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REVIEW ARTICLE

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ENHANCEMENT OF DISTORTION POWER QUALITY INDEX IN DISTRIBUTED POWER GRIDS

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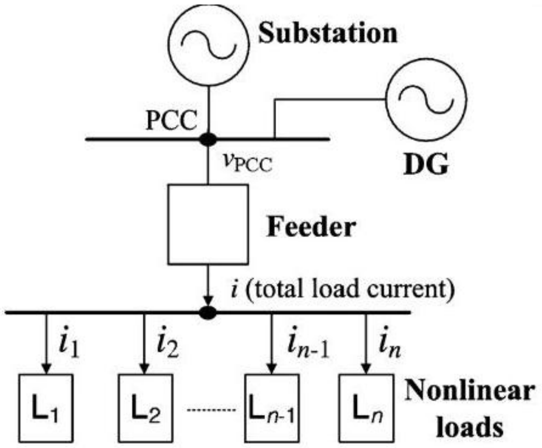
ABSTRACT

This paper presents the Euclidean norm based new power quality index (PQI), which is directly related to the distortion power generated from nonlinear loads, to apply for practical distribution power network by improving the performance of the previous PQI proposed by the authors. The proposed PQI is formed as a combination of two factors, which are the electrical load composition rate (LCR) and the Euclidean norm of total harmonic distortions (THDs) in measured voltage and current waveforms. The reduced multivariate polynomial (RMP)model with the one-shot training property is applied to estimate the LCR. Based on the proposed PQI, the harmonic pollution ranking, which indicates how much negative effect each nonlinear load has on the point of common coupling (PCC) with respect to distortion power, is determined. Its effectiveness and validity are verified by the experimental results from its prototype's implementation in a laboratory with a single-phase 3 kW photovoltaic (PV) grid-connected inverter, which contributes to a small distortion in voltage at the PCC, and practical nonlinear loads.

KEY WORDS—Distortion power, distribution power system, Euclidean norm, harmonic pollution ranking, power quality index, reduced multivariate polynomial (RMP) model

INTRODUCTION

As the increased utilization of power electronic devices and nonlinear loads aggravates the distortion in voltage and current waveforms, the power quality (PQ) in m overpower systems has become a significant issue for both power suppliers and consumers Moreover, there has been an increasing trend towards electric deregulation and independent power producers (IPPs) bas ed on renewable energies such as fuel cell, photovoltaic, wind, and gas fuelled micro turbines, etc. In addition, the distributed generation (DG) [1] by the IPP with poorly controlled synchronization will make it more difficult to handle t he PQ problems related with system reliability and stability at both power generation and distribution levels. In other words, electricity has been generally sold from on supplier to one consumer with ownership changing hands at only one physical point: the revenue meter. In contrast, after deregulation accompanied with the DGs, it is expected t hat the ownership of electric power will be exchanged at several points along the generation transmission distribution chains. Then, the proper PQ solutions will be necessary at each physical location where ownership is transferred [2][4]. Therefore, it is important to develop the appropriate power quality index (PQI)as well as identity the sources and disturbances deteriorating the PQ.



The limits on the amount of harmonic current and voltages generated by customers and/or utilities have been established in the IEEE standards 519 [5] and 1547 [6], and in the IEC61000-3standard [7]. Recently, some techniques to achieve the specified levels of PQ while enhancing its performance have been reported [8]–[11]. In addition, several power quality indices through the analysis of measured voltage and current waveforms [12]–[14]and analytical tools to evaluate the harmonic contributions on a point of common coupling(PCC)[15]– [17] have been developed. In particular, the distortion power quality index (DPQI), which accounts for the direct relationship between distortion power and harmonic components of nonlinear loads, has been reported in [14] by the authors.

- The relative quantity of the injected currents flowing from the PCC to each nonlinear load,
- The degree of distortion in the current wave forms with high-frequency harmonic components, and
- The degree of distortion in the voltage waveforms at the PCC with high-frequency harmonic components.

I. ANALYSIS OF DISTORTION POWER TO VALIDATE THEPROPOSED

A. Distortion Power

To validate the proposed, the theoretical analysis for distortion power is required based on the mathematical derivation. The apparent power, fundamental active power, fundamental reactive power , and distortion power for the each load are computed as given in . Basically, the widely-used Budeanu's concept [20] of reactive power and distortion power, has been controversial with its unsuitability for non-sinusoidal waveforms. Most problems come from the, which consists of the and harmonic reactive power, Generally, the value of is negative in many practical cases. This makes the to be smaller than the ,or even become zero in the worst case. In this case, the decrease in does not mean a reduction of the oscillations. That is, the is subject to mislead giving the impression that can be partially or totally cancelled while in reality the oscillations of power will take place [21]. Similarly to the, the negative value of the harmonic active power indicates to what ex- tent the end-user is polluting the power network with the asso ciated harmonics. Especially, for an ac motor, which is the representative nonlinear load, the is not a useful power. Consequently, IEEE standard 1459 recommends separating the from the [22]. Therefore, it is reasonably acceptable that the dominant components, and are used to represent the reactive and active powers, respectively, as proposed in this paper. Then, all harmonic powers are considered in distortion terms. The formulations in except for the are described in [22].Assume that the dc components of voltage and current are zero. Then, with the THD defined as (5), the and in (4) and(3) can be approximated as (6) and (7), respectively. This transformation is reasonably acceptable in a practical power system because the dc component of voltage and current are mostly close to zero in practice even when there exists some distortion in their waveforms. Moreover, In the case of dc injection into connection point by the DG in Fig. 1, it is limited to within0.5% of its full rated output according to the IEEE standard 1547[6]. Therefore, it can be negligible., it is observed that the distortion power, is related to the fundamental components and THDs of voltage and current. With the detailed analysis for the in Section IV, the proposed is proved to be valid for providing the information with respect to distortion power without its direct measurement, therefore determining the relative HPR of nonlinear loads.

B. Parseval's Theorem on THD Calculation

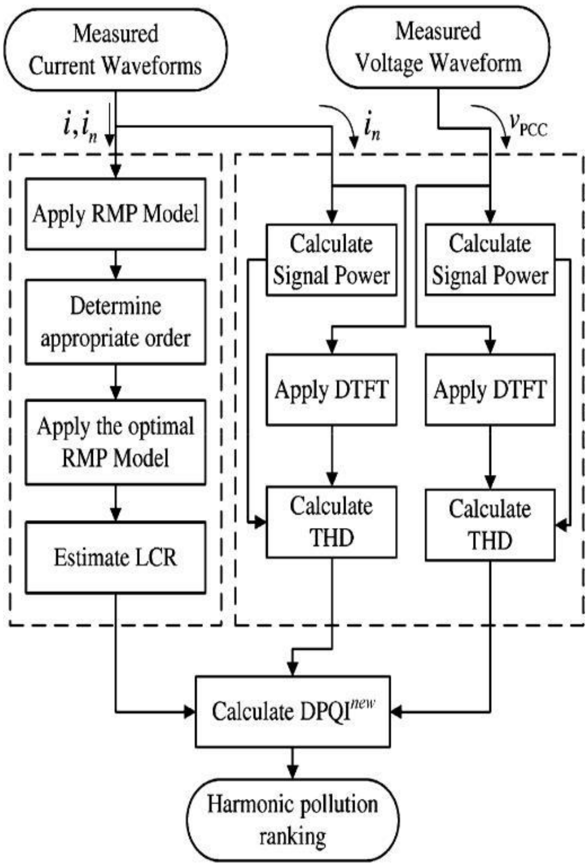
The Parseval's theorem states [23] that the average power in a periodic signal equals the sum of the average powers in all of its harmonic components. And, its mathematical description is given in (8). When there are no inter-harmonics, the values of THD in (5)and (9) become same. In this paper, the proposed is developed to measure the power quality in a stationary condition representing all loads in a steady-state condition, where the effect of inter-harmonics is trivial. Moreover, the same assumption is already applied in derivations of apparent and distortion powers in (4) and (7), respectively. Therefore, the value of THD calculated by (9) is almost same as that by (5) in general circumstances, where these applied. Then, it is required to describe the application of (9) in exceptional situation, where inter-harmonics from unexpected disturbance sexist. Actually, the use of THD defined as (9) to implement hand is more preferable to that defined as (5) since it can reflect the effect of all inter-harmonics intothe signal power, which is calculated in implementation procedure.

On the other hand, the definition of THD as given in(5)cannot consider inter-harmonics. Therefore, the losses in calculation caused by domain change are ignored. For this reason, the equation (9) can help the proposed index to measure the exact level of power quality in practice.

C. Overall Procedure

The overall procedure to implement theis shown in Fig. 2. There are two parts; one is to estimate the LCR by using the RMP model, and the other is simply to calculate their THDs of the measured current and voltage based on the Parseval's theorem.

When the RMP model is applied to estimate the LCR, itis important to determine the proper order, in (17) of the RMP model. In a physical application in the existence of noise and/or complex correlations among the many nonlinear harmonic loads, the relatively high-order of RMP model might be preferably used to enhance estimation accuracy. However, the estimation process by very high-order RMP models requires extensive computations and memory in real-time operation. Also, its weight-solution vector mapping to high dimension is hard to analyze. Moreover, it is not true that the high-order RMP model always outperforms the relatively low-order RMP model. There is no firm solution for selecting its optimal order. By several tests, the sixth-order RMP model is optimally selected to estimate the LCR in this paper. Meanwhile, the estimation of nonlinear load harmonics, which was required to implement thein (1), is not necessary here for calculating the THD of waveforms(see[14]). Therefore, it avoids applying another RMP model. This makes the implementation of more efficient and effective for use in practice.



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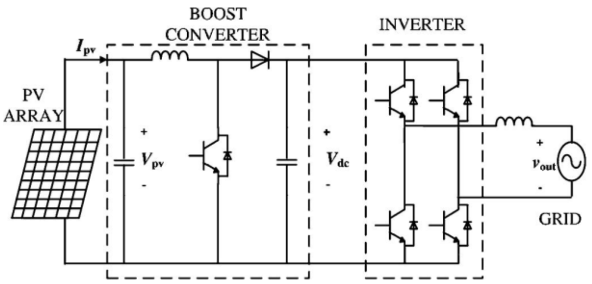
EXPERIMENTAL VERIFICATIONS

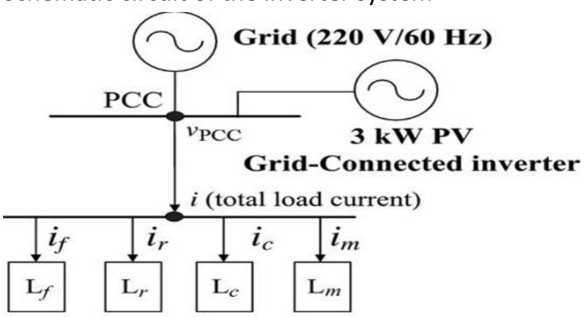
A. Hardware Set-Up and Data Acquisition

The single-phase 3 kW photovoltaic (PV) grid-connected inverter system and its schematic circuit are shown in Figs. 3 and4, respectively. This system is used as the DG in Fig. 1 in hardware set-up.

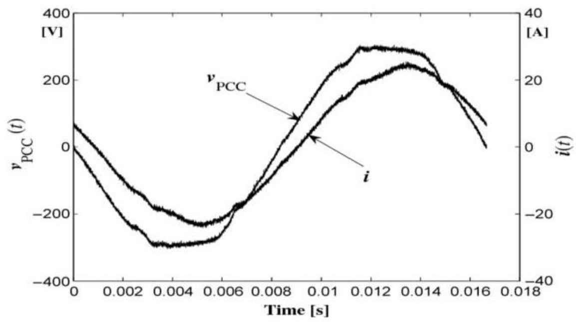
It consists of a dc-dc boost converter, a dc-link capacitor, and a dc-ac inverter. The dc-dc boost converter steps up the PV voltage, which has a wide range corresponding to solar irradiance, to an acceptable level of the dc-link capacitor voltage, by controlling the gate signal. The dc-ac inverter outputs theated voltage of 220V with 60 Hz. It operates with the maximum



Schematic circuit of the inverter system



One-line diagram of hardware set-up for data acquisition. the one-line diagram of the prototype's experimental implementation used to obtain the associated sampling data. As mentioned before, the grid-connected inverter system plays the role in distorting the PCC voltage with the low THD within 5%. Then, the four nonlinear loads, which are selected by the load classification guide in [7], are connected to thPCC. These are the fluorescent lighting, radiator, computer, and motor, which are denoted by the subscripts, and respectively. Without losing the generality, the other experimental set-up can be similarly implemented, for example, as a small distribution system extended in power-scale with a 50kW-scale PV based DG and typical loads such as commercial buildings, factories, and water treatment facilities, etc.



The voltage, and the total electric load current, at the PCC during one period Tbof the fundamental.

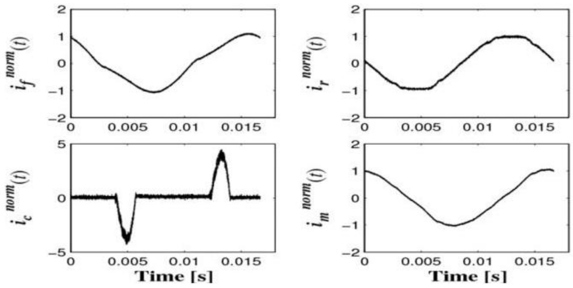
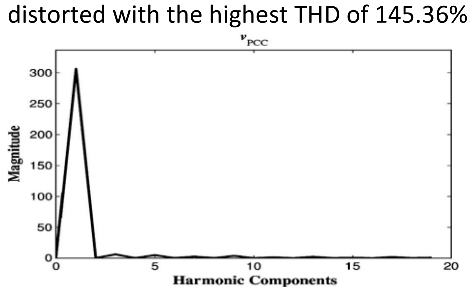
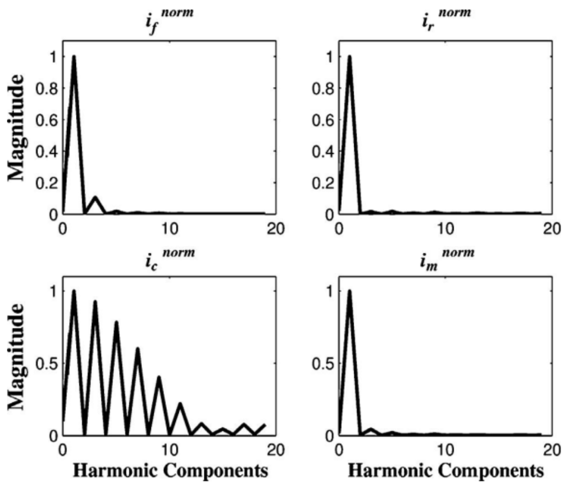


Figure : Normalized load currents of ,ic ,if,im,ir,and during one period of the fundamental.

According to the definition of THD as given in (9),THDs of the PCC voltage and load currents are calculated with the data in Figs. From the results in Table I, it is observed that the PCC voltage, is distorted with the small THDof 3.78%, which is reasonably acceptable. All nonlinear loads are affected by the distortion from and therefore have more harmonic currents than those generated due to their own nonlinearity. Also, note that the load current, injected into the computer is most severely distorted with the highest THD of 145.36%.



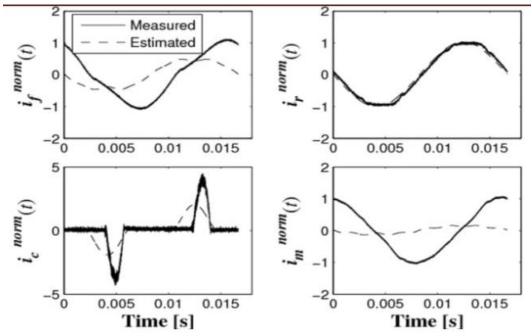
Harmonic components of the PCC voltage.



Harmonic components of each load current.

DPQI new and its corresponding HPR

Load type	Fluorescent	Radiator	Computer	Motor
$DPQI^{new}$	0.7312	4.3853	2.6363	0.8090
$DPQI_R^{new}$	0.0854	0.5122	0.3079	0.0945
HPR	4	1	2	3
D [VA_d]	29.20	192.54	104.11	33.33
D_R	0.0813	0.5361	0.2899	0.0928
SMR	0.0013	0.0008	0.0014	0.0010



Estimation for each load current by the RMP model

DPQI old and its corresponding HPR

Load type	Fluorescent	Radiator	Computer	Motor
THD($\hat{i}$) [%]	12.03	0.97	77.52	21.60
$DPQI^{old}$	0.7459	0.7716	1.4031	2.6715
HPR	4	3	2	1

B. Tests in Three-Phase Balanced System

The clear definition of distortion power is necessary to evaluate and verity the. Although many theories have been developed for the single-phase case, their extension to the three-phase system is also important. Therefore, the proposed index is now applied to a three-phase balanced system in Fig..

CONCLUSION

This paper proposed the new distortion power quality index to replace the previously proposed index. Its computation was carried out based on the load composition rate (LCR) and Euclidean norm of total harmonic distortions (THDs) of the measured voltage and current waveforms at the point of common coupling (PCC).The reduced multivariate polynomial (RMP) model with the one-shot training property was successfully applied to estimate the LCR. Moreover, the use of could avoid applying another RMP model, which is required in the implementation of to estimate the nonlinear load harmonics.

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