# A UNIFIED INDEX AND SYSTEM INDICATOR FOR GLOBAL POWER QUALITY ASSESSMENT

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***ABSTRACT****— In this paper, Global Power Quality Indices are discussed. A group of Global PQ indices are based on the traditional individual indices. Unified Power Quality Index (UPQI) and System Indicators characterize the overall voltage and current quality of a single load point and also the entire network. A modification is proposed for the UPQI index in order to integrate and evaluate the disturbances more thoroughly. Furthermore, a series of System Indicators are presented which represent the global status of the system for each disturbance. The proposed indices are then calculated for the measurement data recorded at a number of load points of a test power system. Various indices are compared and the results of the proposed approaches are interpreted and verified.*

**Keywords**— Power Quality, individual PQ indices, unified PQ indices, system indicators.

## 1. INTRODUCTION

**A**s the electric power system expands, more concern grows about the reliability, security, and power quality of the supply system. Power quality (PQ) is capturing more attention due to the expansion of power electronics devices and other nonlinear loads, and also the proliferation of electronics loads which are sensitive to PQ disturbances. In liberalized electricity market power quality is a contributing factor in determining the price of electricity. The disturbances could be classified in order to be more effectively analyzed. IEC EMC [1] and IEEE 1159-1995 [2] provide classifications for various PQ phenomena. The most and useful way to describe these phenomena is to use PQ indices which characterize the disturbances compactly. Local indices such as individual and total harmonic distortion, unbalance, voltage fluctuations, voltage sags and swells, etc., are the mostly used indices and are widely referenced. However, these indices represent a single disturbance in a single site. In contrast, global indices quantify the overall condition of PQ. These indices remarkably reduce the amount of data. Furthermore, using this reduced data, the system regulators would be able to rank different sites in order of their PQ conditions and for incentive based purposes.

While Individual indices are referenced in a large number of papers, global indices are not widely discussed. Reference [3] introduces a global PQ index for aperiodic waveforms. In this paper, RMS error and Normalized RMS error are defined as the global indices. A unified power quality index (UPQI) for continuous disturbances is proposed as a deciding factor for ranking various sites based on their overall power quality [4]. By appropriately combining this index in different sites, a global indicator for an entire system can be obtained which allows the utilities to be compared. In [5], a novel method is presented for PQ based economic assessment using energy space. In this method, the voltage quality deviation factor (VDQF) is defined, which represent the summation of absolute value of instantaneous energy difference between the actual voltage and the reference voltage. Reliability indices of power systems are also used to characterize the reliability and security of the supply. Service Quality Index is defined to determine the performance of the system in terms of both power quality and reliability requirements [6]. This index appropriately combine the steady state power quality characteristics, reliability indices, low and high voltages, and momentary interruptions. In [7], a Unified Power Quality Index is presented based on Ideal Analytic Hierarchy Process (IAHP). In this process, sustained and momentary reliability, harmonics, and voltage sags are calculated at each load point, and then the overall condition of the system is evaluated. Another approach to unify reliability and power quality indices that considers load dynamics and cost-benefit relationship is presented in [8]. Reliability and PQ indices are first classified and then the indices from each class are converted into cost.

This paper uses global power quality indices to give a comprehensive PQ view of each site and also the overall system. In order to integrate various indices in each load point, some approaches including the Unified Power Quality indicator are evaluated. In order to overcome some shortcoming of this index, a modification is proposed in the unifying process. The resulting index can convey the information about the PQ disturbances more thoroughly. Moreover, an approach is presented to calculate system indices, which refer to a portion of a power network or if needed, the entire network. These indices combine the PQ data of different sites with considering appropriate weighting factor for each site. The proposed approaches are then used to evaluate the power quality status of a segment of Tehran sub-transmission power system. The indices are calculated using the measurement PQ data at a number of load points in a period of one week.

In Section 2, different types of power Global Power Quality Indices are introduced. Section 3 proposed a modified unified index and the system indicators. These indices are then calculated and analyzed in section 4 for the measurement data of a test system. Eventually, Section 5 is devoted to the conclusion.

## 2. GLOBAL POWER QUALITY INDICES (GPQI)

Global indicators of power quality that are used to determine the overall quality of the network voltage can be classified into the following categories:

- GPQI based in the assessment of the difference between the ideal voltage waveform and the actual voltage waveform.
- GPQI based on the proper combination of conventional individual indices to assess the overall power quality of a single site and the grid.

### A. Global indices based on comparing the actual and the ideal waveform voltage

These indicators directly determine the difference between the actual waveform and ideal waveform of the supply voltage. By the ideal supply voltage, we mean the voltage that is without any power quality disturbances. The RMS error is defined as the root mean square value of the difference between the actual and the ideal voltage waveform [3]. The RMSE is dependent on the voltage level. To make this index comparable for different voltage levels, it should be normalized by dividing it by the fundamental voltage. In order to consider all three phases, three-phase normalized RMSE is presented. The principal of this index is similar to that of the single-phase RMSE. However, this approach simultaneously considers the three-phases and takes the phase angles of the waveform into account. Therefore, the voltage imbalance is also seen in the calculations.

Voltage quality Deviation factor (VQDF) is a general indicator that can determine the offset of the actual voltage waveform with the ideal state for a specified time interval. VQDF in a given period is defined as energy deviation of the voltage waveform form that of ideal voltage waveform [5].

**B. Global indices based on the combination of conventional single indices for a single load point**

GPQI index which is based on the combination of conventional indices, can determine the quality of the voltage in the power bus bars. This index unifies all PQ disturbances in a load point and gives a single index for each site. Firstly, individual indices are measured in a specified period based on power quality standards, and a large number of data are produced. In order to summarize the measurement data of the period, the statistical indicators are used. For example, 95% and 99% percentile are often used to characterize a set of data that are sampled in ten-minute intervals for a week. For a measurement period of several weeks, the maximum value of weekly 95 or 99 percentile, which represents the worst case, is considered.

In the second stage, all indices obtained in the first step, will make normalized. The acceptable limit for each indicator is used as the base in normalization.

$$PQI_i^n = \frac{PQI_i}{PQI_{i,\lim}} \tag{1}$$

where $PQI_i^n$ is the normalized i*th* individual index, $PQI_i$ is the actual value of i*th* individual index and is calculated in the first step, $PQI_{i,\lim}$ is the i*th* individual index limit, and n denotes the normalization. Each index limit can be equal to the amount determined by standard. Typical individual indices are slow voltage variation, harmonic distortion, voltage unbalance, over voltage and under voltage, and voltage fluctuations.

In cases that more than one index is attributed to a single disturbance (eg. Harmonics which is represented by THD and individual harmonic voltages Vh), an additional step is required. In this condition, all normalized indicators (according to equation (1)) that are related to a particular disturbance, will be compared with each other, and only the maximum value is considered as the representative of the disturbance.

Now, various approaches are introduced for combining the normalized individual indices. The Maximum Indicator is defined as the maximum value of normalized individual indices, which are calculated in equation (1) [9].

$$PQI_{\max}^n = \max\{\mathrm{PQI}_1^n, \mathrm{PQI}_2^n, \ldots, \mathrm{PQI}_i^n\} \tag{2}$$

where $PQI_{\max}^n$ is the Maximum Indicator. The disadvantage of this approach is that, since the maximum value of individual indices is used, other indices are ignored. The situation will be more exacerbated if some other indices also exceeded the limit, and in this way be overlooked.

In order to consider the effect of all of the indices, their average can be calculated. The Normalized Average PQ Indicator is defined as follows:

$$PQI_{av}^n = Average\{\mathrm{PQI}_1^n, \mathrm{PQI}_2^n, \ldots, \mathrm{PQI}_i^n\} \tag{3}$$

One deficiency of this measure is that the exceeding value of one or more indices may be cancelled out by the other small indices. Thus, the average PQI alone is not suitable for assessing the overall power quality of a load point and should only be used in conjunction with other indicators.

In order to overcome the shortages of the mentioned indicators, Unified Power Quality Index is introduced [4]. This index appropriately combines the normalized individual indices. This procedure is accomplished based on the exceeding value of each normalized individual index from its limit. The exceeding value is calculated using the following equation.

$$\Delta PQI_i = PQI_i^n - 1 \tag{4}$$

where $PQI_i^n$ is the i$^{th}$ normalized individual index. After calculating all these exceeding values, the following process is to be done to determine UPQI.

- If $PQI_i^n s$ are all less than 1, UPQI is equal to the maximum value of them.
- If one or more of these indices exceed 1, according to the following equation all exceeding values add up to make UPQI.

$$UPQI = 1 + \sum_{i=1}^{N} \Delta PQI_i \tag{5}$$

where N is the number of disturbances which exceeded their limit, and $\Delta PQI_i$ is defined in (4).

An important feature of UPQI is that a value of 1 for this index indicates that the index has reached its limit. In each measurement point, in order to adjust the impact of any disturbance on the final UPQI index, a weighting factor ($k_i$) can be used for each disturbance.

$$UPQI = 1 + \sum_{i=1}^{N} k_i \Delta PQI_i \tag{6}$$

To estimate the level of power quality of the entire power system, the system UPQI can be defined using weighting summation of the UPQIs of all measurement points.

$$UPQI_{system} = \frac{\sum_{j=1}^{M} w_j UPQI_j}{\sum_{j=1}^{M} w_j} \tag{7}$$

where $w_j$ is the weighting factor of point j, $UPQI_{system}$ is associated with point j, and M is the total number of measurement points. The value of weighting can be based on the number of customers or maximum demand at the point of measurement. The weighting coefficients can be different in different systems and areas. Therefore, determining the weighting coefficients are of particular importance.

**C. System indices based on the combination of each disturbance for the entire system**

There are two perspectives in the overall index determination. In the former one, at first for a single load point all individual indices are combined and then merging the results for different sits of the network, overall quality index can be calculated. This approach was introduced in the previous section and the Unified Indices calculated. Another approach that could be followed, is to separately combine the individual indices for each disturbance in the entire system. Thus, for the whole system a single indicator will be obtained per each disturbance. We refer to these indicators by system indices. For instance, the measured values of h-order harmonic for different sites have been merged, and an efficient criterion would be offered for h-order harmonic for the entire network or part of it. Therefore, the benchmark of the network status can be obtained for any of the disturbances. In general, for each of disturbances separately, system index can be obtained directly from the local indices. In the first approach, the system index associated with a specific local index (eg. voltage unbalance) can be considered equal to the value that certain percentage (50, 90, 95 or 99 percent) of that local index in every site does not exceed that value. In other words, the 99, 95, … percentile can be defined for the indices of a disturbance at different points. The matter of choosing one of these percentiles shall be decided by system operators and regulators.

## 3. PROPOSED UNIFIED AND SYSTEM INDICES

In the previous sections three categories of GPQI indices were introduced. As noted, each of these indicators has some limitations. In this section, the unified indices are improved and a series of system indicators are proposed so that they would be appropriate representatives of the quality of the network.

**A. Improved UPQI index**

UPQI introduced as a unified indicator of the overall voltage quality of each measurement point. UPQI focuses on only individual indices which exceed the limit. It ignores the indices lower than the limit. As stated in its definition, if none of the individual indices have exceeded the limit, UPQI is equal to the maximum index, and if one or more of the indices exceed the limit, UPQI is calculated using equation (5). Actually, UPQI is sum of the excesses of the limit in all of the individual indices. For a more comprehensive consideration of individual indices, we define a lower bound and an upper bound around the limit value of each index. Thus, two new limits are introduced for each index, and two UPQI indices are presented for each limit.

$$UPQI^{L-} = 1 + \sum_{i=1}^{N} k_i \Delta PQI_i^{L-}; \quad \Delta PQI_i^{L-} = \frac{PQI_i}{(1-\mathrm{L}^-)\,\mathrm{PQI}_{i,\lim}} - 1 \tag{8}$$

where $L^-$ is a positive number smaller than one which represents the lower bound for the limit value; i is the number of single indices which exceed the new limit $(1-\mathrm{L}^-)\,\mathrm{PQI}_{i,\lim}$. Thus, the new index $UPQI^{L-}$ considers all of the individual indices that has a value greater than the new limit $(1-\mathrm{L}^-)\,\mathrm{PQI}_{i,\lim}$.

Similarly, an equation can be defined for the upper bound of the limit.

$$UPQI^{L+} = 1 + \sum_{i=1}^{N} k_i \Delta PQI_i^{L+}; \quad \Delta PQI_i^{L+} = \frac{PQI_i}{(1+\mathrm{L}^+)\,\mathrm{PQI}_{i,\lim}} - 1 \tag{9}$$

where $L^+$ is a positive number smaller than one which represents the upper bound for the limit value; i is the number of single indices which exceed the new limit $(1+\mathrm{L}^+)\,\mathrm{PQI}_{i,\lim}$.

Now, using an example, the interpretation of the defined indicators will be discussed. Suppose that there are four individual indices for a measurement point and their normalized values are 8.0, 9.0, 1.1 and 1.3. Also, assume that $L^-= L^+=0.1$, and $k_i$ = 1. The resulting unified indices are shown in Table 1.

**Table 1. Three unified power quality indices**

| Index | | Limit value | |
|---|---|---|---|
| UPQI | 1.4 | $PQI_{i,lim}$ | $PQI_{i,lim}$ |
| $UPQI^{L-}$ | 1.66 | $[(1-L^-)\times \mathrm{PQI}_{i,\lim}]$ | $0.9(PQI_{i,lim})$ |
| $UPQI^{L+}$ | 1.18 | $[(1+L^+)\times \mathrm{PQI}_{i,\lim}]$ | $1.1(PQI_{i,lim})$ |

UPQI = 1.4 indicates that the individual indices together have exceeded the limit by 40 percent. $UPQI^{L+}$=1.18 shows that the indices are totally 18% more than the new limit $1.1(PQI_{i,lim})$. Finally $UPQI^{L-}$=1.66, indicates that the indices are totally 66% more than the new limit $0.9(PQI_{i,lim})$.

**B. System PQ indices**

As mentioned earlier, system indicators represent the overall quality of the system for each disturbance. One of the main disturbances is voltage distortion. In order to combine the individual harmonic voltage index in different sites of the network, $V_h^{eq}$ is defined using the following equation.

$$V_h^{eq} = \sqrt{\frac{\sum_{k=1}^{N}(\mathrm{a}_k \times \mathrm{V}_{h,k})^2}{\sum_{k=1}^{N}(\mathrm{a}_k)^2}} \tag{10}$$

where $V_h^{eq}$ represents the equivalent h-order harmonic voltage for the entire network, $V_{h,k}$ is h-order harmonic voltage in $k^{th}$ point, $a_k$ is voltage disturbance weighting coefficient for $k^{th}$ point (equation (12)), and N is the number of measurement points. A similar equation can be defined for the network equivalent voltage THD as follows.

$$THD_v^{eq} = \sqrt{\frac{\sum_{k=1}^{N}(\mathrm{a}_k \times THD_{\mathrm{v},k})^2}{\sum_{k=1}^{N}(\mathrm{a}_k)^2}} \tag{11}$$

where $THD_v^{eq}$ represents the equivalent voltage THD for the entire network, and $THD_{v,k}$ is voltage THD in k[th] point.

$$a_k = (P_{Loading} \times V_1)_k \quad (12)$$

$a_k$ is voltage weighting coefficient for k[th] measurement point; $P_{Loading}$ represents the loading of the point and as its value increases, existing voltage distortion in that point will be more important. In addition, given that the measured harmonic voltage is expressed in percent, the fundamental voltage ($V_1$) should be involved in $a_k$ to express the voltage in volts.
Similar equations can be defined for harmonic currents.

$$I_h^{eq} = \sqrt{\frac{\sum_{k=1}^{N}(b_k \times I_{h,k})^2}{\sum_{k=1}^{N}(b_k)^2}} \quad (13)$$

$$THD_i^{eq} = \sqrt{\frac{\sum_{k=1}^{N}(b_k \times THD_{i,k})^2}{\sum_{k=1}^{N}(b_k)^2}} \quad (14)$$

The weighting factor $b_k$ represents the importance of injecting harmonic current into the network through the k[th] load point.

$$b_k = (\frac{I_1}{I_{sc}})_k \quad (15)$$

$I_{sc}$ is short-circuit current at k[th] measurement point, and $I_1$ is the fundamental current. Since the measured harmonic current is expressed in percent, the fundamental current ($I_1$) should be involved in $b_k$ to express the current in amperes. In addition, the amount of harmfulness of injecting harmonic currents into the network is also dependent on the short-circuit current of the injecting point. Harmonic currents passing through the network harmonic impedance introduce harmonic voltages in network. The value of this voltage is proportional to the harmonic impedance value. On the other hand, the harmonic impedance is itself inversely proportional to the short-circuit current. Therefore, resulting harmonic voltage and short-circuit current are inversely related. Thus, the weighting factor which reflects the importance of harmonic currents, should be inversely proportional to short-circuit current.
In order to define a system indicator for voltage unbalance, an equation similar to that of harmonic voltages can be introduced for voltage unbalance individual indices.

$$K_h^{eq} = \sqrt{\frac{\sum_{k=1}^{N}(a_k \times K_{h,k})^2}{\sum_{k=1}^{N}(a_k)^2}} \quad (16)$$

where $K_h^{eq}$ is voltage unbalance indicator of the system; $K_{d,k}$ is the individual voltage unbalance index for k[th] point; and $a_k$ is voltage disturbance weighting coefficient for k[th] point, introduced in equation (12).

## 4. Numerical Results

The PQ indicators presented in the previous sections are calculated for a series of measurements in part of a power network. PQ data are recorded at 11 load points for a week in 10-minute intervals. Parameters measured include voltage fluctuation (short- and long-term flicker), harmonic voltage and current, voltage and current unbalance, and loading power. First we discuss the individual indices.
Figures 1 to 3 show the maximum value of measured voltage THD, current TDD, and voltage unbalance in the measurement period. In these figures, the horizontal axis represents the measurement point-code (first number is the measurement number and the second number represents the voltage level).

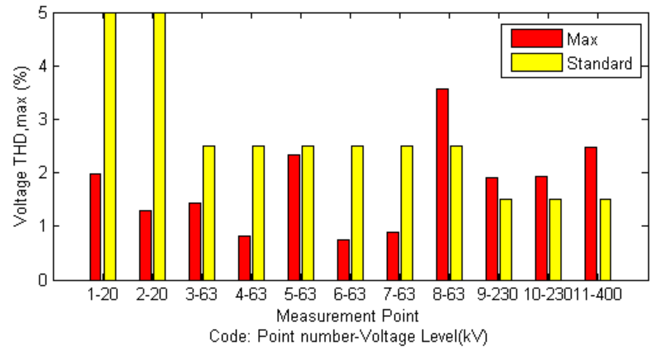


**Fig. 1. Voltage THD for all load points, and the standard values**

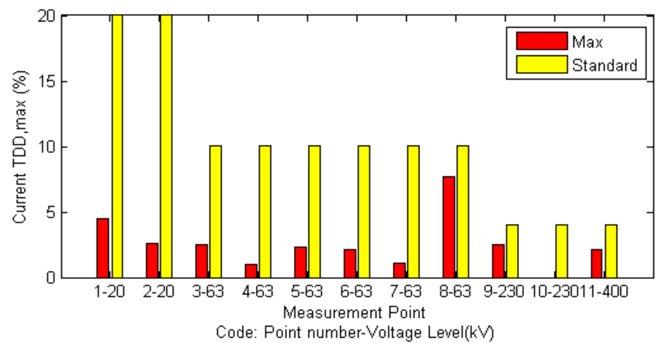


**Fig. 2. Current TDD for all load points, and the standard values**

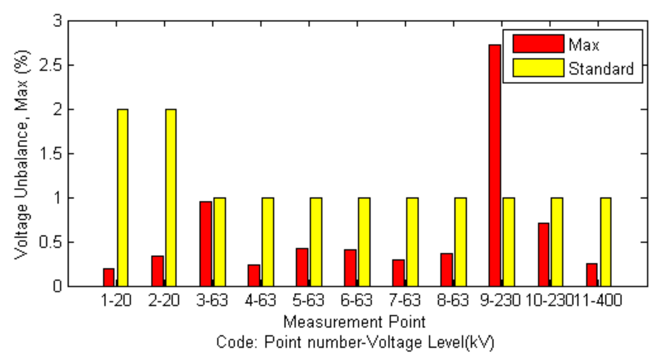


**Fig. 3. Voltage unbalance for all load points, and the standard values**

Now, using the measured data, global indicators based on the combination of conventional single indices for a single load point are presented and analyzed. These indicators include $PQI_{max}^n$, $PQI_{av}^n$, and $UPQI$, and are shown in Fig. 4. The load points 5, 8, 9, 10 and 11 have unified indicators beyond the allowed value.

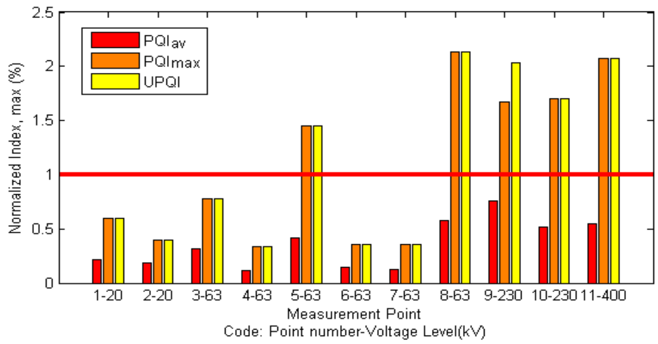


**Fig. 4. Global normalized indices for all measurement points**

In Fig. 5, the normalized value of harmonic index (maximum of all single harmonics and THD), voltage unbalance and the UPQI for all measurement points are represented. First, it can be seen that the dominant component of the index UPQI, is harmonics and unbalance has a negligible impact on UPQI. Recall that UQPI index is obtained by combining individual indices (i,e. harmonic, unbalance, flicker, etc.).

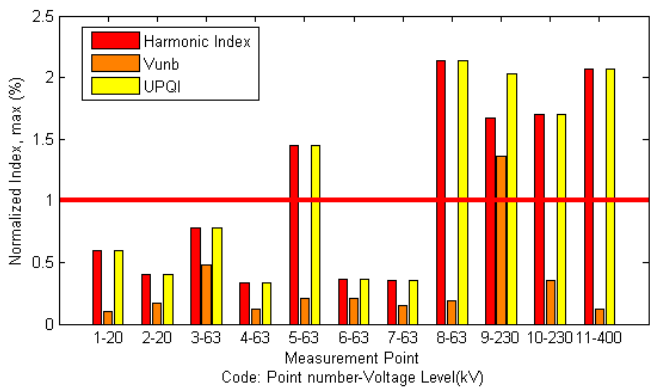


**Fig. 5. Comparison of individual harmonics and voltage unbalance with UPQI index for all measurement points**

Table 2 lists all of the normalized individual indices along with the global indicators. Note that the measurement points are arranged based on the value of the Unified Power Quality Index (UPQI). Since UPQI is a normalized index, values higher than unity are interpreted to be beyond the standard value. Thus, the first five load points have unallowable UPQI index and as mentioned, the main contributing factor is voltage harmonic. The last column of the table represents the improved $UPQI^{L-}$ index, in which $L^{-}$=0.1. This index shows that how much do the individual indices exceed their new limit which is equal to their old limit multiplied by (1-0.1) or 0.9.

Now, we discuss the system indicators defined in section V. System indicators are defined to assess the overall quality of a network in terms of a particular disturbance (e.g. harmonics and unbalance). The equations of system indicators for voltage THD, current TDD, voltage and current single harmonics and voltage unbalance were presented earlier. Using these

**Table 2. Normalized individual indices and the global indicators**

| Code | Voltage Level (kV) | Harmonic Index | Vunb | $PQI_{av}$ | $PQI_{max}$ | UPQI | $UPQI^{L-}$ |
|---|---|---|---|---|---|---|---|
| 8-63 | 63 | 2.13 | 0.19 | 0.58 | 2.13 | 2.13 | 2.37 |
| 11-400 | 400 | 2.07 | 0.13 | 0.55 | 2.07 | 2.07 | 2.37 |
| 9-230 | 230 | 1.67 | 1.36 | 0.76 | 1.67 | 2.03 | 2.30 |
| 10-230 | 230 | 1.70 | 0.36 | 0.51 | 1.70 | 1.70 | 1.89 |
| 5-63 | 63 | 1.45 | 0.21 | 0.41 | 1.45 | 1.45 | 1.61 |
| 3-63 | 63 | 0.78 | 0.48 | 0.31 | 0.78 | 0.78 | 0.87 |
| 1-20 | 20 | 0.60 | 0.10 | 0.22 | 0.60 | 0.60 | 0.66 |
| 2-20 | 20 | 0.40 | 0.17 | 0.19 | 0.40 | 0.40 | 0.44 |
| 6-63 | 63 | 0.36 | 0.21 | 0.14 | 0.36 | 0.36 | 0.40 |
| 7-63 | 63 | 0.35 | 0.15 | 0.13 | 0.35 | 0.35 | 0.39 |
| 4-63 | 63 | 0.33 | 0.12 | 0.11 | 0.33 | 0.33 | 0.37 |

equations, system indicators are calculated for the recorded data related to 11 measurement points.

Fig. 6 shows the system indicator for voltage THD, single harmonics, and unbalance. In addition, for each disturbance, the maximum index value among all of the 11 load points (Top) and also the average index value of them (Average) are represented in the figure.

Among the indicators shown, the system index of voltage THD and 5-order harmonic voltage that are close to 2%, are relatively high. One of the contributing factors in increasing 5-order harmonics in the network is expanding the use of power electronic equipment and also florescent lamps in domestic loads.

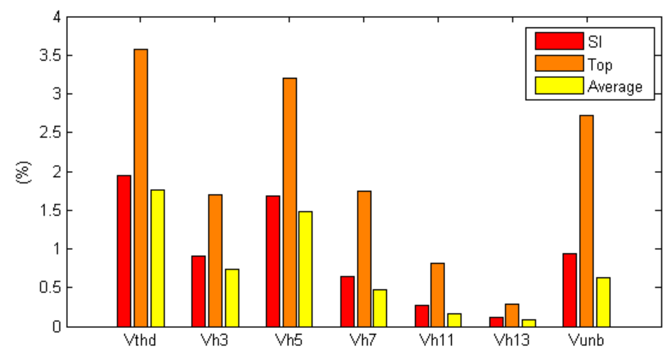


**Fig. 6. System indicators (SI) for voltage THD (Vthd), single harmonics (Vhi), and unbalance (Vunb)**

Fig. 7 shows the system indicator for current TDD, dominant single harmonics, and unbalance based on the maximum value of the indices in measurement period. In this figure, the system indicators (SI) are compared with maximum and average value of each disturbance index in the entire network (respectively denoted by Average and Top). As can be seen, the system index for the current THD, 5-order harmonic, and unbalance has relatively high values, and in other harmonics, the system index is negligible or zero.

## 5. CONCLUSION

Power quality disturbances are characterized using a broad range of indices and criteria. Individual and local indices are well-known and widely referenced in power quality assessment in various studies. However, some applications demand a more comprehensive PQ evaluation. In this paper three prevalent types of Global PQ Indices have been

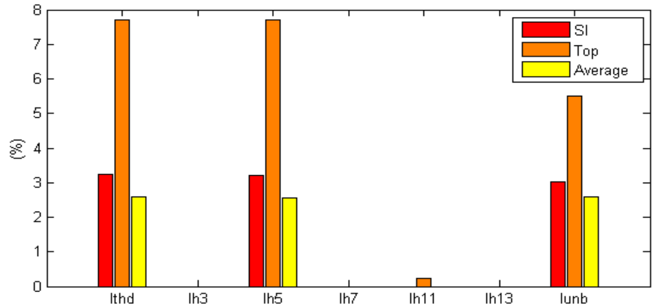


**Fig. 7. System indicators (SI) for current THD (Ithd), single harmonics (Ihi), and unbalance (Iunb)**

introduced. The UPQI and System Indicators are concluded to be efficient respectively in representing the overall PQ condition of a single load point, and the overall status of a single disturbance throughout the entire system. The conventional UPQI index is improved by altering the limit value which is used in the normalization process. This new UPQI index can more thoroughly unifies the disturbances of a load point. In addition, a series of System Indicators are proposed which can be efficient tools in separately combining each disturbance throughout the entire system. Finally, a series of test data which are collected at 11 load points, are used to evaluate the PQ of a test system. The results are presented for individual, unified, and system indices. The UPQI index is compared with the normalized individual indices, so, the relationship between the unified and the individual indices can be clearly seen. Furthermore, the system index of each specific disturbance is depicted along with the maximum and the average value of the individual index of that disturbance for all of the measurement points. Therefore, the diagrams provide an overall insight of the system indices.

## REFERENCES


[1] IEC 61000-4-30, EMC, “Testing and measurement techniques - Power quality measurement methods,” (2003)

[2] IEEE, “IEEE Recommended Practice for Monitoring Electric Power Quality, IEEE Std 1159”, (1995)

[3] Watson, N.R.; Ying, C.K.; Arnold, C.P., "A global power quality index for aperiodic waveforms," in *Harmonics and Quality of Power, 2000. Proceedings. Ninth International Conference on* , vol.**3**, pp.1029-1034, (2000)

[4] Gosbell, V.J.; Perera, B.S.P.; Herath, H.M.S.C., "Unified power quality index (UPQI) for continuous disturbances," *Harmonics and Quality of Power, 10th International Conference on*, vol.**1**, pp. 316-321, (2002)

[5] Chengyong Zhao; Xia Zhao; Xiufang Jia, "A new method for power quality assessment based on energy space," *Power Engineering Society General Meeting, 2004. IEEE*, vol.**1**, pp. 963-967, (2004)

[6] Mcgranaghan, M.F., "Quantifying Reliability and Service Quality for Distribution Systems," in *Industry Applications, IEEE Transactions on*, vol.**43**, no.1, pp.188-195, (2007)

[7] Buhm Lee; Kyoung Min Kim; Yeongjin Goh, "Unified power quality index using ideal AHP," *Harmonics and Quality of Power, ICHQP 13th International Conference on*, Wollongong, NSW, pp. 1-5 (2008)

[8] Buhm Lee; Kyoung Min Kim, "Unified power quality index based on value-based methodology," *Power & Energy Society General Meeting, PES '09. IEEE*, Calgary, AB, pp. 1-8 (2009)

[9] Mamo, X. and Jarzevac, J.L. “Power Quality Indicators,” *PowerTech*, Porto (Portugal), (2001)