for output parameters that determine the system state. This method has significant advantages compared to analytical methods, since the computational procedure is mainly deterministic, and simplifications are not required here when forming a mathematical model with the purpose of possibility to implement the method. The main drawback of the Monte Carlo method is the need for a huge number of repetitive calculations, which leads to the cost of computing resources and, accordingly, the use of this method in operational calculations is associated with difficulties. At the same time, it should be noted that the volume of calculations depends on the size of the sample used for stochastic changing values of the input parameters. For example, the same result can be obtained using 1000 sample values for a 10-node system scheme or 1000-node scheme with 10 sample values.

Stochastic characteristics of the load and generation. The daily load characteristic for one-month period, constructed with 30-minute averaging for one distribution network of Azerenerji system are presented in Figure 4.

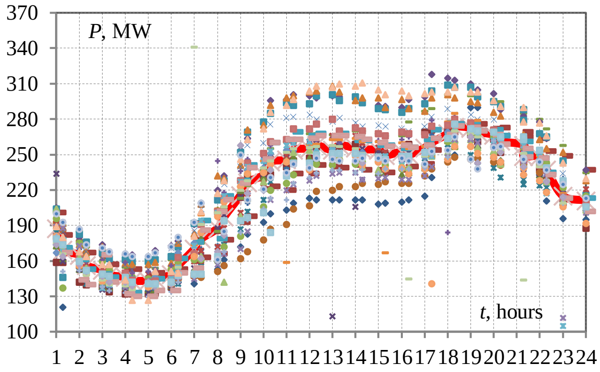
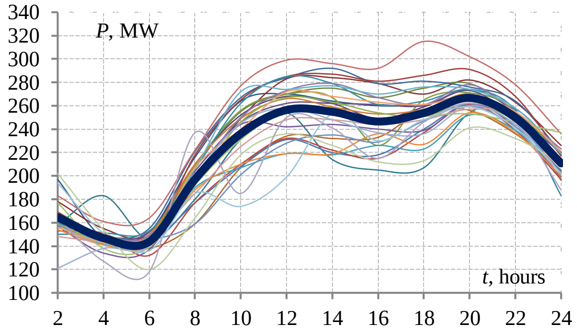
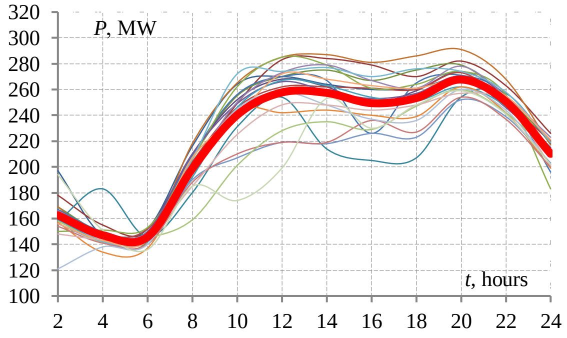


Figure 4. Daily loads for one month

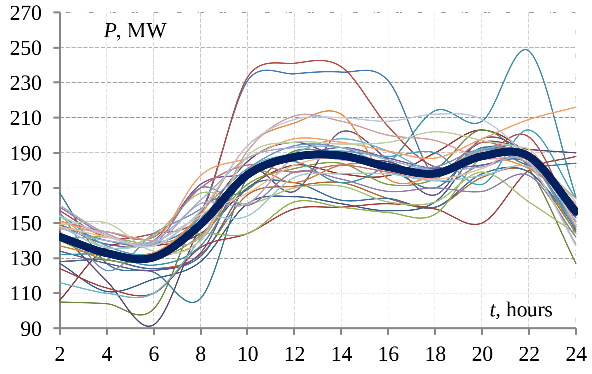
As is obvious, all measurements vary relative to the average curve in the range of small deviations. This is associated with the deterministic cycle of the nature of the daily load; system load power consumption is not stochastic, but it depends on the time of day. Monthly load curves for seasonal periods and for working and nonworking days are presented in Figure 5, a, b.



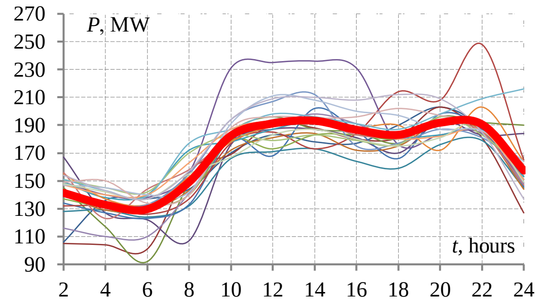
(a) Winter



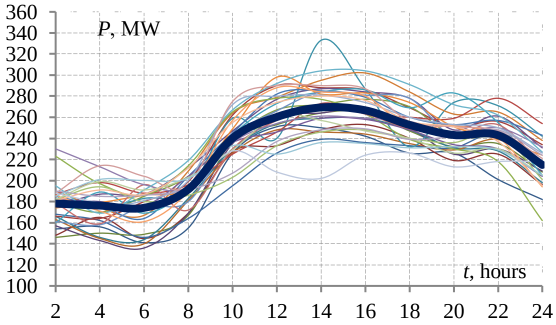
(b) Winter - working days



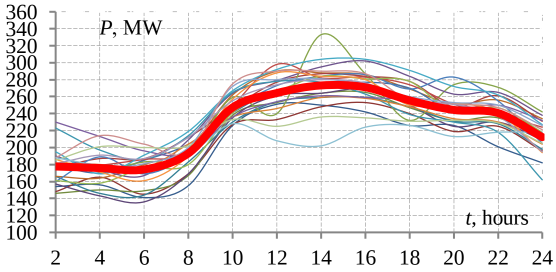
(c) Spring



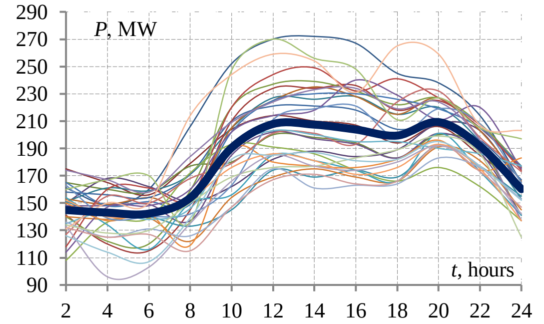
(d) Spring - working days



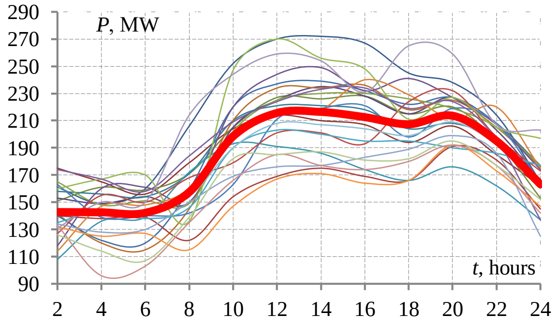
(e) Summer



(f) Summer - working days



(g) Autumn



(h) Autumn - working days

Figure 5. Daily load curves for seasonal periods

5. ANALYSIS OF POWER FLOW IN POWER SYSTEM WITH STOCHASTIC GENERATION

Integration of stochastic generation into the power system, mainly appearing from the generation of power from renewable sources such as wind and solar stations, leads to the need for significant changes in the model of analysis and control of the power system mode. Under these conditions, the topicality of the system simulation with a significant share of stochastic generation increases when solving problems such as choosing the number and location of generating sources, economic load distribution, and the power flow optimization in the system network. Currently, there are three main approaches for solving these problems in probabilistic formulation: numerical method based on simulation of the Monte Carlo method; analytical approach using the convolution method and alternative approaches - the interval method, affine arithmetic and fuzzy arithmetic method [16]. The numerical method requires a large number of computational experiments.

Analytical methods of probabilistic power flow were first proposed in [17, 18], in which the DC model was adopted as a computational model, and nodal loads were specified as independent random variables in the form of a probability distribution function (PDF). The results in the PDF form are determined in the same way when using the convolution method.

Since the stochasticity of the loads is specified with normal PDF, it is assumed that random variables at the output also have normal PDFs according to central limit theorem [19].

However, as the results of other studies [20] show, such assumption is unreliable, since the PDF at the output, depending on the circuit dimension, differs significantly from the normal distribution.

Let us consider the probabilistic power flow model in the power system at stochasticity of inputs - generation and load specified by their PDFs. Similar model can be created on the basis of linearization of power flow equations when considering the generation and load in the corresponding nodes in the form of distribution density characteristics. In general, the power flow model in the system is described in the form of the following nonlinear controls [21,22].

$$\Delta P\left(\delta,\, P_s, \left|U_{\text{наг}}\right|,\, Q_g\right) = P_i^{sp} - -\left|U_i\right| \cdot \sum_{j=1}^{N} \left|U_j\right| \cdot \left(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij}\right) = 0\,,\ \forall i \in N \tag{7}$$

$$\Delta Q\left(\delta,\, P_s, \left|U_{\text{наг}}\right|,\, Q_g\right) = Q_i^{sp} - -\left|U_i\right| \cdot \sum_{j=1}^{N} \left|U_j\right| \cdot \left(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij}\right) = 0\,,\ \forall i \in n_{pa} \tag{8}$$

where, ΔP, ΔQ are nonlinear mismatch functions of active and reactive powers in the node *i*, p.u.; ΔP_i^{sp}, ΔQ_i^{sp} are set values of injections of active and reactive powers in the node *i*, p.u.; δ is nodal voltage vector angle, rad; P_s is active power of basic angle generation, p.u.; Q_g is reactive power of generation in nodes PU, p.u.; ; $\left|U_{наг}\right|$ is voltage in nodes PQ, p.u.; $\left|U_i\right|$ is voltage in the node *i*, r.u.; δ_{ij} - the angle between the bus voltage vectors *i* and *j*; G_{ij}, B_{ij} are real and imaginary parts of the conductivity matrix; and N is number of nodes.

Equations (7) and (8) can be presented in vector form:

$$f\left(x\right)=\begin{bmatrix}\Delta P\left(\delta, P_s U_{PQ}, Q_g\right)\\ \Delta Q\left(\delta, P_s, U_{PQ}, Q_g\right)\end{bmatrix}=0 \tag{9}$$

Since, based on Equation (9), it is impossible to directly obtain several solutions simultaneously, therefore, the solution is performed iteratively using known methods. For example, use of NR method based on linearization of Equations (7) and (8):

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}=\left[J\right]\begin{bmatrix}\Delta\delta\\ \Delta P_s\\ \Delta U_{PQ}\\ \Delta Q_g\end{bmatrix} \tag{10}$$

If in the system of linearized Equations (10), as specified input variables in the nodes PQ and PU, i.e. ΔP_S, ΔQ_g, substitute their probability density functions $\left(PDnF\right)_{\Delta P_s}$, then we can obtain the probabilistic power flow model, the output of which will be voltage vector density functions $\left(PDnF\right)_{\Delta U_i}$ and $\left(PDnF\right)_{\Delta\delta_i}$.

The use of the convolution method to solve the probabilistic equations of the power flow with *PDnF* variables assumes the independence of the pumping power at the nodes $\left(PU\right)_i$.

Let's assume that two random input variables x_1 and x_2, set by their $f_{x_1\,PDnF}\left(x_1\right)$ and $f_{x_2\,ФПВ}\left(x_2\right)$, then *PDnF* of output variable of the model

$$y=x_1+x_2 \tag{11}$$

$$f_Y(y)=\int_{-\infty}^{\infty} f_{x_1}\left(x_1\right)\cdot f_{x_2}\left(y-x_1\right)\,dx_1 \tag{12}$$

In recent years for the solving of the probabilistic power flow problem, the use of affine arithmetic apparatus has been proposed [16]. In accordance with affine - arithmetic simulation, the system state variables are described as:

$$\tilde{U}_i=U_{i,0}+\sum_{j=N}U_{i,j}^{P}\cdot\varepsilon_{P_j^H}+\sum_{j=N}U_{i,j}^{Q}\cdot\varepsilon_{Q_j^H} \tag{13}$$

$$\tilde{\delta}_i=\delta_{i,0}+\sum_{j=N}\delta_{i,j}^{P}\cdot\varepsilon_{P_j^H}+\sum_{j=N}\delta_{i,j}^{Q}\cdot\varepsilon_{Q_j^H} \tag{14}$$

where, $\varepsilon_{P_j^H}$, $\varepsilon_{Q_j^H}$ are noises representing the uncertainties of the active and reactive injection powers in the node *j*, respectively; $U_{i,o}$, $\delta_{i,o}$ are central values of the magnitude and angle of voltage in the node *i*; $U_{i,j}^{P}$, $\delta_{i,j}^{P}$ are deviation of the magnitude and angle of voltage on the *i*th bus caused by change of active power in the *j*th node; $U_{i,j}^{Q}$, $\delta_{i,j}^{Q}$ are deviation of the magnitude and angle of voltage on the *i*th bus caused by change of reactive power in the *j*th node.

The obtained affine Equations (13) and (14) can be used to simulate similar affine equations for active and reactive power at the nodes:

$$\tilde{P}_i=P_{i,0}+\sum_{j\in N}P_{i,j}^{P}\cdot\varepsilon_{P_j^H}+\sum_{j=N}P_{i,j}^{Q}\cdot\varepsilon_{Q_j^H}+P_i^T\cdot\varepsilon_{Ti} \tag{15}$$

$$\tilde{Q}_i=Q_{i,0}+\sum_{j\in N}Q_{i,j}^{P}\cdot\varepsilon_{P_j^H}+\sum_{j=N}Q_{i,j}^{Q}\cdot\varepsilon_{Q_j^H}+Q_i^T\cdot\varepsilon_{Ti} \tag{16}$$

where, ε_{Ti} is variable noise caused by approximation error.

6. ADVANCED α-FUZZINESS TRUNCATION METHOD

Fuzzy parameters are considered as fuzzy numbers with some membership functions. In fuzzy logic this represents a truth degree as extension of the parameter value estimate. Truth degree is often confused with the probability, although these definitions are conceptually different, since fuzzy truth is represented by membership function in a fuzzy defined set that is not probability of some event. Parameter Π of triangular fuzzy number with support A_α is shown in Figure 6.

The method is based on the extension principle, which assumes that the functional relations of probabilistic variables can be extended by including fuzzy probabilistic arguments and can be used to represent the dependent variable as a fuzzy probabilistic set. In this case, the membership function is divided horizontally into a limited number of levels from 0 to 1. For each α level of input parameter, the minimum and maximum possible values of the model output are determined, i.e. the membership function values of voltage at network nodes and power flows in network branches with distributed generation in the power system.

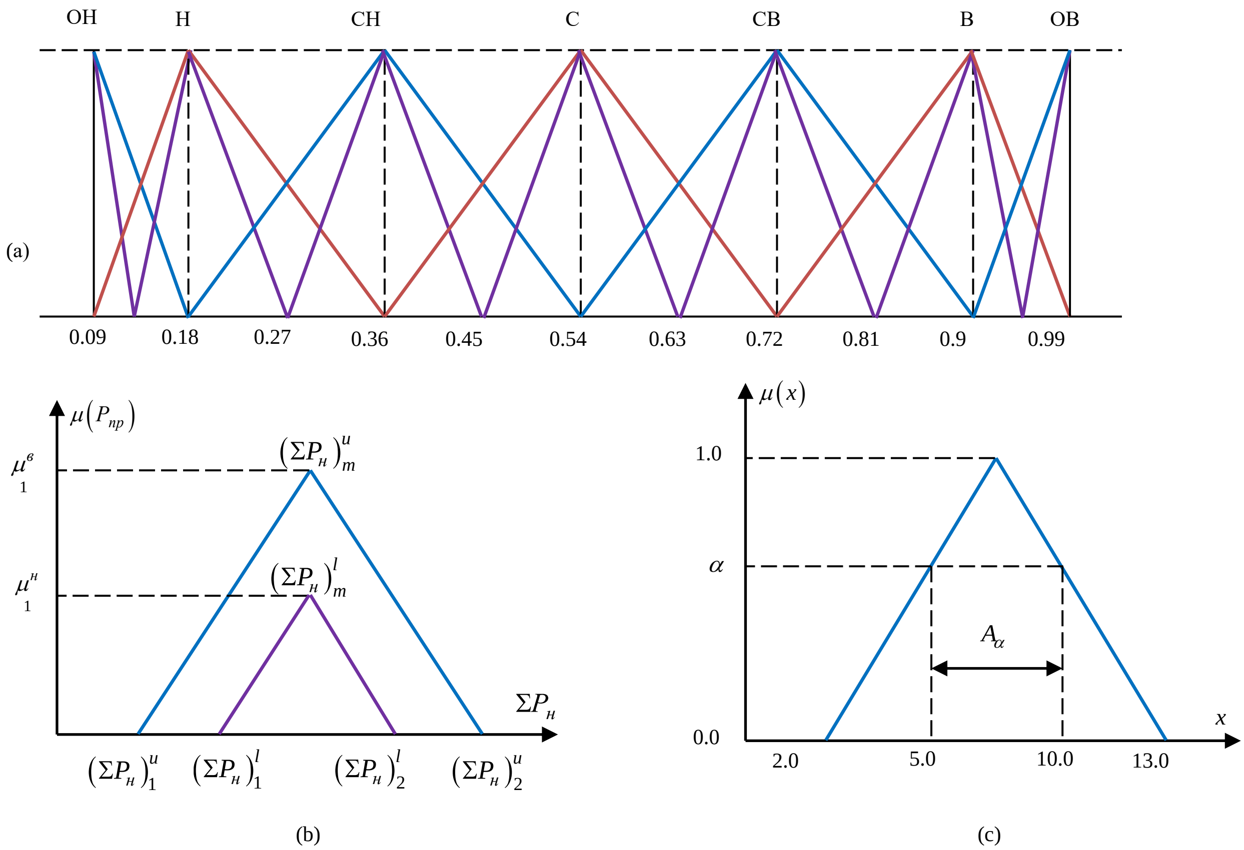
To provide a unified basis for comparing the two methods, the shape of the membership functions that are used in fuzzy modeling is adopted similar to the shape of density function used in Monte Carlo modeling method.

In the paper as example during the modeling is assumed that the load changes in three different intervals (Figure 7).

7. SIMULATION RESULTS

In order to evaluate the results, comparative spatial analysis of the uncertainty of the membership functions of fuzzy output parameters and point analysis of the same parameters were carried out, in which the integral probability density function obtained by the Monte Carlo simulation method is compared with the membership function obtained by the α truncation method.

The voltage probability distribution curve at node 4 is presented in Figure 8. The average value and the standard deviation of this voltage value are equal to $\mu=1.015,\ \sigma=0.0009$, respectively.



(b) (c)

Figure 6. Triangular fuzzy number parameter Π with support A_α,
(a) expression of magnitude of power transfer limit through a linguistic variable;
(b) high and low levels of MF for the interval of triangular set of system states along the perimeter $P_{пр}$; (c) MF of triangular type with α truncation

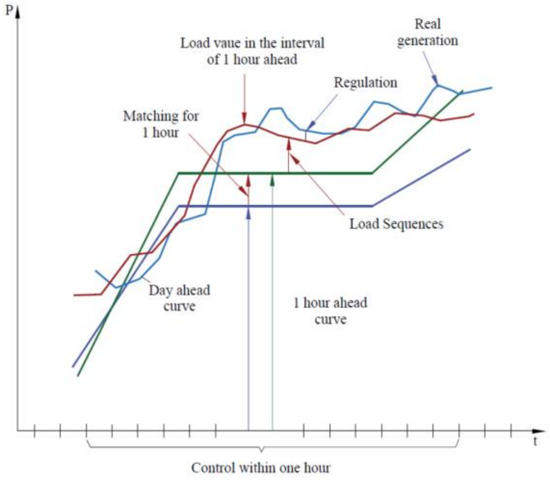
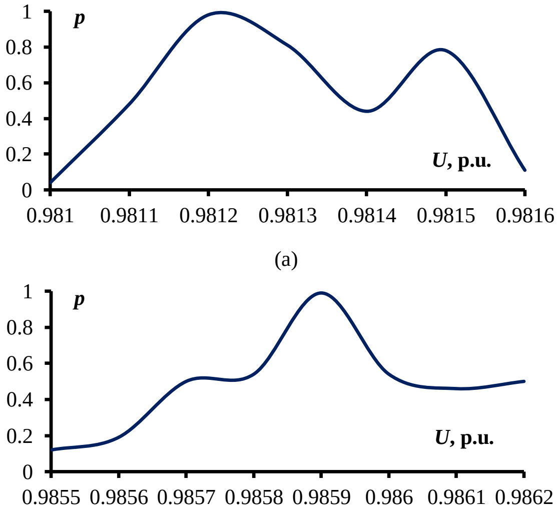


Figure 7. Curves showing the relationship between load and generation processes, subsequent load and control values

To compare the probabilistic estimate of the power flows with the corresponding power flows obtained by traditional deterministic methods, for the 14-node scheme the power flow calculations are performed according to initial data given in [23].

For the studied 14-node IEEE system, the stochastic variability is simulated in accordance with normal, binomial and discrete distribution laws.



(b)

Figure 8. Voltage probability distribution curves,
(a) at nodes 5; (b) at nodes 14

For the load connected to node 9, discrete distribution characteristic is adopted, the mathematical expectation of which is equal to given deterministic value. Two sources connected to node 2 with the installed capacity of 22 MW each, with total off-period of 0.09 per year, also have an average value of this power equal to deterministic value.

Using the Monte Carlo method, it was found that the mathematical expectation of power on the busbars of the basis node 1 of the circuit is 219 MW with the deviation standard of 16.27 MW, which is adopted using the traditional approach.

The values of mathematical expectations and deviation standards for voltages and injections of reactive power in the electric network nodes are also obtained (Table 2).

The results obtained confirm that with the proposed probabilistic-fuzzy modeling of the voltage and power at the nodes of the electrical network, they are more stable and are in the established interval.

Table 2. Probabilistic characteristics of voltages and reactive power at the nodes of the considered electrical network of power systems

Normal distribution						
Busbar		Voltage, p.u.	Active power		Reactive power	
Seq. No.	Type		μ, MW	σ, %	μ, MVAp	σ, %
2	PU	1.04	-24.94	-	-12.7	9.20
3	PU	1.01	-95.01	-	-19	10.50
4	PQ	-	-47.8	-	3.9	9.70
5	PQ	-	-7.6	-	-1.6	5.0
6	PU	1.07	-13.2	-	-2.65	6.30
7	PU	1.085	0.0	-	0.00	0.00
8	PU	1.09	0.0	-	0.00	0.00
10	PQ	-	-10.1	10	-3.7	10.0
11	PQ	-	-3.7	9.5	-1.1	9.50
12	PQ	-	-5.1	7.6	-1.6	8.60
13	PQ	-	-13.5	10.5	-5.8	9.50
14	PQ	-	-14.9	8.6	-5.00	8.60

8. CONCLUSIONS

1. The probabilistic - fuzzy nature of the power of wind and solar stations, as well as the stochasticity of the load power leads to random variability of voltage and power flows in the electrical networks of the power system. The effect of an accidentally - indefinite variability of the mode in the network can increase with the growth of wind and solar power plants integrated into the system of facilities. Probabilistic-fuzzy models, describing the variability of the power system state, caused by stochasticity of load and generation are proposed in the paper. It is shown that the proposed models allow, based on simultaneous considering of stochasticity and uncertainty of the variability of the power system state, for approximating the current and forecast values of its parameters with higher accuracy.

2. To evaluate the voltage value in the electrical system and its compliance with the norms of the international Standard EN 50160, it is also important to evaluate the estimated probability of the indicated value. Before evaluating the maximum voltage deviation from the normal set value, it is necessary to calculate the voltage distribution probability, and only then estimate the maximum deviation value according to the standard.

3. Analysis of the probabilistic power flow at stochastic change of the load power shows that with the growth of the maximum load, the probabilistic estimate of the voltage and losses in the network can significantly change. There are probabilities of exceeding the voltage level, its maximum permissible value when considering the random load variability during the hours of daily maximum. The performed calculations for the probabilistic power flow show that when reactive power is compensated in the load nodes with the probability that the voltage value goes beyond the acceptable limits, the installation of regulating compensating device significantly improves the voltage value and allows for obtaining its estimate with a higher probability.

4. The development of the process of integrating wind and solar sources into the power system creates new problems at each stage of this development, such as the inclusion of power sources with discontinuous and indefinite generation in the power system, the increase of distributed generation systems with a hybrid composition of sources, the choice of location of the wind and solar stations is determined by the economic assessment of their proximity to the consumption nodes of electric energy, the creation of new software and hardware tools for analyzing the mode control based on probabilistic modeling. To assess the significance of these problems, the studies are carried out in the paper for the variability of the power system modes when connecting new volumes of generating wind farm.

REFERENCES

[1] G. Gonzales Rodriguez, A. Colubi, W. Trutsching, "Simulation of Fuzzy Random Variables", Information Sciences, Vol. 179, No. 5, pp. 642-653, NY, 2009.

[2] L.A. Zadeh, "Discussion: Probability Theory and Fuzzy Logic Are Complimentary Rather than Competitive", Technomet, Vol. 37, No. 3, pp. 271-276, 1995.

[3] N.V. Kostarev, Y.I. Barduk, I.A. Trokhimenko, "Assessment of the Technical Condition of Power Transformers Using Fuzzy Algorithms", Engineering, Energy, 2006.

[4] J.A. Momoth, X.W. Ma, K. Tomsovic, "Overview and Literature Survey of Fuzzy Set Theory in Power Systems", IEEE Trans. on Power Systems, Vol. 10, No. 3, Aug. 1995.

[5] P. Smets, "Probabilistic Inference from Statistical Data", The Second World Conf. on Mathematics at the

Service of Man, pp. 611-613, Las Palmas, Spain, June 28 - July 3, 1982.
[6] Z. Lik, H.X. Li, "A Probabilistic Fuzzy Logic System for Modeling and Control", IEEE Trans. Fuzzy Systems, Vol. 13, No. 6, 2005.
[7] A.M. Leite de Silva, et al., "Probabilistic Load Flow Techniques Applied to Power System Expansion Planning", IEEE Trans. Power Systems, Vol. 5, pp. 1047-1053, Nov. 1990.
[8] A.H. Mehdizadi, M.R. Akbarzadeh, "Probabilistic Fuzzy Logic and Probabilistic Fuzzy Systems", 10th IEEE Int. Conf., Vol. 3, pp. 1127-1130, 2001.
[9] H.T. Nguyen, W. Tonghi, W. Berlin, "On Probabilistic Methods in Fuzzy Theory", International Journal of Intelligent Systems, Vol. 19, pp. 99-109, 2004.
[10] J. Schwippe, O. Krase, Ch. Rehtanz, "Extension of a Probabilistic Load Flow Calculation for the Consideration of Interdependencies", 17th Power Systems Computation Conference, Vol. 1, pp. 677-684, Stockholm, Sweden, 2011.
[11] A.M. Hashimov, N.M. Rahmanov, N.M. Tabatabaei, H.B. Guliyev, F.Sh. Ibrahimov, "Probabilistic Evaluation of Voltage Stability Limit of Power System under the Conditions of Accidental Emergency Outages of Lines and Generators", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 43, Vol. 12, No. 2, pp. 40-45, June 2020.
[12] A.M. Hashimov, N.R. Rahmanov, H.B. Guliyev, "Capacitor Bank Placement and Control in Electrical Distribution Systems Using Multiple Objective Fuzzy Optimization Method", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 34, Vol. 10, No. 1, pp. 1-5, March 2018.
[13] K. Tomsovic, M.Y. Chow, "Tutorial on Fuzzy Logic Applications in Power Systems", IEEE - PES Winter Meeting in Singapore, January 2000.
[14] K. Tomsovic, "Fuzzy Systems Applications to Power Systems. School of Electrical Engineering and Computer Science", W. State University, 1998.
[13] I.J. Ramirez Rosado, J.A. Dominguez Navarro, "Distribution Planning of Electric Energy using Fuzzy Models", Int. Journal of Power and Energy Systems, Vol. 16, No. 2, 1996.
[16] P. Jorgensen, J.S. Christensen, J.Q. Tande, "Probabilistic Load Flow Calculation Using Monte Carlo Techniques for Distribution Network with Wind Turbines", The 8th International Conference on Harmonics and Quality of Power, Vol. 2, pp. 1146-1151, 1998.
[17] S. ChlenLien, "Probobilistic Load Flow Computation using Point Estimation Method", IEEE Trans. Power Systems, Vol. 20, pp. 1843-1851, Nov. 2005.
[18] J.C. Pidre, C.J. Carrillo, A.E.F. Lorenzo, "Probabilistic Model for Mechanical Power Fluctuations in Asynchronous Wind Parks", IEEE Trans. Power Syst., Vol. 18, No. 2, pp. 761-768, 2003.
[19] A.M. Hashimov, N.R. Rahmanov, H.B. Guliyev, R.N. Rakhmanov, A.A. Mustafayev, "Probabilistic Flow Distribution as a Reaction to the Load Stochasticity in the Power System", Higher Educational Institutions and Energy Associations of the CIS - Power Engineering: International Scientific and Technical Journal, Minsk, No. 6, pp. 519-528, 2016.
[20] H.B. Guliyev, N.R. Rahmanov, "Probabilistic Modeling of Flow Distribution in Power System with Distributed Generation and Renewable Sources", Electronic Modeling, Vol. 38, No. 5, Kiev, pp. 101-112, 2016.
[21] N.R. Rahmanov, V.G. Kurbatsky, H.B. Guliyev, N.V. Tomin, "Probabilistic Assessment of the Power System Mode with a Different Degree of Integration of Wind Sources", Methodological Issues of Studying the Reliability of Large Energy Systems: Collection of Research Papers, Vol. 66, Actual Problems of System Reliability, Bishkek, pp. 232-241, 2017.
[22] N.R. Rahmanov, V.G. Kurbatskiy, N.B. Tomin, H.B. Guliyev, Z.A. Mammadov, "Probabilistic Assessment of Power System Mode with a Varying Degree of Wind Sources Integration", E3S Web of Conferences, Vol. 25, Methodological Problems in Reliability Study of Large Energy Systems (RSES 2017), Bishkek, Kyrgyzstan, September 11-15, 2017.
[23] ETAP, "PowerStation 4.0, User Guide", Vol. II, Analysis Modules, Operation Technology, Inc. Registered to ISO 9001, Certification No. A3147, 2002.

BIOGRAPHY

Huseyngulu B. Guliyev received his M.Sc. and Ph.D. degrees and is a Lead Scientific Researcher, Head of department "Modes of power systems" in Azerbaijan Research Institute of Energetics and Energy Design (Baku, Azerbaijan). Currently, he is an Associate Professor of Automation and Control Department in Azerbaijan Technical University (Baku, Azerbaijan). He is a member of International Scientific Seminar, Yu.N. Rudenko "Methodological issues of researching the reliability of large energy systems" and International Gnedenko e-Forum on Reliability of Energy Systems. He has more than 220 published articles, 3 patents and 1 monograph. His research interests are power systems operation and control, distributed generation systems, application of artificial intelligence to power systems control design, power system stability, renewable energy integration and power quality.