# Detection of Disturbing Loads in Power Systems using Non-Active Powers

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## ABSTRACT
This paper detects the disturbing loads in distorted and/or un-balanced three phase three wire power system. It is based on the simultaneous measurement of four non-active power quantities, which are found on the IEEE Std.1459-2000 method. It allows, achieving better knowledge of the power system when both harmonic distortion and un-balance are present. The proposed method requires only the fundamental components from the harmonic content of voltage and current. The advantage of this method is, it does not require any spectral analysis of voltage and current. In this paper, usefulness is discussed by means of number of model tests, which were carried out on an effortless test system.

## Keywords
Power Quality, Detection of harmonic sources, Power Definitions, Harmonic Distortion.

## 1. INTRODUCTION
In the last decade, harmonic distortion in power systems has hugely increased, because of increase in non-linear loads, which draw non-sinusoidal currents. Thus, it becomes very important to target the definition of significant electrical quantities that can be used to evaluate power quality levels at the metering section and to determine consumers and utilities polluting contributions, with respect to the harmonic distortion. Harmonic sources can be located both upstream and downstream of the metering segment [1]-[3]. Here, both load and supply may be accountable for harmonic distortion in the system; harmonics may be created by the load, others by the system, and others by both load and system. In the existence of the negative sequence components in currents and voltages, harmonic source detection is difficult because of the overlapping effects due to un-balance and non-linearity.

Considering this, the conventional quantities used for the electrical energy pricing do not take into account the presence of harmonic distortion on the metering segment. The sinusoidal voltages and current case the traditional concepts of active, reactive, apparent power and related power factor that are well defined [4]-[5]. On the other hand, in non-sinusoidal situations, the harmonics on voltages and currents generate several terms of the instantaneous power that do not contribute to the total convey of energy. Here this issue is still in debate and there is not yet a universal power theory that can be held as a common support for power quality evaluation, harmonic sources detection and compensation in power systems.

In this filed, the only accessible standard is the IEEE Std. 1459-2000 [6]. It gives a set of definitions for electric power measurement under nonsinusoidal, sinusoidal, balanced, or unbalanced conditions. The concept for apparent power resolution is the separation of the fundamental positive sequence components of voltages and currents. In three-phase systems, the IEEE standard 1459 introduces the effective voltage and current (Ve, Ie), which are associated to an equivalent essential balanced system, has the similar losses of the unbalanced system. In the survey, different methods have been planned for the detection of harmonic sources.

It can be classified into two groups, namely distributed synchronous method and single point measurement method. Normally distributed synchronous method produce correct details of the harmonic state of the overall power systems. This method of implementation is difficult and it requires more complex and expensive measurement device. On the other side, single-point methods are more advantages such as, easy implementation, low cost, and minimum risk of system failure, but in a few conditions, they can report imprecise in order about the harmonic level of the system.

Many of the above mentioned methods have been based on the amount of the harmonic active power flow at the metering section of the power system. The "non-active" powers are based on the simultaneous measurements of the three different non-active power quantities at the same metering section in the power systems [7]. These quantities were derived from the single phase apparent power resolution of IEEE Standard 1459. The scheme was extended to the three-phase systems, by allowing for each of the non-active powers as the amount of the respective phase quantities.

It was verified that the technique was able to give some useful information for the detection of the loads producing harmonics, in both the single phase and the three-phase case, but this method was not entirely suitable for unbalanced conditions. In reality, in the existence of both harmonic distortion and unbalance, the separation of the effects of the unbalance and non linearity was not directly achievable. Additionally, the method was accessible only for four wire systems [8].

This paper presents a further improvement of the above mentioned method presented for three-phase distorted and/or unbalanced systems in three phase three wire systems. The new method is based on the simultaneous assessment of four non-active power quantities that are conceptually related to those of the previous method, but they are directly derived from the three-phase effective apparent power resolution of the IEEE Standard 1459, for the most general case of a non sinusoidal and unbalanced system. The advantage of this method is that it allows one to achieve better information about the harmonic distortion and un-balance present in the power system. As the previous method, [9] the new method is easy to implement because it is based on the separation of the fundamental component from the harmonic content of voltage and current. It can be fully implemented in the time domain, by using a technique already developed in [10] for the detection of fundamental and harmonic components of voltages and currents.

# 2. THE PROPOSED METHOD

## 2.1 Overall Summary and Limitations Of Previous Method

In non-active power, [7] and [11] presented a new method for the detection of harmonic sources in upstream or downstream at the metering section. Here only three quantities are determined, which is not sufficient. The fictitious reactive power ($Q_X$) is derived from the IEEE Standard 1459-2000.

In detail for the single phase case, the above mentioned method was based on the comparison of the fictitious reactive power ($Q_X$) with the other two quantities previously defined in IEEE 1459 -2000. These quantities are measured in the same metering section and same working conditions.

- Fundamental of the reactive power,

$$Q_1 = V_1 I_1 \sin\theta_1 \tag{1}$$

- Non-active power for three phase,

$$N = \sqrt{S^2 - P^2} \tag{2}$$

- Fictitious reactive power of the system ,

$$Q_X = V\sqrt{[I_1^2 \sin^2\theta_1 + I_H^2 \sin^2\theta_H]} = V\sqrt{\left[I_1^2 \sin^2\theta_1 + \frac{D_H^2}{V_H^2}\right]}, \tag{3}$$

where, P is active power, θ is angle between voltage and currents, S is the apparent power; $I_1$ is the rms of the fundamental current, V is the rms value of voltage. $D_H$ is the distortion power and VH is the rms value of the harmonic voltage content (Considered as a whole system harmonic). This method is extended to three phase test systems by taking the individual non-active powers.

In a specified distorted working condition: Q1 can be measured as a minimum value. This value is taken as the reference value and it is the only non-active power in the sinusoidal case, the non-active power N is a maximum reference value, since it groups all the Non-active components of the apparent power, the three quantities Q1 ≤ QX ≤ N, here QX includes Q1 but it is not the power component of the non-active power. In sinusoidal case all the three quantities are equal. The arithmetic method is suitable only for single phase systems since the phase to neutral voltage is necessary. It was extended to the three wire balanced system.

## 2.2 Enhanced Method

The enhanced method is to develop, to avoid the above limitations. Fig. 1. Shows the IEEE Standard 1459-2000 the effective apparent power resolution is decomposition of unbalanced and non-sinusoidal case. For the enhanced method, these two quantities can be used as an alternative of $Q_{1(abc)}$and $N_{1(abc)}$. Table. 1. Shows the summary and grouping of IEEE Std.1459-2000 quantities for three phase system.

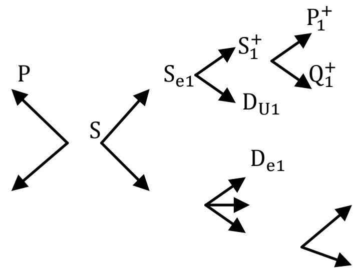



**Fig.. 1. IEEE 1459-2000 effective apparent power resolution**

In the enhanced method, the formulation of the fictitious reactive power should be customized, in order to take the effective power quantities of the system and for the indication unbalanced case. With the same method new fictitious effective reactive power can be established by substituting the, single phase quantities of the formulation effective power quantities

$$\mathbf{Q_{eX}^{*}}^{\mathbf{2}} = \mathbf{9V_e^2[I_{e1}^2\left(1 - \frac{P_1^2}{S_{e1}^2}\right) + \frac{D_{eH}^2}{9V_{eH}^2}]} \tag{4}$$

Where, the two addenda should correspond to the assistance to the non-active power correspondingly due to the fundamental and the harmonic effective current. Still this formulation does not put in confirmation for the contribution of the unbalance, which is essentially included in the first addendum. The fictitious effective reactive power can be found by using the $S_{U1}$ (Fig.1.).

$$Q_{eX}^2 = 9V_e^2[I_1^{+2}\sin^2\theta_1^+ + (I_{e1}^2 - I_1^{+2}) \times (1 - \frac{P_1^2 - P_1^{+2}}{S_{U1}^2} + \frac{D_{eH}^2}{9V_{eH}^2})] \tag{5}$$

Where

The first add-on represents the involvement to the Non active power due to the fundamental positive- sequence component of the current.

The second add-on represents the contribution due the load unbalance.

The third addendum denote the contribution due to the Harmonic current and last one was considered as a complete with this formulation the charity of unbalance and harmonics can be separated.

The above formulation can be divided into another quantity namely fictitious effective harmonic reactive power (3) i.e.,

$$Q_{eXH}^2 = 9V_e^2[I_1^{+2}\sin^2\theta_1 + \frac{D_{eH}^2}{9V_{eH}^2}] \tag{6}$$

Finally it can be noted that Q1+ ≤ $Q_{eXH}$ ≤ $Q_{eX}$ ≤ N. Here $Q_{eXH}$ and $Q_{eX}$ include $Q_1^+$. The four quantities are equal in sinusoidal balanced condition at the same time arithmetic method also equal but three quantities only present. The values differ in harmonic distortion and unbalance condition. In the case of non-sinusoidal and balanced condition, the second term of (5) is not absent. The enhanced method and arithmetic method are same because of $Q_1^+ = Q_{1(abc)}$, $N = N_{(abc)}$and $Q_{eXH}$ = $Q_{eX}$ =$Q_{X(abc)}$. These differences are depends on the supply and load conditions.

The four power quantities are calculated in the same metering section and in the same working condition. It can balanced and unbalanced cases in three phase systems. Finally the enhanced method gives complete information on the state of the system as compared with those of the arithmetic method.

**Table.1. Summary and grouping of ieee std. 1459-**

| Quantity | Combined | Fundamental | Non-fundamental |
|---|---|---|---|
| Apparent (VA) | $S_e = 3V_eI_e$ | $S_{e1} = 3V_{e1}I_{e1}$, $S_1^+ = 3V_1^+I_1^+$ <br> $S_{U1} = \sqrt{S_{e1}^2 - {S_1^+}^2}$ | $S_{eN} = \sqrt{S_e^2 - S_{e1}^2}$, $S_{eH} = 3V_{eH}I_{eH}$ |
| Active (W) | $P = \sum_{a,b,c}\sum_{h=1}^{n} V_hI_h\cos\theta_h$ | $P_1^+ = 3V_1^+I_1^+\cos\theta_1^+$ | $P_H = \sum_{a,b,c}\sum_{h=1}^{n} V_hI_h\cos\theta_h$ <br> $= P - P_1$ |
| Non-active (VAR) | $N = \sqrt{S_e^2 - P^2}$ | $Q_1^+ = 3V_1^+I_1^+\sin\theta_1^+$ | $D_{e1} = 3V_{e1}I_{eH}$, <br> $D_{eV} = 3V_{eH}I_{e1}$ <br> $D_{eH} = \sqrt{S_{eH}^2 - P_H^2}$ |
| Line utilization | $PF = P/S_e$ | $PF_1^+ = P_1^+/S_1^+$ | - |
| Harmonic Pollution | - | - | $S_{eN}/S_{e1}$ |
| Load Balance | - | $S_{U1}/S_1^+$ | - |

Table. 2 shows the conclusion about the enhanced method. It gives the disturbing load detection.

**Table. 2. The Enhanced Method**

| **QUANTITIES** | **CONCLUSION** |
|---|---|
| 1.The values obtained for all the non-active powers are equal. | It is purely sinusoidal and balanced |
| 1.The difference between $Q^+_1$ and N is high, and $Q_{eXH}$ and $Q_{eX}$ are closer to N than to $Q^+_1$ ; <br> 2. Moreover, $Q_{eX} = Q_{eXH}$ | 1.Non-linearity of the load is detected <br> 2.Load is balanced |
| 1.The difference between $Q^+_1$ and N is high <br> 2. $Q^+_1 \cong Q_{eXH}$ and $Q_{eX} \cong N$; <br> 3.The difference between $Q^+_1$ and N is | 1.Indicating that a disturbing load is present <br> 2.Load is linear <br> 3.Due to unbalance |
| 1.The differences among $Q^+_1$ , $Q_{eXH,}$ $Q_{eX}$ , and N are high, and <br> 2.$Q_{eXH} < Q_{eX}$ | 1.Load is nonlinear and <br> 2.unbalanced |
| 1.Four power quantities are close to each other <br> 2. $Q_{eX} = Q_{eXH}$ | 1.Load is not disturbing <br> 2.Load is balanced |
| 1. $Q^+_1$ and N is high, $Q_{eXH}$ and $Q_{eX}$ are closer to N than to $Q^+_1$ ; <br> 2. $Q_{eX} = Q_{eXH}$ | 1. Disturbing load is nonlinear <br> 2. Load is balanced |
| 1. $Q^+_1 = Q_{eXH} < Q_{eX} \cong N$ <br> 2. Values are different from test C | 1.Unbalanced load is present <br> 2.Supply is non sinusoidal |
| 1. $Q^+_1 < Q_{eXH} < Q_{eX} < N$. <br> 2. Values are different from test D | 1.Load is unbalanced <br> 2.Supply is nonlinear |

## 3. SIMULATION RESULT FOR PROPOSED SYSTEM

The simulation tests were out on a simple three phase three wire test system, which was already developed by the authors for the arithmetic method.

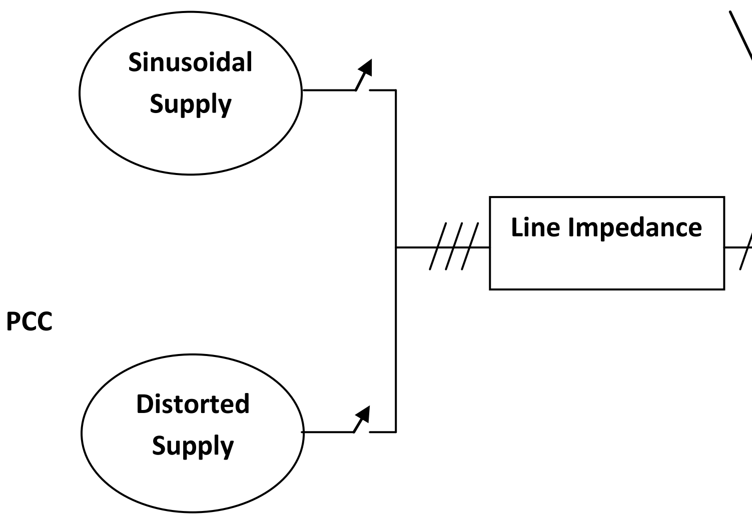


**Fig 2. Three phase test system**

The three phase three wire test system is to simulate under various working conditions with sinusoidal or distorted supply and non-linear or linear and/or balanced or unbalanced loads (see fig. 2). Simulation tests are carried out for the following working conditions. Test

Test A - Sinusoidal supply voltage and linear balanced load (Switches 1 and 3 blocked; 2, 4, and 5 releases);

Test B - Sinusoidal supply voltage and nonlinear balanced load (Switches 1 and 5 blocked; 2, 3, and 4 releases);

Test C - Sinusoidal supply voltage and linear unbalanced load (Switches 1 and 4 blocked; 2, 3, and 5 releases);

Test D - Sinusoidal supply voltage and nonlinear unbalanced Load (Switches 1, 4, and 5 blocked; 2 and 3 releases);

Test E -Non sinusoidal supply voltage and linear balanced load (Switches 2 and 3 blocked; 1, 4, and 5 releases);

Test F -Non sinusoidal supply voltage and nonlinear balanced load (Switches 2 and 5 blocked; 1, 3, and 4 releases);

Test G -Non sinusoidal supply voltage and linear unbalanced load (Switches 2 and 4 blocked; 1, 3, and 5 releases);

Test H -Non sinusoidal supply voltage and nonlinear un-balanced load (Switches 2, 4, and 5 blocked; 1 and 3 releases).

In all the above simulation cases, line to neutral voltages, line to line voltages and line currents were noted at the point of common coupling (PCC). Also four power quantities $Q_1^+$, $Q_{exh,}$ $Q_{Ex}$ and N were evaluated. In fig. 3 obtained results are tabulated and it can be observed that the enhanced method is able to detect the existence of the nonlinear loads. It discriminated whether the system is balanced or unbalanced.

In overall view, the following considerations can be made for individual test conditions.

Test A: The obtained values for all the non-active powers are identical. Thus, it determined that the functioning Circumstance is virtuously sinusoidal and balanced (i.e., sinusoidal source energy and direct balanced load).

Test B: In arithmetic method, the difference between the values of $Q_{1(abc)}$ and $N_{(abc)}$ is high and $Q_{X(abc)}$ is near to $N_{(abc)}$. So, it concludes that disturbing load is present. On the other hand the enhanced method leads to the same result. i.e. the difference between $Q_1^+$ and N is high values and $Q_{eX}$ and $Q_{eXH}$ are closer to N than to $Q_1^+$. Thus indicate the non linearity of the load is detected. Moreover, $Q_{eX}$ and $Q_{eXH}$ have equal values. These values indicate that the load is balanced. Finally enhanced method leads to the conclusion that the disturbing load is nonlinear and balanced.

Test C: In enhanced method, the difference between $Q_1^+$ and N is high, thus represents that, a disturbing load is present. $Q_1^+ \cong Q_{eXH}$ and $Q_{eX} \cong N$. therefore , the load is linear and $Q_1^+$ and N difference is high due to the unbalance condition. But the arithmetic method gives only the harmonic distortion condition. i.e., equal values for $Q_{1(abc)}$, $Q_{X(abc)}$ and $N_{(abc)}$

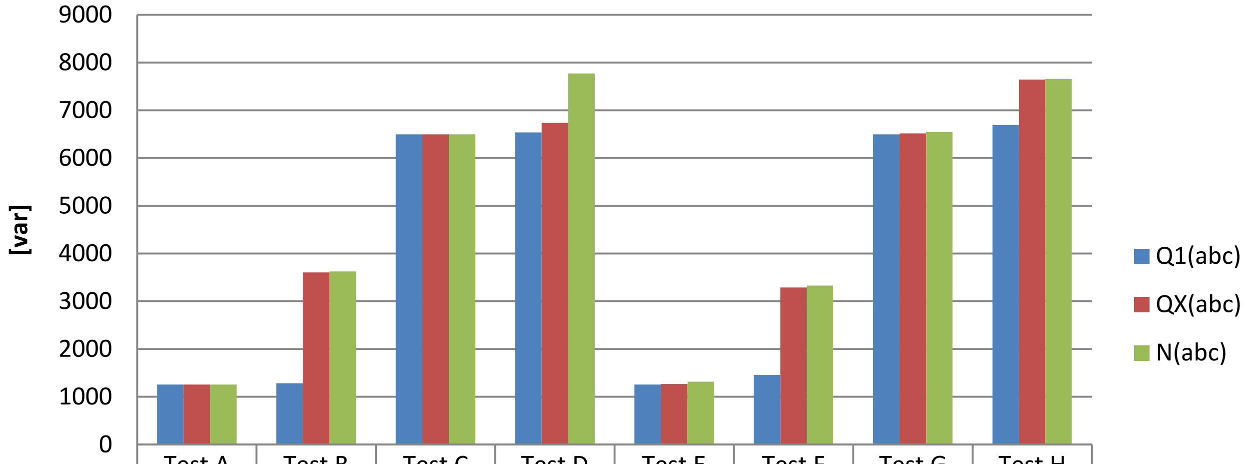
Test D:The result of the arithmetic method leads to the conclusion that, disturbing load is in attendance. Seeing as the difference among $Q_{1(abc)}$and $N_{(abc)}$ is high, and $Q_{X(abc)}$ is closer to $N_{(abc)}$. This approach is not able to clearly understand whether the load is unbalanced. The enhanced method it is possible to achieve the above information. Here the difference among the power quantities are high and $Q_{eXH} < Q_{eX,}$ this indicating that the load is unbalanced and nonlinear.

Test E: In these cases, three quantities of the arithmetic method are close to each other but the small variance among them due to the distortion in the system that is introduced by the supply. But the four quantities of the enhanced method are equal so conclude load is not disturbing. The quantities $Q_{eX} = Q_{eXH}$ indicate that the load is balanced.

Test F: Since for test B, the results of the arithmetic method leads to the termination that a disturbing load is present. The values of $Q_{1(abc)}$ and $N_{(abc)}$ are high, and $Q_{X(abc)}$ is near to $N_{(abc)}$. On the other hand, the enhanced method leads to the termination that the disturbing load is non-linear and balanced. The variation between $Q_1^+$ and N is high. $Q_{eXH}$ and $Q_{eX}$ are closer to N than to $Q_1^+$ and $Q_{eX} = Q_{eXH}$. Observably, the values obtained are dissimilar from individuals of test B, because of the distortion in the system that is introduced by the supply

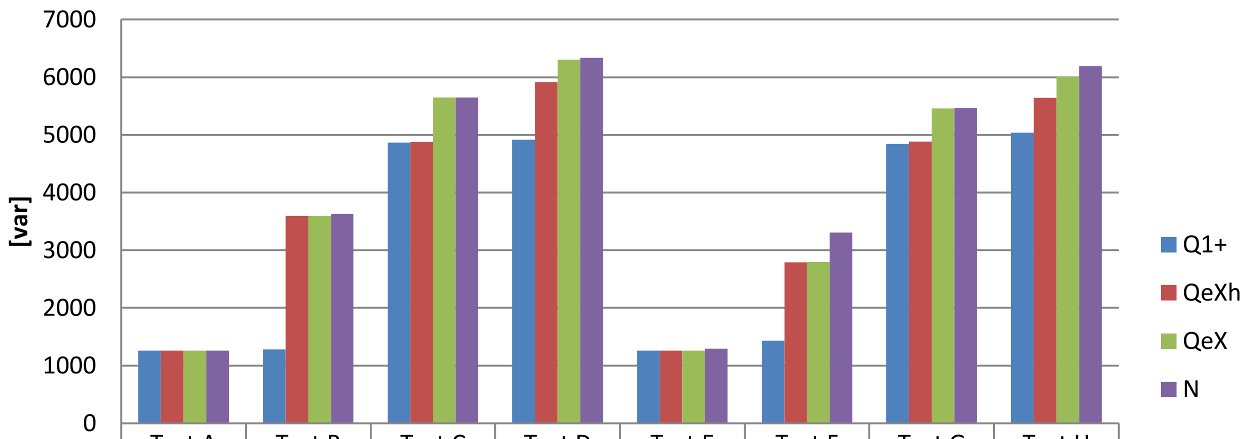
Test G: Because for test C, the values assumed by the three power quantities of the arithmetic method are not very dissimilar from each other. It represents the incidence of a harmonic disturbance that is introduced by the supply side of the system. Again,

**Arithmetic Approach**




| | Test A | Test B | Test C | Test D | Test E | Test F | Test G | Test H |
|---|---|---|---|---|---|---|---|---|
| Q1(abc) | 1258 | 1282 | 6501 | 6540 | 1258 | 1459 | 6501 | 6692 |
| QX(abc) | 1258 | 3608 | 6501 | 6740 | 1271 | 3291 | 6519 | 7642 |
| N(abc) | 1258 | 3629 | 6501 | 7770 | 1315 | 3333 | 6542 | 7659 |

**Enhanced Approach**




| | Test A | Test B | Test C | Test D | Test E | Test F | Test G | Test H |
|---|---|---|---|---|---|---|---|---|
| Q1+ | 1258 | 1282 | 4868 | 4915 | 1257 | 1432 | 4842 | 5038 |
| QeXh | 1258 | 3595 | 4878 | 5914 | 1260 | 2792 | 4882 | 5640 |
| QeX | 1258 | 3595 | 5649 | 6304 | 1260 | 2794 | 5461 | 6009 |
| N | 1258 | 3629 | 5649 | 6335 | 1290 | 3306 | 5463 | 6190 |

| **Test A** | **Test B** | **Test C** | **Test D** | **Test E** | **Test F** | **Test G** | **Test H** |
|---|---|---|---|---|---|---|---|
| Sinus. supply Linear balanced load | Sinus. supply Linear balanced load | Sinus. supply Linear unbalance d load | Sinus. Supply Nonlinear unbalance d load | Nonsin. supply Linear balanced load | Nonsin. supply Nonlinear balanced load | Nonsins. supply Linear unbalance d load | Nonsin. supply Nonlinear unbalanced load |

**Fig. 3. Simulation results for three phase three wire test system.**

Again, this method is not able to sense the occurrence of an unbalanced load of the enhanced method, it can be deduced that an unbalanced load is present. The values of the power quantities are different from those of test C because of the non-sinusoidal supply present in the system.

Test H: As in the case of test D the result of arithmetic method $Q_{1(abc)}$, $Q_{X(abc)}$ and $N_{(abc)}$ lead to the termination that a disturbing load is present, here $Q_{X(abc)}$ is closer to $N_{(abc)}$ and $Q_{1(abc)}$, $N_{(abc)}$are from test D since of alterations introduces by the supply. But this method is not able to detect whether the load is unbalanced condition or not. The enhanced method is possible to achieve these details .i.e., the values of $Q_1^+ < Q_{eXH} < Q_{eX} < N$.

Finally, the results of the enhanced method are able to give more complete information on the test system as compared with those of the arithmetic method.

## 4. CONCLUSION

In this paper an enhanced method is presented for the detection of disturbing loads in three phase three wire power systems. It is based on the instantaneous evaluation of four non-active power quantities. These power quantities are derived from the effective apparent resolution of IEEE Standard 1459-2000. It allows, achieving better understanding of the power systems when both harmonic distortion and un-balanced condition are present. The proposed method requires simply the separation of the fundamental components of voltage and current. It does not require any spectral investigation.

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