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An Improved Power Quality Evaluation for LED Lamp Based on G1-Entropy Method

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ABSTRACT Nowadays, light emitting diode (LED) lamps have been widely utilized for lighting system due to its low-energy consumption. The harmonic emission standard is ignored by most of the manufacturers, high harmonic current will increase harmonic injection and cause fire risk. Existing research focuses on investigating harmonic emissions from several specific LED drivers, but a systematic evaluation approach is not given. The contribution of this paper proposed a LED harmonic evaluation in the management view, which can evaluate the harmonics of the LED lamps, accelerate the elimination of inferior LED lamps, and improve the power quality of distribution network. The evaluation approach combines G1 method and entropy method, which can make the weighting more scientific and rational. An evaluation model is established by collecting data, then the G1-entropy method is used to calculate the weights of harmonic characteristics in this model. Finally, we analyze and discuss the results, a specific evaluation approach is proposed, which can thoroughly and accurately represent the harmonic characteristics of LED lamps.

INDEX TERMS Power quality, evaluation approach, light-emitting diode lamp, sequential analysis method, entropy weighting method.

I. INTRODUCTION

With the exponential growth of population and economy, energy demand is rising, and countries are confronted with massive energy challenges. Building construction sector consumes the most energy and emits the most greenhouse gases [1]. According to the International Energy Agency (IEA) [2], Housing and its construction industry account for about one third of the world's electricity demand and about 40% of gross carbon dioxide (CO_2) emissions. United Nations Environment Program (UNEP) statistics also show that more than 40% of electricity is used by residential and business properties [3], [4]. China has therefore taken steps in the direction of peak CO_2 emissions by 2030 and is striving to achieve this target more quickly [5], [6]. Using energy-saving methods and improving energy efficiency in buildings is one means of improving the energy situation [7].

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The proper use of lamps in buildings is an extremely efficient way to increase energy efficiency. That is due to the fact that lighting systems use a significant amount of energy, accounting for about 20%-30% of overall building electricity usage [8]. Energy conservation in lighting systems has been the primary task for building users. Hence, many countries and regions have built and adopted lighting energy efficient policies to encourage the use of LED lamps. LED lamps have distinct benefits over other conventional lighting equipment due to their peculiar physical arrangement, electrical, and optical properties, e.g., 1) energy efficiency; 2) long life; 3) quick launch; and 4) environmental friendliness, free of harmful elements such as Pb and Hg. LED lights are widely used in residential, commercial and other places. The number of LED lamps has grown substantially. As shown in Fig. 1, LED lamps are gradually replacing incandescent lamps (ILs) and compact fluorescent lamps (CFLs) [9], with their share of the lighting market growing from 5% in 2013 to nearly half in 2019 [10].

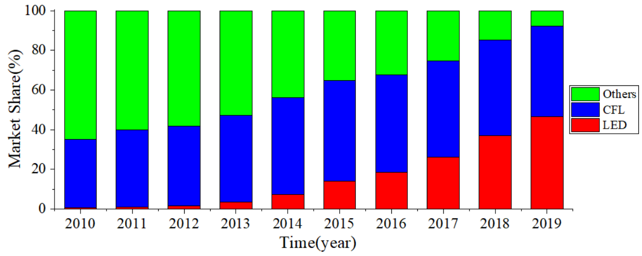

FIGURE 1. Market share of various lamp categories.

Although LED lights have some advantages, the harmonic injection caused by switching devices inside of LED lamps should be considered. Harmonic is a major threat to the entire power grid, which is decreasing system reliability and potentially causing fires [11], [12]. Therefore, harmonic emissions of LED lamps must be investigated to prevent damaging the building electrical grid and other facilities. Research on the harmonic emission of LED lamps can be classified as follows: (1) measuring the harmonic characteristics of various brands of LED lamps; (2) modeling the harmonic emission of LED lamps; and (3) simulating the harmonics of grouped LED lamps in a fixed region. The following three paragraphs are introduced separately.

Over the past two or three decades, the variety and number of LED lamps has grown dramatically. Harmonic tests on local LED lamps are carried out by academics from various countries and regions. Some research [13]–[17] investigated the harmonic emissions of different LED lamps available on the market in Turkey, Sweden, Spain, Indonesia, Romania and China. They show that harmonic amplitudes and phase vary due to the different manufacturing processes of low-power LED lamps and the wide variety of drivers, and the harmonic distortion rates are distributed over a wide range (5%-175%). The harmonics of most LED lamps surpassed the IEC harmonic normal limits. In addition, the effects of various influences on the harmonic emission were discovered, such as supply voltage [18]–[20], lamp brand [21], whether dimming [22], and so on.

Existing LED harmonic models can be classified into time domain models and frequency domain models. A circuit representation is typically used in the time-domain model. The benefit of this model is that it can be used specifically to evaluate current harmonic distortion under various conditions. The design method is not systematic due to the diversity of drivers [23], and due to the secrecy of the manufacturer's patents, existing experiments are difficult to access the internal circuits of the test lamps and therefore cannot apply circuit theory for calculating harmonic current projection. As a result, much of the research has been done using generalized circuit models [24], such as bridge rectifier circuit. The frequency domain model is a black box modeling approach, and the Norton model is widely used because of its simplicity [25]. It has been used to research the harmonic characteristics of lighting systems in [25] and [26]. Both models to lamp simulation have benefits and have been extensively used in previous research.

The investigation of the integrated use of nonlinear load harmonics has emerged as a hot subject of current research around the world. In existing studies, a typical method is to use different simulation tools to first create a model of an individual luminaire, and then use that model to build the entire lighting system or distribution network to see if the line harmonics surpass the limit value. The effect of LED lamps mass access was calculated in [27] by varying the scaling factor in Easy Power software to model three cases of 100, 200, and 300 bulbs, respectively. This research mentioned that if all LED lamps are associated in such amounts, it is possible to surpass the IEEE standard. Similarly, the results of [28] show that when 80% of the incandescent lamps were replaced with LED lamps, the voltage distortion can reach the 8% limit in IEC standard. From the results of existing studies, the use of LED lamps in large quantities may still make the line exceed the limit, and cause a greater fire hazard.

The above studies have investigated the harmonic issues of LED lamps from different perspectives, all of which are valuable and worth learning. They reflect that numerous manufacturers in the global lighting industry are focused on the economics and do not grasp the harmonic characteristics of the lamps, ignoring the harmonic emission requirements that these energy-saving lamps can follow [29]. In addition, there is a lack of design specifications for LED drivers making the variety of drivers unrestricted and difficult to manage [23] These issues need a systematic evaluation approach of LED lamps harmonic that can accurately and comprehensively evaluate and provide the corresponding comparison scores to show the harmonic characteristics of LED lamps. However, there is few study on it [15], [30]. Hence, from the perspective of harmonic management, this paper proposed a harmonic evaluation approach for LED lamps based on G1-entropy method. The approach can evaluate the harmonic emission of LED lamps and thereby accelerate the elimination of inferior lamps, and reduce the fire risk.

The paper is organized as follows. The scheme for evaluating harmonic features is defined in Section II. Section III describes how the evaluation approach works, including the G1 method and entropy method. Section IV sets up a research platform and performs harmonic experiments on 58 different kinds of LED lamps. The evaluation technique is used to determine the harmonic properties of the lamps. The findings are discussed in Section V. Section VI summarizes the whole paper and shows the course of implementation.

II. EVALUATION APPROACH

Traditional weight calculation method are mostly split into arbitrary and quantitative assignments [31], [32]. While the subjective evaluation approach is inherently subjective and closely linked to the evaluator's information structure, job history, and desires, the overall procedure is less straightforward and repeatable [33]. The analytical assignment method

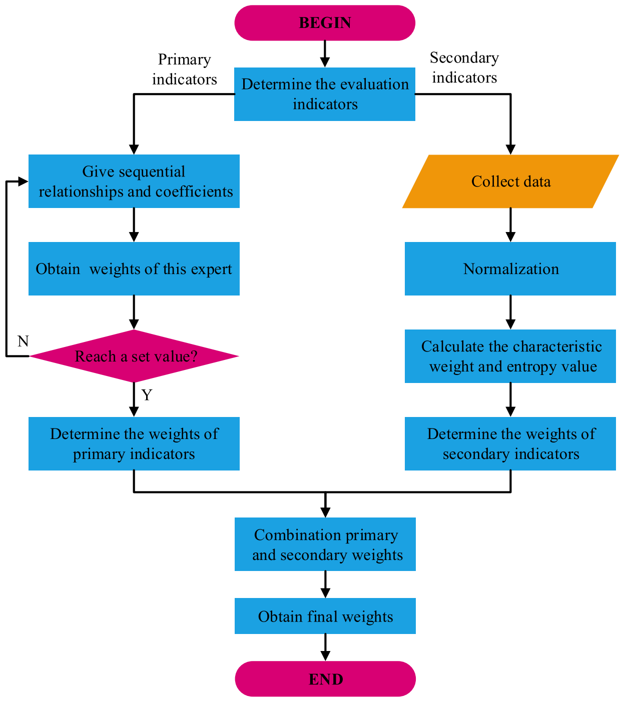

FIGURE 2. **Diagram illustration of technology.**

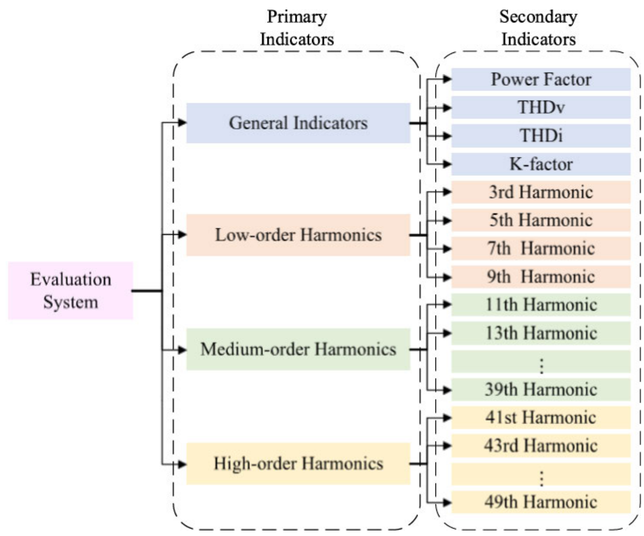

FIGURE 3. **LED lamp harmonic evaluation approach.**

is based on the knowledge discrepancy between data, which eliminates the effect of discretionary factors. However, it is difficult to represent the actual applicability of metrics, and it is often outside of objective truth. Therefore, this paper combines two ways to form a systematic stepwise assignment process. The mixed weighting method incorporates the benefits of both discretionary and quantitative weighting. It is capable of obtaining fair indicators weights [34], [35]. First, two-level evaluation indicators are calculated. Second, the primary indicators are allocated subjectively using the sequential relationship analysis method of group judgment improvement, and the secondary indicators is assigned objectively via the entropy weighting process. Finally, the primary and secondary weights are combined to yield the final weights. Fig. 2 depicts the technical path of this article.

The relevant domestic and international harmonic emission standards is combined based on the current situation of LED lamp harmonics. Finally, four primary indicators (general indicators, low-order harmonics, medium-order harmonics, and high-order harmonics), as well as 28 secondary indicators, were defined to form a comprehensive evaluation indicators framework that accurately represents the level of harmonic emission of lighting devices. Fig. 3 depicts the harmonic emission evaluation indicators scheme of energy-saving lamps proposed in this paper.

A. GENERAL INDICATORS

Power factor (PF), total voltage harmonic distortion (THDv), total current harmonic distortion (THDi), and K-factor are general indicators that offer details for each harmonic and can more comprehensively reflect the harmonic characteristics of the lamp and the overall harmonic state of the circuit than other indicators.

THDv and THDi explain the distortion between the voltage and current waveforms and the sinusoidal waveform, respectively, and are valuable indicators for measuring the power efficiency of LED lamps. THDi is defined as the ratio of the RMS value of the fundamental current to the 2nd to 40th harmonic current components, as in (1). PF is also a significant predictor to represent the appliance's harmonics. Equation (2) expresses its relationship with THDi, where $\cos\varphi$ is the phase angle difference between voltage and current. Harmonics can be reduced by increasing the power factor. In addition, the K-factor shows the maximum amount of harmonic currents that can be tolerated when the fundamental current equals the rated load current [36].

$$\mathrm{THD_i} = \sqrt{\sum_{\mathrm{h}=2}^{40}\left(\frac{I_{\mathrm{h}}}{I_1}\right)^2} \tag{1}$$

$$\mathrm{PF} = \frac{1}{\sqrt{1+(\mathrm{THD_i})}}\cos\varphi \tag{2}$$

B. OTHER INDICATORS

The distinction of low-order, medium-order, and high-order harmonics in Fig. 3 is based on Class C equipment limits specified in IEC61000-3-2, the 3rd-9th, the 11th-39th harmonic, and the high-order harmonic.

1) 3RD-9TH HARMONIC

These harmonics, which have a high amplitude and a broad distribution, are the most dangerous harmonics in the power grid. They are a major source of power line fires and are often discussed in harmonic management. The 3rd harmonic occupancy rate of some LED lights on the market exceeds 80%.

2) 11TH-39TH HARMONICS

These harmonics have a modest amplitude and a harmonic occupancy of around 10%, making them less dangerous than the 3rd-9th harmonics. However, because of their sheer numbers, the energy demand they generate should not be underestimated.

3) HIGHER HARMONICS

The main cause of such harmonics is LED lamps. They will disrupt the normal operation of electrical equipment, cause equipment malfunction, increase noise at the equipment, and disrupt carrier communications. Nowadays, international knowledge of super harmonics is still limited, applicable standards are lacking, and study in related fields in China is in its infancy. As a result, using those harmonics in the LED lamp harmonic assessment scheme is critical and meaningful.

III. EVALUATION METHODS

A. G1 METHOD

G1 weight assignment method was developed to overcome the shortcomings of the hierarchical analysis (AHP) method. As compared to AHP, G1 method is simpler to quantify and does not require accuracy checking. The estimation time is also small [34], [37]. It works under the following principle: for two evaluated indicators x_1 and x_2, the experts assess the importance of x_1 and x_2, and if the importance of x_1 is greater than x_2, then it is noted as "$x_1 > x_2$". Assume there is a set $X = \{x_1, x_2, \ldots, x_m\}$ that contains m evaluation indicators. According to the preceding principle, the unique set of sequential relations for this expert decision can be obtained, provided that the sequential relations are compatible with (3).

$$x_1 > x_2 > \cdots > x_m \tag{3}$$

The importance level between adjacent indicators can be expressed by (4).

$$r_k = w_{k-1}/w_k \tag{4}$$

where w_k denotes the weight of x_k and the weight of indicator x_{k-1} for w_{k-1}. Tab. 1 shows the meaning of r_k. Then, the weights of evaluation indicators determined by this expert can be calculated by (5) and (6).

$$p_m = \left(1 + \sum_{k=2}^{m} \prod_{i=k}^{m} r_i\right)^{-1} \tag{5}$$

$$p_{k-1} = r_k p_k \tag{6}$$

Since the weights obtained by the standard G1 method are determined by only one specialist, they are more affected by their influence. As a result, this paper incorporates group decision-making theory for improvement, and two (or more) experts are asked to decide weights. The weights determined by each expert are measured first, and the average value is used as the method's final weight.

TABLE 1. Diagram of an example.

r_k	Description
r_k =1.0	x_{k-1} is as important as x_k
1.0< r_k <=1.2	x_{k-1} is slightly more important than x_k
1.2< r_k <=1.4	x_{k-1} is significantly more important than x_k
1.4< r_k <=1.6	x_{k-1} is strongly more important than x_k
1.6< r_k <=1.8	x_{k-1} is more extremely important than x_k
1.8< r_k <=2.0	x_{k-1} is extremely important than x_k (More than the previous level)

B. ENTROPY METHOD

Entropy is a function that describes the state of a system and illustrates the system's development mechanism and hierarchy. The higher the entropy value, the less knowledge the machine possesses and the lower the indicator weight [38]. In contrast, the more deterministic the system, the more detail available and the higher the predictor weight. The entropy method is an objective weighting method [38] that uses the actual data of the collected indicators to determine the weight of the evaluation indicators [39], [40]. The entropy weighting method is used in this paper to apply weights to secondary indices of harmonic evaluation, and the basic measures are as follows.

(1) Collect the harmonic evaluation data of LED lamps.

(2) Normalization. Since the magnitudes of the indicators are different from each other, they are first de-normalized. The positive and negative indicators were normalized separately according to (7) and (8). To prevent invalid value of characteristic weight, the normalization method was improved and normalized to 0.001-0.999.

$$R_{ij} = \frac{x_{ij} - x_{min}}{x_{max} - x_{min}} \tag{7}$$

$$R_{ij} = -\frac{x_{ij} - x_{min}}{x_{max} - x_{min}} \tag{8}$$

x_{max} denotes the maximum value in each category of evaluation data, and x_{min} denotes the minimum value; x_{ij} denotes the *i* th data in each *j* category of evaluation data; R_{ij} denotes the result after normalization of this data.

(3) Calculate the characteristic weight as (9).

$$t_{ij} = x_{ij} / \sum_{i=1}^{n} x_{ij} \tag{9}$$

where t_{ij} denotes the characteristic weight of the *i* th system in the *j* th evaluation indicators.

(4) Calculate the entropy value.

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} t_{ij} \ln\left(t_{ij}\right) \tag{10}$$

where e_j denotes the entropy value of the *j* th evaluation indicators.

(5) Calculation of the coefficient of variability g_j for the *j* th evaluation indicator.

$$g_j = 1 - e_j \tag{11}$$

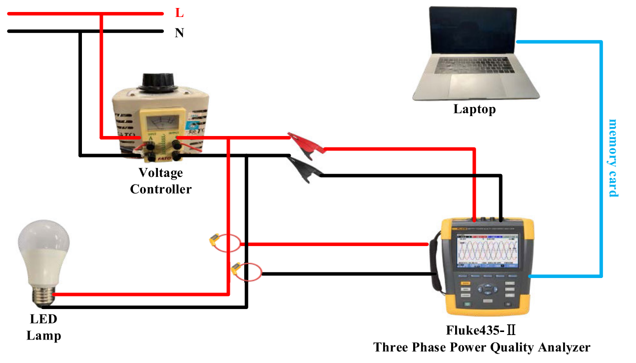

FIGURE 4. Test circuit schematic.

(6) Obtain the weight q_j of the j th evaluation indicator.

$$q_j = g_j / \sum_{i=1}^{n} g_i \tag{12}$$

C. DETERMINATION OF INTEGRATED WEIGHTS

Assuming that the above method obtains the set of primary indicator weights denoted as $P = (p_1, p_2, \ldots, p_m)$ and the set of secondary indicator weights under i th primary indicator denoted as $Q = (q_{i1}, q_{i2}, \ldots, q_{in})$, the harmonic assessment score of this LED lamp can be calculated by (13).

$$y = 100 * \sum_{i=1}^{m} p_i * \left(\sum_{i=1}^{n} q_{ij} x_{ij} \right) \tag{13}$$

IV. EVALUATION PROCESS

A. COLLECTION OF EVALUATION DATA

LED lamps are commonly available in a variety of brands. Various manufactures use various circuit designs and manufacturing techniques. In order to make the findings more generalizable, 58 LED lamps from 12 different brands were chosen for harmonic calculation in the sample (see the Appendix A). Fig. 4 depicts the experimental circuit, which includes a voltage controller, a FLUKE435-II three-phase power rating analyzer, a current clamp, research LED lamps, and a monitor for data analysis. During the inspection, the voltage controller ensures that the lamp's voltage remains constant at 219.5-220.5V. The FLUKE435-II is used to measure the current, voltage, and amplitude of each harmonic current, phase, current distortion rate, K-factor, and other associated measures of the circuit in which the lamp is situated. The collected data would be exported and processed on the computer using Power Log and MATLAB tools. To prevent interference from unanticipated causes, each lamp will be uniformly pre-heated for 30 minutes prior to the measurement [19].

Fig. 5 shows the trend of the odd harmonic current inclusion rate of some LED lamps. Fig. 6 shows the measured lamp current harmonic distortion rate THDi. Among them, the harmonic emission limits of the lamps with rated power below 25W should meet the following requirements:

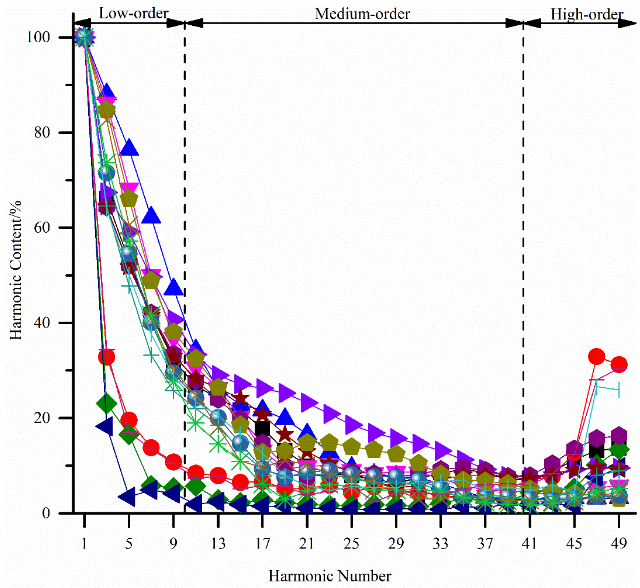

FIGURE 5. Harmonic content of partial lamps.

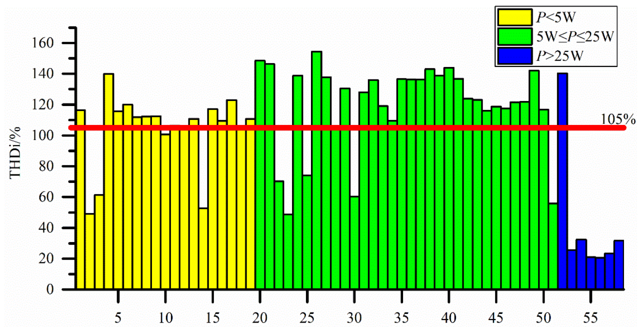

FIGURE 6. THDi of the measured lamps.

TABLE 2. Order relation and importance indicators.

No.	Relationship	r_2	r_3	r_4
Expert 1	$p_1 > p_2 > p_4 > p_3$	1.1	1.6	1.4
Expert 2	$p_1 > p_2 > p_3 > p_4$	1.5	1.3	1.1

the 3rd harmonic current should not exceed 86% of the fundamental wave, while the 5th harmonic should not exceed 61%, i.e., the total harmonic distortion of the current should not exceed 105%. However, it can be seen from Fig. 5 that most of the lamps are difficult to meet the requirement of 105%.

The harmonic data collected in the experiment is brought into the entropy weight method for calculation. The weight of secondary evaluation index can be obtained, as shown in Tab. 4. After obtaining the primary and secondary indicators, the harmonic evaluation scores of LED lamps at different power ratings can be derived according to (13). Tab. 5, Tab. 6, and Tab. 7 respectively show the power quality scores of LED lamps with P <5W, 5W≤ P ≤25W and P >25W under the evaluation criteria proposed in this paper.

TABLE 3. Primary indicators weight coefficient.

No.	P_1	P_2	P_3	P_4
Expert 1	0.3468	0.3153	0.1408	0.1971
Expert 2	0.4157	0.2772	0.1938	0.1762
Results	0.3813	0.2963	0.1673	0.1867

TABLE 4. Weight coefficient of subsystem secondary indicators.

No.	Primary indicators weights	Secondary indicators weights	
General Indicators	p_1=0.3813	q_{11}=0.2178	q_{12}=0.2427
		q_{13}=0.1966	q_{14}=0.3429
Low-order harmonics	p_2=0.2963	q_{21}=0.1768	q_{22}=0.2613
		q_{23}=0.2670	q_{24}=0.2949
Medium-order harmonics	p_3=0.1673	q_{31}=0.0460	q_{32}=0.0524
		q_{33}=0.0548	q_{34}=0.0684
		q_{35}=0.0739	q_{36}=0.0782
		q_{37}=0.0752	q_{38}=0.0685
		q_{39}=0.0711	q_{310}=0.0666
		q_{311}=0.0714	q_{312}=0.0889
		q_{313}=0.0717	q_{314}=0.0616
		q_{315}=0.0512	
High-order harmonics	p_4=0.1867	q_{41}=0.1713	q_{42}=0.1517
		q_{43}=0.2125	q_{44}=0.2385
		q_{45}=0.2260	

V. DISCUSSION

The lamp harmonic emission is rated according to the magnitude of the evaluation value and is divided into six grades, as in Tab. 8. The larger the evaluation value, the higher the level of harmonic emission of the lamp, i.e., the more harmonics injected into the grid by the lamp. From the evaluation results, B30-fan has the least harmonic emission, and B80-fan has the second-highest evaluation value of 0.1886 and 0.4418, respectively, both of which are grade I. C3 has the highest evaluation value and the most harmonic emission, which is grade IV. However, in terms of local evaluation, these more than 50 lamps have their advantages and defects. For example, B3-2 has a very low scores of low-orders and middle-orders harmonics, while the scores of high-orders harmonics is relatively high.

A. EVALUATION LEVEL AND RATED POWER

Fig. 7 illustrates the distribution between the evaluation value and the power of the lamp. According to IEC61000-3-2:2018, lighting equipment is divided into three categories according to rated power to specify harmonic limits, respectively $P<5$W, 5W$\leq P\leq$25W, $P>$25W. The analysis is as follows.

(1) $P<5$W: harmonic rating values are distributed between 1.4 and 3.1 in the grade III to grade VI. It shows that the lamps and lanterns with $P<5$W often use relatively backward technology and process, which makes more harmonic emission. However, since this type of lamp does not present much of a problem in small quantities due to its small current, but the impact of its mixed-use with other harmonic sources on the distribution network is worth exploring. Besides, the study species also found that this type of LED lamp dominates in the high harmonic emission, and this part of the score also tends to be higher than the other two types of lamps.

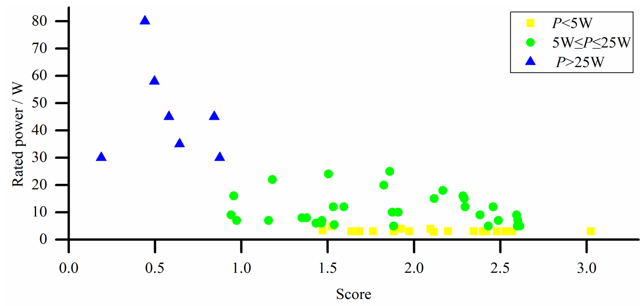

FIGURE 7. Assessed value and rated power.

(2) 5W$\leq P\leq$25W: The evaluation value of this type of lamp has a wider distribution, between grade II and grade VI. It indicates that they have a wider choice of drive circuits. The research found that this category of lamps has the drive circuits the same as those in the $P<5$W lamps. Some introduce the PFC drive circuit, which is often related to the manufacturer and price. In 5W$\leq P\leq$ 25W lamps and lanterns drive circuit is mixed, still lacking a certain limit value standard. This part can be used as a supplement to the focus of domestic and international standards.

(3) $P>$25W: Such lamps tend to have a lower evaluation value, and harmonic emission is lower, which is closely related to the IEC regulations on the one hand and the use scenario of such lamps. Commonly used in factories, venues, street lights, and other commercial scenarios to achieve good reliability, the cost is also generally relatively high, using more advanced technology.

B. EVALUATION LEVEL AND HARMONIC PHASE

In a sense, the harmonics phase can reflect the type of drive circuit inside the lamp. Fig. 8 shows the phase distribution of the third harmonic of the measured lamp. The third harmonic amplitude of the measured lamp is scattered in the first, third, and fourth quadrants. The harmonic values of different quadrants are shown in Tab. 9, according to which the range of harmonic values varies in these three quadrants, with average values of 1.8563, 1.9049, and 0.4696, respectively. Compare with the findings of [41], and it is found that the first and third quadrants of the lamp are using constant buck current and resistive buck driver circuits, while the fourth quadrant represents the use of PFC technology for LED lamps. The lamp using PFC technology has a substantial advantage both in the score and in gear, and the technology has a good contribution to the improvement of the power quality of LED lamps. It also verifies the feasibility of the harmonic evaluation approach of LED lamps proposed in this paper from the side.

TABLE 5. Evaluation result of lamps (rated power <5w).

Trade Name	Score	Trade Name	Score	Trade Name	Score	Trade Name	Score
C3	3.0239	E3-2	2.3968	B3-2	1.9711	B3-1	1.6844
J3	2.5695	A3	2.3443	F4	1.9238	F3	1.6368
D3	2.5276	F3-1	2.1965	H3	1.9135	I4.8	1.5249
E3-3	2.4793	I2.8	2.1131	K3	1.8823	G3.3	1.4694
E3-1	2.4185	I4	2.0958	F3-2	1.7615		

TABLE 6. Evaluation result of lamps (5W≤ rated power ≤25W).

Trade Name	Score	Trade Name	Score	Trade Name	Score	Trade Name	Score
B5-2	2.6123	E12-2	2.2953	B25	1.8598	F6-1	1.4324
E7-2	2.6011	E15-1	2.2909	B20	1.8248	F8-1	1.3776
B5-1	2.5982	B16-2	2.2842	F12-1	1.5927	F8-2	1.3511
E9-2	2.5938	B18	2.1663	G5.5	1.5384	B22	1.1785
E7-1	2.4876	E15-2	2.1159	F12-2	1.5328	B7-2	1.1579
E12-1	2.4586	B10-1	1.9089	B24	1.5041	H9	0.9740
E5-2	2.4299	E5-1	1.8814	F7-2	1.4663	B7-1	0.9725
E9-1	2.3821	B10-2	1.8740	F6-2	1.4629	B16	0.9559

TABLE 7. Evaluation result of lamps (rated power >25W).

Trade Name	Score	Trade Name	Score	Trade Name	Score	Trade Name	Score
B30	0.8741	B35-fan	0.6415	B58-fan	0.4956	B30-fan	0.1886
B45	0.8428	B45-fan	0.5806	B80-fan	0.4418		

TABLE 8. Grading standard.

Score	Grade
0.1≤y<0.6	I
0.6≤y<1.1	II
1.1≤y<1.6	III
1.6≤y<2.1	IV
2.1≤y<2.6	V
2.6≤y	VI

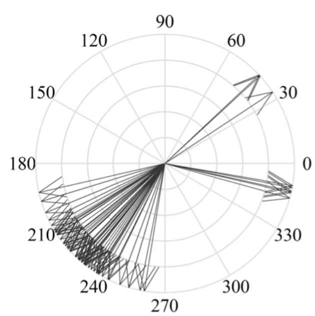

FIGURE 8. Phase of the measured lamps.

C. COMPARISON WITH OTHER APPROACH

In this section, the evaluation approach proposed in this paper is compared with the existing approach mentioned in [15] to check the validity degree. In [15], the power quality of LED lamps is evaluated from two aspects: grouping and labeling. However, the groups do not consider the classification of power in IEC61000-3-2 and the labels only considers two indicators (THDi and PF). Compared with the existing approach, the proposed approach analyzes three groups (P <5W, 5W≤ P ≤25W, P >25W) and it is consistent with IEC61000-3-2, so the proposed approach is more practicable and easy to apply. In addition, our approach considers two more indicators than the existing approach, the low-order harmonic and the high-order harmonic. The former makes the wire hot, and may break out of fire, and the latter is the main cause of electromagnetic interference. Meanwhile, the addition of these indicators allows the model to reflect the harmonic characteristics of LED lamps more comprehensively.

TABLE 9. Harmonic evaluation values of different quadrants.

Quadrant	Average score	Ranges
First quadrant	1.8563	1.6844-1.9135
Third quadrants	1.9049	0.8428-3.0239
Fourth quadrants	0.4696	0.1886-0.6415

There are still some improvements and shortcomings in this study. First, due to the objective conditions, only 41st-49th superharmonics of LED lamps were collected.

TABLE 10. Information of measured lamps.

Trade Name	Rated Power(W)	Description (CCT, or other)	Trade Name	Rated Power(W)	Description (CCT, or other)	Trade Name	Rated Power(W)	Description (CCT, or other)
A3	3	6500K	B45-fan	45	6500K/With fan	F3-2	3	6500K
B3-1	3	3000K	B58-fan	58	6500K/With fan	F4	4	6500K
B3-2	3	6500K	B80-fan	80	6500K/With fan	F6-1	6	4000K
B5-1	5	3000K	C3	3	-	F6-2	6	6500K
B5-2	5	6500K	D3	3	-	F7.5	7	3000/4500/6500K
B7-1	7	3000K	E3-1	3	3000K	F8-1	8	4000K
B7-2	7	6500K	E3-2	3	4000K	F8-2	8	6500K
B10-1	10	3000K	E3-3	3	6500K	F12-1	12	4000K
B10-2	10	6500K	E5-1	5	3000K	F12-2	12	6500K
B16-1	16	6500K	E5-2	5	6500K	G3.3	3.3	6500K
B16-2	16	6500K	E7-1	7	3000K	G5.5	5.5	2700K
B18	18	6500K	E7-2	7	6500K	H3	3	6500K
B20	20	6500K	E9-1	9	3000K	H9	9	4000K
B22	22	6500K	E9-2	9	6500K	I2.8	2.8	6500K
B24	24	6500K	E12-1	12	3000K	I4	4	6500K
B25	25	6500K	E12-2	12	6500K	I4.8	4.8	6500K
B30-1	30	6500K	E15-1	15	3000K	J3	3	-
B30-2	30	6500K	E15-2	15	6500K	K3	3	6500K
B35-fan	35	6500K/With fan	F3	3	5700K			
B45	45	6500K	F3-1	3	4000K			

When constructing the evaluation model using the proposed approach in the future, if the 2-150kHz harmonics of LED lamps can be collected, it will make the model more comprehensive and reflect more comprehensive characteristics. Second, it is necessary to increase the number of lamps involved in the test and collect the harmonic data from lamps of different drivers to obtain more reasonable and scientific weights. The evaluation method can be extended to different types of small commercial applications to reduce harmonic emissions.

VI. CONCLUSION

In this paper, a harmonic evaluation approach of LED lamps is proposed using the G1-entropy method. The subjective weights for four primary evaluation indicators are assigned using the G1 group method, and the objective weights for 28 secondary indicators are assigned using the entropy weight method. The combination of the two methods yields more rational and empirical weights. The proposed evaluation approach was used as an example to validate the test results of 58 LED lamps. The results indicate that the score is closely related to power and harmonic phase. The harmonic emission of low-power lamps is often more than that of high-power lamps. Meanwhile, the harmonic characteristics of various power LED lamps is compared at the same level. The proposed approach can improve the structure of LED lamp driver, decrease grid harmonics, and reduce harmonic fires.

APPENDIX

The technical data of the test lamps are shown in Tab. 10.

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