DETECTION OF HARMONIC POLLUTION RANKING OF NON-LINEAR LOAD IN THE HORMOZGAN DISTRIBUTION POWER SYSTEM BY USING NEW POWER QUALITY INDEX

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ABSTRACT

In this paper ranking of harmonic distortion of each non-linear load like economical, ministerial, residential and others include hotels, hospitals, universities and terminals in the HORMOZGAN Province Electrical power Distribution network is determined by using new power quality index which is directly related on harmonic distortion sources in the distribution power system. Then, the ranking of distortion power for each non-linear load, which has adverse effect on entire system, is determined.

INTRODUCTION

Generation of harmonics and the existence of waveform pollution in power system networks are important problems facing the power utilities. Due to the widespread proliferation of many nonlinear harmonic loads, by various power-electronic-based equipment on a consumer side, serious power quality problems can be caused by distorted currents from those nonlinear loads. In addition, the increase in nonlinear loads might even distort the grid voltage. As a result, a distributed power system can be placed in an undesired situation by these power quality problems. For example, it is known that a power outage may occur as a result of serious voltage distortion. To tackle these problems, the limits on the amount of harmonic currents and voltages generated by customers and/or utilities have been the waveform is distorted with high frequency harmonic components. The THD regulates the harmonic pollution of each load. However, it is insufficient for analyzing the effects of polluted loads on an overall power system with the only THD factor. Therefore, a new index is necessary to deal with this issue. This paper concentrates on using new power quality index to determine the effect of each non-linear load on a point of common coupling (PCC) of the HORMOZGAN distribution power system by using the concept of distortion power generated from each load. Then, the reduced multivariate polynomial (RMP) model [1],[2] is used to estimate the electric load composition rate (LCR) and electric loads harmonics [3], required for computation of the new distortion power quality index.

DISTORTION POWER QUALITY INDEX (DPQI)

Fig.1 shows a typical distribution power network. When the nonlinear loads are supplied from a sinusoidal voltage source, its injected harmonic current is referred to as contributions from the load. Harmonic currents cause harmonic voltage drops in the supply network and therefore distort the voltage at the PCC.
Any loads, even linear loads, connected to the PCC will Have harmonic currents injected into them by the distorted PCC voltage. Such currents are referred to as contributions from the power system or supply harmonics [3]. In this circumstance, a distortion power generation from each load depends mainly on two factors.
1) How much current is injected from the PCC in Fig.1 to each nonlinear load?
2) To what extent current waveforms are distorted with high frequency harmonic components?
The preceding two questions can be solved by computation
of the electric LCR for each nonlinear load and THD of the load currents ($i_1, \ldots, i_n$), respectively.

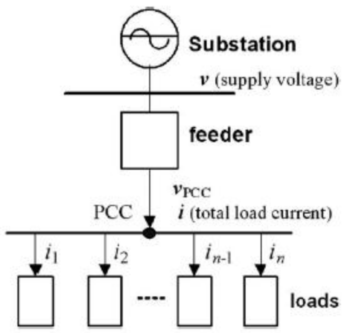

Fig1.One line diagram of a typical distribution power network[8]

DPQI is relevant to the distortion power of a certain electric load and can be obtained by inner product of the LCR and the THD, as given in (1). The waveform of each load current in (1) can be represented by

$$\mathrm{DPQI(n) = LCR(in).THD(in)} \quad (1)$$

$$\mathrm{i_n(t)_T = i_{n,1}(t)_T + \sum_{h=2}^{\infty} i_{n,h}(t)_T} \quad (2)$$

Where T is the period of the measured current i, and h is the number of high-frequency harmonic components. For all electric loads connected to the PCC in Fig.1, the DPQI provides important information of how much effect each load has on PCC with the relative ranking for harmonic pollution of distortion power generation.
In this study, the RMP model [1], [4] ,which is summarized in the next section, is applied to estimate the LCR and the Nonlinear load harmonics required to obtain the proper THD of each load current. This optimization technique is a kind of training algorithm to search the weight parameters for the nonlinear input–output mapping, such as the neural networks (NNs). The main advantage of the RMP model over the NNs is that it has the *one-shot* training property [1]. In other words, it does NOT require iteration procedures during the process of obtaining a solution weight vector.

RMP MODEL

The preceding MP regression provides an effective way to describe complex nonlinear input-output relationships. However, for the rth-order model with input dimension l, the number of independent adjustable parameters would grow with L^r. Thus, the MP model would need a huge quantity of training data to ensure that the parameters are well determined. To significantly reduce the huge number of terms in the MP model, the following model in (3) is considered:

$$\hat{f}_{MN}(\alpha, x) = \alpha_0 + \sum_{j=1}^{r}(\alpha_{j1}x_1 + \alpha_{j2}x_2 + \cdots + \alpha_{jl}x_l)^j \qquad (3)$$

It is noted that this gives rise to a nonlinear estimation model where the weight α_{jl} parameters ( ) may not be estimated in a straightforward manner. Although an iterative search can be formulated to obtain some solutions, there is no guarantee that these solutions are global. The following RMP model can be written as [4]:

$$\hat{f}_{RMP'}(\alpha, x) = \alpha_0 + \sum_{j=1}^{l}\alpha_j x_j + \sum_{j=1}^{r}\alpha_{l+j}(x_1 + x_2 + \cdots + x_l)^j + \sum_{j=2}^{r}(\alpha_j^T \cdot x)(x_1 + x_2 + \cdots + x_l)^{j-1}, \quad l \geq 2 \qquad (4)$$

The RMP model, in which the number of weight parameters linearly increases, is a much more efficient algorithm in a complicated polynomial system with higher order, compared with the MP model, in which the number of parameters exponentially increases with respect to the order of polynomials**.**
As mentioned before, it is necessary to compute the values of the LCR and THD for the harmonic load currents to implement the DPQI in (1). The RMP model is now applied to estimate the two aforementioned factors.

The overall procedure to calculate the DPQI is shown in Fig. 2. The left flow of Fig. 2 shows how to estimate the LCR by applying the RMP model. Meanwhile, the right flow of Fig. 2 shows how to calculate the THD for the nonlinear load harmonics predicted by the RMP model when the voltage at the PCC in Fig. 1 is not a purely sinusoidal waveform. Generally, it has slight harmonics in practice. Note that the proposed DPQI in (1) exploits distortion in the only current waveform without considering that in voltage for both the LCR and THD. To take into account the case in existence of a distorted voltage, the nonlinear load harmonics are predicted by the same RMP model to calculate the proper THD.

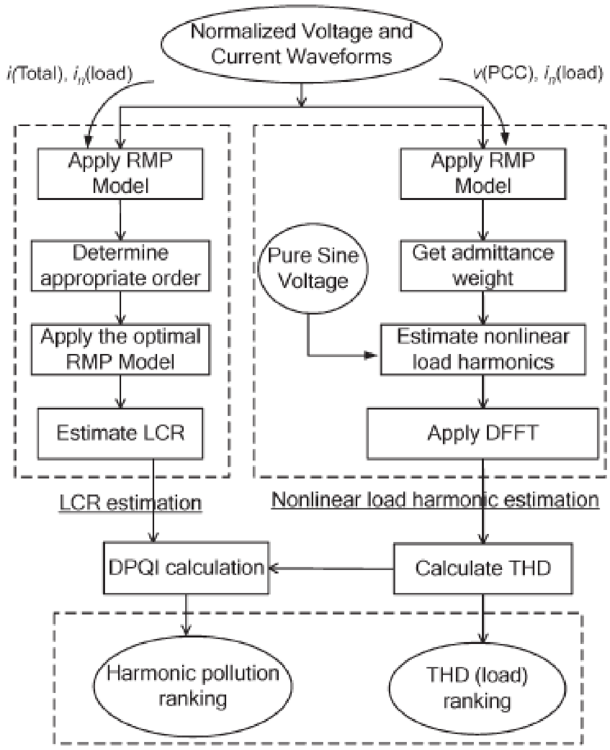

Fig. 2. Overall procedure to implement the DPQI. [8]

For the formulation of load composition, the total electric Current i(t) in Fig. 1 is modeled by

$i(t) = k_1 i_2(t) + k_2 i_2(t) + \cdots + k_{n-1} i_{n-1}(t) + k_n i_n(t)$ (5)

with several electric load classes connected to the distribution power system, where $k_1, k_2, \ldots, k_{n-1}$, and k_n are the unknown coefficients, which provide the actual rate of the composition of each load current with respect to the total current. This rate is called the LCR.
As mentioned before, harmonic currents at nonlinear loads might have the distorted PCC voltage VPCC in Fig. 1. Then, the nonlinear correlation between the distorted VPCC and load current harmonics occurs. This relationship is complex and therefore difficult to analyze.
The estimation of LCR in (1) can be carried out without considering whether a pure sinusoidal or a distorted voltage

is supplied to several loads. The reason is that it deals with the only portion of each load current over the total current at the PCC. However, when the THD is calculated, the additional consideration for nonlinear load harmonics is necessary in the existence of distorted VPCC in Fig. 1. This problem even exists

When a single load is connected to the PCC. If the true harmonic current injections from the load were known, then a utility could penalize the offending consumer in some appropriate way, including, for example, a special tariff, or insist on corrective action by the consumer. Simply measuring the harmonic currents at each individual load is not sufficiently accurate since these harmonic currents may be caused by not only the nonlinear load but also a nonsinusoidal PCC voltage. This is not a new issue, and researchers have proposed tools based on traditional power system analysis methods to solve this problem. The harmonic active power method [5], [6] and critical impedance measurement method [7] yield results to a certain degree of accuracy.

However, they are based on some fundamental assumptions, such as prior knowledge of the source impedance. To overcome this drawback, the NN algorithm has been used in [3].

To predict the nonlinear load harmonics by the NN, the weighting vectors of the NN for load harmonics (this is called the admittance weights) are trained in the first stage, as shown in Fig. 3, with a distorted VPCC and current waveforms, which should be measured in the practical situation. In this paper, the sixth-order (r = 6) RMP model replaces the conventional recurrent NN in [3]. Due to the one-shot training property of the RMP model, the nonlinear load harmonics can be estimated in a more exact and effective manner than the other conventional NNs.

At any moment in time after the one-shot training by the RMP model has converged, its trained admittance weights are transferred to the second stage, where the RMP model is supplied with a mathematically generated sine-wave voltage to estimate its output. Therefore, the output of the RMP model in the second stage represents the currents that the nonlinear loads would have injected when a sinusoidal voltage source is supplied at the PCC. In other words, this gives the same information that could have been obtained by quickly removing the distorted PCC voltage (if this were possible) and connecting a pure sinusoidal voltage to supply the nonlinear load, except that it is not necessary to actually do this interruption.

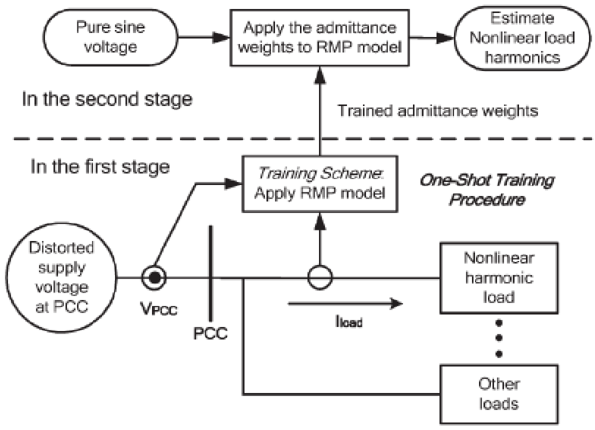

Fig. 3. Estimation procedure for nonlinear load harmonics. [8]

After estimating nonlinear electric load harmonics using the RMP model, the discrete fast Fourier transform is applied to the predicted load harmonics currents in each load. Then, the THD is computed by

$$\mathrm{THD}(i_n) = \left(\sqrt{\sum_{h=2}^{\infty} i_h^2 / i_1}\right) \times 100\ [\%]$$

Where i_1 and i_h are the values of the fundamental and harmonic components in the estimated load currents, respectively.

EXPERIMENTAL RESULTS OF HARMONIC POLLUTION RANKING OF NONLINEAR LOADS IN THE HORMOZGAN DISTRIBUTION POWER SYSTEM

For detection of harmonic pollution ranking in the HORMOZGAN distribution power system, simulation and measurement are done for an area in the BANDARABBAS city by Unilyzer902 Devices in accordance with IEC 61000-4-7. Loads are divided into 4 types include commercial, ministerial, residential and others (hospitals, hotels, universities, terminals). Normalized current of each load with harmonic components is considered in table (1).

Table 1.Currents waveforms

Load type	Current waveform
Commerci	$i_T(t) = 1.0\cos(\omega t) + 0.08\cos(3\omega t) + 0.24\cos(5\omega t)` + 0.54\cos(7\omega t) + 0.07\cos(9\omega t)$
Ministeria	$i_A(t) = 1.0\cos(\omega t) + 0.075\cos(3\omega t) + 0.15\cos(5\omega t) + 0.0744\cos(7\omega t) + 0.033\cos(9\omega t)$
Residentia	$i_{Ms}(t) = 1.0\cos(\omega t) + 0.039\cos(3\omega t) + 0.4799\cos(5\omega t) + 0.2996\cos(7\omega t) + 0.019\cos(9\omega t)$
Other	$i_{Mo}(t) = 1.0\cos(\omega t) + 0.095\cos(3\omega t) + 0.34\cos(5\omega t) + 0.24\cos(7\omega t) + 0.06\cos(9\omega t)$

The estimation is done by the RMP model and the corresponding harmonic components of estimated currents are calculated. The THD [%] of the measured and estimated currents are compared in Table (2). It is clearly shown that there is a small difference in THD values between the measured and estimated currents.

Table 2.Camparison of THD in measured and estimated current

Load type	Commercial	Ministerial	Residential	other
THD[%] measured currents	26.26	12.19	24.60	33.01
THD[%] estimated currents	23.30	10.28	21.16	30.26

DETERMINATION OF HARMONIC POLLUTION RANKING

With the estimated LCR and THD previously obtained, the DPQI for each load is determined by (1). Then, its normalized relative ratio (DPQIR) of $[0.1954, 0.2033, 0.2515, 0.3419]^t$ is obtained. The associated HPR can finally be determined by the order of magnitude of the DPQIR given in Table (3). Each factor of DPQIR indicates how much each load takes the portion of distortion power generated from each load with respect to a PCC in an overall system. It is clearly shown from the result in Table (3) that the residential loads has the worst effect on the system by aggravating the power quality problem with the highest HPR, even though its THD value is not highest among the four different types of loads.

Table3.DPQI and HPR

Load type	Commercial	Ministerial	Residential	other
THD%	26.26	12.19	24.60	23.01
THD Ranking	2	4	3	1
DPQI	15.60	10.10	24.36	9.41
$DPQI_R$	0.2515	0.1833	0.3419	0.195 4
HPR	2	4	1	3
D_R	0.3914	0.2566	0.6090	0.221 8

CONCLUSION

This paper has used a new DPQI has been proposed in [8] to determine the HPR of several nonlinear loads using only current waveforms. The computation of the DPQI has required the computation of the LCR and the THD of the load currents. The LCR has successfully been estimated by the RMP model with the one-shot training property. This RMP model has also been applied to predict the nonlinear harmonics of measured currents when the voltage at the PCC was distorted. It can be preferably used in a practical situation without disconnecting each load from the PCC with the higher convergence speed and accuracy when compared with the other traditional NNs.

The proposed DPQI is expected to provide the important information to a supervisory control and data acquisition system or an advanced metering infrastructure for monitoring and regulating the power quality in a more effective manner.

Each factor of DPQIR indicates how much each load takes the portion of distortion power generated from each load with respect to a PCC in HORMOZGAN distribution power system. It is clearly shown that the residential loads has the worst effect on the system by aggravating the power quality problem with the highest HPR, even though its THD value is not highest among the four different types of loads.

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