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Study on Pricing Method of Power Quality Differentiated Market Service in Distribution Grid

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ABSTRACT With the development of society and economy and the application of the high-tech equipment, the structure of power load in modern power system has greatly changed. In the power market environment, the relationship between power quality and customer demand has caught more and more attention among power suppliers and customers. In this circumstance, quality factors are inevitably taken into account when we price for power transactions. The prices of electricity market service also vary with the quality of such a service. This paper analyzes the power market environment and technical support required by the quality pricing of the power transaction in the power market environment on this basis, and proposes a power quality differentiated market service pricing method for the distribution grid, which involves power quality governance, loss and user response. The primary system diagram and RBTS-bus3 in the practical application of distribution grid are used for case analysis. The results show that this method is feasible and effective, and provides a new approach for the quality pricing of power market services.

INDEX TERMS Differentiated market service, power quality, pricing, power market environment.

I. INTRODUCTION

At present, China's power system reform centering on ''controlling the middle and opening up both ends'' has entered the deep water zone. The reform measures such as power transmission and distribution price reform, establishment of trading institutions, medium and long-term power transactions, pilots of incremental power distribution business and construction of spot market etc. are being carried out in an orderly way [1]. China's electricity price reform has been moving towards a three-section electricity price chain concerning power generation on-grid electricity price, transmission and distribution electricity price and final sale electricity price of differentiated service price adjustment. The ancillary services market is an important component of the electric power market, and the power quality is an important auxiliary service content. Therefore, on the basis of the electricity price management chain, transmission and distribution service and power quality service should be separated, and differential electricity price of power quality service should be introduced [2]. And also the final sales price of power users connected to the distribution network needs to be adjusted by adding differential service price.

This separation enables power supply enterprises to separately evaluate power management investment and the incentive compatible constraint investment of power quality differentiated service in the distribution grid, thus realizing reasonable pricing. In References [3], [4], the basic marginal cost pricing model is revised and some inequality constraints to suppress harmonic distortion are added.

However, such methods are difficult to fully cover all kinds of power quality problems and cannot satisfy the increasingly detailed requirements of the power customers connected to the distribution grid in the power market environment. Moreover, the solution of the mathematical model will become very difficult with the increase of constraint conditions. In References [5]–[8], the idea of power quality liability insurance is introduced into electricity pricing mechanism; And it is stipulated that the electricity price that power customers need to pay should be composed of the basic electricity price and the power quality liability insurance premium. This enables the power supplier to maintain the required level of reliability in accordance with the insurance terms, and also helps the customer to transfer a part or all of

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the loss caused by the power failure to the insurer. The power customers need to pay the power price by the superposition of basic electricity price and power quality liability insurance, which will prompt the power suppliers to maintain power quality reliability according to the insurance terms, and is also helpful for the users to transfer some or all of losses caused by the power outage to the underwriters. This turns the economic compensation of power quality accident into the compensation choice of the participants. However, the price set by this method cannot reflect the governance cost.

With the in-depth study of power quality problems, more and more advanced technologies are used to improve power quality [9], [11], [13]. Advanced control technologies make it possible to meet the requirements of various quality levels of users. At present, the main comprehensive control technologies include client power (CP) technology and FRIENDS technology [10]. For CP technology, high and new technologies such as power electronics, microprocessors and modern control technologies are applied to the medium and low voltage power distribution system. This makes it possible to meet various power quality level requirements of users. For example, in [10], by adding different quality control center (QCC) in different power supply levels, various functions of CP has been realized. For power supply enterprises, the establishment of QCC and CP will become a powerful technical support for quality pricing of power.

The differentiation of electricity price level for power quality service is not only closely related to the cost of power quality management and the response of users, but also takes full account of the development level, regional differences, economic level and users' bearing capacity for power price level. Under the above market environment and technical conditions, this paper proposes a pricing method of power quality service based on differentiated pricing, thus, reasonably realizing the quality pricing of user power linked to the distribution grid.

II. POWER QUALITY SERVICE PRICING METHOD

A. THE THEORETICAL BASIS OF DIFFERENTIATED PRICING FOR POWER QUALITY SERVICE

The market demand for the same product produced or operated by an enterprise varies with time and place. Differentiated pricing is to set two or more kinds of price for a certain commodity based on the demand of consumers in different parts of market. For example, industrial electricity and domestic electricity, they individually own the same production cost, but their sales price is individually different. The two necessary conditions under which differentiated pricing is applied to power quality service pricing must be satisfied [14]: (1) Users' demand for power quality is diverse in the market, and enterprises have a strong market power. And the power supply enterprises, as the main market components, have a certain control over power quality, and can select and decide their own prices without accepting the unified market pricing. (2) The power cannot be stored, production and consumption nearly take place at the same time, and the governance of power quality problem, which is aimed at users, is mainly to meet the different needs of users. Therefore, there is very little user's arbitrage behavior after the market segmentation. Furthermore, power supply enterprises should try their best to accurately identify different users' payment intentions and segment the market according to their payment intentions.

It can be seen from the analysis above that the pricing of power quality differentiated service conforms to the condition of differentiated pricing. Therefore, it is feasible to introduce the theory of differentiated service pricing into power quality service pricing.

B. PRICING PRINCIPLES AND PROCESSES

The pricing principle and process of power quality service for power supply enterprises can be outlined as follows:

1) For each quality declaration period, the users should put forward specific power quality requirements to the power supply enterprises. The users that fail to do so should be deemed to require the basic power quality service (initial implementation) or to maintain the previous quality level.

2) The power supply enterprises should make statistics on the power quality level of all users, and then make reasonable segmentation for the users market after comprehensive consideration of the factors such as economy, effective range of the governance measures, users' geographical location and willingness to pay.

3) The differentiated pricing is made after market segmentation, forming a price list related to power quality level.

4) Price selection is performed by users.

5) The power supply enterprises sign power quality service contracts with the users who reach an agreement.

C. MARKET SEGMENTATION-POWER QUALITY SERVICE LAYER

The key to the implementation of the differentiated pricing for power quality service is how to segment the market reasonably. The fixed cost of power quality management is huge. Therefore, in market segmentation, the effectiveness and economy of power quality management should be put in the first place, and then the willingness of users to pay should be considered. The two factors are not contradictory, and either is based on the user's demand for power quality level. Obviously, it is extremely uneconomical for each user to simply independently install power quality control devices, which is difficult to achieve the optimality. Therefore, it is necessary to make economically optimal adjustment according to the structure of distribution grid and the characteristics of distribution equipment. The requirements of all users for power quality determine the most economical and effective governance measures for the distribution grid as a whole. At the same time, if the user's non-authenticity declaration is not taken into account, generally speaking, the higher the power quality requirement put forward by the user, the stronger his/her willingness to pay. Since it is difficult to count and weight the payment intention of user one by one, this paper proposes a method of market segmentation based on power quality governance–power quality service hierarchy.

After collecting the power quality level declared by all users, the power supply enterprise conducts the segmentation of governance level: Firstly, the users that can be managed collectively are segmented in a layer according to the minimum requirements. That is, the jurisdiction is divided into several large areas. In each area, the users with further requirements are counted and the area is divided into several smaller levels by the power supply enterprise according to the governance scope, and so on, until the requirements for all users are completely distributed. In the stratification process, the following factors which affects the power quality management effectiveness of distribution grid should be comprehensively considered [15]: ① Reliability of the upper and local power grids; ② Economic optimization; ③ Structural characteristics of middle and low voltage distribution grid; ④Load characteristics and its distribution. Then the most economical governance method to reach the level of power quality of each layer is determined. And then the cost analysis is conducted according to the type, quantity, power consumption, recycling period and profit of governance measures of the users in each layer, so as to make full preparation for the subsequent pricing.

It should be pointed out that under the current condition of the governance technology, the final power quality level in the market cannot be continuous over-dense distribution, but a hierarchical situation. Even if the governance capacity can meet any requirement, it is not economical to form a continuous power quality level distribution. This will make statistics and pricing calculation too heavy. Therefore, there will not be too many layers, which cannot correspond to the specific requirements declared by users. When the final price list is determined, users who have not been stratified can weigh to adopt which layer to meet their own requirements of power quality according to their specific requirements.

D. A MATHEMATICAL MODEL FOR PRICING

Before establishing the mathematical model of pricing, we make the following assumptions:

1) The market segmentation is conducted according to the governance scope. Therefore, users can only choose the quality-cost combination within their own regional level, and the pricing model is also targeted at a regional scope.

2) For the users who declared their quality level in the previous stage, they can only choose a combination of quality-expenditure which is equal to or lower than their declared level in the final contract selection.

3) Users' purchase of power quality service is regarded as unit demand. That is, no matter what power quality level and price they choose, the purchase quantity, namely the load quantity, is constant. Specifically, the users composed of multiple loads can be decomposed via load types and power quality purchased separately by users.

4) If there are the users whose power quality service requirements are higher than their declared level, the power supply enterprises can only manage them separately after the end of pricing, and the expenditure shall be determined by both sides through negotiation.

Pricing is based on each domain, and the following data can be obtained after stratification: N is the number of layers in this domain; Q is the total load in this domain; S_i is the power quality level of layer i; C_i is the governance cost of power quality per unit electricity consumption; W_i is the proportion of user load related to layer i in total user loads in this domain, $i = 1,2,\ldots, N$. The higher the user level is, the greater the demand intensity for power quality is. Therefore, the greater the willingness to pay for the same quality level is, but the demand type of the same level is approximately consistent.

Assume that the power quality level s in the power market is continuously distributed, the marginal willingness payment model of the users in the i^{th} level market is $P_i(s)$(the formation for this model will be detailed in section 2.5). Therefore, the total willingness payment for the quality service in the i^{th} level is $\int_0^{S_i} p_i ds$. Provided that the total charge of the power supply enterprises for selling s_i services to the users of this layer is R_i, then when the users of level i purchase s_i services, the net utility surplus of the electricity is:

$$U_i(s_i) = \int_0^{s_i} p_i ds - R_i \tag{1}$$

In the power market environment, power supply enterprises aim at maximizing profits, but only carry out accounting cost pricing without considering users' response to the prices. Therefore, the "self-selection constraints" proposed here include:

1) "INDIVIDUAL RATIONALITY – IR" CONSTRAINT

$U_i(s_i) \geq \overset{*}{U}$ (U is reserve utility for users, for the users who do not buy power quality service, its value is 0) . That is, the net surplus obtained by users who purchase s_i power quality service at level i is not less than the other consumption utility obtained by the same user. The constraint motivates users to purchase power quality services.

2) "INCENTIVE COMPATIBLE – IC" CONSTRAINT

$U_i(s_i) \geq U_k(s_k)$, $i>k$. That is, when they purchase the optimal power quality level, the utility obtained by users at level i is not less than that specially designed for other users. $i>k$ indicates that users can only choose the power quality service below their own declared level, and there is no arbitrage behavior. This constraint ensures that users disclose their true power quality type as their optimal choice.

After stratification, the power supply enterprises obtain the governance cost data of unit load per layer, and gets the governance cost function of per layer by fitting $C_{S_i}(s)$, and then take the derivative of 's' to obtain the marginal governance cost function $c_{S_i}(s)$.

Therefore, the profit function of power supply enterprises can be expressed as:

$$\prod = Q \cdot \left\{ \sum_{i=1}^{N} w_i (R_i - \int_0^{s_i} c_{S_i} ds) \right\} \quad (2)$$

At this moment, the decision problem that the power supply enterprises face with is: quality-price combination design $\{(s_1, R_1), (s_2, R_2), \ldots, (s_N, R_N)\}$. Under the two "self-selection constraints" conditions of the users mentioned above, the pricing model of the maximum profit function is:

$$\max \prod = \max \left\{ Q \cdot [\sum_{i=1}^{N} w_i (R_i - \int_0^{s_i} c_{S_i} ds)] \right\} \quad (3)$$

$$\textbf{s.t. IR}: U_i(s_i) = \int_0^{s_i} p_i ds - R_i \geq 0 \quad (4)$$

$$\textbf{IC}: \int_0^{s_i} p_i ds - R_i \geq \int_0^{s_k} p_i ds - R_k, (i > k) \quad (5)$$

where, **IR** is the boundary condition, which is equivalent to: $U_1(s_1) = 0$. That is, the net surplus is 0 for the lowest layer users. Thus we have:

$$R_1 = \int_0^{s_1} p_1 ds \quad (6)$$

The boundary conditions of IC are equivalent to the fact that: there is no difference between the users data groups at the *i-th* layer, (s_i, R_i) and (s_{i-1}, R_{i-1}), $(2 \leq i \leq N)$

Thus yielding:

$$U_i(s_i) = U_i(s_{i-1})$$

That is,

$$R_i - R_{i-1} = \int_0^{s_i} p_i ds - \int_0^{s_{i-1}} p_i ds = \int_{s_{i-1}}^{s_i} p_i ds \quad (7)$$

From Eq. (6) and (7), we can obtain:

$$R_i = \int_0^{s_1} p_1 ds + \sum_{k=2}^{i} \int_{s_{k-1}}^{s_k} p_k ds, (2 \leq i \leq N) \quad (8)$$

Substituting Eq. (6) and (8) into Eq.(2), we can obtain from the first order conditions:

$$\frac{\partial \Pi}{\partial s_N} = w_N p_N - w_N c_{s_N}(s_N) = 0$$

$$\frac{\partial \Pi}{\partial s_i} = p_i \sum_{k=i}^{N} w_k - p_{i+1}(s_i) \sum_{k=i+1}^{N} w_k - c_{s_i}(s_i) w_i, (1 \leq i < N)$$

Solving for the two equations above, we yield:

$$\begin{cases} p_i^* = \dfrac{p_{i+1}(s_i) \sum\limits_{k=i+1}^{N} w_k + c_{s_i}(s_i) w_i}{\sum\limits_{k=i}^{N} w_k}, (1 \leq i < N) \\ p_N^* = c_{s_N}(s_N) \end{cases} \quad (9)$$

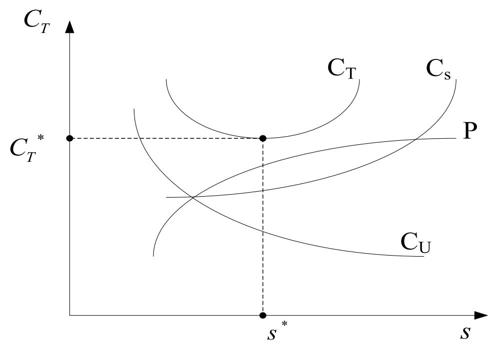

FIGURE 1. Users' payment willingness model.

E. USER PAYMENT WILLINGNESS MODEL

As the electric energy of different quality with characteristics of commodities in the power market environment, it is basically equivalent in the function of commodities. The main reason for the differentiated pricing of electric energy quality services does not lie in the degree of satisfaction of users' demand, but in the cost of using different power quality. The electricity service with different quality levels has different utilization costs for different power users, even for the electricity service with same quality level, different users have also different use-costs. The higher the users' utilization cost, the greater the potential economic loss caused by unstable power quality. And the more inclined the users are to use high-quality power service.

Based on the above analysis of the economic characteristics of power quality and the differentiated service pricing model of power quality, the users' willingness payment model shown as in FIGURE 1 is proposed. Where, C_s is the power quality cost; C_U is the users' use-cost; C_T is the total cost of users ($C_T = C_s + C_U$); P is the users' willingness to pay.

C_S is formulated by the accounting cost method of power supply enterprises, which is only the preliminary pricing intention. Rational users will not blindly accept the price. Some electric power users are willing to buy high-quality electric power at a higher cost, mainly because high-quality electric power service will bring low use-cost. But the users will not blindly pursue quality, but pursue the best electric power quality service at the principle of economy. As can be seen from FIGURE 1, the most economical users' power quality level is s*, and the minimum value $C_T{}^*$ of $\mathbf{C_T}$ will be obtained by adopting this power quality. Therefore, when the rational users choose power quality service, they will undoubtedly choose s^* point as the target power quality service level and the corresponding $C_T{}^*$ as the target cost. If the actual electricity service level deviates from s^*, the users' use-cost C_u will inevitably change. Therefore, the rational users will take C_T* as a fixed reference target and deduct the use-cost C_u from it to get $P(s)$. That is, $P = C_T^* - C_u = min(C_s + C_u) - C_u$. The users' marginal willingness payment $P(s)$ can be obtained by the derivative with respect to s.

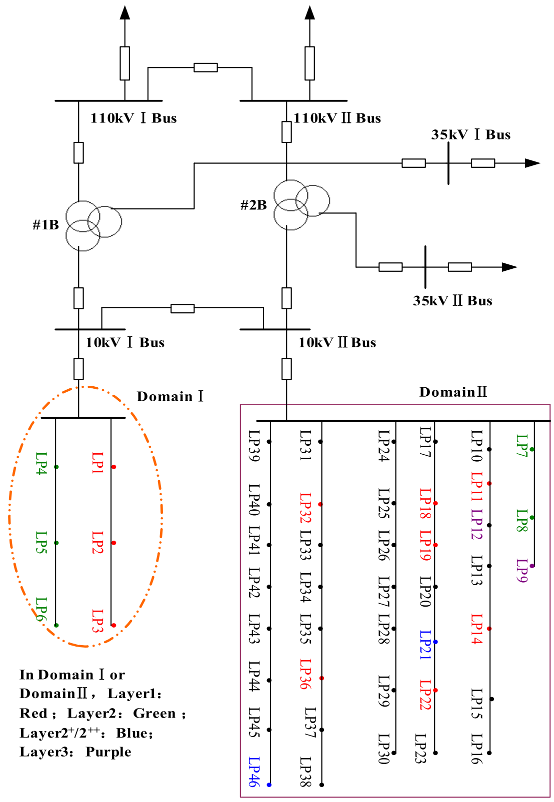

FIGURE 2. Hierarchy for power quality.

III. CASE ANALYSIS

In order to verify the feasibility of the proposed pricing method, a case analysis is given here. The users' data for the case analysis are provided by an electric power research institute (EPRI), which are shown in TABLE 1:

In the case analysis, RBTS-Bus3 distribution system is used. The system is a typical complex medium and low voltage distribution grid including the users such as industry, commerce, office and residents, with a total of 46 load points, 6,571 users and a total average load of 56.796MW. For the sake of clarity, they are given by mixing it with the primary system diagram, and their simplified wiring illustration is shown in FIGURE 2:

Since all the users at each load node are of the same type, one assumes that all the users at each node have the same power quality requirements. That is, the distribution grid is regarded as only 46 users.

A. USERS' DEMANDS FOR POWER QUALITY LEVEL

Before declaring the power quality level, users should have a general understanding of their current power quality service level and the causes of power quality problems. And then they can make requirements on specific indexes. The power users who are not familiar with power quality issues may turn to a third party such as experts or specialized power quality consulting departments to provide such consulting services. In this paper, it is assumed that the current power quality level of all power distribution grid users has all reached the basic power quality level. That is, the power quality pollution problem below the basic level has been solved in the electromagnetic pollution emission right market [16]. At the same time, it is assumed that the coordination of existing power quality management measures and new management planning in the distribution grid is not considered.

TABLE 1. Users' data (provided by 'EPRI').

Load Quantity	Load Point	Users' Types	Load Levels at Each Load Point (MW)		Users' Quantity
			Load Peak Value	Load Average	
15	10,12,13,23-31, 15-17	residents	0.8365	0.4686	251
5	37-39,40,45	residents	0.8503	0.4759	231
8	20,33-35,41-44	residents	0.7753	0.4341	191
3	4-6	large enterprises	7.1167	5.3886	1
3	1-3	large enterprises	11.5836	7.3498	1
3	7-9	small enterprises	1.0169	0.8474	1
7	11,14,18,19, 22,32,36	commerce	0.5225	0.2888	16
2	21,46	office	0.9252	0.5681	1
Total			87.661	56.796	6571

TABLE 2. Requests of different users to power quality.

Load Point	Users' Type	Comprehensive Index
4~6	large enterprises	10
1~3	large enterprises	8
9	small enterprises	8
7, 8	small enterprises	6
21, 46	office	5
11,14,18,19,22 32,36	commerce	4
Others	residents	0

Note: "0" means the users has not service requirements

The measurement of power quality level requires effective evaluation methods. The existing method such as fuzzy theory is mostly adopted, which classifies power quality into several fixed levels such as high quality, qualification, low quality and unqualification according to the degree of membership [17]. Since the power quality level involved in this paper is stratified according to users' requirements, the method has greater flexibility. Therefore, the membership degree evaluation method is not adopted, but the comprehensive indexes evaluated are only used. According to the general requirements of all kinds of users, the comprehensive indexes after evaluating the specific requirements of power quality proposed by users in the distribution grid are shown in TABLE 2.

B. STRATIFICATION RESULTS AND AVERAGE GOVERNANCE COST PER LAYER

By users' requirements, we take into account the various factors mentioned above, and assume that the distribution grid

TABLE 3. Results of heirarchy and the load ratio per layer.

Domain	Layer	Load Point	Load Ratio(%)
I	1	1~3	57.698
	2	4~6	42.302
II	1	11,14,18,19,22 32,36	35.467
	2	7,8	29.733
	3	9	14.867
	2^{+}	21	9.967
	2^{++}	46	9.967

can be segmented into two domains. That is, I and II,then the domain heirarchy results and load ratio can be obtained, which are as shown in TABLE 3. Meanwhile, the heirarchy schematic diagram can be also gotten, which is shown in FIGURE 2.

C. THE SOLUTION OF USERS' MARGINAL WILLINGNESS PAYMENT MODEL

Assume that the average governance cost and service use-cost per layer have a quadratic function relationship with the power quality comprehensive index. Namely:

$$C_{Si}(s) = a_{Si}s^2 + b_{Si}s + c_{Si}$$
$$C_{Ui}(s) = a_{Ui}s^2 + b_{Ui}s + c_{Ui}$$

Then the marginal governance cost function can be expressed as:

$$c_{Si}(s) = C'_{Si}(s) = 2a_{Si}s + b_{Si} \tag{10}$$

The users' payment willingness function can be expressed as:

$$P_i(s) = \min[C_{Si}(s) + C_{Ui}(s)] - C_{Ui}(s)$$

Then the users' marginal payment willingness function will be:

$$p_i(s) = P'_i(s) = -2a_{Ui}s - b_{Ui} \tag{11}$$

The statistical data related to power quality control measures cost and users' loss is provided by the EPRI. By fitting them per layer, we can separately obtain the parameters of management cost and use-cost functions per layer, as shown in TABLE 4 (Assume that the users' marginal payment willingness curve slope per domain is the same).

D. PRICING RESULTS AND ANALYSIS

From the above marginal governance cost function and users' marginal payment willingness cost function and Eq. (6), (8) and (9), we can calculate the price of power quality service and marginal price per layer, as shown in TABLE 5.

TABLE 4. Parameters of the power quality governance & cost function per layer.

Domain	Layer	a_s	b_s	c_s	a_U	b_U	c_U
I	1	38	320	0	30	-1100	6880
	2	38	320	0	30	-1500	12000
II	1	17	180	0	50	-400	800
	2	50	100	0	50	-900	3600
	3	50	100	0	50	-1500	8800
	2^{+}	10	190	0	50	-600	1750
	2^{++}	10	190	0	50	-600	1750

TABLE 5. Service price per layer.

Domain	Layer	Service Price/ (dollar·MW^{-1})	Marginal Price/ (dollar·MW^{-1})	Marginal Cost/ (dollar·MW^{-1})
I	1	6880	977.868	928
	2	8880	1080.000	1080
II	1	1200	369.525	316
	2	2000	766.667	700
	3	3600	900.000	900
	2^{+}	1750	290.000	290
	2^{++}	1750	290.000	290

For each user, the total power quality differentiated market service charge is the price multiplied by the total load in the selected service layer. From Eq. (9) and comparison of marginal price with marginal cost in TABLE 5, it can be seen that the marginal price is equal to the marginal cost in local higher layers per domain (i.e., the layers 3, 2^{+} and 2^{++} in domain II, and layer 2 in domain I), while the marginal price is higher than the marginal cost in lower layers per domain. The equilibrium analysis of quality difference products shows that when the marginal price of quality is equal to the marginal cost of quality, the optimal social effectiveness can be achieved. Therefore, the power quality service consumption for users in the higher layers has reached the optimal level of social benefits. The marginal price is higher than the marginal cost in local lower layers per domain. The reason is that the power supply enterprises should lose the purchase intention of some users in lower layers in order to ensure the maximization of overall profit and the purchase intention of users in higher layers.

The results of service pricing show the users' power quality differences in different layers may lead to a big difference in price. This is associated with a big governance cost difference in different quality layers. But the big difference in users' payment willingness in different layers will make this price difference bigger. This is because the big difference is caused by a difference in the users' power quality accident loss in different layers. It embodies the essence of differentiated pricing.

IV. SUPPLEMENTARY INSTRUCTION

1) The differentiated pricing method and model proposed in this paper is mainly aimed at different power quality service requirements advanced by more users in power distribution grid. For only a fewer users or requests advanced by scattered users, it is difficult to manage collectively. For this, generally, the power quality improvement devices are installed for the users separately, and the charge is determined through negotiation between both sides. Therefore, there is no unified pricing problem.

2) There may be the following situations to happen. That is, the users in domain II in FIGURE 2 do not advance service requirements of power quality. But in consideration of the factors such as the geographical location, governance, or economy, when users are layered, a fewer users' requirements of power quality service cannot be separated from the users in layer 1 (i.e. Load Point 12). Their requirements do not belong to layer 1, but they enjoy power quality service from layer 1, and the power supply enterprises should not charge for it. Although such users receive high-quality power service, such a high quality service is not guaranteed. This is because the power supply enterprise is not aimed at such users like Load Point 12. Therefore, the stratification based on the method conforms to the fairness principle.

3) For the case above, if 2, 2^{+} and 2^{++} in the same layer in domain I Tare separated, the following two kinds of situation perhaps appear: (1) The requirements of the power quality service are different in level or index, such as 2 and 2^{+}. (2) Although the requirements of the power quality service are the same, in consideration of the factors such as farther geographical distance, disparity for governance costs, unreasonable average allocation of governance costs and limited governance measures, it is difficult to unify the management (such as 2^{+} and 2^{++}). Therefore, 2^{+} and 2^{++} are divided into different levels. For this situation, there will be the following two price results: one is that some power quality problems are relatively easy and economical to control in a large range, and the final shared cost for each user in a large range will be relatively less than that in a small range, and there may even be a big difference in price between two layers. The other is that for some power quality problems, it may be more economical for the users to deal with them separately. Under the circumstances of the same governance cost, the users' service price of the same requirements is ultimately consistent. This is as shown in the price results of layers 2^{+} and 2^{++} in the calculation example. From a practical point of view, this kind of pricing method based on power quality service considers the regional domain and cost of governance, thus the method is more reasonable than that based on power quality level.

4) Since in the differentiated service pricing method proposed in this paper is fully considered the power quality loss of the users, the power supply enterprises only need to return the price difference between the selected quality level and the actual quality level to the users after the occurrence of power quality accident. And there is no difficulty in assessing the loss of users after the occurrence of accident. Due to full consideration of their own management ability in layering, the power supply enterprises need not sign the power supply service contract with the users whose power quality problems cannot be controlled beyond their capability. For power quality accident loss brought by some unexpected reasons, power supply enterprises can circumvent the risk of their own through purchasing power quality liability insurance.

5) The mathematical model established by this method has taken into account the mechanism of "incentive compatibility constraint". This ensures that the profit which the users obtain from the report of the real power quality level is higher than that from the non-real report.

V. CONCLUSION

This paper analyzes the factors related to the differentiated market service pricing of power quality, and puts forward a differentiated pricing method of power quality market service in distribution grid. It is realized by reasonably stratifying the market service of power quality in consideration of the users' payment willingness, taking the maximization profit of power supply enterprise as the objective, and making the differentiated pricing of market service of power quality in distribution grid. The pricing method has the following advantages: (1) The implementation of differentiated pricing of power quality services can stimulate power supply enterprises to improve power quality services, and to achieve the overall planning of the distribution grid; (2) The hierarchical governance of power quality services is aimed at the whole distribution grid, which is beneficial for power supply enterprises to optimize governance resources by planning as a whole, thus promoting the improvement of social overall benefits. (3) By this method, the market environment and technical requirements of power quality problems can be satisfied, thus fully considering the elements of pricing in the power market environments; (4) The users report power quality requirements and provide clear information about the power supply enterprises in order to facilitate the power supply enterprise to carry out purposeful investment and planning; (5) The power service is separated into basic power service and power quality service so as to achieve a result of reasonable high price of high quality power and to ensure the fairness in the power service market. The calculation and analysis from the case given show that the differentiated pricing method of market service of power quality is feasible and effective, which provide a new approach for power market service pricing according to quality. However, this method is not perfect. The main disadvantage is: The non-real behaviors of the two parties between the power supply enterprises and customers are not taken into account in the pricing model. For this, it is still necessary to adopt the method of game theory to perfect it.

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