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ASSESSMENT STABILITY GENERATION OF SOLAR POWER PLANTS IN THE PROBLEMS OF PROVIDING BALANCE RELIABILITY

The paper analyzes the operation of solar power stations, taking into consideration the possibility of consumption graphic provision. The mathematic model of Gauss mixtures was used, that allows to get basic probability characteristics of generation and power supply processes. The algorithm of stability coefficient estimation , based on analysis of derived characteristics, is developed.

Key words: *solar power plant, balance reliability, probabilistic characteristisc, Gauss mixtures, reserve power, generation stability.*

Introduction

Graphic of electric energy generation by renewable sources of energy directly depends of natural conditions of the region of their location. This characteristic feature of renewable sources of energy (RSE) contributes certain problems in the process of the solution of the problem, dealing with provision of reliable and qualitative energy supply of the consumers. State support of RSE development and relative cheapening of the equipment, needed for construction of RSE resulted in the growth of their portion in the balance of United Energy System (UES) of Ukraine. In such conditions, the problem of coordination of the graphs of energy consumers with the graphs of RSE generation to improve the efficiency of operation both of consumer and electric grid emerges. This would lead to reduction of organic fuel consumption and, as a result, reduction of the negative impact on the environment.

It is impossible to obtain the desired effect from the matching of consumption and generation graphs without application of the facilities for Smart Grid technologies realization [1]. However, “smart” realization of operation mode is impossible without prior evaluation of potential possibilities of energy source to cover the consumers needs in electric energy.

The aim of the given research is the development of the method for the evaluation of the stability of the preset consumption graph covering by the potentially possible solar power plant (SPP) generation and determination of the reserve source power by the results of the evaluation carried ant.

Evaluation of SPP stability

Evaluation of RSE operation stability was studies in numerous research [2, 3, 4]. In [2] for determination of the stability of consumption graph covering by the source of renewable energy, it is suggested to introduce the stability coefficient. It characterizes the probability of the loading graph covering by the source of energy of certain capacity and generation graph:

$$k_{stab} = \sum_{i=1}^{24}\left[p_{dayi} \sum_{j\in M}\left(p_{RSE_j} \sum_{l\in N} p_{cons_l} \right)\right], \tag{1}$$

where p_{day} – probability of the emergence of daily graph step $p_{day} = \frac{1}{24}$; p_{RSE} – probability of the emergence of generation step during the preset period; M – set of non-zero generation steps; p_{cons} – probability of the emergence of consumption stage during the preset period; N – set of consumption steps, located below the generation level of corresponding period of the day.

The advantages of this method of stability coefficient determination comprise its relative stability, however such an approach is rather limited for the forecast problems solution. The research contains the suggestions aimed at improvement of this method, using the mixture of normal distribution laws.

Proceeding from the fact, that SPP change their generation power during the day (fig. 1a) and the year (fig. 1b), it is suggested to carry out the evaluation of the stability of consumption graph covering by seasons.

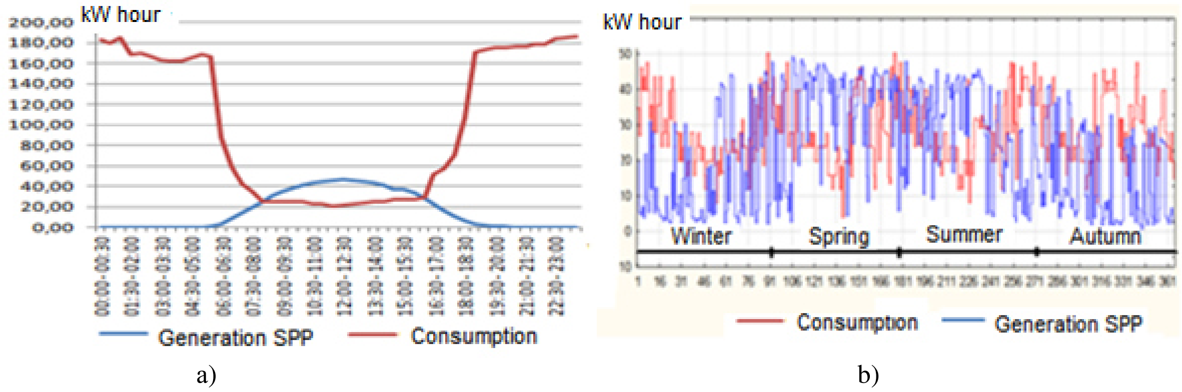


Fig. 1. a) daily graph of consumption and SPP generation, b)variation of generation power and consumption during the year

As it is seen from fig. 2 transition to seasonal analysis of stability is substantiated. As in the period of maximum SPP generation is in winter (fig. 2a) the most probable power of SPP is within the limits of 10…30% from the installed power. In summer period the most probable value of SPP power is within the range of 70-85%.

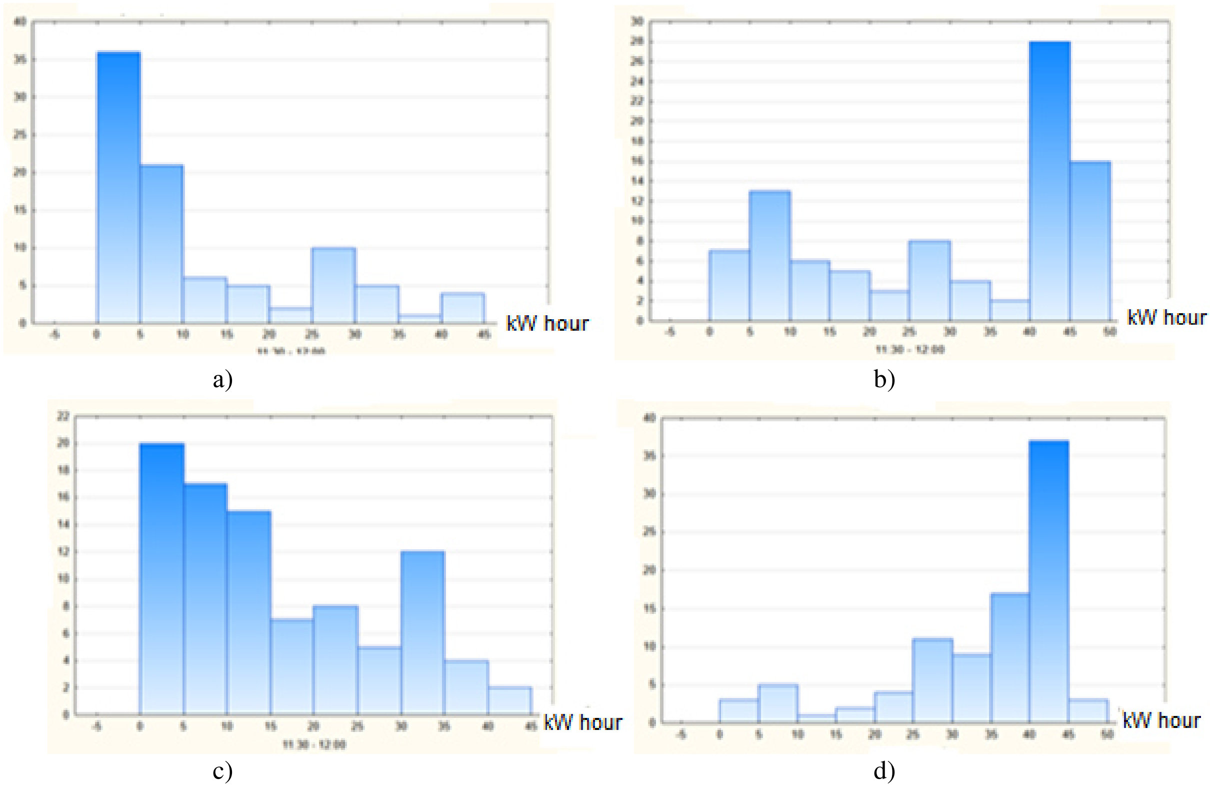
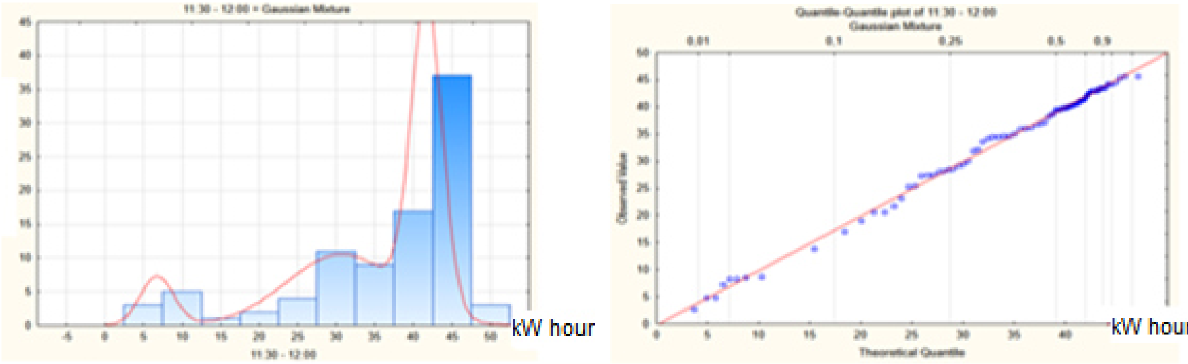


Рис. 2. Histogram of SPP generation density by seasons: a)winter, b) spring, c) autumn, d) summer

For determination of the necessary volume of reservation, we will evaluate the stability not only by seasons, but at each time interval.

The evaluation of SPP generation stability will be illustrated on the example of summer period in the time interval from 11:30 to 12:00 (fig. 3).



a) b)

Рис. 3. a) Gauss mixture, that describes the law of SPP generation distribution, b) graph of quantile - quantile type for theoretically suggested distribution law

For the suggested distribution, as it is show in [5], Kolmogoroff-Smirnoff's test is proposed, that shows the correspondence of theoretically suggested distributions to empirical data as p=0.98 that is far greater than 0.05. It is seen from fig. 3 a, that rather accurate reproduction of random value density could be obtained by means of the mixture of three components of Gauss distribution. Evaluation of probabilistic characteristics of the suggested mixture is carried out by the criterion of maximum likelihood, by means of EM- algorithm [6]

$$p(x) = \sum_{j=1}^{k} w_j p_j(x), \qquad (2)$$

where $p_j(x)$ – function of distribution density of the j^{th} component of the mixture , w_j – weight of the j^{th} component of the mixture (a-priori probability) $\sum_{j=1}^{k} w_j = 1,\ w_j \geq 0,\ j = 1...k$ – number of the components in the mixture.

Function of distribution density has the from:

$$p_j(x) = \frac{1}{(2\pi)^{\frac{k}{2}} \left|\varsigma_j\right|^{\frac{1}{2}}} e^{\left(-\frac{1}{2}(x-\mu_j)^T \varsigma_j^{-1}(x-\mu_j)\right)}, \qquad (3)$$

де μ_j – mathematical expectation of the j^{th} component, ς_j – covariation matrix of the j-th component, that has the content of standard deviation.

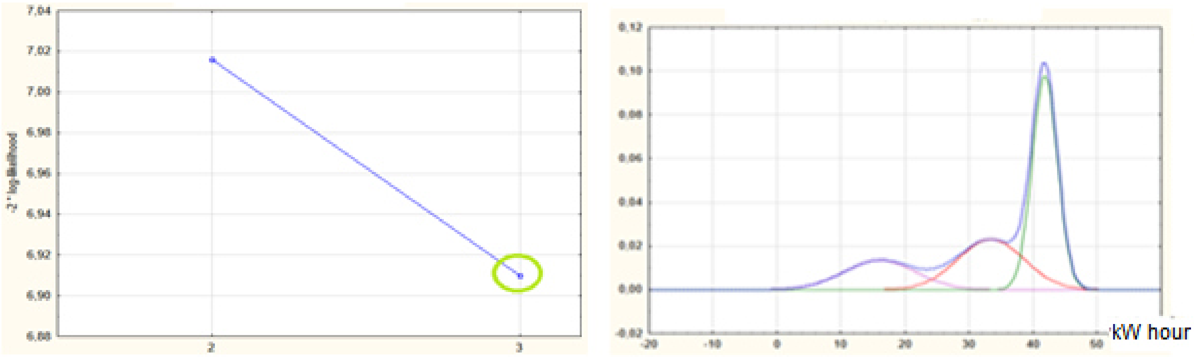
Functions of likelihood belong to the parametric family of distributions $\varphi(x;\theta)$ and differ only by the values of parameter $p_j(x) = \varphi(x;\theta_j), \theta_j = \{\mu_j, \varsigma_j\}$ and φ - is a fixed function. In other words, to select object x from the mixture $p(x)$ means to select it from distribution $p_j(x)$ with probability w_j.

The problem of mixture splitting is solved when, having the sample X^m of random values from the mixture $p(x)$, knowing the number k and function φ, it is necessary to evaluate the vector of parameters:

$$\Theta_j = (w_j, \theta_j). \qquad (4)$$

Optimal number of components in general model of Gauss distribution mixture can be obtained by the search of possible variants. At the same time we solve the problem several times for gradual increasing (decreasing) values of k, for which we construct the graph of likelihood dependence

$\theta_j = \arg\max_{\theta} \sum_{x_i \in X^m} \ln \varphi(x_i, \theta_j)$ on k, and choose the least k, at which the graph shows dramatic jump of the likelihood (fig. 4).



a) b)

Fig. 4. a) Determination of the optimal amount of the components of the mixture of SPP generation power distribution, b) image of SPP generation power distribution

The results of determination of probabilistic characteristics of SPP generation and loading are given in Table 1.

Table 1

Results of determination of probabilistic characteristics of SPP generation power and consumption

Parameters	SPP generation			Consumption	
	K1	K2	K3	K1	K2
Expectation, μ	12.65	31.88	41.79	21.913	37.36
Average deviation σ	3.09	3.86	1.92	5.378	2.98
Variation koef. V	0.244	0.12	0.046	0.24	0.08
Weight,w	0.19	0.31	0.5	0.81	0.19
Min. Value	2	25.36	38.196	7.2	33
Max. Value	23.16	37.18	45.76	32.41	44.32

For the assessment of the preset consumption graph covering by SPP generation it is suggested to divide each component of the generation and load into elements, this will considerably increase the accuracy of calculation and enable to find the probability of their emergence by means of probability integral:

$$F(X_u) = \frac{1}{\sqrt{2\pi}} \int_{X_u}^{X_{u+1}} e^{-\frac{r^2}{2}} dX_u, \quad (5)$$

where $r = \frac{(X_u - \mu)}{\sigma}$ and X_u correspondingly takes the values of X_u and X_{u+1} of each component of SPP generation or consumption.

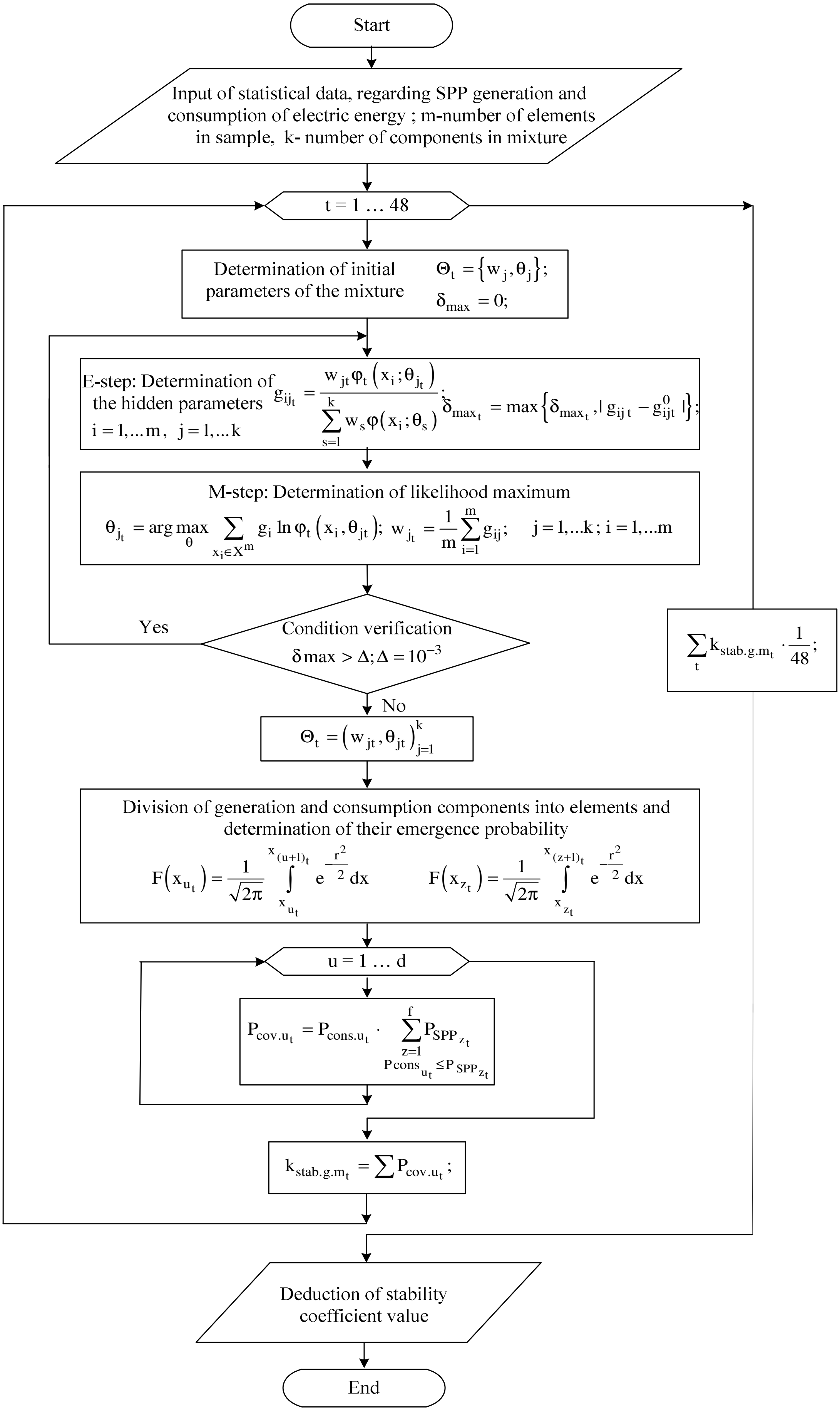
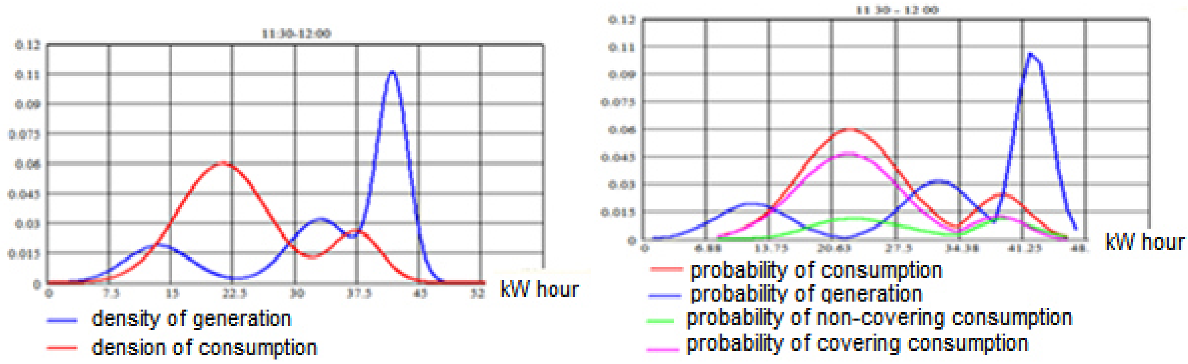


Fig. 5. Algorithm for determination of stability coefficient of SPP generation

The suggested algorithm of determination of SPP generation stability coefficients (fig. 5) enables to determine the probability of balance reliability provision.

Distribution of generation density and load for the considered example in the interval of time 11:30 – 12:00, is shown in fig. 6a. The character of probabilities change is show in fig. 6b.



a) b)

Fig. 6. a) density of SPP power of consumption and generation distribution; b) graphic representation of the probability of covering and non-covering of the set consumption graph by SPP generation

In the time interval 11:30 – 12:00 of summer period the probability of consumption graph covering is $\sum_{u} P_{покр_u} = 0.72$. The results of the calculation and character of their change is show in fig. 7.

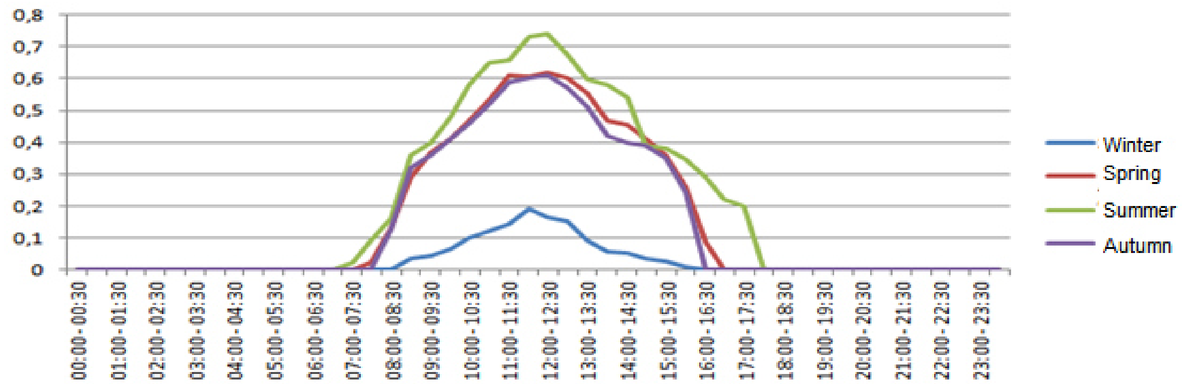


Fig. 7 Change of the probability of consumption graph by SPP generation during the day of each season

Generalized stability index, determined by the algorithm, shown in fig. 5 and stability coefficients determined by (1) for different seasons , are presented in Table 2.

Table 2

The results of determination of SPP generation stability coefficients

Coefficients	Winter	Spring	Summer	Autumn
$k_{stab\ g.m.}$	0.025	0.151	0.191	0.143
$k_{stab.}$	0.031	0.160	0.201	0.151

The difference in the results is explained by the assumption regarding the same probability of emergency of each generation and loading stages, that is assumed in [2]. This assumption simplifies the calculation process, but leads to certain error in the results. This drawback is the most appreciable during stability coefficient determination for winter period.

Determination of reserve power

One of the main methods of providing balance reliability is reserving. That is why, the problem of determination of the necessary reserve level, in conditions of introduction of renewable sources of energy, generation of which is not stable, is especially important.

To provide balance stability of the consumer, we will determine the volume of electric energy, to be supplied by the source of reserve in the t^{th} time interval of the day, of each season, taking into account the stability coefficient:

$$W_{res_t} = \left(1 - k_{stab.g.m_t}\right) \cdot W_{cons\ max_t} \qquad (6)$$

where W_{res_t} – amount of electric energy, to be supplied by the source in the j^{th} time interval of the day, $k_{stab\ g.m}$ – stability coefficient of generation, determined by the algorithm (fig. 5), $W_{cons\ \max_t}$ – maximum amount of electric energy, consumed in the j^{th} time interval of the day.

By the amount of electric energy, to be delivered during half an hour, using the known formulas [7], we can switch to the values of reserve source power.

SPP generation depends on the change of the light day duration , in its turn, the latter depends on the change of seasons, that's why, the given research analyses the change of reserve power separately for each season and correspondingly with different duration of SPP operation. For summer period, the quantity of SPP operation hours is the greatest, for winter – the least.

Change of reserved power value during the day for winter, spring, summer and autumn is shown in the form of curves (fig. 8).

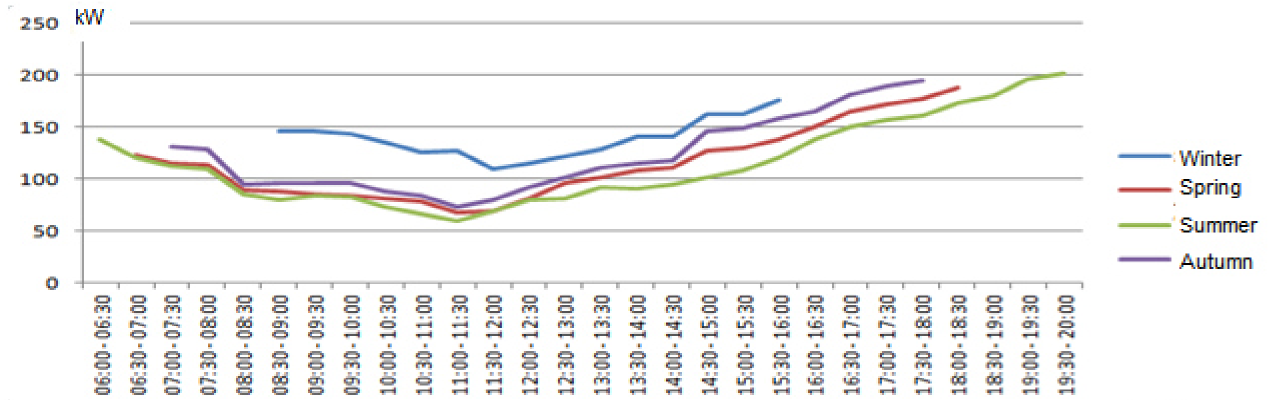


Fig. 8. Dependence of the reserved power on the period of the day for winter, spring, summer and autumn

By the obtained curves start-stop characteristics of the reserve power source and its power in each time interval can be determined.

Conclusions

State promotion and relative price decrease at the market of equipment for renewable sources of energy contributes to their intensive development. However, the dependence of their operation on natural conditions does not allow to provide the reliable energy supply of the consumers without the reserve, that is provided by the sources of traditional power engineering.

The paper contains the analysis of statistical data, dealing with solar power plants generation. For the analysis of the probability of load graph covering the method of stability coefficient determination was improved by means of using Gauss mixtures model. This enabled to increase the accuracy of the results obtained.

Algorithm of stability coefficient determination, developed in the given research, enables to determine the character of reserve power change during the day and further to evaluate start-stop characteristics of the reserve source and its power.

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