

Technique of a choice the optimal combination of Renewable Energy Sources in the Power Supply System taking into account the random nature of changes in weather conditions

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In the following paper questions how to increase an efficiency of renewable energy sources in power supply systems are considered. The new additional criterion in choosing a combination of renewable energy sources is offered — the operational risk of consumer's electricity (ORCE), which takes into account the random nature of changes in weather conditions. Design procedure ORCE based on application of the portfolio analysis theory is developed.

Keywords and phrases: renewable energy sources, operational risk of consumer's electricity, portfolio analysis theory, renewable energy source portfolio.

Introduction

The development of renewable power is the priority direction of electric power industry in many countries.

Nowadays, the main criteria in choosing renewable energy sources (wind plants, solar batteries) are: size of the developed electric power, cost of the developed electric power, cost of installations for applied renewable energy sources, a share of replacement of hydrocarbonic fuel, distance from renewable energy sources to networks of the centralized power supply, the amount of renewable energy source installations.

Development of the electric power of renewable energy sources strongly depends on weather conditions. The change of weather conditions has casual character. In existing techniques used for choosing appropriate renewable energy source risk of power supply discontinuity connected with casual character and inconstancy of renewable energy is not considered.

Thus, the object of this research is power supply system with renewable energy sources. The purpose of the research is to develop a new technique used for choosing an optimum combination of renewable energy sources taking into account the random nature of the change in weather conditions.

In the course of the research the following problems are solved:

- 1) Risk analysis in power supply systems with renewable energy sources.
- 2) Development of a design procedure of the operational risk of consumers' electricity.
- 3) Development of an application technique of the operational risk of consumers electricity supply for a choice of an optimum combination of renewable energy sources.

The urgency of the research is that at identical cost various combinations of renewable energy sources enable for diversification of the operational risk of consumers electricity. Design procedures of operational risk at using renewable energy sources are absent.

Materials and methods

Risk analysis

Risk analysis, which is characterized for power supply systems with renewable power sources, was carried out. As a result two groups are allocated: systematic risks and non-systematic risks. All systems of power supply are equally subject to systematic risk. It cannot be excluded. Examples of systematic risks are financial and political risks. Non-systematic risk is typical for each concrete system of power supply. Non-systematic risks are: risks of inconstancy of the energy carrier, risks of presence of

consumers, risks of supply and demand. Importance of non-systematic risks can be reduced at design of power supply system by choosing an optimum combination of renewable power sources.

The most dangerous for consumers is the volatility risk of energy source. The negative property of renewable energy is power generation, which strongly depends on weather conditions. The random nature of the change in weather conditions may be the cause of:

- additional cost of hydrocarbon fuel;
- stop the production process;
- financial damage;
- information loses.

For the accounting of inconstancy of renewable energy a new criterion is offered — the operational risk of consumers' electricity (ORCE). The operational risk of consumers' electricity allows for determining of the probability of non-consumers of power required due to the random nature of the change in weather conditions. The operational risk of consumers' electricity is an additional new criterion in selecting the optimal combination of renewable energy sources.

Development of a design procedure of ORCE

The operating risk of electricity at using renewable energy sources by the main signs is identical to economic risk of yield securities. In economy for decrease in risk of profitability the theory of the portfolio analysis is used [1]. Therefore, for calculation of ORCE it is offered to use methods of the theory of the portfolio analysis. A mathematical model of optimal portfolio based on the provisions of the probability theory and mathematical statistics. The advantages of the portfolio analysis theory are:

- portfolio analysis solves the problem of minimizing the risk of under specified conditions;
- portfolio theory is characterized by simplicity and clarity.

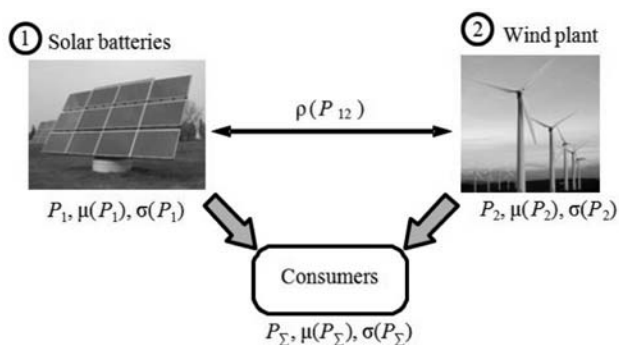


Fig. 1. Application of apparatus portfolio analysis to calculate the operational risk of consumer's electricity.

Figure 1 shows the use of the portfolio analysis device for ORCE calculation in power supply system with renewable power sources.

Basic provisions of the portfolio analysis theory for calculation of ORCE consist of the following:

1) Portfolio of renewable energy is a combination of renewable energy sources, which are used in electricity supply system. The portfolio may consist of one type of plant — only from wind plants, or solar batteries. Also, in the same portfolio of renewable energy diverse renewable power sources can be applied — for example a combination of wind plants and solar batteries.

2) The main indicator of the portfolio is P_i — the developed power of renewable power sources. Owing to dependence on the weather conditions, it is possible to consider P_i as a random variable.

3) Statistical properties of the portfolio of renewable energy are determined by:

- $\mu(P_i)$ — expected value of developed power;
- $\sigma(P_i)$ — standard deviation of developed power.
- $\mu(P_i)$ determines the predicted value of generated power. $\sigma(P_i)$ is a measure of the spread of generated power values.

4) At calculation of ORCE the hypothesis that the distribution of power generated by each source of energy corresponds to the Normal distribution is allowed [2]. Function of the Normal distribution of the developed capacity of renewable power sources is presented in Fig. 2.

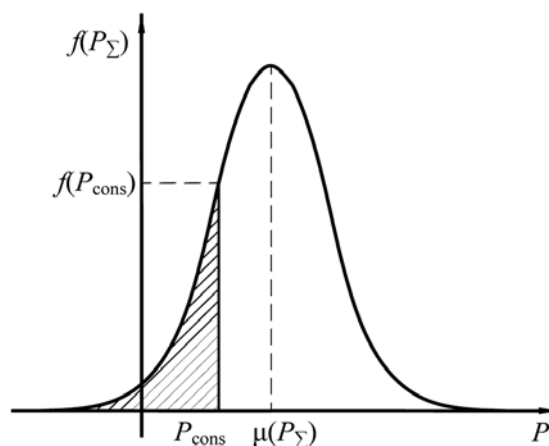


Fig. 2. The normal distribution of a renewable energy source power.

5) The operational risk of consumers' electricity is defined as the probability that the total power of the portfolio of renewable energy is less than the required power of consumers:

$$R = P_{\Sigma} \leq P_{\text{cons}}$$

In Fig. 2 the operational risk of consumer's electricity is equal to the square of the shaded area.

6) At calculation of the operational risk of consumer's electricity it is necessary to consider interrelation between the power generated by heterogeneous renewable energy sources (for example, wind plants — solar batteries) introducing — correlation coefficient $\rho(P_{ij})$, where:

- P_i — the developed power of the wind plants;
- P_j — the developed power of the solar batteries.
- $\rho(P_{ij})$ between one type of renewable energy (for example, wind turbine — wind turbine) equals 1. If the correlation coefficient is equal 0, it means that developed power of renewable energy sources are not connected with each other. A negative correlation coefficient means that the developed power of renewable energy sources vary in antiphase.

For example, for many territories in an antiphase there is a solar radiation and speed of wind. When there is strong wind as a rule there is no sun, and in a sunny day often there is a light breeze. Sharing of diverse renewable energy sources (wind plant — solar battery) as a rule allows to reduce probability of violation of consumers' power supply. $\rho(P_{ij})$ in a design procedure of ORCE considers sharing of wind plants and solar batteries.

ORCE design procedure is developed [3]. Algorithm of calculation of ORCE:

1) To define value ORCE (R), it is necessary to calculate $\mu(P_i)$, $\sigma(P_i)$ and $\rho(P_{ij})$. Therefore, at the first stage for each renewable energy sources according to initial data values pay-off of the developed power is calculated (in a year). Initial data are:

- technical characteristics of renewable energy sources;
- daily average speed of a wind and daily average sunlight for the studied district. Information on speed of a wind and sunlight can be taken from archives of meteorological stations

2) Determination of the expected value (1) and standard deviation of developed power (2) for each renewable energy sources:

$$\mu(P_i) = \sum_{i=1}^n \frac{P_i}{n}, \quad (1)$$

$$\sigma(P_i) = \sqrt{\frac{1}{n} \sum_{i=1}^n (P_i - \mu(P_i))^2}, \quad (2)$$

where: n — number of observations during the year.

$\mu(P_i)$ and $\sigma(P_i)$ are necessary for calculation of an expected value and a standard deviation of the developed power of renewable portfolio.

3) An expected value and a standard deviation of developed power of renewable portfolio are calculated:

$$\mu(P_\Sigma) = \sum_{i=1}^N \mu(P_i), \quad (3)$$

$$\sigma(P_\Sigma) = \sqrt{\sum_{i=1}^N \sum_{j=1}^N \sigma(P_i)\sigma(P_j)\rho(P_{ij})}, \quad (4)$$

where: N — number of renewable energy sources.

The size of ORCE depends on size $\mu(P_\Sigma)$ and $\sigma(P_\Sigma)$.

4) ORCE (R) is defined by a solution of integrated function of the normal distribution (5):

$$R = \int_{-\infty}^{P_{\text{cons}}} \frac{1}{\sqrt{2\pi}\sigma(P_\Sigma)} e^{-\frac{(P_i - \mu(P_\Sigma))^2}{2\sigma(P_\Sigma)^2}} dx, \quad (5)$$

For simplification of calculations it is possible to pass to the standardized distributed normally random variable — y . For the standardized distributed normally random variable: $\mu = 0$ and $\sigma = 1$ [4]:

$$y = \frac{P_{\text{cons}} - \mu(P_\Sigma)}{\sigma(P_\Sigma)}, \quad (6)$$

After calculation y by means of special tables it is possible to return to R . Application y allows to simplify ORCE calculation.

The final result (the formula 6) is the operational risk of consumer's electricity, considering casual nature of weather conditions changes.

Development of an application technique of ORCE for a choice of an optimum combination of renewable energy sources.

Nowadays the wide range of the various models of the renewable energy sources is offered to consumers. Renewable energy sources models differ in technical characteristics and cost. Therefore the problem of a choice of an optimum combination of renewable energy sources in power supply system is actual. The choice of a combination of renewable energy sources only by criterion of the smallest cost cannot provide high reliability of power supply of consumers. For increase reliability of power supply consumers at a choice of renewable energy sources it is offered to consider casual nature of change of weather conditions. That is it is offered to use new additional criterion — ORCE.

Technique of a choice of an optimum combination of renewable energy sources taking into account ORCE:

1) Taking into account requirements of the consumer (the area of solar batteries, wind plant height) is defined the list of renewable energy sources installations, which are perspective for use in power supply system. All possible combinations of renewable energy sources (renewable portfolio) form on the basis of the selected installations. Examples of possible combinations of renewable energy sources: wind turbine — wind turbine, solar panel — solar panel, wind turbine — solar power.

2) For each renewable portfolio the developed power is defined (P_{Σ}). P_{Σ} is compared to a P_{cons} . From set of portfolios, the portfolios satisfying following condition are selected:

$$P_{\Sigma} \geq P_{\text{cons}}$$

3) The minimum cost of a combination of renewable energy sources which satisfies the consumer is set. From point 2 renewable portfolios which cost does not exceed the minimum preset value are selected.

4) The portfolio gets out of portfolios of point 3 with the smallest value of ORCE. The chosen combination of renewable energy sources is optimal for using it in the electricity supply system.

Results

The developed technique for choosing of renewable energy sources is used to develop energy-efficient power supply system of recreation, located in rural areas. As renewable energy sources three models of wind turbines, and two models of solar panels were considered. Information on speed of a wind and intensity of sunlight is taken from archives of meteorological data of the Nizhny Novgorod. 62 different combinations of renewable energy sources was formed. Renewable portfolios contain from 2 to 6 units. On formulas 1-6 the analysis of combinations of power sources is carried out at the demanded power of consumers — 16 kW. For each renewable portfolio following are defined: generated power (formula 3), standard deviation (formula 4), and the operational risk of consumer's electricity (formulas 5, 6). The calculations showed that the combination of renewable energy sources in the recreation electricity system is 4 wind turbines and 2 solar batteries.

Main characteristics of an optimum renewable portfolio:

- developed power — 17,5 kW;
- cost — 3 million rub;
- ORCE — 18%.

For other portfolios with cost no more than 3 million rub ORCE considerably exceeded 18 %.

Also, the results of calculations showed that the cost of a combination of renewable energy sources and the operational risk of consumer's electricity are independent of each other. High values of the operational risk of consumer's electricity can be characterized for portfolios of renewable energy sources with low cost. The lowest value of the operational risk of consumer's electricity is observed at the portfolios, which consist of

a diverse renewable energy sources (a combination of solar panels and wind turbines). Thus, the choice of sources by the criterion of minimum cost does not guarantee the reliability of consumers' electricity. To improve the reliability of power supply it is necessary to choose a combination of renewable energy sources, taking into account the operational risk of consumer's electricity.

Acknowledgement

Work is executed with financial support of the Ministry of Education and Science of Russia (the state contract No. 16.516.11.6114 from 25.08.2011).

Conclusion

On the basis of the carried-out research it is possible to make the following conclusions:

- 1) Risk analysis in power supply systems with renewable energy sources is carried out. For the accounting of influence of casual nature of weather conditions changes on development of the electric power it is offered to use the operational risk of consumer's electricity (ORCE).
- 2) ORCE design procedure is developed. When developing provisions of the economic theory of the portfolio analysis are used.
- 3) The technique of the accounting of ORCE is developed at a choice of an optimum combination of renewable energy sources. The accounting of the operational risk of consumer's electricity allows to reduce probability of violation of consumer's power supply.
- 4) The carried-out calculations showed that the operational risk of consumer's electricity decreases at complex use of diverse power sources.

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