Theoretical Aspects of Risk Assessment in Power Supply System Operation

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***Abstract*—During the design, construction and operation of any technological system one of the major problems that has to be addressed is a question of ensuring reliability. The problem is especially relevant for complex systems, such as an electric power supply system, which consists of numerous elements and nodes with extensive internal and external interconnections. At the start of a new project and during the development of a technical maintenance and repair software, a statistical data is available, which accounts for the damageability and malfunction probability regarding every element of an electric power supply system. The purpose of this publication is a quantitative assessment and optimization of reliable operation of electric power systems which would account for every consumer remains a difficult task due to a significant amount of elements and a variety of connections between each separate element.**

***Index Terms*—assessment of risks, optimization, reliability, system of power supply**

I. Introduction

To date, the concept of "complex reliability" of modern Electrical Power System (EPS) is considered as a complex category, including such characteristics as reliability, maintainability, sustainability, survivability and controllability, while indicators of sustainability and survivability of organizational and technological scheme of energy supply to consumers, providing localization of accidents, preventing their cascading development and possible automated recovery modes of EPS are defining ones in the conditions of operation and development of power system [1]. As it is known, power supply failures both in traditional EPS and in new smart systems occur for many reasons, among which two main groups can be distinguished: "objective" reasons that do not depend on the actions of Energy Company (EC) personnel; "subjective" reasons caused by human factor [2]. Objective reasons of power supply failure include natural disasters, technological shortcomings of the equipment due to noncompliance with the technical requirements in the process of its production, installation and maintenance, equipment problems associated with the end of its lifecycle. In the group of subjective reasons for the decrease of the power supply reliability, it is necessary to emphasize the following factors: a human factor associated with incorrect actions of operative personnel, deliberate actions of aggressors, disagreement of economic interests of the EC and other subjects of energy markets, as well as shortcomings and uncoordinated actions of regulatory bodies [3]. In this regard, it is extremely important to identify all possible risks of the normal functioning of the EPS and to assess the quantitative parameters of each risk in order to determine the causal relationships between the initial emergency events related to equipment, personnel or the environment, as well as to find approaches to eliminate the initiating events by upgrading the equipment and improving the maintenance protocols, i.e. to manage the risks in the optimal way [4].

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II. The Key Risk Groups for Electricity Supply Systems and Their Assessment

The risk in electricity supply is the possibility of an event, action or lack of action to adversely affect the organization's ability to effectively implement its business objectives and strategic plans. [5] In general, the assessment of the risk of a dangerous state of a technical or any other system can be considered from the point of view of the interaction of the consumer and the supply system that provides the given consumer with a certain type of resource. The methodology of risk and damage assessment in the electricity supply system considered in this article is based on certain fundamental concepts. According to [1], [2], security implies the absence of unacceptable risk; risk is a combination of the likelihood of damage and the severity of this damage; danger is a potential source of damage; failure is the loss of ability to perform the required function (which is an event that leads to a malfunction) [4].

In general, a risk assessment problem can be presented as a comparison of the probability of occurrence of a dangerous event to the consequences of this event, taking into account its minimization [4]:

$$\overline{R} = \sum_{i=1}^{n} R_i; \qquad (1)$$

$$R_i = P_i \cdot W_i \cdot \psi_i, \qquad (2)$$

where R is the risk of system malfunctioning;

R_i – i[th] level of the output resource;

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P_i – the probability of occurrence of a dangerous state at the ith level of the output resource, received by calculation or experimental way;

W_i – consequences of a dangerous event (damage) at the ith level of the output resource;

ψ_i – is the risk reduction factor at the ith level of the output resource.

III. Risk Management in Energy: Processes and Technologies

Risk management consists of four main components (Wilks, 2005):

- Identification;
- Evaluation;
- Control;
- Management.
- At the same time, all risks can be divided into two [6]:
- Non-business risks are usually beyond the control of the company, unpredictable and can be catastrophic. This group includes physical, political (regulatory), economic, social, technological, environmental risks, etc.;
- Non-business - financial, including market, production and credit risks, Table I [6].

TABLE I. Type Sizes for Camera-Ready Papers

Groups of risks	Probability	Rank
Regulatory risks:		
Tariff regulation	0,5	10,134
Risks in security	0,1	2,861
Environmental risks	0,3	0,858
Tax risks	0,2	0,572
Antirust regulation	0,3	0,858
Business risks:		
Physical	0,4	8,107
Political	0,6	12,16
Social	0,2	0,572
Technological	0,4	8,107
Non-business risks:		
Financial	0,6	12,16
Market	0,6	12,16
Production	0,5	10,134
Credit	0,3	0,858
Information and technological risks:		
Company goodwill losses	0,2	0,572
Violation of the continuity of production	0,6	12,16

Electric power industry has always been a business with a high degree of technological risks due to the pauseless character of energy production, distribution and delivery to the consumer which is also exposed to regulatory risks associated with the actions of regulatory bodies and relating to potential changes in activity caused by political (regulatory) solutions. The most appropriate way to minimize the above mentioned risks is associated with the maximal (preferably legislative) regulation and implementation of rates (tariffs) [2], [5].

Physical risks are closely related to production risks and address to physical events, which can affect the company's operation. The company control over them is impossible or limited (for example, weather conditions). This also includes the risks of possible damage caused by third parties. In many cases, the only available mechanism for managing physical risks is insurance and reservation clauses in contract clauses related to guarantees [6].

Production risks are risks of losses due to the existence of inadequate systems and management procedures, human factor or management errors [6].

Operational rules, procedures and permits, approved in the form of a document and communicated by management prior to execution by personnel and/or internal (and in some cases external) audit body are used to manage the production risks. Often, formal disciplinary cooperation and meetings between the parties are used to ensure more complete control and management of operational risks due to the existence of wider (for example, market) risks, and vice versa. The choice of instruments for managing production risks largely depends on an understanding of their own production activity, the manufacturer's specifications and any previous technical analysis and/or relevant experience [6].

Credit risks are risks of non-payments on a loan. To minimize them, the creditworthiness assessment is carried out with the involvement of external agencies, own financial modelling of the parties, etc. [6]

Market risks are divided into the following types: [6]

- Price - the risk of price movement at a spot price;
- Basic - the risk of movement of the price difference for related goods, depending on their origin and quality;
- Related to the interest rate-risk of change in the capital cost;
- Temporary - the risk of outstripping price break in terms of urgent contracts as a function of supply and demand for the short-term perspective and more serious factors-for the long-term perspective;
- Transactional - the risk of the impact of large transactions on market parameters (for example, price).

When developing market risk management strategies, it is recommended to hold on five key points:

- Effective establishment, quantitative estimation and distribution of capital risk;
- Setting price for deals in relation to value and risks;
- Detailed strategy including the actual situation on the market;
- Corresponding trade infrastructure;
- Effective measurement and management of the production, credit and market risks.

Another group of risks is related to the incompleteness and instability of the regulatory and legal framework governing electrical energy industry. Companies should rely on established clear rules and regulations in their activities, which is an important condition for building trust in market structures and confidence among market participants. Energy-specific fuel risks (the price of fuel and its availability in required quantities at the right time) are also significant. In connection with this additional risk, there is a uncertainty with the creation of a gas market and the necessary reserve of generating capacities for a full-fledged electricity market [7].

The most acute problem of the quality of the supplied electricity is manifested during the breaks or restrictions in electricity supply. According to experts, direct and indirect damages from planned and unplanned interruptions in the supply of electricity in developed countries is several times greater than the damage from natural disasters. The volume of damage essentially depends on the reliability category of the consumers, the duration of the interruption, the time of the year and other characteristics. Disconnection of electricity consumers is a fairly frequent event with a wide range of consequences. Breaks can be caused both by random events having internal and external background and planned outages. Risk management aims to prevent the occurrence of failures and to mitigate the negative consequences if such situation occurs. To effectively manage the risks of the electricity company, it is necessary to solve the following [2], [5]:

- Risk management policy - a description of the role and extent of responsibility of all company employees, setting limits, risk assessment and management; management tools of key types of risks and the basic principles of the reporting system;
- Methodology is the definition and description of measurement techniques, qualitative/quantitative assessment and management of the main types of risks: market, credit, operational, strategic, etc.;
- Processes - design and clarification of the most important processes in terms of risk management;
- Organizational structure is a design of the new organizational structure (basic requirements and key components): necessary conditions for organizational changes, a role, competence and responsibility of personnel;
- IT support is the development of requirements for the IT system necessary to ensure effective collection of information on positions and contracts, controlling and generating reports both for the company as a whole and for individual business units.

According to Table I, the priorities of each risk are obvious, taking into account that risks of the highest rank have the greatest impact on the electricity supply system [2], [5].

IV. Operational Risk of Power Undersupply for Consumers of Autonomous Power Systems with Renewable Energy Sources

Approaches to the assessment of the power flow security as a component of the complex reliability assessment are presented in numerous literature sources, including monographs and manuals [3], [5], [8]-[22], etc. Until recently, these approaches have been considered as an object of a passive distribution electrical network which does not contain generating sources other than traditional electrical power stations that are distant from the consumer and have relatively large capacity. However, it should be understood that presence of distributed generation (DG) in power supply system requires development of methods for assessing the power flow security [12].

When analyzing the risks characteristic for local power supply systems with RES, two groups can be identified: systematic risks and non-systemic risks. All power supply systems are equally affected by a systematic risk. It cannot be excluded. Examples of systematic risks are: legislative, financial, political risks, etc., Table I A non-systematic risk is intrinsic for each particular power supply system. Non-systematic risks include: the risks of instability of an energy carrier, the risks of having consumers, the risks of demand and supply. The volume of non-systemic risks can be reduced when designing a power supply system by choosing the optimal combination of RES [23].

As a rule, the main criteria for choosing renewable energy sources are: the developed power, the cost of electricity generated, the size and cost of the energy installations used, the share of replacement of hydrocarbon fuel, the distance from RES to the networks of centralized power supply, etc. However, the above-mentioned criteria do not take into account the main shortcomings of renewable energy - its instability. The generation of electricity by solar and wind power plants is highly dependent on weather conditions, the change of which is random. Therefore, in local power systems with renewable energy sources, there are risks of electricity supply to consumers associated with the instability of the energy carrier. The consequences of these risks are a high probability of a violation of electricity supply to consumers [23].

Thus, in order to take into account the instability of renewable energy, one additional criterion must also be taken into account: the operational risk of electrical power supply of consumers (OREPSC), which determines the probability of non-receipt by consumers of the required capacity due to the random nature of changing weather conditions [23].

The OREPSC is defined as the probability that the aggregate capacity of the RES portfolio will be less than the required capacity of consumers [23]:

$$R = P_{\Sigma} \leq P_{demand}, \quad (3)$$

where R is the operational risk of electricity supply to consumers;

P_{Σ} is the generated aggregate capacity of the RES portfolio;

P_{demand} – power required by consumers.

When calculating the OREPSC, it is necessary to take into account the relationship between the generated power of dissimilar RES (for example, the wind turbine - solar battery) using the correlation coefficient $\rho(P_{ij})$, where P_i is the generated capacity of the wind turbine; P_j is the generated capacity of the solar battery. $\rho(P_{ij})$ between RES of one type (for example, wind turbine -

wind turbine) is equal. At the same time, if the correlation coefficient is equal to 0, then the generated capacities of RES installations are not interconnected. Negative correlation coefficient means that the generated capacities of RES installations change in an opposite phase [23].

V. Method of Damage Assessment (Factor Model of Losses)

The factor model of losses (excess costs) is built on the basis of possible outcomes (alternatives) or their consecutive change with the implementation of private events at each step. Factorial loss model (FLM) for the purposes of damage assessment $Y_j^i(k)$ during the operation of an enterprise in the conditions of specific pricing on the Wholesale Market for Electricity and Power (WMEP) and the occurrence of additional (excess) financial costs for electricity and capacity assumes an independent occurrence of the events shown below or their joint and consistent occurrence. The main factors (sources) of the model of losses are [24]:

- Deviations of the actual electrical energy and power consumption from the Request for Proposal (RFP) submitted for trading on the Day-ahead Market (DAM, WMEP);
- Deviation of actual prices for electricity and capacity in WMEP from the forecast prices and their values, which are the basis for the standardization of specific indicators;
- Deviation of consumption or prices within one day (t), several days (t +) or period Z;
- Joint occurrence of deviations in consumption and prices within one day (t), several days (t +) or period T;
- Excess or shortage of current assets required for working under the WMEP conditions and compliance with the requirements of the regulation of the WMEP financial calculation rules.

Let us consider the calculated cases in more details. Estimation of losses for private cases of occurrence of events is as follows: [24]

1) As a result of the change in current consumption (deviation from the RFP) by electricity and capacity $Y_j^i(k) = Y_j^i(k)^{El.en.} + Y_j^i(k)^M$:

a) For the case of a reduction in the consumption of electricity ($\Delta V_i^h(g)$) and power ($\Delta N_i^h(g)$) within the current day (t) is determined by the reduction in consumption of the de-energized object - g (machine, line, shop, enterprise) per hour h or within the time period for the reduction of consumption (t_t^1, t_t^2) and the price of the allowed deviation (C), i.e.:

$$Y_j^i(k)^{El.en.} = \sum_t \sum_g V_i^t(g) \times C_t^{BM}(t) \quad (4)$$

where $C_t^{BM}(t)$ is the WMEP balancing market price and:

$$Y_j^i(k)^M = \sum_t \sum_g \Delta N_i^t(g) \times C_t^{CCA}(t) \quad (5)$$

where $C_t^{CCA}(t)$ is the price of the actual purchase of capacity of competitive capacity auction (CCA) of the WMEP;

b) For the case of reduction in the consumption of electricity ($\Delta V_i^h(g)_x$) and power ($\Delta N_i^h(g)_t$) within the current day (t) in the CCA and further reduction in the electricity consumption ($\Delta V_i^h(g)_{t+}$) and power ($\Delta N_i^h(g)_{t+}$) of the period hours of the following day (t+) DAM and CCA, i.e.

$$Y_j^i(k)^{El.en.} = \sum_t \sum_g V_i^t(g)_t \times C_t^{BM}(t)\Big|_t + \sum_t \sum_g V_i^t(g)_{t+} \times C_t^{DAM}(t)\Big|_{t+} \quad (6)$$

where $C_t^{BM}(t)\Big|_t$ is a weighted average price of the balancing market WMEP of the day t, but $C_t^{DAM}(t)\Big|_{t+}$ - a weighted average price of the day t+ WMEP and:

$$Y_j^i(k)^M = \sum_t \sum_g \left\{\Delta N_i^i(g)_t + \Delta N_i^i(g)_{t+}\right\} \times C_t^{CCA}(t) \quad (7)$$

c) For the case of banning (interdict, deprivation of the status of the WMEP entity) of purchase of electricity and capacity on the WMEP (group risks $R_{II}^1(B)$) and forced purchase from a local guaranteeing electricity ($\Delta V_i^h(g)_T$) and power ($\Delta N_i^h(g)_T$) supplier during the T period on the basis, economic damage is calculated in the first day on the basis of point b, from the period of transmission to electricity supply to the guaranteeing supplier or a local network company as follows:

$$Y_j^i(k)^{El.en.} = \sum_t \sum_g \Delta V_i^t(g)_T \times \left\{C_t^{El.en.}(t)_{GS} - C_t^{El.en.}(t)\right\} \quad (8)$$

where $C_t^{El.en.}(t)$ is the lost weighted average price of a possible purchase of electricity on the WMEP (by regulated agreement (RA), in the DAM) in the period of T, but $C_t^{El.en.}(t)_{GS}$ - the price of the guaranteeing supplier (GS, network company), taking into account the regulated and unregulated price for electricity;

$$Y_j^i(k)^M = \sum_t \sum_g \Delta N_i^t(g)_T \times \left\{C_t^M(t)_{GS} - C_t^M(t)\right\} \quad (9)$$

where $C_t^M(t)$ is the lost weighted average price of a possible purchase of power on the WMEP (by RA, from Hydroelectric Power Plant (HPP), Non-regulated Electricity and Capacity Sale and Purchase Contract (NRECC) and CCA (2)) in the period of T, but $C_t^M(t)_{GS}$ the price of the guaranteeing supplier (network company), taking into account the regulated and unregulated price for power.

2) As a result of changes in prices on the WMEP relative to the planned (normalized for the reporting period values) $Y_j^i(k) = Y_j^i(k)^{El.en.} + Y_j^i(k)^M$:

$$Y_j^i(k)^{El.en.} = \sum_t \sum_g V_i^t(g)_T \times \Delta C_t^{El.en.}(t) \quad (10)$$

where $C_t^{El.en.}(t)$ – change of the weighted average price of purchase of electricity on the WMEP during the period of T;

$$Y_j^i(k)^M = \sum_t \sum_g N_i^t(g)_T \times \Delta C_t^M(t) \quad (11)$$

where $\Delta C_t^M(t)$ – change of the weighted average price of purchase of capacity on the WMEP during the period of T.

3) As a result of changes in prices on the WMEP and consumption volumes per unit of output in relation to the planned (normalized for the reporting period values) $Y_j^i(k) = Y_j^i(k)^{El.en.} + Y_j^i(k)^M$, where $Y_j^i(k)^{El.en.}$ and $Y_j^i(k)^M$ are the functions calculated on the basis of the methods of clause 12-13 valid for the conditions:

$$Y_j^i(k)^{El.en.} = f\left\{\Delta C_t^{El.en.}(t), (V_i^t(g)_T + \Delta V_i^t(g)_T)\right\} \quad (12)$$

$$Y_j^i(k)^M = f\left\{\Delta C_t^M(t), (N_i^t(g)_T + \Delta N_i^t(g)_T)\right\} \quad (13)$$

4) As a result of changes in prices on the WMEP and/or consumption volumes that lead to an increase in current assets and interest losses on bank loans, it is estimated, as indicated in paragraph 1-3, multiplied by interest of the actual loan.

The deviation of the actual prices for electricity and capacity on the WMEP from the forecast ones is characterized by the quality of the analysis of the price situation on the WMEP. The deviation of actual consumption by electricity and capacity from the planned one is the result of a shortage of individual subunits involved in the formation of a chain of energy costs and the fulfilment of requirements, regulations, procedures and standards, and their interaction. From the point of view of risk management, the task of introduction of the Energy Cost Management System is the solution of the minimization problem with boundary conditions [24]:

$$\begin{aligned} &P_j^i(k) \to \min \\ &Y_j^i(k) \to \min \\ &P_j^i(k) \le P_j^i(k)\big|_{norm} \end{aligned} \quad (14)$$

In order to realize a consistent approximation of the volume of energy risks to the minimum, the method of preventing and corrective measures is used. The main goal of the introduction of the ECMS (3) is to achieve and maintain a normative (or prospective) level of energy efficiency. The starting point for activities to improve energy efficiency is the level $1 - P_j^i(k)\big|_{norm}$ for regulatory risk $P_j^i(k) \le P_j^i(k)\big|_{norm}$ [24].

VI. Conclusion

The analysis of risks in power supply systems without and with renewable energy sources is carried out. For the latter, taking into account the influence of the random nature of the weather conditions on the generation of electricity, it is necessary to take into account the additional risk - the operational risk of electricity supply to consumers (OREPSC).

The greatest risks in the power industry have the following risks:

- Political (rank 1) - to manage them, specialists are attracted, who are engaged in regulatory activities, whose function is to advise and represent the business interests;
- Financial (rank 1) - combating this risk is the conclusion of reliable contracts;
- Market (rank 1) - when developing market risk management strategies, it is recommended to be guided by the main provisions: the effective establishment, quantitative estimation and distribution of capital risk; setting price for deals in relation to value and risks; detailed strategy, including the actual situation on the market; appropriate trade infrastructure; effective measurement and management of production, credit and market risks;
- Violation of the continuity of production (rank 1) - it is necessary the implementation of industry standards and the creation of a unified concept of IT security;
- Tariff regulation (rank 2) - fight: liberalization of prices in the electric power industry, increase in the predictability of tariff regulation;
- Production (rank 2) - for management, operating rules, procedures and permits, approved in the form of a document and communicated by management prior to execution by personnel and/or internal (and in some cases external) audit body are used;
- Physical (rank 3) - in many cases, the only available mechanism for managing physical risks is insurance and reservation clauses in contracts related to guarantees;
- Technological (rank 3) - use of modern technologies;
- Security risks (rank 4) - while legitimate standards of public security requirements in the legal field are not available, it is difficult to estimate what compliance with established security requirements is;
- Environmental risks (rank 5) - fight: it is necessary to achieve greater transparency of legislative requirements;
- Antitrust law (rank 5) - use of the Law “On competition”;
- Credit (rank 5) – to minimize them, the creditworthiness assessment is carried out with the involvement of external agencies, own financial modelling of the parties, etc.;

- Tax risks (rank 6) - maximum (preferably legislative) regulation and rates, and the procedure of their application;
- Image losses of the company (rank 6) - for this risk, it is necessary to implement industry standards and create a single concept of IT security.

In addition, the most dangerous for consumers is the risk of instability of energy carriers. The dependence of renewable energy generation on the random nature of changing weather conditions can lead to additional costs of hydrocarbon fuel; stopping the technological process; loss of information; financial damage.

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