From Power Quality to Power Experience

Tian Gao, Junwei Cao, Yanxiang Xu
Research Institute of Information Technology
Tsinghua National Laboratory for Information Science and Technology, Tsinghua University, Beijing 100084, China

Huaying Zhang, Peng Yu, and Senjing Yao
Shenzhen Power Supply Co. Ltd.
Shenzhen 518020, China
Email: jcao@tsinghua.edu.cn

***Abstract*—With development of information technology and high-tech companies, power requirements have turned from quantity to quality. Power quality issues are becoming more essential for power companies. Existing power quality standards are described by stable or transient states of current and voltage, from a perspective of power supply. In practice, it is up to customers' sensitivity and actual experiences for evaluation of power quality. In this work, power experience is proposed as a composite criterion of both existing power quality standard and related customers' information. From a perspective of customers' experience, the concept, features, and standards are proposed for power quality of experience. A case study from Shenzhen Power Supply Company is given, demonstrating that power quality of experience is more feasible in actual work for power quality evaluation.**

Keywords—Power Quality; Power Experience; customers' sensitivity, Power Experience Assessment

I. Introduction

Power quality is a type of quality of service (QoS) for customer and electric power service providers, which should be considered an important factor in power supply and demand contract [1]. The QoS flaw of power service is called power quality disturbances, which are classified into the following categories by the IEC (International Electrotechnical Commission): harmonics, voltage fluctuations, voltage sag and interruptions, low frequency voltage, voltage imbalance, power frequency variations, and oscillatory transients [2-3]. Recently, the power quality issue has sharpened because of the proliferation of power electronic devices and nonlinear loads, which are becoming the main sources of degradation of electric power quality by the generation of disturbances. Furthermore, the increased use of sensitive loads exacerbated the situation of power quality. For example, the sensitive loads, such as computers, process controls, and communication equipment, could be affected or damaged in a short-time voltage disturbance to cause huge financial loss [4-5].

According to the statistical data, the most common power quality disturbances are the voltage sag, voltage interruptions and harmonics, which not only affect customer equipment but are also detrimental to the operation of the power utility. It is evident that different types of loads result in different power acceptability. From 2010 to 2012, the largest number of complaints (Over 72% of the time), which received from the large customers in city A of China, is caused by voltage sag , which may bring severe loss to those sensitive customers such as makers of semiconductor equipment, production of precision molds, and data center. Therefore, the voltage sags are the most harmful power quality disturbance to the sensitive customers. Consequently, many study of power quality disturbance focus on the techniques of real-time disturbance detection and mitigation [6]. As a result, manufacturers are integrating power quality monitoring functions in their products such as power meters, digital relays and event recorders, which becomes the main source of monitoring data to research the power quality disturbance. Many significant scientific creativities have been achieved based on the monitoring data, so that it made essential contributions to improve the power quality.

As a typical case of QoS, the quality of power service should concern both the power provider side and the power customer side. However, most of the relevant study rarely considers the experience of power customers in quality assessment of power service. It is obvious that power quality cannot fully describe the characteristics of the power service. Especially from the perspective of sensitive users, a good power service quality does not necessarily lead to a good user experience. In recent years, with the opening of power markets and the restructuring of the electric power industry, the customer experience become more important in which power quality is addressed. Therefore, this paper proposed a new conception of ***Power Experience*** mainly according to the power customers' satisfaction. We also design an assessment model of power experience to assess the quality of power service convincingly for both service provider and service consumer.

II. From the Power Quality Assessment to Power Experience Assessment

A. Power Quality Assessment

From early of 1990s, International Electrotechnical Commission (IEC) gradually published the 61000 series standard, which built a complete power quality assessment model including many indicators, such as the definition, environment description, deviation limits, and the sensitivity of electrical equipment. The similar work is also committed by the Institute of Electrical and Electronics Engineers (IEEE) and European Committee for Electrotechnical Standardization (CENELEC). In China, 6 national standards about power quality had been made and revised at regular intervals, and prescribes the deviation limits of voltage, current and harmonic.

According to the different perspective, the types of power quality assessment can be classified as follow: comprehensive disturbance assessment and single type disturbance assessment based on the evaluation indicator, quantitative assessment and grade assessment based on the result request, monitoring evaluation and system evaluation based on the spatial data hierarchy, planning assessment and compatibility assessment in term of the applied scope. Recently, many assessment concerns of power quality focus on the comprehensive evaluation method by integrating evaluation result of single type disturbance, and how to determine the item weight and establishing a reasonable utility function. Table 1 shows the common power quality indicators for comprehensive assessment.

TABLE I. COMMON POWER QUALITY INDICATORS FOR COMPREHENSIVE ASSESSMENT

Power Quality Indicators	***Voltage Quality***	Voltage Deviation
		Voltage Fluctuation
		Flicker
		Voltage Sag and Swell
		Voltage Interruptions
		Voltage Harmonics
		Three-phase Voltage Imbalance
	Frequency Quality	Power Frequency Variations

B. Power Experience Assessment

Compared with the power quality assessment, the user experience of power quality can reflect the objective and subjective satisfaction better. Therefore, this paper introduced the concept of power experience referring to the experience in the QoS of information technology. We also summarize the characteristics of the power experience, and establish the assessment model based on the existing power quality standards and relevant customer sensitivity analysis. In this assessment model, quality of power experience not only depends on the quality of power provider side, and also relevant to load sensitivity and subjective experience of the power consumer side.

Generally speaking, for a specific assessment content, the assessment model include the assessment method and the assessment indicators. The power quality disturbance contains a variety of disturbance type, and one type is different in the evaluation method and indicator to another [7-8]. Thus, in order to establish the assessment model, it is necessary to evaluate each disturbance type first by establishing the sub-model for them, and each sub-model has its own indicators and evaluation methods, which are relatively independent to each other. Meanwhile, comprehensive assessment model should be established at the same time, combining with each single evaluation result from the sub-model, using appropriate comprehensive evaluation method to achieve a final evaluation . The key issue of comprehensive assessment method is how to determine the item weight and establish a reasonable utility function [9-10]. As to the comprehensive assessment model in this paper, there are two parts: the objective quality of power supply and the user experiences of that. In detail, the second part include the load sensitivity, load type, load capacity and user satisfaction.

III. CUSTOMER SENSITIVITY ASSESSMENT

The customer sensitivity is an important evaluation indicator to assess the power experience. Under the same intensity of power quality disturbance, the customers who use high sensitivity loads will be more affected. In practice, according to the different features of power load and the requirement of power quality, power load can be generally divided into normal load and sensitive load. The power consumers who run a lot of sensitive loads are called sensitive customers [11-12]. Because the power quality disturbance is unavoidable, the sensitive customers are in a huge risk caused by the load characteristic, which means even a short-time voltage disturbance will affect the sensitive load badly. For this type of user, even a slight power quality problem can lead to serious economic loss. Therefore, the sensitivity assessment and classification of the sensitive customers is benefit to reducing the risk of power supply and demand, and promoting the technical transformation of power infrastructure.

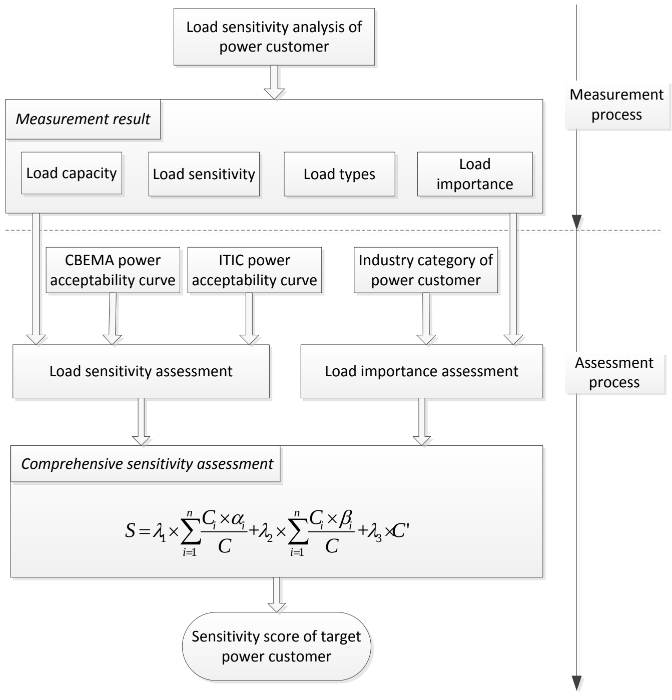

Fig. 1. The steps of customer sensitivity assessment under voltage sag disturbance

At present, with regard to how to calculate quantitatively the sensitivity of the sensitive customers, there is no relevant standards, patents, common industry method. Among various kinds of power quality disturbance, the voltage sag disturbance influences on sensitive equipment most significantly, which is also the largest reason of customers complaints. Therefore, we take voltage sag as an example to propose a sensitivity assessment model, which can calculate the sensitivity grade of target customers. For the other power quality disturbance, similar models can be used to evaluate their sensitivity score. Because the same user may use a variety of sensitive loads, our method need to consider more aspects about the target customer, such as load sensitivity, capacity of sensitive load, and the importance of the load, resulting in the comprehensive sensitivity score. The figure 1 shows the steps of customer sensitivity assessment under voltage sag disturbance.

A. Load Sensitivity Analysis of Power Customers

This step aims to achieve the relevant data of power customers, such as the load capacity, load importance, load types and load sensitivity. The data source mainly include the contract of power supply and demand, and the investigation and measurement result.

B. Assessment of Load Sensitivity

The fundamental characteristics in voltage sag generally focuses on the depths of the sag and its duration. In the figure 2, the voltage sag depth and time duration can describe the intensity of sag disturbance by forming a two-dimensional region. The threshold of sag depth is 90%, which means only when the voltage of a disturbance event is lower than 90%, it should be consider as a voltage sag, like the first sag and third sag in the figure 2.

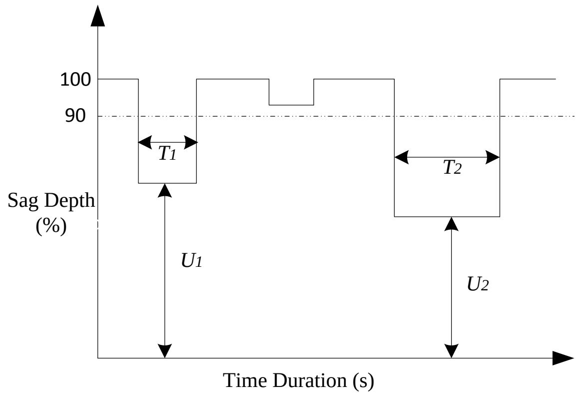

Fig. 2. The two-dimensional region to describe the intensity of sag disturbance

Therefore, as to the common sensitive load that we can confirm their electronic component, we divide the sensitive levels for different kinds of load in the two-dimensional region, which is based on the CBEMA and ITIC power acceptability curve. As is shown in table 2, considering the intensity of voltage sag disturbance, we divide the duration time into 20ms, 50ms, 100ms, 200ms, 500ms, and 3s, and divide the sag depths into 90%, 80%, 70%, 60%, 50%, and 40%.

TABLE II. SENSITIVE LEVEL OF DIFFERENT KINDS OF LOAD

Sag Depths (%)	**Time Duration (s)**						
	t≦0.02	***0.02<t≦0.05***	***0.05<t≦0.1***	***0.1<t≦0.2***	***0.2<t≦0.5***	***0.5<t≦3***	***t>3***
80≦U<90	*I*	*I*	*I*	*I*	*I*	*I*	*I*
70≦U<80	*I*	*I*	*I*	*I*	*I*	*III*	*III*
60≦U<70	*I*	*II*	*II*	*II*	*III*	*III*	*III*
50≦U<60	*I*	*IV*	*IV*	*IV*	*V*	*V*	*V*
40≦U<50	*I*	*IV*	*V*	*V*	*V*	*V*	*V*
U<40	*I*	*IV*	*V*	*V*	*V*	*V*	*V*

In the two-dimensional region of Table 2, five sub-regions (*I*~V) are divided to indicate the tolerance of customer load under voltage sag disturbance. In the region *I*, the precision equipment (e.g., medical equipment) and electronic controller might be affected. In the region *II*, the semiconductor production might be affected. In the region *III*, the computer equipment, PLC, and the AC relay might be affected. In the region IV, the DC motor, variable speed motor and sodium lamp might be affected. The sensitivity level (*I*~V) of loads correspond to the region where they belong.

If the electronic component of power customer cannot be achieved directly, the sensitivity of relevant load is usually evaluated by experimental measurement method.

In order to calculate conveniently, the relation between sensitivity level and sensitivity score is as fellow: level *I*=100, level *II*=80, level *III*=60, level *IV*=40, level *V*=20。

C. Assessment of Load importance

The load importance is usually assessed by the power provider according to the industry catalogue of the power quality. The opinion of customer should be considered as the bases to determine the importance of each load. Five importance level (*I*~V) are divided. Accordingly, the relation between importance level and importance score is as fellow: level *I*=100, level *II*=80, level *III*=60, level *IV*=40, level *V*=20。

D. Comprehensive Sensitivity Assessment of Power Customer

According to the above work, we obtain the load types and capacity of power customers, and evaluate the sensitivity and importance for each load type. The comprehensive sensitivity can be assessed as follow:

$$S = \lambda_1 \times \sum_{i=1}^{n} \frac{C_i \times \alpha_i}{C} + \lambda_2 \times \sum_{i=1}^{n} \frac{C_i \times \beta_i}{C} + \lambda_3 \times C' \qquad (1)$$

Where n is type number of sensitive load. i is the identifier of sensitive load types. C_i is the capacity of load type i. C is the total capacity of the customer's sensitive load. $\lambda_1, \lambda_2, \lambda_3$ are the weights of load sensitivity, load importance, and load capacity, which meet the condition $\lambda_1 + \lambda_2 + \lambda_3 = 1$. Based on the experience from sufficient experiments, we believe λ_1=0.6, λ_2=0.25, λ_3=0.15 are reasonable weights. α_i is sensitivity score (0-100) of load type i, and β_i is importance score (0-100) of load type i. C' is the relative total capacity of power customer, which can be calculated as formula (2)。

$$C' = \begin{cases} 100 & C > 5000\text{kVA} \\ \dfrac{C}{5000} \times 100 & C \le 5000\text{kVA} \end{cases} \qquad (2)$$

Eventually, we get the value of S as the comprehensive sensitivity score of target power customer.

IV. POWER EXPERIENCE ASSESSMENT MODEL

A. The Characteristics of Power Expeirence

To some extent, quality of power service is dependent on the customers' experience. Because some customers are more sensitive than others, the same objective quality of power supply will result in different levels of power experience. Quality of power experience cannot always be determined quantitatively, but any companies hope to maximize their quality of power experience. Some subjective result about power experience can be achieved by customers' polls or sampling surveys, but our study is still hoping to extract some quantifiable characteristics. We extract many quantitative characteristics that may affect the power experience, and believe the customer sensitivity is the most important indicator. The assessment indicator should also include the number of complaints as well as the customer's subjective experience.

B. The Assessment Model of Power Expeirence

Existing assessment model of power quality is mainly based on the objective quality of power supply. We judge whether the power quality is good or bad through the grid voltage, current, steady-state and transient-state aspects of quantitative indicators. For example, for the voltage sag disturbance, the power provider only monitored the number of voltage sag as evaluation criteria. However, in the practical application, the quality of power supply more depends on the on the power experience and the load sensitivity. Therefore, this paper established an assessment model to evaluate the quality of power service in perspective of power experience, which also considered both the existing power quality standards and customer relevant information.

The assessment model of power experience include two sorts of indicators: power supply part and customer part. The indicators of customer part mainly contains the customer complaints times, customer load sensitivity and customer experience investigation.

1) The customer complaints times (count as M): refers to measure the customer complaint times caused by the power quality disturbance.

2) The comprehensive sensitivity of power customers (count as S): refers to evaluate the sensitivity scores through the formula (1). When the power quality disturbances happen, the customer with higher sensitivity indicates more possibility to breakdown.

3) The investigation score of customer experience (count as P): investigate the dissatisfaction degree and economic losses caused by power quality disturbance in a period of time, and get the subjective experience score(1%~100%) of target customer. For this indicators, A higher investigation score means a worse power experience.

TABLE III. . THE COMPARISON OF POWER QUALITY ASSESSMENT AND POWER EXPERIENCE ASSESSMENT

Assessment Model	Assessment Indicators	Wight of Indicators	Assessment Score
Quality of Power Supply	Voltage Sag Times (N)	100%	N'
Power Experience	Voltage Sag Times (N)	λ_N	$E = \lambda_N \times N' \times S + \lambda_M \times M' + \lambda_P \times P$ Where, $\lambda_N + \lambda_M + \lambda_P$ =100%
	Customer Complaints Times (M)	λ_M	
	Comprehensive Sensitivity of Customer (S)		

	Investigation Score of Customer Experience (P)	λ_P	

Taking voltage sags disturbance for example, table 3 shows the comparison of power quality assessment model and power experience assessment model about their indicators and assessment methods. In order to easily compare assessment results of different customers, we normalized the voltage sag times and the user complaints times as formula (3).

$$N' = \frac{N - N_{\min}}{N_{\max} - N_{\min}}$$
$$M' = \frac{M - M_{\min}}{M_{\max} - M_{\min}} \quad (3)$$

Where $N_{\max}$ and $N_{\min}$ represent the maximum and minimum value of voltage sag times in the statistical period. $M_{\max}$ and $M_{\min}$ represent the maximum and minimum value of customer complaint times in the statistical period.

The indicators used for power experience assessment are listed in table 3. The detailed method to calculate the scores of the power experience is as follow:

$$E = \lambda_N \times N' \times S + \lambda_M \times M' + \lambda_P \times P \quad (4)$$

In this assessment formula, the value of λ_N , λ_M and λ_P represent the importance of indicators in assessment model, such as quality of power supply, customer complaints times and investigation score of customer experience. It should be noted that the sensitivity of customer determines the affection degree by the power quality disturbance. Thus, we use $N' \times S$ to represent the influence caused by the voltage sag, not only considering the indicator of voltage sag times, but also taking the sensitivity degree indicator into account.

V. CONCLUSION

This paper presented a new concept called power experience to indicate and evaluate the quality of power service. The basic characteristics of power experience were also summarized. We established an assessment model to evaluate the power experience by integrating the existing power quality indicators and customer relevant indicators, as well as a utility function to calculate the assessment result. The result of customer investigation and analysis showed that the power experience is a suitable model to indicate the quality of power service, which can reflect the actual impact of power quality disturbance more accurately.

Therefore, the combination of power supply monitoring data and customer analysis information, power experience assessment model fully considered both the power provider and power consumer, which is a significant guidance in practical applications of power market. The future work focus on abstracting new indicators related to the power experience, such as the internal electric connections and environmental factors of customers, in order to constantly improve and perfect the power quality assessment model.

ACKNOWLEDGMENT

This work is supported by the National 973 Basic Research Program of China (2013CB228206), National Natural Science Foundation of China (61233016), and China Southern Power Grid R&D project (K-SZ2012-026).

REFERENCES

[1] Han Yingduo, Yan Gangui, Jiang Qirong, M. C. Wong. Electric power in information society and facts & dfacts[J]. Automation of electric power systems, 2000. 24(19): 1-7.

[2] H. He and J. A. Starzyk. A self-organizing learning array system for power quality classification based onwavelet transform. IEEE Trans. Power Del, 2006, 1(21): 286-295.

[3] M. A. S. Masoum , S. Jamali and N. Ghaffarzadeh "Detection and classification of power quality disturbances using discretewavelet transform and wavelet networks", IET Sci. Meas. Technol, 2010, 4(4): 193-205.

[4] George J Wakilehz. Power system harmonics [M]. Beijing: Industry of Machine Press, 2003.

[5] A. Thapar , T. K. Saha and Y. D. Zhao Investigation of power quality categorization and simulating its impact on sensitive electronic equipment[J]. Proc. IEEE Power Eng. Soc. Gen. Meeting, 2004: 528-533.

[6] M. R. Banaei , S. H. Hosseini and M. D. Khajee. Mitigation of voltage sag using adaptive neural network with dynamic voltage restorer, Proc. 5th Int. CES/IEEE Power Electronics and Motion Control Conf., 2006: 1-5.

[7] A. Salarvand, B. Mirzaeian, M. Moallem. Obtaining a quantitative index for power quality evaluation in competitive electricity market. IET Journal, Generation Transmission and Distribution, 2010, 7(4): 810-823.

[8] Mei Liang, Yongqiang Liu. A New Method on Power Quality Comprehensive Evaluation [C]. The Ninth International Conference on Electronic Measurement and Instruments (ICEMI), 2009: 1057-1060.

[9] JIANG H, PENG J C, OU Y p, LI Z J. Power quality unitary quantification and evaluation based on probability and bector algebra [J]. Journal of Hunan University, 2003, (30)1: 66-70。

[10] HUANG J, ZHOU L, JIA Q H. Evaluation of power quality based on the method of matter-element [J]. Journal of Chongqing University, 2007, 30(6)

[11] S. Z. Djokic, l. Desmet, G. Vanalme, J. V. Milanovic, and K. Stockman. Sensitivity of personal computers to voltage sags and short interruptions, IEEE Trans. Power Del., 2005, 20: 375-383.

[12] J. Barros and R. I. Diego. Measuring voltage tolerance of equipment under practical conditions. Proc. IASTED Int. Conf. Power Energy Systems, 2002: 289 -293.