

New conditions for applying surcharges (discounts) to electricity payments for generation and consumption of harmonic component currents

Vladislav Chikin* and Anatoly Kuznetsov

UIGTU, Department of Electrical Supply, Ulyanovsk, Russia

Abstract. Technical means of suppression of harmonic component currents installed in the consumer's electric network are able to reduce the level of harmonic component currents and reduce the harmful effects of their flow. The consumer's interest in installing such means is significantly increased when discounts (surcharges) are applied to the payment for electricity consumed for generation and consumption of harmonic currents. However, the attempt to apply allowances (discounts) has failed in the past. The article proposes to review and discuss new conditions for the application of surcharges (discounts) to the payment for electricity for generation and consumption of harmonic currents, taking into account the unsuccessful experience of use in the past. The article proposes a methodology for calculating and using surcharges (discounts) to the payment for electricity consumption for generation and consumption of harmonic component currents to manage the power quality in the power supply systems of consumers of a grid organization with nonlinear loads.

1 Introduction

One of the problems inherent in power supply systems is the problem of low power quality (PQ) when providing consumers with electricity [1, 2]. It is associated with such harmful consequences as premature failure of electrical installations, etc. The problem of low PQ is multifaceted and is associated with a number of power quality indicators (PQI), which are specified in GOST 32144-2013. Indicators K_U and $K_{U(n)}$ characterize the non-sinusoidality of the power supply voltage at the point of power transmission and are caused by the generation of nonlinear loads of consumers and the flow of harmonic component currents through the electrical network.

The PQ management model assumes control factors of technical and economic nature. Economic factors with their legal support complement technical factors and provide the most significant control effect. Legal support is provided by one of the ways to ensure fulfillment of obligations provided for in the Civil Code of the Russian Federation. A well-known method of ensuring fulfilment of obligations is payment of the cost of harmful

* Corresponding author: powersupply96@mail.ru

consequences of harmonic currents flowing through the electric network. Payment of the cost of harmful consequences can be made in the form of compensation for real damage, in the form of penalty, in the form of surcharge (discount) to the cost of consumed electricity.

From the authors' point of view, payment of the cost of harmful effects in the form of surcharges (discounts) to the payment of the cost of consumed electric power for generation and consumption of harmonic component currents [3] is a more effective control factor. However, the attempt to apply surcharges (discounts) in the past has failed. The surcharges (discounts) were cancelled in 2000 as inconsistent with the current legislation [4]. The authors propose to consider the possibilities of application of surcharges (discounts) for PQ management. To make an attempt to revive surcharges (discounts) taking into account the unsuccessful experience of their use in the past.

2 New terms of application of surcharges (discounts)

The calculation of surcharges (discounts) is based on the cost of harmful consequences arising for all participants in the technological process of electricity transmission and consumption in the grid organization's customer power supply systems with non-linear loads. In the management process, it is important to determine both the value of the cost of harmful consequences and the specific participants of legal relations to which the surcharges (discounts) are supposed to be applied. Such participants of legal relations can be:

- consumers whose non-linear loads generate harmonic component currents beyond the point of electricity transmission into the grid organization's electric network (hereinafter - distorting consumers);
- the grid organization;
- other consumers of the grid organization that are not sources of harmonic component currents in the grid organization's electric network (hereinafter referred to as "non-distorting consumers").

At first glance, it seems that the grid organization and non-distorting consumers should make claims to distorting consumers for payment of the cost of harmful effects. However, analysis of the Methodological Guidelines for Calculation of Regulated Tariffs and Prices for Electric (Heat) Energy in the Retail (Consumer) Market shows that the grid organization takes into account the cost of harmful effects when calculating the tariff for electricity transmission. In the management process, the cost of harmful effects arising in the grid organization's electric network may not be taken into account. The control factor in the form of a surcharge to the distorting consumer and a discount to the grid organization may not be considered in the model. It is proposed to include such participants of legal relations as distorting consumers and non-distorting consumers in the management model.

The value of the cost of harmful consequences is currently estimated by the amount of real damage caused. Unfortunately, the calculation of the amount of real damage caused is associated with significant difficulties. It is practically impossible to determine the exact value of the amount. At present, there are no approved methods that allow estimating the real damage caused [2, 5]. In the literature there is a proposal to the legislator to replace the amount of the caused real damage with the costs of the implementation of activities to suppress harmonic currents [6]. Payment of the cost of harmful consequences, in such a case, is realized in the form of penalty recovery. In contrast to the real damage caused, the penalty is a contractual amount and does not require linkage to specific prices for failed electrical installations. In our opinion, the liquidated damages may well be measured by the costs of suppressing harmonic component currents by installing noise suppression devices such as filter compensating devices (FCD), active filters or hybrid filters [7]. A penalty is proposed to be used in the control model.

Considering the above, when using a formalized method of payment for the cost of harmful effects in the form of a surcharge (discount), it is proposed to consider only consumers without a grid organization as participants of legal relations to which surcharges (discounts) are supposed to be applied, and to estimate the cost of harmful effects by the costs of suppression of harmonic component currents.

The question remains to be answered as to how to calculate surcharges (discounts) for specific consumers of a grid organization. Obviously, the value of surcharge (discount) for a particular consumer is a payment for the consumed electricity, its part or other parameter of the consumption mode associated with the flow of harmonic component currents.

In the literature there are proposals to use the values of duration of exceeding the normal and maximum permissible normative values of PQI as a paid parameter of the consumption mode [8]. The value of the energy of harmonic components generated into the electric network of the grid organization by one consumer and consumed by other consumers [9]. For narrowly professional specialists they can be perceived as paid parameters. However, for a wide range of the public, legislators, etc., these concepts are considered from the point of view of the classical system of commodity turnover and tariff formation. They are not perceived as goods or services and cannot be paid for. There is a need for another chargeable parameter of the consumption regime, which is perceived by the public and the legislator.

The authors propose to introduce the concept of "volume of distorted electricity" and use it as a chargeable parameter for calculating the amount of the surcharge. The volume of electricity distorted by the consumer is a part of the volume of electricity consumed during the billing period. At each ten-minute interval of PQI averaging time established by GOST 32144-2013, electricity is considered distorted if at the same time interval there is:

- generation of harmonic component currents into the electric network of the grid organization;
- the $K_{U(n)}$ indicator for any n -th order of harmonic components exceeds the normal and maximum permissible standardized values;
- the ten-minute interval under consideration is included in the seven-day time interval during which the assessment of PQ compliance with GOST 32144-2013 norms is given. At the same time it is found out that the electric power at this seven-day time interval does not meet the requirements established by GOST 32144-2013.

The sum of the distorted electricity at ten-minute time intervals may represent the distorted electricity for the calculation period. The value of the volume of consumed electricity is clear and familiar to the public and legislative bodies. There are no fundamental difficulties in including the volume of distorted electricity in the legislative acts for its use in paying the cost of consumed electricity for generation and consumption of harmonic component currents for PQ management.

To calculate the amount of the surcharge, the value of the specific cost of distorted electricity is required. It is found by dividing the calculated costs of installation of technical means for suppression of harmonic currents by the volume of distorted electricity. Application of surcharges is provided for distorting consumers. For non-distorting consumers it is necessary to apply discounts. According to the new conditions, the discounts should be dependent on the surcharge values. Thus, the formalized method presented assumes monetary compensation of harmful effects in the form of a discount for non-distorting consumers at the expense of distorting consumers by applying a surcharge.

3 Mechanism of application of surcharges (discounts)

In order for the mechanism of surcharges (discounts) to work, there must be a relationship between consumers on the basis of which a financial payment scheme can be built. The

current situation does not provide for such relationships. The process of charging payments cannot be realized in the absence of contractual relations between consumers. It is reasonable to use the existing scheme of financial relations between consumers and electricity suppliers. Collection of payments in the form of a surcharge and compensation of the cost of harmful effects in the form of a discount should be entrusted to organizations engaged in energy sales activities (hereinafter referred to as PSO) - guarantee supplier or other energy sales organization. The functions of PSOs are reduced to collection of payments, their distribution and transmission to non-distorting consumers.

When collecting and distributing payments, it is necessary that the amount of payment in the form of surcharges $\Delta P_{s,j}$ to each j -th of M distorting consumers of the grid organization be equal to the amount of payment in the form of discounts $\Delta P_{d,i}$ to each i -th of L non-distorting consumers of the grid organization. The fulfilment of the equality of payments in the form of surcharges and discounts ensures independence of two processes from each other. One of them is the process of payment by consumers for electricity consumed to electric power industry entities participating in the process of electricity supply. The second is the process of payment by distorting consumers for the cost of harmful effects of harmonic currents to non-distorting consumers.

When the equality is not met, there is a difference between the sums of payments $\sum_{j=1}^M \Delta P_{s,j}$ and $\sum_{i=1}^L \Delta P_{d,i}$. For the grid organization as an electric power industry entity, the difference represents an additional unplanned expense or income. Makes gross revenue from payment for electricity transmission services not corresponding to economically justified costs of electricity transmission in the grid organization. The principle of economic feasibility of costs established by the legislation for natural monopolies is violated [10]. The legitimacy of the application of surcharges (discounts) is questioned.

The known mechanism of application of surcharges [3] did not assume the equality of payments for surcharges and discounts, which is associated with a possible violation of the principle of economic feasibility of costs. Literature sources note that this is one of the main reasons for cancelling the application of surcharges (discounts) as not corresponding to the current legislation [4, 10]. The legitimacy is ensured if surcharges and discounts will not affect the amount of gross revenue generated on the basis of the application of economically justified tariff.

4 Methodology for calculating surcharges (discounts)

Let's consider the case when there is only one distorting consumer in the grid organization. For this consumer we denote the volume of distorted electricity as $W_{dist,1}$. Then the surcharge $\Delta P_{s,1}$ for this consumer is determined as follows:

$$\Delta P_{s,1} = C_{dist,1} \cdot W_{dist,1}, \quad (1)$$

where $C_{dist,1}$ is the specific cost of distorted electricity, which is the specific cost of suppressing harmonic component currents when the quality of one kWh of electricity is distorted.

Discount $\Delta P_{d,i}$ to each i -th of L non-distorting consumers of the grid organization represents compensation of harmful effects and is paid by the distorting consumer. The discount represents a part of the surcharge or costs of the distorting consumer's activities to suppress harmonic currents. It is proposed to distribute the amount of the surcharge in the form of discounts among non-distorting consumers depending on their share of electricity

consumption d_i . Then, equality of allowance and discount payments, the expression for determining the discount is as follows:

$$\Delta P_{d,i} = -\Delta P_{s,i} \cdot d_i = -C_{dist,i} \cdot W_{dist,i} \cdot \frac{W_i}{\sum_{i=1}^L W_i}, \tag{2}$$

where W_i is the volume of electricity consumed during the billing period by the i -th non-distorting consumer.

A negative value of the discount indicates compensation (payment) to the non-distorting consumer. If the grid organization has not one but M distorting consumers, then expression (1) for each j -th distorting consumer and expression (2) for each i -th non-distorting consumer will take the following form:

$$\Delta P_{s,j} = C_{dist,j} \cdot W_{dist,j}, \tag{3}$$

$$\Delta P_{d,i} = -\left(\sum_{j=1}^M C_{dist,j} \cdot W_{dist,j}\right) \cdot d_i = -\left(\sum_{j=1}^M C_{dist,j} \cdot W_{dist,j}\right) \cdot \frac{W_i}{\sum_{i=1}^L W_i}, \tag{4}$$

The value of the surcharge determines the amount of financing of the activities of the distorting consumer for suppression of harmonic currents. This amount depends on the value of the unit cost of costs $C_{dist,j}$. It is important that the unit cost of the costs of the distorting customer's harmonic current suppression activities ensures the interest of the distorting customer in the realization of the project of installing FCD, active filters or hybrid filters in its electricity network. The distorting consumer makes a decision on the basis of analyzing the technical and economic indicators of the project, interest investors. One of the indicators is the payback period, which should suit and ensure the interest of the investor. In the case of applying the surcharge (3), the payback period for the j -th distorting consumer is calculated as follows:

$$T_{payback,j} = \frac{Inv_j}{C_{dist,j} \cdot W_{dist,j} - E_{op,j}} \tag{5}$$

where Inv_j – investments (capital investments) in the project of the j -th distorting consumer, determined by the cost of the selected FCD, active filters or hybrid filters of the required capacity; $E_{op,j}$ – annual maintenance costs of FCD, active filters or hybrid filters.

It follows from (5) that the unit cost of the cost of the distorting consumer's activity to suppress harmonic component currents can be calculated by the expression:

$$C_{dist,j} = \frac{\frac{Inv_j}{T_{payback,j}} + E_{op,j}}{W_{dist,j}} \tag{6}$$

At the same time, the type and capacity of FCD, active filters or hybrid filters should be selected beforehand in accordance with the known methods [7, 11] and the consumer's capabilities.

Obviously, the unit cost is calculated according to expression (6) for each j -th distorting consumer of the grid organization individually. Individualization of the unit cost greatly complicates the methodology of their calculation and application in practice. From these

positions, the unit cost for all distorting consumers of the grid organization should be reduced to one value similar to the boiler tariff for electric power transmission. In this case, according to the authors, the reduced unit cost of expenses, which is the same for all distorting consumers of the grid organization, can be called a single-rate tariff for the implementation of activities of the distorting consumer to suppress currents of harmonic components and denoted as $C_{dist,0}$. There are several options for selecting the $C_{dist,0}$ tariff.

In one of the options, the minimum value of the calculated unit cost of all distorting customers is selected as the tariff. This tariff provides full financing of the project for the installation of FCDs, active filters or hybrid filters in the distorting consumer for whom the selected minimum unit cost is calculated. For the rest of the distorting consumers the financing will be partial. But there will be an incentive effect. In the second option, to select the tariff, it is necessary to initially identify the most intensive distorting consumer in terms of generation of harmonic currents. For this consumer it is necessary to calculate the value of unit costs and take its value as the $C_{dist,0}$ tariff, according to which allowances for other distorting consumers will be calculated.

5 Conclusions

1. Generation of harmonic currents by nonlinear consumer loads and their flow through the electric network causes a decrease in the level of PQ according to K_U and $K_{U(n)}$ indicators and generates harmful consequences. It is possible to eliminate harmful effects by installing technical devices for suppressing harmonic currents in the electric network of an electric power consumer. For this purpose it is necessary to interest the consumer in this by applying mainly economic control factors.

2. From the authors' point of view, the application of such factors as compensation for real damage caused and penalties does not effectively stimulate the installation of technical devices for suppressing harmonic currents. A formalized method of payment for the cost of harmful effects in the form of a surcharge (discount) to the payment for electricity consumed for the generation and consumption of harmonic currents has a more effective impact on consumers.

3. The attempt to apply surcharges (discounts) in the past failed. The surcharges (discounts) were cancelled in 2000 as inconsistent with the current legislation. The authors propose to consider and discuss new conditions of application of allowances (discounts), taking into account the unsuccessful experience of use in the past.

4. In contrast to the well-known approach, the new conditions assume:

- all consumers of the grid organization should be considered as participants of legal relations to which the surcharges (discounts) are supposed to be applied. The grid organization is excluded from the participants of legal relations;

- the value of the surcharge shall be estimated by the costs of the distorting consumer's activities to suppress harmonic component currents;

- to use a new technical parameter "volume of the distorted electricity" instead of values of the duration of exceeding the normal and maximum permissible standardized values of PCI and energy of harmonic components generated in the grid network of the grid organization to calculate the amount of the surcharge as a paid parameter of the electricity consumption mode;

- to calculate the amount of the surcharge, the concept of the specific cost of distorted electricity is introduced. It is calculated by dividing the calculated costs of installing technical devices for suppressing harmonic currents by the amount of distorted electricity. The unit cost of distorted electricity is the unit cost of suppressing harmonic currents in the case of distortion of the quality of one kWh of electricity or a single-rate tariff for the implementation of activities of the distorting consumer to suppress harmonic currents;

- duties to regulate legal relations between consumers on application of the surcharge (discount) shall be assigned to the PSO. The functions of the PSO are reduced to collection of payments from distorting consumers in the form of surcharges, their distribution and transfer to non-distorting consumers in the form of discounts.

5. The methodology of calculation and use of surcharges (discounts) to the payment of the cost of consumed electric power for generation and consumption of harmonic component currents for management of PQ by K_U and $K_{U(n)}$ indicators in the power supply systems of consumers of the grid organization with nonlinear loads is proposed.

6. Application of surcharges (discounts) does not change payments under the existing tariffs. The PSO accepts payments under these tariffs and distributes them among electric power industry entities participating in electric power supply to consumers. The surcharges (discounts) are not components of the existing tariffs. They are used for consumers' settlements with each other. The PSO accepts payments in the amount of surcharges and distributes them among the grid organization's consumers in the form of discounts.

7. Application of surcharges (discounts) in practice requires legal support. This should be taken into account when improving the regulatory and legal framework in the field of PQ.

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