A COMPENSATION SYSTEM OF DAMAGE CAUSED BY ACCIDENTS AT ENERGY OBJECTS: PROBLEMS, METHODS, MODELS

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Problem contents

During operation, energy objects (boilers, thermal, hydro and nuclear power plants, electric and heat networks, systems of oil and gas supply etc.) are exposed to a set of random factors of both internal and external character. The whole spectrum of disturbing and disruptive events may be divided into failures, accidents, extreme situations and catastrophes. Disturbing events lead to deviation of physico-technical and economic indices from the standard and forecasted ones for normal operation. In some cases these deviations can be extreme, when hazard of the economic stability loss, including ruin of the energy object (EO) owners, arises.

There are two key ways for achieving sustainable economic development:

- elimination of sources of disturbing effects, decrease of their rate of occurrence, restriction of the consequences of these effects;
- creation of mechanisms for damage compensation.

The first way is a classical problem of improving the EO's reliability and security with comprehensively devised methods and approaches. As to the second way, its understanding as a scientific concept with own tasks and solution methods is only at the stage of perception. New forms of property and economic activity, development of a legislative base of liability for consumers and a third party make the damage compensation problem urgent.

Different classes of EOs are characterized by the different scopes of potential disturbing events. The impacts of such events differ correspondingly and, as a consequence, it can be asserted that the most rational mechanism for damage compensation should be constructed for each class of EOs [1]. The purpose of damage compensation is to:

- decrease the gravity of the economic impacts for EOs;
- regularise this random component of the EO's financial state.

For the statement of the compensation problem we consider briefly the principal ways for economic damage compensation.

Ways of damage compensation

The economic damage caused by disturbing events can be compensated by using different economic and institutional mechanisms. A short review of potential ways of compensation is given below. Currently this list is naturally excessive, as far as there is neither institutional nor legislative base for all forms of compensation in our country as yet. On the other hand, this list is not complete, since there is no information on the detailed analysis of damage compensation mechanisms operating in developed countries.

Creation of reserves to cover unforeseen expenditures at a separate EO (object fund) allows the problem of damage compensation to the object itself and the third party to be solved, when the damage value is relatively small. Consequences of more rare events, but with a larger damage value, may be compensated by different joint funds, which are formed on the base of a branch (energy, petrochemistry, aviation etc.) or territorial (regional ecological funds and funds of extreme situations) principle. These funds are formed from payments of enterprises, which are potential risk sources. The object and joint funds now play an important role in the damage compensation problem, even though they are not the most effective from the economic standpoint.

An intermediate position between the joint funds and insurance is occupied by the societies of mutual insurance, which can be created by the branch or territorial principle similarly to the joint funds. However, the mechanism of their operation is radically different. The principle of forming the funds of such societies is close to insurance, but it does not pursue the objective of getting profit from using the money of the fund. Nowadays the legislative base of mutual insurance societies, which played an important role before the revolution, is being formed in Russia [2].

The insurance way of damage compensation has been intensively developed in Russia since the early 90s. Such a way is based on redistribution of money of many insurance participants in favour of those experiencing an insurance event. The abundant experience of developed countries shows that the insurance can successfully solve the damage compensation problems in different forms (insurance of property, liability, life and health, financial risks, investments etc.), considerably increasing the volumes of damage to be compensated. Absence of the legislatively authorized assignment of insurance payments relative to the production costs retards an extensive application of the insurance protection for EOs. Absence of the legislative base also hinders the introduction of insurance in the sphere of liability of the energy producers to its consumers.

If the damage volumes exceed the abilities of EO, joint funds and the insurance coverage limits, the remaining damage can be compensated using the mechanism of retroactive compensation. Its appearance results from the advancement in the legislative base of liability and concerns, primarily, the damage compensation for a third party. The retroactive coverage does not use specially organized funds and is based on the contract between potentially hazardous EOs. If damage exceeds some value, its remaining part is evenly shared among all the contract participants. The fraction of each EO is determined by the number of objects and the value of damage to be compensated, but does not usually exceed some limiting value. Application of this mechanism to the nuclear insurance system of the US and FRG is given as an example.

Events with drastic impacts lead, as a rule, to damages, which cannot be compensated without centralized funds, including the federal budget. The mechanisms of the formation and the use of the centralized funds should be further developed, since their variety in developed countries allows the choice of the most effective mechanism (for example, Super Fund in the US, ADAC in Germany and so on) for different types of objects and events. An overview of these methods of centralized compensation is presented in [3].

In general, the above mentioned compensation mechanisms are not absolutely independent and hence, it is valid to say about a system of economic damage compensation (SEDC). The pattern and properties of such a system greatly depend on the properties of the risk objects and external economic environment.

Problem formulation

The damage compensation problem, which is based on the assumption that some reliability and security level of energy objects (EOs) is fixed, is stated below. The case, when these properties can change simultaneously with the solution to the compensation problem, is treated in the end of the paper. Qualitatively the problem of choosing a rational mechanism for damage compensation can be formulated as follows: find such a pattern of a system of economic damage compensation (SEDC) and connection parameters that would increase the economic stability of EOs to the greatest extent and would be economically feasible for all used levels of SEDC.

To formulate the problem mathematically some functions, describing a financial state of EO and SEDC levels with regard to the whole scope of disturbing events, should be analysed. Let the algebraic sum of all incomes and expenditures for some time interval t be the EO's financial state. Then the financial state dynamics $D(t)$ can be described by the equation:

$$D(t) = P(t) - C(t) - Y(t) + \sum_i Y_i(t) \qquad (1)$$

where $P(t)$ - conditionally determined income; $C(t)$ - conditionally determined expenditures; $Y(t)$ - total damage caused by disturbing events; $Y_i(t)$ - part of damage compensated by the i-th way of compensation.

The total and compensated damages are random variables, whose values depend on the function (functions) of damage distribution. Therefore, the financial state at time interval t is in general a random variable too. The structure of conditionally determined expenditures can be represented as two components: expenditures on operation in normal conditions and a regularized component of random expenditures $C_2(t)$. The second component can be represented in the form

$$C_2(t) = \sum_i A_i \qquad (2)$$

where A_i - systematic payments of EO to the i-th SEDC level.

If the compensation system fully covers any damage due to disturbing events, the random component of financial state is meant to be fully regularized. This is naturally possible only in some idealized cases.

The equations for assessment of the financial state $D_i(t)$ of the i-th SEDC level, taking into account the corresponding mechanisms of their operation, can be written similarly to (1). Assessment of the random component of state $D_i(t)$ is characterized by the fact that the damage volume is determined for the corresponding region of the distribution function for the total damage $Y(t)$.

The financial states of EO and SEDC are determined by both the internal mechanism of the operation and the connection parameters. In this case, they are limits of damage compensation for each SEDC level (Y^{max}) and payments of EO to the i-th SEDC level (A_i). In the whole set of possible realizations of the financial states and the corresponding pairs ($Y^{max};A_i$) of concern are those which satisfy some additional constraints. These constraints can be imposed on both the expected values of the financial states at the end of the studied period and some special functionals. The ruin probability that is taken as the probability for the realization of condition $D_i(t) < b$, where b is the barrier of ruin for EO or some SEDC level, may be referred to one of such functionals.

Thus, the problem of compensating accident-caused damages at EOs, can be formulated as follows: find a minimum set of the SEDC levels and the appropriate pairs ($Y^{max};A_i$), for which constraints on some functionals (ruin probability, expected income, expected expenditures etc.) are met:

$$F[D_i(t)] \le F_i^*, \text{ for } \quad t \in [0,T] \tag{3}$$

Approaches and methods of solution

The stated above problem is complex and requires elaboration of the new approaches or extension of the existing ones for its solution. The solution is based on the analysis of statistical data on disturbing events at EOs. Unlike the analogous analysis in reliability problems, here attention is paid to both the mix of events and their frequency and to evaluation of scales, the spatial-time pattern of chiefly economic impacts for the EO itself and for all external systems, which are exposed to the impacts of risk realization. Since the whole scope of disturbing events is considered, the statistical data are supplemented by theoretical estimates of frequency and impacts of severe accidents and catastrophes.

This step in the compensation problem solution may be independent and concern the problems of economic risk analysis. The aim is to obtain a "frequency-damage" dependence for different classes of EOs. This dependence can be continuous, discrete, pointwise or mixed. In general, when constructing this dependence, the following three areas can be distinguished:

- failures and accidents, for which there exists an extensive sample of events realized for a long time period (statistical values can be calculated from experimental data);
- failures and accidents with a small sample for a limited mix of equipment (probabilistic indices are calculated on the base of standard methods and experimental data);
- accidents and catastrophes, for which only descriptions of individual events or scenario description of hypothetical events are known (statistical indices are calculated by the methods of probabilistic risk analysis).

Some approaches to the construction of such distribution functions are presented in [4]. The studies performed have shown that transition from material damage to economic damage presents the greatest difficulties, particularly if it becomes necessary to assess damage to energy consumers and in other external systems, suffered from consequences of an accident or a catastrophe.

The next step consists in construction of mathematical models to forecast the EO's financial state and the SEDC levels in terms of disturbing events. Incompleteness of statistical data, the complicated nature of "frequency-damage" dependence and a number of other factors, make the use of simulation models preferential for forecasting the financial state. Such models have been constructed and realized for some classes of EOs at the Siberian Energy Institute of the Russian Academy of Sciences. Special studies have been performed to construct a simulation model of insurance [5]. These models allow parametric investigations to be performed. As a result, estimation of the insurance tariff levels, which are acceptable for both EOs and insurance companies, is obtained [6].

In general, direct and inverse methods for tariff calculation may be distinguished. In the first case the direct calculation of the tariff a is made from the corresponding statistical information:

$$a = f(X,Y,Z,N)_E \qquad (4)$$

where X - vector of parameters that determines the insurance company state (initial reserve, pattern of the insurance portfolio, tariff pattern etc.); Y - vector of parameters of the risk to be insured (mix of insurance events, function of damage distribution); Z - vector of parameters of the insurance contract (deductible, liability limits, credits etc.); N - expected number of insured objects; E - external conditions for company operation (bank interests, licensing limitations, consideration of competition).

In the second case an auxiliary problem concerning some functional, in which tariff is one of its parameters, is solved. Introduction of additional constraints determines the boundary (limiting) values of the tariff a. The utility function and the insolvency (ruin) probability are commonly known functionals of the inverse problem. When the indirect approach is applied, the problem of tariff estimation will have the form:

$$H^* = g(X,Y,Z,N,a^*)_E \qquad (5)$$

where H^* - limiting value of some functional.

It is also advisable to use simulation to forecast the SEDC state, which would also include other compensation mechanisms. The analogous direct and inverse methods for calculation of the values of A_i can apparently be devised.

Besides the simulation approach resulting in a numerical solution, in some cases the use can be made of analytical models for estimation of the SEDC efficiency. In [7] it is shown, for example, that for the Brownian motion approach the problem of insurance efficiency estimation can be reduced to a classical ruin problem. Other analytical methods as applied to the two-level SEDC (energy object - insurance company) can be used, if one succeeds to construct a generalized Poisson distribution, describing the damage distribution for a group of objects.

A large number of parameters that determine the SEDC pattern lead to necessity and expediency to state optimization problems. Some classes of extremal problems can be formulated as stochastic programming problems, where the total ruin probability of all SEDC levels serves as the criterion in some cases [4]. A preliminary analysis performed at the Siberian Energy Institute has revealed that such problems are not classical and require special algorithms to be elaborated for their solution.

Conclusions

The described approaches and the models have been realized and applied to solve compensation problems for some classes of energy objects (thermal and nuclear power plants, main gas pipelines). Main attention has been paid to insurance efficiency assessment as a particular case of the system of economic damage compensation (SEDC). Further extension of the models is aimed at a description of non-insurance mechanisms of damage compensation and a solution of the problem related to the determination of the SEDC's rational structure.

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