

## A SINGLE-POINT METHOD BASED ON DISTORTION POWER FOR THE DETECTION OF HARMONIC SOURCES IN A POWER SYSTEM

**Dejan Stevanović<sup>1)</sup>, Predrag Petković<sup>2)</sup>**

1) *Innovation Centre of Advanced Technologies(ICAT), Vojvode Mišića 58/2, 18000 Niš, Serbia (✉ dejan.stevanovic@icnt.rs, +381 18 529 321)*

2) *University of Niš, Faculty of Electronic Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia(predrag.petkovic@elfak.ni.ac.rs)*

### Abstract

This paper describes a new and efficient method for quantifying and detection of the source of distortion caused by a single customer in a case when many other customers exist in a power grid. It is based on measuring distortion power, a component of apparent power that only exists with a nonlinear load. Different definitions for distortion power calculation are investigated. All these definitions show without doubt that the proposed method is feasible. Moreover, this method allows to develop fair and reliable billing schemes for controlling harmonic pollution. Measurement and simulation results confirm the effectiveness and applicability of the method. The proposed solution is suitable for software/hardware upgrade of existing electronic power-meters.

Keywords: distortion power, harmonic pollution source detection, power meter.

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### 1. Introduction

The last few decades enhanced our lives with plenty smart electronic appliances that make life comfortable. Simultaneously, electronic control systems became inevitable parts of equipment for industrial production. Most of electronic gadgets and apparatus require a DC supply. Therefore, AC to DC converters have become the most numerous loads in a power grid. Unfortunately their nonlinear nature generates harmonics in the power network causing numerous unwanted problems [1, 2, 3]. The permanent growth of the number and types of nonlinear loads aggravates the problems caused by harmonics. That enforced almost every country to introduce its own standard that restricts the allowed amount of each harmonic. Two widely known standards in this area are the IEEE 519-1992 and IEC 61000 series [1], [3]. The standard IEC/EN61000-3-2 entered into force in the European Union. It specifies the limits for the allowed nonlinear distortion of the input current up to the fortieth harmonic. The standard is applied to the distortion produced by electronic and electrical appliances in households. This includes loads up to 16A per phase supplied with voltage up to 415 V. Both standards regulate limits for the harmonics pollution but do not specify what happens if a customer exceeds them. There are two possibilities: the first suggests that the utility could disconnect that customer but that is a stressful and not profitable solution. The better way and the most effective tactic is to charge the harmonics producers a penalty tax if they exceed limits of harmonics pollution. The penalty tax should be proportional to the pollution levels. However, the tax driven regulation may be obstructed by two technical problems: the identification of the harmonics producers, and isolation of the system from the effects of impedance variation. Therefore, a number of experts deal with the problem of load quality measurement and location of nonlinear loads. The main issue that inhibits finding the

global solution to this problem lies in disagreement within the power engineering community on the best definition of the harmonic pollution level [4]. Using the THD factor (Total Harmonic Distortion) as an indicator is not sufficient for analyzing the effects of the pollution load in the power grid [4]. Namely, THD only defines how much the waveform of current/voltage is distorted and does not give information about the nominal power of the load. Disadvantages of THD bring into focus finding other ways to define a Power Quality Index (PQI). The problem with detecting the source of harmonic pollution becomes very urgent and should be solved as soon as possible. Therefore the authors of this paper are motivated to offer a solution that could be implemented as an upgrade to household power meters. Led by this mission we suggest a method capable to locate harmonic producers on the grid and provide the utility with data related to the amount of the pollution for each particular customer.

The paper is organized as follows. In the next section the basic definitions that correlate power parameters with measured current and voltage data will be given. The third section presents a brief survey of existing solutions for location of harmonics producers on the grid. The fourth section will propose a new method that can be used to discover the source of harmonic pollution. Results of simulation and measurement that confirm the proposed method are given in the fifth section before a conclusion.

## 2. Basic definitions of electric power quantities

When harmonics are present in a power system the effect of harmonics should be taken into account. The instantaneous values of the signal (voltage and current) can be expressed as:

$$x(t) = \sum_{h=1}^M X_h \sin(\omega_h t + \alpha_h), \quad (1)$$

where  $h$  is the number of the harmonic,  $M$  denotes the highest harmonic, while  $X_h$ ,  $\omega_h$  and  $\alpha_h$  are the amplitude of the signal (voltage or current), frequency and phase angles of the  $h^{\text{th}}$  harmonic, respectively. The RMS value for a signal expressed by (1), is given as:

$$X_{\text{RMS}} = \sqrt{\sum_{h=1}^M X_{\text{RMS}_h}^2}, \quad (2)$$

where  $X_{\text{RMS}_h}$  is the RMS value of the  $h^{\text{th}}$  harmonic. The product of the voltage and current at the same harmonic frequency gives the harmonic power. The total active power is defined as:

$$P = \sum_{h=1}^M V_{\text{RMS}_h} I_{\text{RMS}_h} \cos(\theta_h) = P_1 + P_H. \quad (3)$$

It could be presented as a sum of components related to the fundamental and other harmonics, where  $P_1$  is the *fundamental active power* while  $P_H$  is *harmonic active power*.

According to Budeanu [3], [5] reactive power is defined as:

$$Q_B = \sum_{h=1}^M V_{\text{RMS}_h} I_{\text{RMS}_h} \sin(\theta_h) = Q_1 + Q_H. \quad (4)$$

where, similarly to (3),  $Q_1$  and  $Q_H$  denote *fundamental reactive power* and *harmonic reactive power*, respectively. The usefulness of  $Q_B$  for quantifying the flow of harmonic nonactive power has been questioned by many authors [6, 7]. However, according to [8], the “postulates of Czarnecki have not won universal recognition”. Field measurements and simulations presented in [7] proved that in many situations  $Q_H < 0$ , leading to cases where  $Q_B < Q_1$ . The reactive power, despite its negative value, contributes to the line losses in the same way as the positive reactive power. As harmonic reactive powers of different orders oscillate with different frequencies one can conclude that the reactive powers should not be added arithmetically, [7]. Thereafter Standard IEEE Std 1459-2010 suggests reactive power to be calculated as:

$$Q_{\text{IEEE}} = \sqrt{\sum_{h=1}^M [V_{\text{RMS}_h} I_{\text{RMS}_h} \sin(\theta_h)]^2} = \sqrt{Q_1^2 + \sum_{h=2}^M Q_h^2}. \quad (5)$$

Equation (5) eliminates the situation where the value of the total reactive power  $Q_B$  is smaller than the value of the fundamental component  $Q_1$ . Besides the previously mentioned, some other definitions for reactive power are given in [9, 10].

Despite all variations, the definition (4) is widely known and is a part of IEEE Standard Dictionary 100-1996. Moreover, most of measurement equipment for reactive power metering is designed according to this definition. Therefore the authors of this paper decided to use it as a reference. It should be noted that in the real world, the actual contribution of harmonics to active and reactive power is small (usually less than 3% of the total active or reactive power [5]). To the contrary, their influence to the total power balance is significant, as will be presented later in this paper.

The main contribution of harmonic components of voltages and currents is related to the *distortion power*  $D$ . According to [5] the phasor power is a vector sum of active and reactive power. This statement is true only for sinusoidal conditions. In the presence of harmonics it is applicable to each harmonic component of active and reactive power separately. The apparent power  $U$  represents a vector sum of phasor power and distortion power [5]. Accordingly, its intensity is calculated as:

$$U = \sqrt{S^2 + D^2} = I_{\text{RMS}} \cdot V_{\text{RMS}}. \quad (6)$$

The term distortion power  $D$ , that is an integral part of the apparent power, was introduced by C. Budeanu in 1927 [11]. Fig. 1 illustrates the geometrical relationship between active  $P$ , reactive  $Q$ , phasor  $S$ , distortion  $D$  and apparent power  $U$ , in a single-phase system with harmonic pollution.

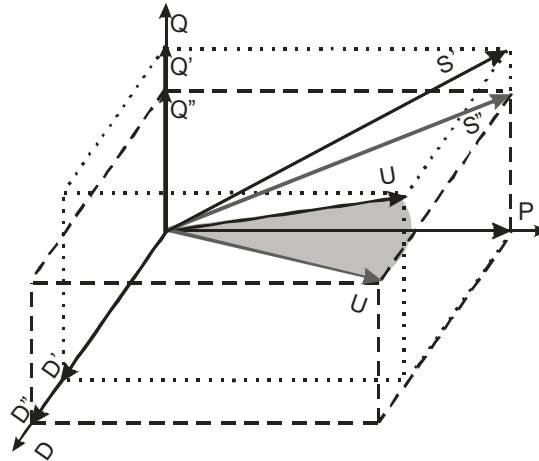


Fig. 1. Geometrical representation of the relationship between active, reactive, phasor, distortion and apparent powers.

According to Fig. 1 it is obvious that distortion power will be equal to zero and apparent power  $U$  will be equal to phasor power  $S$  if there is no distortion (no nonlinear load). Besides, Fig. 1 shows the correlation between different definitions for  $D$  and  $Q$  (denoted as  $D'$ ,  $D''$  and  $Q'$ ,  $Q''$ ). If one considers the case when  $Q' > Q''$ , consequently  $S' > S''$ , he will observe  $D' < D''$ . Notice that apparent power will retain the same value  $U' = U'' = U$ . Namely its value only depends on the RMS value of voltage and current.

### 3. Survey of harmonic producer detection methods

At present, there are several proposed solutions for harmonic source detection in a power grid. All of them can be divided in two groups:

- multi-point methods and
- single-point methods.

The first group of methods is based on a distributed and synchronous measurement system and data collection from different points in the power grid. This method provides precise and complete information about propagation of harmonics in the grid. However, its practical realization is difficult because it requires complex and expensive measurement instrumentation. On the other hand, single-point methods are more convenient for implementation, but less precise. Table 1 summarizes the state of the art of single-point methods that are used for harmonic source detecting or sharing harmonic responsibility between utility and consumer.

Table 1. The state of art focus on the harmonic source detection and sharing harmonic responsibility method.

Method (Indices)	Required Data	Aims
Active Power Direction (APD)	Voltage and current obtained by single point measurement	Harmonic Source Detection
Reactive Power Direction (RPD)		
Nonactive Power Method (NP)		
Harmonic Polluted Ranking (HPR) method	Current obtained by single point measurement	
Critical Impedance Method(CI)	Thevenin's equivalents of utility and consumer sides	Sharing harmonic responsibility between utility and consumer

One of the most common used single-point strategies from Table 1 (APD) is based on monitoring the sign of the harmonic active power  $P_H$  [1, 11, 12]. According to this method a consumer represents a source of harmonic pollution just in case when  $P_H < 0$ . Otherwise, the utility-side pollutes the power grid. This identification of the nonlinear consumer is widespread and has been used in the industry for many years [1, 12]. Many manufactures present this possibility as a key feature of their equipment despite the proofs that it is not 100% accurate [12].

RPD proposes tracking the sign of the harmonic reactive power,  $Q_H$ . It is a complement to APD. Which one will be applied depends on the balance of resistances and reactances of the loads [1, 12]. However, determining the character of impedance is, in most cases, a difficult problem.

NP is based on comparison of three non-active power components [13, 14] that complicates the DSP software of a power meter.

The authors of the HPR method introduce a new power quality index to monitor the effect of each nonlinear load on the *Point of Common Coupling* (PCC) of a power distribution system. It is defined as a product of *Load Composition Rate* and THD. Both parameters are derived from the load current waveform using a complex *Reduced Multivariate Polynomial* model[4].

An alternative group of methods able to share responsibility between harmonic sources relies on measurement of impedance at the grid and the customer side (CI). Theoretically, the method is reliable. Therefore it appears in numerous variations [15]. However this method cannot be implemented easily. The practical problem is that one can determine the impedances only by intruding the system.

The main drawbacks of aforesaid methods are:

- neither of them gives exact quantitative information of a customer which pollutes the grid;
- they cannot be easily implemented within an ordinary electronic power meter, consequently cannot be used for each customer.

Considering all disadvantages of the proposed methods the authors of this paper were inspired to suggest their own solution. The proposed method will be explained in the next section.

#### **4. Harmonic pollution source detection based on distortion power metering**

Here we suggest a quite obvious but entirely new method suitable to identify the location of the sources of harmonic pollution on the network. The method is based on the calculation of distortion power  $D$  according to (6) as:

$$D = \sqrt{U^2 - P^2 - Q^2} . \quad (7)$$

The method will be explained on a theoretical example. We observe a nonlinear load connected to a power system supplied with voltage distorted by 3<sup>rd</sup> harmonic, as presented on the top of Fig. 2. The nonlinear load introduces harmonics 5, 7, 9 to the spectral components of current as presented in the second top diagram of Fig. 2.

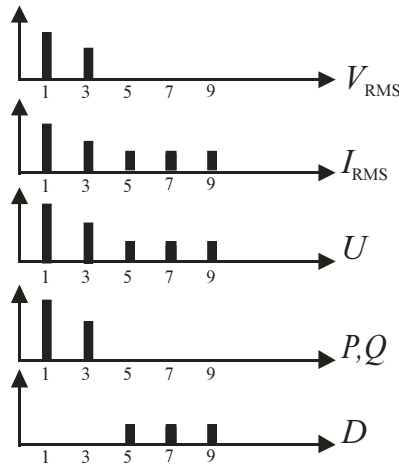


Fig. 2. Spectral components of voltage, current and power on a nonlinear load.

All harmonics will affect the apparent power  $U$ . As stated in Section 2, active and reactive power have only components produced by the same harmonics of voltage and current. Therefore, except the fundamental component, only the 3rd component appears for  $P$  and  $Q$ . On the opposite, the distortion power consists of all other harmonic components. This expresses its nature caused by products of mutually different harmonic components of voltage and current. The lower part of Fig. 2 illustrates the spectral components of  $U$ ,  $P$  and  $Q$ , and  $D$ , respectively.

One easily concludes that  $D > 0$  decidedly means that a nonlinear load exists on the grid. This is the basis of the method that we propose. Its benefits rely on the fact that it is suitable to be implemented in electronic power meters. Namely, all solid state power meters available on the market are able to register  $P$ ,  $Q$  and  $U$ . Therefore only a minor intervention in the software (or DSP hardware) enhances the capabilities of the meter. However, one should not forget that the amount of measured  $Q$  in the presence of harmonics depends on the applied definition. According to different definitions for  $Q$  in presence of nonlinear loads one can argue about the accuracy of the approach.

It is important to remind that the purpose of the method is to provide the utility with means to penalize harmonics producers. Therefore the intention is to suggest a method capable to detect and quantify the amount of the distortion. According to Standard IEC 62052-11, commercial electronic meters register  $Q$  with less accuracy than  $P$ . Consequently Eq. (7) will result with reduced accuracy compared with  $P$ .

Independently of the applied definition for  $Q$ ,  $D$  is proportional to the level of harmonic distortion. The diversity between different values of  $D$  (due to different definitions of  $Q$ ) will cause systematic measurement errors. We want to prove that they will not discriminate any customer. In general there are two types of errors that a measuring method could produce. The first is not to register a value of a quantity when it does exist. The second is detecting a value even if it does not exist. In the context of the suggested method the first one corresponds to the case when the meter reads  $D=0$  on a nonlinear load. The second case matches to reading  $D > 0$  in cases of linear loads.

We claim that the first is not possible because, according to (2),  $I_{RMS}$  in presence of harmonics is always larger than  $I_{RMS}$  of the fundamental harmonic. Therefore  $U^2$  will be always larger than  $(P^2+Q^2)$  in presence of harmonics. The second is possible and requires some deeper analysis that follows.

The main drawback of Budeanu's definition of  $Q_B$  in the context of  $D$  is that there are cases when  $D > 0$  even if the load is linear. However, this can happen only if the voltage is already distorted and the load has a reactive component. Standard IEEE 519-1992 limits voltage THD on the grid to less than 5%. Moreover the main interest of the utility is to keep the distortion as small as possible in order to save expensive equipment. Therefore there is no doubt that the distributor will preserve the supply voltage within  $\text{THD} < 5\%$ . However if voltage is distorted, it is easy to prove (mathematically) that some  $D > 0$  will be registered according to (7). Namely, load impedances at different harmonics are not equal ( $Z_1 \neq Z_3 \neq \dots \neq Z_h$ ). Therefore, the ratio between voltage and current at different frequencies is not equal ( $V_1/I_1 \neq V_3/I_3 \neq \dots \neq V_h/I_h$ ). Consequently, the current waveform is more distorted and some amount of distortion power occurs.

In order to validate the different definitions of  $D$  according to (7), we compared the values obtained for  $D$  when it is assessed using  $Q_B$ ,  $Q_{\text{IEEE}}$  and  $Q_1$ . A linear load was assumed with constant  $|Z|$  for different phase angle  $\theta$ . It was supplied the by a grid voltage of 230V distorted with the third harmonic of 6.9V (3%). In all cases it was registered that  $D_{\text{IEEE}} \approx D_1$ . In all three cases,  $D_B = D_{\text{IEEE}} = D_1 = 0$  for purely active loads,  $\theta = k\pi$ , and is maximum for purely reactive loads,  $\theta = (2k+1)\pi/2$ . Then the greatest discrepancy between  $D_B$  and  $D_{\text{IEEE}} = D_1$  exists. Namely for the given case study it is  $D_B/U = 2\%$  while  $D_{\text{IEEE}}/U = D_1/U = 3.16\%$ . Having in mind that the load is linear, this power can be treated as a *phantom distortion power* that should not be registered and appears as an error.

This analysis shows that Budeanu's definition for  $Q$  leads to a smaller amount of error. Besides, from the point of view of real billing, a meter can be set not to register  $D$  if it is smaller than a threshold specified by the utility ( $D_t$ ). Practically, the utility should specify a margin of acceptable  $D$  that will not jeopardize the power system. Consequently, this criterion prevents the utility to charge the customer for producing an allowed amount of harmonics by the standards IEEE 519-1992 and IEC/EN61000-3-2.

Another problem appears with Budeanu's definition of  $D$  if the signs of harmonic components of  $Q$  are opposite. According to possible cancellation of harmonic components in  $Q_B$  with opposite sign, the total  $Q_B$  can be less than  $Q_1$ . However, it is obvious that  $U$  does not depend on  $Q_B$ . Therefore  $D$  will increase when  $Q_B$  decreases and the utility will have insight into the harmonic producer.

All three approaches to  $D$  calculation within a power meter, related on  $Q_B$ ,  $Q_{\text{IEEE}}$  and  $Q_1$ , indubitably detect the location of the nonlinear source whenever  $D > D_t$ . Unlike some other approaches, this method does not require spectral analysis of voltage and current [1, 11, 12]. All required values of  $U$ ,  $P$ , and  $Q$  can be easily calculated using measured samples of voltage and current obtained from an analog/digital converter. This approach is common in electronic power meters. Therefore only slight upgrades are sufficient to capacitate the meters with ability to identify sources of harmonic pollution. Thereafter the utility is able to warn, penalize with extra tax or even to disconnect the harmonic producers from the grid.

The effectiveness of the suggested method is confirmed by a set of simulations of the most frequently used benchmark loads. Besides, the method has been verified by real measurement using industrial power meters. The following section summarizes simulation and measurement results.

## 5. Simulation and measurement results

### 5.1 Simulation results

The easiest way to confirm the suggested method was to code equations (2, 3, 4, 6) and (7) as an original MATLAB script and run a set of simulations. In order to simulate a realistic case, we supposed that the voltage is polluted with 3<sup>rd</sup> harmonics whose amplitude is 3% of the fundamental. Actually it corresponds to the sine characterized with 50Hz and 230V RMS but with flattened top and bottom peaks of the sine-wave. We considered six cases with different types of loads connected to the grid. Namely they are:

- a) Heater (HR)
- b) Fluorescent lamp (FL)
- c) Delta Connected TCR (DTCR)
- d) Adjustable speed drive (ASD)
- e) Six-Pulse HVDC (HVDC)
- f) 6-pulse PWM controlled variable speed drive (PWM VSD)

The current waveform of simulated load is shown in Fig. 3. Fig. 3.a illustrates currents of HR, FL and DTCR, while Fig. 3.b presents waveforms of currents through ASD, HVDC and PWM VSD. The first simulated load has a linear characteristic. Therefore, the obtained currents track the voltage waveform. All other loads are nonlinear. Consequently they draw current with new harmonic components. Their amounts for all aforementioned nonlinear loads are measured and published in [3], [16]. Therefore we used the data considering them as benchmarks known to the power electronic community.

Table 2 reviews the simulation results. All quantities in Table 2 are denoted according to annotation in equations (2–7). Two additional parameters are  $THD_V$  and  $THD_I$ . They stand for total harmonic distortion of voltage and current waveforms, respectively. As stated in the previous section,  $D_{IEEE}$  and  $D_I$  are obtained when  $Q_B$  is replaced with  $Q_{IEEE}$  and  $Q_I$  in (7), respectively. Moreover, Table 2 includes another form for distortion power estimation. It relies on  $THD_I$  and consequently is denoted as  $D_I$ . Namely, this defines distortion power as a multiplication of  $THD_I$  and  $U_1$  (fundamental apparent power), according to [7].

Table 2. Simulation results.

	Heater	FL	DTCR	ASD	HVDC	PWMVSD
$I_{RMS}[A]$	10.00	0.1	10.03	11.52	10.33	14.23
$V_{RMS}[V]$	230.10	230.1	230.10	230.10	230.10	230.1
$P_i[W]$	2300.00	17.31	1570.94	2299.21	1491.90	2300
$P_H[W]$	2.07	0.01	0.00	37.40	0.00	3.11
$P[W]$	2302.07	17.31	1570.94	2336.61	1491.90	2303.11
$Q_i[VAR]$	0.00	15.15	-1679.92	60.21	1750.50	0
$Q_H[VAR]$	0.00	0.14	0.00	-0.46	0.00	-5.38
$Q_B[VAR]$	0.00	15.29	-1679.92	59.75	1750.50	-5.38
$Q_{IEEE}[VAR]$	0.00	15.15	1679.92	60.21	1750.50	5.38
$U[VA]$	2302.07	23.6	2307.79	2649.93	2377.95	3274.51
$THD_V[\%]$	3.00	3	3.00	3.00	3.00	3
$THD_I[\%]$	3.00	22.85	7.65	49.60	25.23	101.25
$D_B[VAR]$	0.00	4.86	189.45	1248.53	603.87	2327.68
$D_{IEEE}[VAR]$	0.00	5.28	189.45	1248.51	603.87	2327.68
$D_I[VAR]$	0.00	5.28	189.45	1248.51	603.87	2327.68
$D_I[VAR]$	68.97	5.26	175.84	1140.74	580.25	2328.69



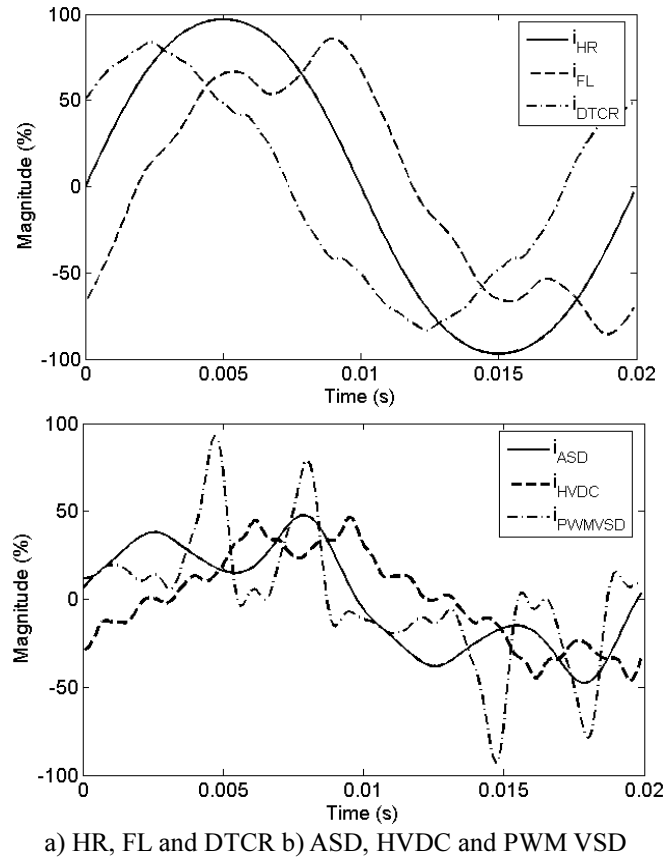


Fig. 3. Current waveforms.

As expected, for linear resistive loads, the active power,  $P$ , equals phasor power,  $S$ , and the apparent power,  $U$ . Therefore the distortion power calculated using (7) equals zero independently of the definition for  $Q$ . However  $D_i$  gives quite inaccurate results for linear resistive loads because the nonlinearities of the current are caused entirely by a nonlinear voltage supply. Consequently, this power quantity cannot be used for identification of the source of harmonic pollution.

For nonlinear loads, all four methods for determining  $D$  offer comparable results. The obtained value for  $P_H$  in Table 2 shows that this value in some situation gives incorrect information about the location of the source of harmonic pollution as claimed in [12]. Namely, the waveforms of currents and calculated  $THD_i$  clearly indicate the level of nonlinearity for each particular load. Consequently, it is expected that the sign of harmonic active power will be negative and show that the harmonic producer is a customer, but that is not the case. The obtained sign of harmonic active power shows that the utility is mainly responsible for the harmonic distortion, but that is not true.

The achieved data for distortion power show three very important facts. Firstly, for all nonlinear loads  $D_B$ ,  $D_{IEEE}$  and  $D_1$  are greater than 0. Consequently, this confirms the suggested method. Secondly, all three definitions of  $D$  ( $D_B$ ,  $D_{IEEE}$  and  $D_1$ ) applied at real loads give very similar results. Slight differences in definitions for  $Q$  and  $D$  introduce systematic errors that could be compensated with billing politics. Actually overcharge in  $Q$  causes undercharge in  $D$ . Finally, results indicate that the amount of distortion power ( $D_B$ ,  $D_{IEEE}$  and  $D_1$ ) should not be neglected because it could be of the same order of magnitude as active power. Overlooking  $D$  could cause considerable losses in the power grid [17, 18] Simulation results confirmed the presented theory. The following verification step

was to implement the method within an off-the-shelf power meter and to perform measurements of true loads. The subsequent section presents the obtained results.

## 5.2 Measurement results

The major challenge for implementation of any new method is its applicability. Although the theory is quite plain and intuitively promises usability it should be proved on a real commercial power meter. The only requirement was that the meter is capable to register  $U$ ,  $P$  and  $Q$ . We used a meter produced by “EWG electronics” [19]. It is based on a standard integrated circuit 71M6533 provided by MAXIM. The power meter completely fulfills IEC 62052-11 standard [20]. It offers data for  $P$ ,  $Q$ , and  $U$  according to expressions (3), (4), and (6), respectively. The only additional effort was to collect data provided by the meter and to acquire them using a PC.

Fig. 4 illustrates the implemented set-up. The simplicity of the set-up is obvious. It consists of the meter, the load and a PC. The meter sends the measured data over its optical port. The PC collects them through its RS232 port. Dedicated software processes data and transfer them to a Matlab script that calculates the distortion power.

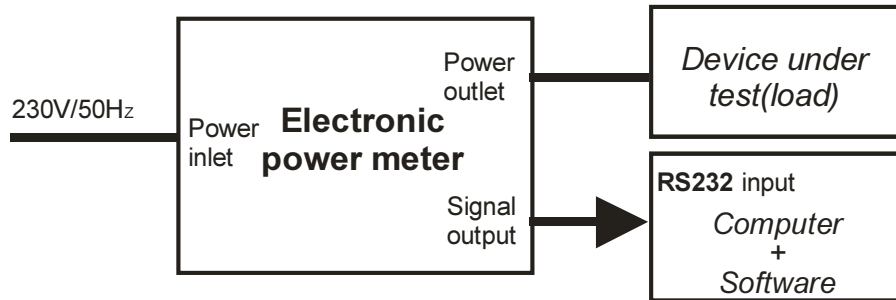


Fig. 4. System set-up for distortion power measurement.

Table 3 presents the measured results of the most frequently used loads in households and offices. The first load in Table 3 represent a group of linear resistive loads. According to the theory, distortion power for these loads needs to be zero but that is not the case. Someone can say that the method is not good, but that will not be true. The small value of  $D$  for linear resistive loads occurs due to inaccuracy of power meters. The error that occurs during calculation of distortion power in our case is 0.8% of apparent power. Notice that the power meter is designed according to the standard [19]. So the amount of the error depends on the accuracy class of the power meter.

The rest of loads from Table 3 represents a group of non-linear loads. The value of distortion power for these loads is between 17% of apparent power for an air conditioner (cooling mode) and 87% of apparent power for a LED Parlamp15W. The percent of distortion power related to apparent power is not negligible, especially for energy saving lamps. This type of ballast lamps was chosen as a representative of increasingly used nonlinear loads. Although they are small when considered separately but in total they reach up to 20% of the total power consumption [21]. All obtained results undoubtedly show that the value of distortion power clearly indicates if a consumer produces harmonic pollution or not. Moreover, the amount of the contamination corresponds to the registered distortion power. The obtained results for similar types of energy saving lamps are in consistence with data recently published in [22].

Table 3. Measurement results for different types of household loads and energy saving lamps.

Load	$V_{RMS}[V]$	$I_{RMS}[A]$	$U[VA]$	$P[W]$	$Q[VAR]$	$D[VAR]$
Water kettle	216.24	7.906	1709.59	1709.54	0.39	13.51
Air conditioner-cooling mode	217.14	4.729	1026.86	1006.03	107.44	175.48
Air conditioner-fan mode	221.07	0.15	33.16	22.00	18.32	16.73
Dell E2310H	222.36	0.18	40.91	23.33	-7.06	32.86
DELL-Optiplex980	221.25	0.30	66.15	55.83	-33.05	12.92
CFL20W bulb	218.55	0.13	29.07	18.30	-8.81	20.79
CFL20Wtube	216.91	0.11	24.08	13.86	-7.15	18.34
CFL15W helix	218.55	0.15	32.13	18.95	-10.26	23.83
CFL11Whelix	221.73	0.08	17.74	10.42	-5.38	13.31
CFL9Wbulb	216.06	0.06	12.75	7.58	-3.64	9.58
LED Parlamp15W(9x1.5W)	217.27	0.16	34.11	16.90	-3.87	29.38
LED Reflector 30W	222.72	0.27	60.58	32.23	-8.96	50.51
LED Reflector 10W	223.05	0.09	20.74	10.81	-3.75	17.30
LED Bulb 6W	222.65	0.04	9.35	5.10	0.96	7.78
LED MiniBulb 3x1W	215.86	0.03	7.34	3.91	-1.00	6.13
LED Bulb 3W	217.9	0.034	7.41	3.96	-0.89	6.20

The main advantage of the proposed method lies in its compatibility with the existing electronic power meters. Actually, instead of using the PC, an updated firmware could make the microprocessor unit embedded in the power meter to calculate  $D$ . In addition, this solution can be implemented as a hardware upgrade of DSP that is a part of solid state power meters. We intend to enhance the features of the DSP block in own ASIC power meter circuit that was designed in the LEDA laboratory, University of Nis [23].

## 6. Conclusion

This paper suggested a new method for detection of nonlinear loads in a power grid. The technique is based on distortion power measurement. Different definitions of distortion power seem to be an obstacle to such approach. Therefore the authors compared four definitions on six practical examples. Thereafter the authors claim that differences between them do not affect the possibility to locate a nonlinear load. Actually in a system with distorted supply voltage all definitions result with an offset distortion power on linear reactive loads. However, as the utility has to keep voltage distortion in narrow limits defined by a standard, the amount of the offset could be predicted for every type of distortion power definition. The method is established on using Budeanu's relationship between apparent, active, reactive, and distortion power. The confirmation of the proposed method is done on the set of lamps and some gadgets that commonly appear in offices and households.

Power meters enhanced with distortion power metering provide the utility an insight into location and the amount of pollution with harmonics introduced to the grid by every particular consumer. The amount of distortion power correlated with penalty tax policy afford the utility a mechanism to extra-charge the harmonics producers. Large nonlinear loads are a reality on the grid and their devastating effects to the system should be prevented. The first step in that direction is their reliable location.

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