Topical problems of electric power industry reliability

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Abstract

The paper briefly describes some problems of EPS reliability that are currently urgent within the framework of liberalized electricity market. It presents a statement of reliability estimation problem under these conditions and its solution by the software package.

Introduction

Transition from the classical market conditions that are characterized by vertical integration of basic technological subsystems of electric power systems (EPSs) to the so-called liberalized market of electric power and capacity that is characterized by breakdown of the vertical integration and its conversion into horizontal integration to intensify market competition among both electricity producers and suppliers gave rise to the following actual reliability problems:

- provision of all types of power plants, first of all fossil fired power plants, with primary energy resources in the competitive environment. However, consideration of fluctuations in water inflow to hydro power plant (HPP) reservoirs plays a significant role;

- justification of the necessity and the rational volumes of the so-called commercial (market) reserve of generation capacity;

- decomposition of system reliability of EPSs into its main components: reliability of generation subsystem and reliability of network subsystem.

Solution to these problems required new or modified available computational tools to estimate reliability of power system operation in new economic conditions.

A brief description of the indicated problems arising due to restructuring the Russian energy sector and the methods suggested for their solution on the basis of the modified software package YANTAR are given below.

Characteristic of the problems.

1. Assessment of constraints on primary energy resources to estimate reliability assumes the choice of the strategy and policy of primary energy consumption that should be described in model algorithm. With some exceptions there are no clear principles of such a choice, and in reality a great variety of variants for choice are observed. And this variety is caused by both the objective reasons (e.g. a factual role of HPPs in the system, high uncertainty of prediction of subsequent conditions for EPS operation), and the subjective factors (professional skills of personnel, financial principles of system administration and rules of the regional energy commission, momentary benefits and ways of limiting consumers: reduction of frequency and voltage, “rotation” disconnections, etc.).

It is intended to apply, from the standpoint of the authors, a simple, but efficient principle of considering constraints on primary energy resources by specifying the volumes of available energy resources by their types and for different power plants (water in hydro power plant reservoirs, fuel at thermal power plants). As a rule, the volumes are set in kilowatt-hours on the basis of their predicted values (mathematical expectations). Consumption of all primary energy resources is also determined in the process of EPS operation simulation to optimize rated conditions. In going from one operating condition to another the volumes of energy resources consumed are accumulated and compared with the given volumes. If for a certain type of energy resource consumption reaches a set constraint at some stage, participation of the corresponding capacities in meeting load is not dealt with in what follows.

Acquaintance with practical operation of some Russian power systems reveals that this is usually the way done. Exceptions are only HPPs with daily storage (their capacities are small) and large HPPs that are due to provide sanitary drawdowns to the tail water at a certain level (capacity of these drawdowns is also small), i.e. the indicated specific features of HPPs can be neglected. Constraints may be imposed not on the whole studied period (a year), but for intervals of the year (including division into months, if such information is available).

In our opinion this simple algorithm is somewhat artificial, but virtually exactly describes the situation concerning the reliability of EPS supply with primary energy resources in the integral way. In this case it is possible to estimate required volumes of individual types of primary energy resources. Uncertainty of the predicted data on primary energy resources can be taken into consideration on the basis of variant calculations at different values of prediction.

If data on the probability of one or other level of provision with primary energy resources are available, the probability distribution function of meeting load can be determined versus the distribution functions of provision with fuel and water.

2. When reserves of generation capacity and electric power are chosen, each power generating company must have a certain minimum level of own reserve, on the one hand and the total level of reserves should be higher than those obtained by calculations of technological types of reserve (routine maintenances, overhauls, midlife repairs, reserve for modernization works, operating reserve).

The minimum level of own reserve is determined by the specified standard of consumers' power supply reliability for the power generating company in the case of its isolated operation. Such standards are known, for example for the USA ($\mathscr{P}$ is no less than 0.9998, where $\mathscr{P}$ – probability of operation without shortages) [1]. In Russia such standard is at the stage of development.

In the electric power industry besides the technological risk of non-fulfillment of major functions due to equipment failures the most important factors at the transition to the market economy shift towards the economic (commercial) risk. This is due to the fact that in the market and competition environment any economic activity is related with risks because of impossibility to predict exactly and to take into account conditions, in which the planned activity will be implemented.

The problem is to find ways and means to neutralize or reduce negative impacts of the commercial risk. Such impacts can be avoided by creation of additional (in excess to technological) reserve in EPS that will be called for convenience "commercial reserve".

The volume of the commercial reserve is based on the necessity to decrease a loss caused by the possible commercial risk r because of electricity undersupply to consumers.

In [2] it is shown that the commercial electric power reserve should be equal to:

$$R^e_{com} = p_r E_d ,$$

where p_r – profit rate with respect to the cost price, E_d – commercial capacity reserve

$$R^c_{com} = R^e_{com} / T_{ins} ,$$

where T_{ins} – installed capacity usage in hours.

Unfortunately the liberalized Russian market of electric power and capacity does not accept these recommendations so far.

3. Decomposition of the system reliability. In the horizontally integrated system of EPS management the problem of estimating the contribution of each technological subsystem of EPS is an important one among the set of problems of reliability assurance. It includes provision of

power plants with primary energy resources, power generation, electricity transport and distribution. The problem should be solved in order that the boundaries of responsibility of numerous economic subjects of the market for reliability be determined, reliability of individual subsystems of EPS be harmonized. Among the enumerated EPS subsystems those of the main structure of EPS, and namely the subsystems of electricity generation and transport (network subsystem) are of particular importance and concern [4]. The problem was solved by the devised method of system reliability decomposition that consists of the following operations:

A. Calculation of reliability for the main structure of EPS (system reliability) based on the actual data, i.e. the data corresponding to real EPS. Determination of the probability of failure-free operation $\mathcal{P}_{sys}$, the mathematical expectation of power undersupply ΔE_{sys} and the coefficient of consumer provision with electricity π_{sys}.

B. Calculation of reliability for the main structure of EPS on the assumption that the network subsystem is absolutely reliable. This calculation estimates the contribution of the generation subsystem to the system reliability. The same reliability indices are determined as in the experiment A: $\mathcal{P}_{gen}$, ΔE_{gen}, π_{gen}.

C. Calculation of the contribution share of the network subsystem by the formulas:

$$\mathcal{P}_{net} = \mathcal{P}_{sys} / \mathcal{P}_{gen}$$

$$\Delta E_{net} = \Delta E_{sys} - \Delta E_{gen}$$

$$\pi_{net} = \pi_{sys} - \pi_{gen} + 1,$$

where: $\mathcal{P}_{net}$, ΔE_{net}, π_{net} – reliability indices for the network subsystem.

The formulas are obtained on the assumption that EPS is a chain of successively connected subsystems: generation subsystem, network subsystem, electricity consumers and the system reliability indices are divided based on the key concepts of the reliability theory.

D. Analysis of the indices obtained. They allow the estimation of the less reliable subsystem in EPS and the reliability harmonization problem for the main technological subsystems of the system to be solved.

Characteristic of the model.

The software package YANTAR developed at Energy Systems Institute SB RAS is intended to estimate reliability in terms of infallibility and repairability (recoverability) of bulk power systems that are represented by any (radial, loop) multi-node calculated scheme with limited transfer capabilities of ties among the nodes. The problem is solved for development management and long-term operation planning at the levels of Unified, interconnected and regional EPSs.

The problem is solved by the simulation method of EPS operation for the considered period (a year). The states of loads and equipment of EPS are modeled by the Monte-Carlo method. The series of generation capacity distribution for units at the nodes and transfer capabilities of ties are calculated in advance. The binomial distribution is taken as a generating function. The rated conditions are optimized on the basis of the specified strategy of distributing power shortages by power node of the system.

The maximum parameters of the scheme are 100 nodes and 160 ties. More detailed information about the software package YANTAR can be found in [3].

New approaches to EPS management in Russia make it necessary to take into account in YANTAR specific features of the Russian EPSs. First of all, the indicated properties substantially change optimization of the rated conditions of EPS.

The work [3] presents principles of optimizing the EPS operating conditions for the reliability analysis and synthesis and methods of solving some problems. Besides the technical and economic characteristics of electricity generation and transmission the model described below takes into consideration specific features of electricity market operation of the regional and federal levels, since they influence distribution of power deficits and optimization of deficit-free conditions.

The experience of different countries and companies shows that the principles of organizing the wholesale electricity markets differ. The main distinction lies in formation of electricity prices (tariffs), i.e. the own tariffs of power companies, the tariffs of regional wholesale market of the unions of power companies and the tariffs of the federal wholesale market within the Unified EPS of the country can be different.

Mathematical formulation of the problem and a method suggested for its solution.

The calculated scheme of EPS is represented as a connected graph with M nodes (vertices) and N ties (arcs) among the nodes. Each node is characterized by the amount of required load $\overline{P}_m^l$ and the value of operable generation capacity $\overline{P}_m^g$, and each tie – by the transfer capabilities in the direct and reverse directions $\overline{P}_n$ and $\underline{P}_n$ respectively, and by the loss factor $K_{loss\ n}$.

Denote the covered load power at the m-th node by P_m^l, the generation capacity participating in load meeting by P_m^g, the flow along the n-th tie by P_n. The optimization problem functional of any (deficit and deficit-free) system condition is described by the following expression:

$$\max \sum_{m=1}^{M} (c_m P_m^g + c_e \sum_{n \in N_0} P_n + g_m \Delta P_m^g - d_m P_m^g - f \Delta P_m^g) \tag{1}$$

subject to:

$$\left.\begin{aligned} &\sum_{n=1}^{N} (a_{mn} P_n + b_{mn} k_{loss\,n} P_n^2) + P_m^l - P_m^g = 0 \\ &0 \le P_m^g \le \overline{P}_m^g \\ &0 \le P_m^l \le \overline{P}_m^l \end{aligned}\right\} \quad m = \overline{1, M} \tag{2}$$

$$\underline{P}_n \le P_n \le \overline{P}_n \ , \qquad n = \overline{1, N}, \tag{3}$$

where $\Delta P_m^l = \overline{P}_m^l - P_m^l$ – power deficit at the m-th node;

$\Delta P_m^g = \overline{P}_m^g - P_m^g$ – excess of generation capacity at the m-th node;

$a_{m,n}$ – elements of the matrix A of ties.

b_{mn} – elements of the matrix B, such that

$$b_{mn} = \begin{cases} 1, & if\ \ P_n < 0; \\ 0, & if\ a_{mn} \cdot P_n \ge 0. \end{cases}$$

N_0 – set of ties, which are used by the m-th node to sell (buy) the electricity of the higher-level wholesale market as compared to the local (internal) market.

In functional (1) there are the following technical and economic coefficients:

c_m – price of electricity supplied to consumers at node m (Rub/kWh);

$c_э$ – electricity price in the wholesale interregional market (Rub/kWh);

d_m – costs on production of 1 kWh of electricity at the corresponding node (Rub/kWh);

g_m – cost of fuel used for generation of 1 kWh of electricity (Rub/kWh);

f_m – specific loss, compensation costs or penalties due to electricity undersupply (Rub/kWh).

In functional (1) dimensionality is violated, as far as the costs per 1 kWh are multiplied by the capacity (kW), this being its specific feature. The time for existence of this condition that is common for all functional components is factorized and determined beyond the considered optimization block of the software package.

In general the optimal solution can be obtained for real relations between the functional coefficients $f_m > c_m$, $c_m > d_m$, $d_m > g_m$ in the majority of system nodes.

The problem was solved by applying the interior points method [5] that proved to be rather flexible, fast and properly convergent for similar problems.

In the outlined statement YANTAR also solves the mentioned problems. In this context the studies were performed on reliability of electricity supply to consumers both depending on provision with energy resources and in combination with provision with generation capacities.

The software package YANTAR is adjusted to estimate a required level of capacity reserves in each regional EPS in the case of its isolated operation at the given $\mathscr{P}$.

The commercial reserve is estimated in YANTAR by using R^e_{com} and R^c_{com} and the values of balance characteristics:

$$E_{rec} = E_d + R^e_{com} \text{ and}$$

$$P^g_{ins} = P^l_{reg\max} + R_T + R^c_{com} + P^g_{unused},$$

where P^g_{ins} – installed generation capacity; $P^l_{reg\ \max}$ – regular maximum of load; R_T – technical reserve; P^g_{unused} – generation capacity unused in the system.

The first results of system reliability decomposition are described in [4] on the example of a power system. They showed an adequate functionality of the suggested technique.

Hence, the considered model allows the reliability calculations based on the specific market factors. In addition the model can be applied for comparative estimation of different methods of organizing markets of electric power and capacity in EPS, taking into account possible operating conditions in the system and different strategies to minimize power deficits [2].

Conclusion.

The above said makes it possible to conclude that estimation of electric power industry reliability continues to be an important factor for management of its development and operation. The market factors require additional conditions to be taken into account for estimating EPS reliability.

The model YANTAR suggested to specialists can be applied for solving EPS management problems topical at the current stage: provision of power plants with primary energy resources; minimization of risks of the competitive environment by creating commercial reserves in EPS; decomposition of system reliability into reliabilities of technological subsystems forming it.

The obtained results of studies confirm expediency of the suggested approaches to solve the relevant problems and efficiency of the suggested model.

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