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Organizational and Economic Mechanism of End-Users Power Supply Reliability Ensuring

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Abstract: The analysis of providing reliability mechanisms of power supply operating in Russia leads to the conclusion that interruptions of end-users energy supply aren't taken into account. In the current situation the development of an address approach to end-users interests is on the front burner. We adhere to the decomposition of power supply reliability into the system and address ones. To ensure the latter we propose the free bilateral relations between the electric grid company and the end-users. Customers are expected to determine reliability level according to the estimation of an adequate indemnity in cases of an interruption or a power limitation. The author develops the mechanism and calculating options of the counterparties' mutual obligations to provide the power supply reliability of end-users and mathematical model for technical indexes optimization of end-users power supply reliability.

Keywords: Power Supply Reliability, End-Users, Grid Distribution Company (GDC), Address Reliability, Customer Interruption, Electricity Sacrifice, Customer Response

1. Introduction

Ensuring power supply reliability of end-users is widely discussed problem and generates a wide range of economic aspects [1]. The important sector is accounting of individual requirements and sensitivity of consumers to power supply reliability [2–4].

The analysis [5] of current mechanisms of power supply reliability ensuring in Russia shows that normative order [6, 7] inspires grid distribution companies (GDC) to increase the system reliability index. At the same time the individual levels of end-users supply reliability remain below the standards defined in the Rules for installing electrical facilities [8]. Consequently the problem of GDS–end-user dialog [1] was declared in Development Strategy of the integrated power grid of the Russian Federation in the field of power supply reliability [9]. In other words, it is necessary to develop a system of relations between GDCs and the end-users, which would take into account the demand for power supply reliability.

1 «To ensure dialogue with consumers about their preferences – power supply reliability or price of the appropriate level of reliability…», see [9].

This problem attracts attention of Russian authors (e.g., see [10, 11]). The widespread idea to solve this is developing a system of discounts and surcharges to the tariff for electricity transmission.

Such approach, according to the author, is rather complicated for the practical implementation for the following reasons.

First, it would require a revision of the retail electricity market rules.

Second, the procedure for calculating the transmission tariff will be more difficult. In accordance with the current legislation, GDC is calculated and transmitted to the regulatory authorities the actual values of reliability and quality of provided services for the reporting period. Defined by these values, reducing or increasing coefficients allow to correct tariff for electricity transmission basing on the total for operation area network reliability level [6, 7].

It's obvious, that the introduction of an additional system of discounts and surcharges makes tariff opaque to the end-user. GDC will not receive price signals to ensure an optimal level of electricity supply reliability to the consumers.

To avoid the marked situation we offer the approach based on bilateral contracts between GDCs and end-users [12].

Worldwide practice already uses system of contracts to ensure the reliability of power supply to meet customer requirements [4, 13, 14]. However, these contracts are adapted to local conditions and cannot be taken over in the Russian Federation without significant processing. The reason for this lies in the peculiarities of Russian legislation and the specific market conditions [15].

2. The Approach to Providing of Address Power Supply Reliability

We propose to solve the problem of customer oriented power supply realization basing on the following assumptions:

- power supply reliability is decomposed into the system (SPSR) and address (APSR) ones;
- system-wide reliability is ensured in accordance with retail electricity market rules, it is not expected to make changes in this area;
- the address power supply reliability providing is a separate service; it is proposed to be realized through free bilateral contracts between the electric grid company and the end-users;
- reliability agreement is optional for end-user;
- if consumer make a reliability contract with the grid distribution company, one gets the right to indicate adequate individual level of reliability within the non-discrete range (versus discrete range in [8]);
- the price for APSR providing should be connected with the required reliability level: the more reliability, the higher price of service.

Thus APSR providing service is optional, the corresponding demand is formed by the end-users, which are not satisfied with the current power supply reliability level.

As an indicator of technical level of end-user power supply reliability it should be considered undersupply of electricity ΔE and capacity constraints ΔN. However, in many cases customers haven't meters to detect the capacity values, and payments are counted according to the straight-line rate. So below we will take into consideration electricity sacrifice only.

To create a customer-oriented model of the relationship between an electric grid company and end-users it is necessary to introduce one more factor, namely, customer sensitivity to power supply restrictions. It can be represented as the size of the denied profit or losses due to the undersupply of 1 kWh.

3. The Scheme of Relations Between the GDC and End-User on Address Power Supply Reliability Providing

Let us suppose that the end-users are able to estimate their own losses due to electricity shortage. Taking this into consideration the interaction model for the GDC and the end-users can be constructed as follows.

Let n end-users enter into the address reliability contract with GDC. Each one of them stated the required level of power supply reliability in the form of the size of the specific losses due to the electricity sacrifice y_i (i = 1,…, n). Obviously, the greater is the declared amount of damages y_i, the higher is level of reliability, which customer requests.

The GDC undertakes to ensure contractual level of reliability for a cash consideration P_i. The received from consumers payments P_i. are accumulated in the grid company's earmarked fund. It is the targeted fund intended for financing of reliability increase technical projects and compensation payments in favor of end-users in cases of the mains supply interruption:

$$\sum_{i=1}^{n} C_i + \sum_{i=1}^{n} Y_i \le \sum_{i=1}^{n} P_i \,, \qquad (1)$$

here C_i are the costs for technical project focused on i-th end-user supply reliability increase, Y_i are compensation payments in favor of the i-th end-user.

GDC pays compensation to the end-user for undersupply of each kWh in the case of power supply interruption. The latter takes place also if GDS failed to provide the reliability due to the technical measures implementation.

The amount of compensation is determined on the basis of specific losses contractual values:

$$Y_i = y_i \cdot \Delta E_i \,, \qquad (2)$$

where ΔE_i is actual customer curtailment.

In this formula the technical level of reliability becomes indifferent for the end-user, because grid company reimburses all losses arisen out of the electricity undersupply[2]. In more detail relational scheme for the end-user and GDC in the framework of APSR ensuring agreement is considered in [12].

The service cost of the address power supply reliability providing may be determined in proportion to end-user's electricity needs:

$$P_i = p_i \cdot \overline{E}_i \,, \qquad (3)$$

where p_i is specific cost of service for i-th end-user or cost of service on a per 1 kWh basis, $\overline{E_i}$ is average annual amount of i-th end-user electrical energy consumption.

To exclude the situation when end-users increase the declared amount of damages due to the lost energy, the cost of services upon APSR ensuring should depend on the compensation value amount they wish to receive in the case of the power supply interruption. For the sake of simplicity, we may use the linear function:

$$p_i = \alpha \cdot y_i \,, \qquad (4)$$

2 If the end-user has specified the actual amount of damages in the contract.

where α is unknown proportionality factor.

We propose the calculation of specific service cost p_i to be defined by condition, that end-users must pay an amount equal to compensation payments, which the grid company has to repay with absence technical measures in order to improve the address power supply reliability:

$$\sum_{i=1}^{n} p_i \cdot \bar{E}_i = \sum_{i=1}^{n} y_i \cdot \Delta\bar{E}_i \,, \quad (5)$$

where $\Delta\bar{E}_i$ is average annual volume of i-th end-user electricity sacrifice.

Taking into account (4) and (5) we get the following:

$$\alpha = \frac{\sum_{i=1}^{n} y_i \cdot \Delta\bar{E}_i}{\sum_{i=1}^{n} y_i \cdot \bar{E}_i} \quad (6)$$

For a particular end-user value of the coefficient α reflects an individual character of the statistical evaluation of electricity sacrifice and transforms into formula:

$$\tilde{\alpha}_i = \Delta\bar{E}_i / \bar{E}_i \quad (7)$$

It is expected, that the end-users with a higher category of power supply reliability have the share of electricity shortage, which is lower than the same value for customers with a lower reliability category.

Accordingly, the formula (7) allows different coefficient values $\tilde{\alpha}_i$ for end-users, which have specified in the contract equal reliability level (i.e. equal values of specific losses y_i). Therefore service cost p_i values are also different. It is appropriate result because end-users with a higher reliability category have had greater connection charge, and during the contract they have greater current technical reliability level.

Since neither end-users nor the network company does not have sufficient information about the electricity shortage, the use of equations (6) and (7) is difficult. In accordance with the Order of the Ministry of Energy of the Russian Federation № 296, grid companies must record a duration of customer interruption at a node of connection to the power grid.

Using these data undersupply estimation for i-th end-user can be made as follows:

$$\Delta E_i = t_{\mathrm{dur}\, i} \cdot P_{\max\, i} \cdot \gamma_i \,, \quad (8)$$

where $t_{\mathrm{dur}\, i}$ denotes an interruption duration for i-th end-user, $P_{\max\, i}$ is maximum capacity of i-th end-user;

γ_i is load curve density of i-th end-user.

Another way to estimate the value of α in (4) is based on the generalized index expressing the average relative undersupply of electricity throughout the electric power supply system:

$$\tilde{\alpha} = \frac{\sum_{i=1}^{n} \Delta\bar{E}_i}{\sum_{i=1}^{n} \bar{E}_i} \quad (9)$$

In the calculation using the formula (9) the cost of services will be equal for those customers, who declare the same values of specific damages, regardless of their reliability categories. However it can be assumed, that the majority of end-users, which are not satisfied with current reliability level, belongs to the third category of reliability (see [8]). Just these end-users should be considered as potential customers of providing services for the address power supply reliability. Under this assumption, the calculation by the formula (9) can be considered adequate to the solving problem. So cost targeted level of power supply reliability will be determined exclusively by the size of the declared compensation for damages incurred due to the electricity undersupply.

4. Address Power Supply Reliability Optimization with Regard to the Requirements of End-Users

By the choice of certain technical and organizational measures in order to ensure the reliability of power supply for each end-user, GDC will compare its implementation costs and the reduction of compensation payment due to increased reliability of the address power supply (fig. 1).

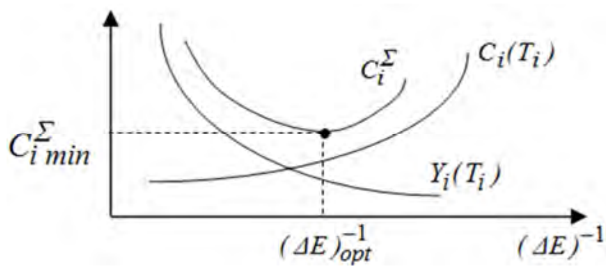

Figure 1. *Optimal level of power supply reliability.*

Corresponding objective function is the following:

$$\sum_{i=1}^{n} C_i(T_i) + \sum_{i=1}^{n} Y_i(T_i) \rightarrow \min \,, \quad (10)$$

where $C_i(T_i)$ denotes costs for technical project T_i, focused on i-th end-user supply reliability improvement;

$Y_i(T_i)$ is compensation payments in favor of the i-th end-user in case of technical project T_i implementation.

Increasing the technical level of reliability and the reducing of electricity shortage duration leads to decrease the size of compensation payments by a grid company.

So GDC will seek technical, technological, organizational and other ways to increase the address power supply reliability, provided that the costs of its implementation is less than expected decline in compensation payments. The grid company's economic effect due to technical reliability optimization of the network nodes can be estimated as the following:

$$B = \sum_{i=1}^{n} \overline{Y}_i - \left(\sum_{i=1}^{n} C_i^{opt} + \sum_{i=1}^{n} Y_i^{opt} \right), \tag{11}$$

where B is economic benefit of reliability optimization;

$\overline{Y}_i$ is compensation payment to the i-th end-user in case of absence of reliability increasing technical projects; C_i^{opt} are costs for the technical project focused on i-th end-user supply reliability optimization; Y_i^{opt} are compensation payments to the i-th end-user in case of optimum technical reliability providing.

Thus, the GDC can get a positive economic effect only by optimizing the technical level of end-users address reliability. In turn, providing contract execution to ensure power supply reliability latter will not incur unnecessary costs.

However, a priori calculation creates the following problem. The amount of i-th end-user electricity shortage is uncertain and depends on many diverse factors, a significant part of which may not be affected by the grid company.

For its own risk restriction GDC may provide the maximum amount of compensation

$$\Delta E_i^{\max} = t \cdot \Delta \overline{E}_i, \tag{12}$$

where ΔE_i^{max} is maximal electricity sacrifice value of the i-th end-user, which GDC is committed to compensate during the contract; t is duration of contract for address power supply reliability providing to the i-th end-user.

5. Discussion

The offered mechanism of APSR providing is close to an assurance one. The risks connected with electricity undersupply to certain end-user are distributed between all end-users which signed contracts on the individual reliability level providing.

It should be noted that the proposed mathematical model of a cost calculation of the individual reliability level providing is developed with an assumption that a sizeable end-user number will wish to sign the relevant contracts.

Another approach involves the time diversity of risks. Formula (9) takes the following form:

$$\hat{\alpha}_i = \frac{\sum_{t=1}^{T} \Delta \overline{E}_{ti}}{\sum_{t=1}^{T} \overline{E}_{ti}}, \tag{13}$$

where T is a duration (e.g. in years) of contract on the APSR providing.

With this approach, the coefficient $\hat{\alpha}_i$ is calculated for each end-user and it has a value close to probability of 1 kWh electricity undersupply to an end-user.

The limits of this approach applicability are determined by contract duration. Obviously, this model is relevant only in the case of perennial agreements. When establishing contract duration one can be guided by terms used in the tariff calculation under the RAB-regulation.

In order to select the optimal mathematical model to calculate service costs to APSR providing, we are to analyze the end users need to increase the reliability and their willingness to pay for it.

Currently author together with colleagues conduct actual survey of end-users on these issues. Preliminary results suggest, that companies located in urban areas and connected to grids on 1st or 2nd reliability rating of reliability, do not feel the urgent need to change the conditions of power supply.

Conversely, this is especially important for end-users, connected to grids on 3rd reliability rating or located in rural areas, e.g. agricultural enterprises. The food industry is usually having 3rd reliability rating, and so it is carrying significant losses due to power supply interruptions.

In addition, this service may attract the interest of new consumers, who want to receive uninterrupted electricity, but for one reason or another have no possibility to connect to grid on 1st or 2nd reliability rating.

Therefore we expect, that the proposed service will have demand, because power supply reliability level is not perfect [16]. Several Interregional distribution grid companies determine the level of technology risk materiality[3] as a significant [17, 18].

6. Conclusion

We propose to decompose of power supply reliability into the system and address ones. The system power supply reliability ensuring is subjected to current retail market rules. It should not be corrected. The address power supply reliability ensuring is proposed to hold out as self-contained service providing within the free bilateral contracts between the electric grid company and the end-users.

The suggested relationships model allows accommodating the interests of both parties. Due to additional payments GDC is able to raise specialized funds for technical measures in order to increase the power supply reliability. At the same time grid company receives price signals to optimize reliability, taking into account end-user requirements.

Customers get higher reliability level either technically or economically. In the first case end-users put up money for technical measures, which lead to increasing of address power supply reliability level. In the second one end-users

3 Risk materiality level is defined as the combination of risk probability and magnitude of consequences for the company in money and other terms [18].

get compensation for losses from GDC.

Service costs can be calculated in different ways: using formula (6), (7) or (9). The choice between alternatives will be done after practical approbation and actual survey.

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Biography

Marina Vasilyeva is a assistant professor of Energy Department, Novosibirsk State Technical University. She has published 20 articles on energy economics and power supply reliability.