P-Q THEORY AND APPARENT POWER CALCULATION FOR ACTIVE FILTERING

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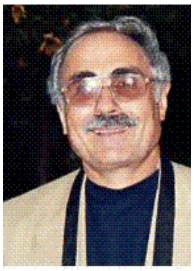

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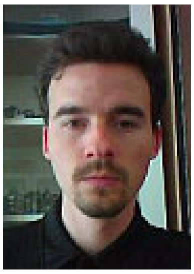

REZUMAT. Lucrarea sugereaza doua noi definitii ale puterii aparente pe baza teoriei p-q (teoria puterii aparente complexa instantanee). Astfel, se pun in evidenta componentele puterii neutile si relatia de cuadratura existenta intre puterile aparenta, activa, reactiva si deformanta. Multe studii de caz arata ca exista o corespondenta intre relatiile propuse si cele exsistente in literatura. Astfel, daca tensiunea este sinusoidala, relatiile propuse conduc la valori egale ale puterii aparente, ca si relatiile propuse de Bucholtz si Czarnecki. In conditii de tensiune nesinusoidala, prima relatie propusa conduce la valori mai mari. A doua relatie conduce, intotdeauna, la aceleasi valori ale puterii aparente ca si relatiile propuse de Bucholtz si Czarnecki. Semnificativ este ca relatia recomandata de IEEE (The IEEE Standard Dictionary of Electrical and Electronics Terms, 6th), conduce la rezultate eronate daca sarcina este dezechilibrata si se aduc noi argumente in acest sens.

Cuvinte cheie: Puterea aparenta complexa instantanee, putere aparenta, putere deformanta, factor de putere.

ABSTRACT. This paper suggests a new two definitions of apparent power based on the instantaneous p-q power theory. The component corresponding to the non-useful power and the quadratic relationship between apparent, active, reactive and non-useful powers are also highlighted. A lot of case-studies draw a parallel between the results according to the well-known definitions gathered from previous literature and the results based on the new expression. It is shown that, under sinusoidal and balanced conditions, all definitions of the apparent power lead to the same results. However, in the case of sinusoidal unbalanced situations, the results based on the new definition are identical only with those corresponding to Buchholz's and Czarnecki's definitions. In contrast, under non-sinusoidal conditions, one of the suggested definitions leads to higher values of the apparent power. The second suggested definition leads to the same results as relations proposed by Bucholtz and Czarnecki, for all analyzed cases. It stressed that the relation recommended by IEEE (IEEE Standard Dictionary of the Electrical and Electronics Terms, 6th), leads to erroneous results if the load is unbalanced and new arguments are brought in this regard.

Keywords: Instantaneous Complex Apparent Power, Apparent Power, Distortion Power, Power Factor.

1. INTRODUCTION

A large number of research publications and specialists have discussed and are still discussing issues related to the properties of the powers flow in three-phase loads operating under non-sinusoidal voltages and currents conditions [1]-[16]. The main phenomenon is the increasing of the apparent power of the power supply over the values corresponding to the active and reactive powers under sinusoidal conditions. The quantitative identification of this increase is very important due to the impact on the power factor in power distribution systems and electrical equipment. Moreover, under non-sinusoidal conditions an important answer must be given – which is the value of the apparent power that must be compensated? It is generally accepted that under non-sinusoidal conditions, along with the active power (P) and the reactive power (Q), another power – frequently named the distortion power (D) – is present. The quadratic relation between these powers and the apparent power (S) is broadly accepted too:

$$S^2 = P^2 + Q^2 + D^2 . \quad (1)$$

The definitions and the interpretations of the active and reactive powers are almost near unanimously accepted. In the case of complete compensation the power of active filter is given by

$$S_F = \sqrt{S^2 - P^2} . \quad (2)$$

Under these conditions, it is clear that defining the apparent power will determine the compensation power and the distortion power. The active power has a clear physical signification and a well-argued mathematical definition, as the average instantaneous power over one cycle. In this respect, the question is whether defining the apparent power by a mathematical expression is relevant or not, because in the literature there are four relations.

The phasor theory applied to the three-phase system proved to be a very useful tool in control applications and determined good practical results and important physical interpretations. Last but not least, applying the instantaneous complex apparent power theory to the active filters control proves its usability and its connection to the physical phenomena in three-phase systems [17]-[19].

This paper is not intended to starting a debate, but to be nothing but a point of view based on mathematical relations and many case studies.

2. CURRENT DEFINITIONS OF APPARENT POWER

Now, there are four different definitions of the apparent power in literature. Thus, in the IEEE Standard Dictionary of Electrical and Electronics Terms there are two different definitions, respectively [20]:

- the first uses the RMS values of phases voltages and currents

$$S_A = U_R I_R + U_S I_S + U_T I_T ; \quad (3)$$

- the second uses the active and reactive powers

$$S_G = \sqrt{P^2 + Q^2} . \quad (4)$$

It is clear that the relation (4) is valid only in the sinusoidal conditions.

There is a third definition, introduced by Buchholz [21],

$$S_{Bh} = \sqrt{U_R^2 + U_S^2 + U_T^2}\sqrt{I_R^2 + I_S^2 + I_T^2} . \quad (5)$$

The one of most consistent researchers in this area is Professor Leszek S. Czarnecki from Electrical and Computer Engineering Department of Louisiana State University, Baton Rouge, USA, which developed the Currents' Physical Components (CPC) theory [22]. He proposed generalizing relation (5) for nonsinusoidal conditions as,

$$S_C = \|u\|\|i\| = \sqrt{\|u_R^2\| + \|u_S^2\| + \|u_T^2\|}\sqrt{\|i_R^2\| + \|i_S^2\| + \|i_T^2\|} , \quad (6)$$

where,

$$\|u_{R,S,T}^2\| = \sum_{k=1}^{\infty} U_{R,S,T(k)}^2 \quad (7)$$

are the rms values of "k" order harmonics on each phase.

It is obvious that relation (6) is another form of relation (5).

3. THE P-Q THEORY AND POWERS IN STEADY STATE REGIME

The apparent instantaneous complex power is defined starting of voltage and current phasors ($\underline{u}$ and $\underline{i}$) [15], [22], [23] as,

$$\begin{aligned} \underline{s} &= p + jq = \frac{3}{2}\underline{u} \cdot \underline{i}^* = \\ &= \frac{3}{2}\left[u_d i_d + u_q i_q + j\left(-u_d i_q + u_q i_d\right)\right] \end{aligned} . \quad (8)$$

The direct and alternating components can be outlined in the real and imaginary parts (sometimes named instantaneous active and reactive powers [15]), p and q:

$$p = P + p\sim, q = Q + q\sim . \quad (9)$$

P and Q are the average values resulting from

$$P = \frac{1}{T}\int_{t-T}^{t} p dt, Q = \frac{1}{T}\int_{t-T}^{t} q dt . \quad (10)$$

Obviously, in steady state, P and Q are constants and

$$\int_0^{2\pi} p_\sim d(\omega t) = \int_0^{2\pi} q_\sim d(\omega t) = 0 . \quad (11)$$

In the square of the instantaneous complex power modulus, the components of the instantaneous powers can be separated as follows

$$\begin{aligned} |\underline{s}|^2 &= p^2 + q^2 = (P + p_\sim)^2 + (Q + q_\sim)^2 = \\ &P^2 + Q^2 + p_\sim^2 + q_\sim^2 + 2(Pp_\sim + Qq_\sim) \end{aligned} . \quad (12)$$

The root mean square values are calculated from relation (9)

$$\frac{1}{2\pi}\int_0^{2\pi}|\underline{s}|^2 d(\omega t)=\frac{1}{2\pi}\int_0^{2\pi}P^2 d(\omega t)+$$
$$+\frac{1}{2\pi}\int_0^{2\pi}Q^2 d(\omega t)+\frac{1}{2\pi}\int_0^{2\pi}\left(p_\sim^2+q_\sim^2\right)d(\omega t)+. \quad (13)$$
$$+\frac{1}{2\pi}\int_0^{2\pi}2\left(Pp_\sim+Qq_\sim\right)d(\omega t)$$

In the relation (13), the square of active and reactive powers P and Q can be identified. In these conditions, comparing with relation (1), the relation (13) suggests a new definition for apparent power: the root mean value of instantaneous complex power modulus

$$S=\sqrt{\frac{1}{2\pi}\int_0^{2\pi}|\underline{s}|^2 d(\omega t)}\,. \quad (14)$$

Thus, because the last term from relation (13) is zero, the following relation can be obtained

$$S^2=P^2+Q^2+\frac{1}{2\pi}\int_0^{2\pi}\left(p_\sim^2+q_\sim^2\right)d(\omega t). \quad (15)$$

Comparing the relations (15) and (1), a new definition for distortion power can be

$$D=\sqrt{\frac{1}{2\pi}\int_0^{2\pi}\left(p_\sim^2+q_\sim^2\right)d(\omega t)}\,. \quad (16)$$

Also, the relations (2), (4) and (16) suggest defining of following complex powers:

- the instantaneous distortion complex power,

$$\underline{d}=p_\sim+jq_\sim \quad (17)$$

- the average apparent complex power,

$$\underline{S}_{av}=P+jQ\,. \quad (18)$$

So, the apparent instantaneous complex power can be expressed as the sum of the two powers,

$$\underline{s}=\underline{S}_{av}+\underline{d}\,. \quad (19)$$

The relations (15), (16) and (17) show that the distortion power and instantaneous distortion power contain all non-useful powers (distortion power and the power because of unbalanced load).

From relation (2), the instantaneous apparent complex power modulus is obtained

$$|\underline{s}|=\frac{3}{2}|\underline{u}|\bullet|\underline{i}|=\frac{3}{2}\sqrt{\left(u_d^2+u_q^2\right)}\bullet\sqrt{\left(i_d^2+i_q^2\right)}\,. \quad (20)$$

Thus, the apparent power defined by (8) becomes

$$S=\frac{3}{2}\sqrt{\frac{1}{2\pi}\int_0^{2\pi}|\underline{u}|^2\cdot|\underline{i}|^2 d(\omega t)}\,. \quad (21)$$

Relation (21) reveals two aspects:

a) in the sinusoidal voltage conditions, the voltage phasor modulus is constant and

$$S=\frac{3}{2}UI\,, \quad (22)$$

$$U=\sqrt{\frac{1}{2\pi}\int_0^{2\pi}|\underline{u}|^2 d(\omega t)};\ I=\sqrt{\frac{1}{2\pi}\int_0^{2\pi}|\underline{i}|^2 d(\omega t)}\,; \quad (23)$$

b) in the non-sinusoidal voltage conditions, the voltage phasor modulus is not constant and

$$S\neq\frac{3}{2}UI\,, \quad (24)$$

Now, starting from the correct definition of active current in p-q theory under non-sinusoidal conditions [24], other instantaneous apparent complex power can be defined as,

$$\underline{s_1}=\frac{3}{2}\frac{U^2}{|\underline{u}|^2}\underline{u}\cdot\underline{i}^*=\frac{U^2}{|\underline{u}|^2}\underline{s}\,, \quad (25)$$

and a new possible relation for apparent power as the rms value of new instantaneous apparent complex power can be done, i.e.

$$S_1=\sqrt{\frac{1}{2\pi}\int_0^{2\pi}|\underline{s}_1|^2 d(\omega t)}=\frac{3}{2}UI\,. \quad (26)$$

It is simple to see that:

- in this case, the relation (22) is obtained;
- if the voltages are sinusoidal the relations (25) and (8) are identical because

$$U=|\underline{u}|\,. \quad (27)$$

4. CASE STUDIES

We will compare the results obtained by relations (3) and (5) with the results obtained by the new relations (21) and (26). It should be emphasized that, under sinusoidal conditions and balanced load, all four relations become identical.

On the other hand, the apparent power of parallel active filter can be calculated using the current that must be compensated. So, in the total filtering case, the active filter current phasor ($\underline{i}_F$) is calculated on the base of the load current phasor ($\underline{i}_L$) and of the active current phasor ($\underline{i}_A$) [24]

$$\underline{i}_F=\underline{i}_L-\underline{i}_A\,. \quad (28)$$

The active current phasor in non-sinusoidal or sinusoidal conditions is given by [24]

$$\underline{i}_A=\frac{2P}{3U^2}\underline{u}\,. \quad (29)$$

Having the active filter current and the voltage, apparent power of active filter can be calculated by (3), (5), (21) or (26) as a check.

In the next tables, the notations significance is:

- S_f – apparent power calculated by relation (21);
- S_{f1} – apparent power calculated by relation (26);
- S_{IEE} – apparent power calculated by relation (3);
- S_{Bh} – apparent power calculated by relation (5);

- P –active power;
- Q –reactive power;
- PF_f – power factor calculated by S_f;
- PF_{f1} – power factor calculated by S_{f1};
- PF_{IEE} – power factor calculated by S_{IEE};
- PF_{Bh} – power factor calculated by S_{Bh};
- SFA_f – apparent power of active filter calculated by relation (2) and S_f;
- SFA_{IEE} – apparent power of active filter calculated by relation (2) and S_{IEE};
- SFA_{Bh} – apparent power of active filter calculated by relation (2) and S_{Bh};
- $\Delta SFA = \dfrac{SFA_{f1} - SFA_{IEE}}{SFA_{IEE}} \cdot 100$;
- SFA_{f1cal} – apparent power of active filter calculated by relation (26) and active filter current (28);
- SFA_{IEEcal} – apparent power of active filter calculated by relation (3) and active filter current (28).

4.1. Sinusoidal Three Phase Voltage and Unbalanced R-L Load

Let us assume that a three phase resistive-inductive unbalanced load ($R_R=R_S=2\Omega;\ L_R=L_S=2mH;\ R_T=\infty$, *Y* connection), is supplied from a symmetrical source of a sinusoidal, positive sequence voltage (*Y* connection), with $u_R = \sqrt{2}U \sin \omega t;\ U = 50V;\ \omega = 100\pi$.

The values of apparent power are shown in Table 1.

In this case, the apparent power calculated by relation (3) is the lowest (2065VA instead of 2530 VA). Also, the apparent power of active filter using this value is by 38% lower (1163VA instead of 1867 VA). In the same times, the value of apparent power of active filter using its current is different (1867VA versus 1163VA).

Table 1. **The results corresponding of Sinusoidal Three Phase Voltage and Unbalanced Resistive-Inductive Load**

S_f (21)	**S_{f1} (26)**	**S_{IEE} (3)**	S_{Bh} (5)	P_f (10)	PF_f	PF_{f1}	PF_{IEE}	PF_{Bh}	SFA_f	SFA_{f1}	SFA_{IEE}	SFA_{Bh}	ΔSFA	**SFA_{f1calf}**	**SFA_{IEEcal}**
2530	**2530**	**2065**	2530	1706	0,67	0,67	0,83	0,67	1867	1867	1163,52	1867	38	**1867**	**1867**

4.2. Sinusoidal Three Phase Voltage and Balanced Unlinear Load (Static Converter)

Let us assume that a three phase static converter (Variable phase controlled AC source) supplies a balanced R-L load,

$(R_R = R_S = R_T = 1\Omega;\ L_R = L_R = L_T = 1mH)$.

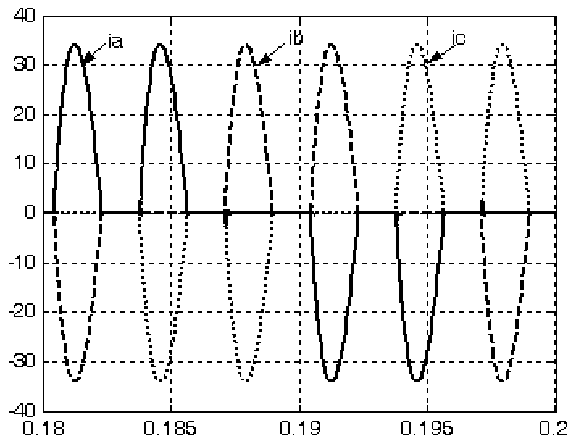

Fig. 1. The phases currents of the R-L load supplied by variable phase controlled AC source

The phase currents are symmetrical and strong distorted (Fig. 1).

In this case, all the four relations give the same result. Also, the active filter apparent powers calculated by (2) and using active filter current are the same.

4.3. Sinusoidal Three Phase Voltage and Unbalanced Unlinear Load (Static Converter)

Let us assume the same circuit but, the phase c of the load is broken. In this case, the current of phase c is zero. The phase currents remain strong distorted and in addition they are unsymmetrical.

Because of this, the apparent power calculated by IEEE recommended relation (3) is lower than the values given by relations (5), (21) and (26) that give the same result (Table 2). The active filter apparent powers calculated by (2) and using active filter current and (3) are different. The values obtained by (5), (21) and (26) are the same, again.

It is very important that the active filter apparent power obtained by IEEE recommended relation is 26% lower than the values obtained by (5), (21) and (26).

Table 2. **The results corresponding of Variable phase controlled AC source and unbalanced R-L load**

S_f (21)	$\mathbf{S_{f1}}$ **(26)**	$\mathbf{S_{IEE}}$ **(3)**	S_{Bh} (5)	P_f (10)	PF_f	PF_{f1}	PF_{IEE}	PF_{Bh}	SFA_f	SFA_{f1}	SFA_{IEE}	SFA_{Bh}	ΔSFA	$\mathbf{SFA_{f1calf}}$	$\mathbf{SFA_{IEEcal}}$
4426	4426	3613	4426	1359,3	0,3071	0,3071	0,3762	0,3071	4212,10	4212,10	3347,55	4212,10	26	4212,00	3820,6

4.4. Non-sinusoidal Three Phase Voltage and Balanced Resistive Load

Next, we will consider a three-phase non-sinusoidal voltage source that supplies a balanced pour resistive three-phase load (R=4Ω). The voltage contains the first harmonic U_1=100V and the 5th harmonic U_5=50V. The currents are distorted and contain the same harmonics as the voltages. In this case, the apparent powers calculated by (3), (5) and (26) are the same, but (21) leads to a higher value (Table 3). The active power and the apparent power are equal.

Table 3. **The apparent powers corresponding of non-sinusoidal voltage and balanced R load**

S_f (21)	$\mathbf{S_{f1}}$ **(26)**	$\mathbf{S_{IEE}}$ **(3)**	S_{Bh} (5)	P_f (10)
10771	9375	9375	9375	9375

4.5. Non-sinusoidal Three Phase Voltage and Unbalanced Resistive Load

Let us assume the same circuit as in the subsection 4.4 but, the phase c of the load is broken. In this case the current of phase c is zero. The phase currents remain strong distorted and in addition they are unsymmetrical.

Because of this, the apparent power calculated by IEEE recommended relation (3) is lower than the values given by relations (5) and (26) that give the same result (Table 4). In the same times, the apparent power obtained by (21) is higher. The active filter apparent powers calculated by (2) and using active filter current and (3) are different. They differ by 42%.

Table 4. **The results corresponding of non-sinusoidal voltage and unbalanced R load**

S_f (21)	$\mathbf{S_{f1}}$ **(26)**	$\mathbf{S_{IEE}}$ **(3)**	S_{Bh} (5)	P_f (10)	PF_f	PF_{f1}	PF_{IEE}	PF_{Bh}	SFA_f	SFA_{f1}	SFA_{IEE}	SFA_{Bh}	ΔSFA	$\mathbf{SFA_{f1calf}}$	$\mathbf{SFA_{IEEcal}}$
7616	6629	5412,5	6629	4687	0,62	0,71	0,87	0,71	6002,96	4687,82	2706,88	4687,82	42,26	4687,50	4687,50

4.6. Non-sinusoidal Three Phase Voltage and Balanced R-L Load

If the load is of R-L type, although the waveforms of the voltage and current are different, the results are similar as the balanced R load case. It should be noted that the apparent power obtained with (21) is again greater than the value on the other three relations.

4.7. Non-sinusoidal Three Phase Voltage and Unbalanced R-L Load

If the load is unbalanced (the phase c is broken), the results are similar as the subsection 4.5. Quantitatively, the active filter apparent powers calculated by (2) and IEEE recommended relation (3) are lower than the values given by relations (5) and (26) by 33% (Table 5)

Table 5. **The results corresponding of non-sinusoidal voltage and unbalanced R-L load**

S_f (21)	$\mathbf{S_{f1}}$ **(26)**	$\mathbf{S_{IEE}}$ **(3)**	S_{Bh} (5)	P_f (10)	PF_f	PF_{f1}	PF_{IEE}	PF_{Bh}	SFA_f	SFA_{f1}	SFA_{IEE}	SFA_{Bh}	ΔSFA	$\mathbf{SFA_{f1calf}}$	$\mathbf{SFA_{IEEcal}}$
12065	11752	9596	11752	7365	0,61	0,63	0,77	0,63	9556,20	9157,85	6151,42	9157,85	33	9157,00	9054,00

4.8. Non-sinusoidal Three Phase Voltage and Balanced Unlinear Load (Static Converter)

The next case refers to a practical situation when the voltage is medium distorted (THDU=11%) (Fig. 2).

This voltage supplies a variable phase controlled AC source that has a balanced R-L load.

The current is strong distorted and the apparent power values calculated by all the four relations are practically equal.

4.9. Non-sinusoidal Three Phase Voltage and Unbalanced Unlinear Load (Static Converter)

The last case study is the same circuit considered in subsection 4.8 but the phase c is broken. The current shape changes and has only one pulse. The apparent power calculated by IEEE recommended relation (3) is lower than the values given by relations (5), (21) and (26) that give the same result (Table 6).

The active filter apparent power calculated by (2) is by 20% smaller than the apparent power calculated using active filter current and by (3)

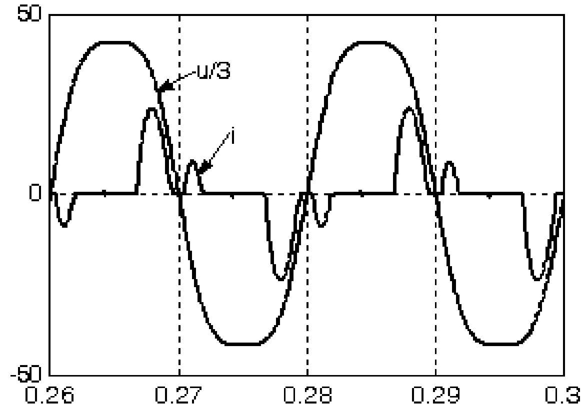

Fig. 2. The phases voltage and current of the balanced R-L load supplied by variable phase controlled AC source and non-sinusoidal voltage

Table 6. **The results corresponding of the unbalanced R-L load supplied by variable phase controlled AC source and non-sinusoidal voltage**

S_f (21)	$\mathbf{S_{f1}}$ **(26)**	$\mathbf{S_{IEE}}$ **(3)**	S_{Bh} (5)	P_f (10)	PF_f	PF_{f1}	PF_{IEE}	PF_{Bh}	SFA_f	SFA_{f1}	SFA_{IEE}	SFA_{Bh}	ΔSFA	$\mathbf{SFA_{f1calf}}$	$\mathbf{SFA_{IEEcal}}$
909	909	746,75	909	279,25	0,3072	0,3072	0,3740	0,3072	865,04	865,04	692,57	865,04	19,94	865,03	789,57

5. CONCLUSIONS

After analysis of naine case studies, a lot of conclusions can be underlined.

1. The all four relations give the same results for balanced load, regardless of the current waveform.
2. The relation (21) gives the same values as (5) and (26) for the sinusoidal voltage, regardless of the current waveform, for balanced or unbalanced load.
3. The relation proposed by Bucholtz and Czarnecki (for non-sinusoidal voltage) (5), gives the same results as relation proposed by us in p-q theory (26), in all the analyzed cases.
4. The relation recommended by IEEE (3) is wrong if the load is unbalanced. We draw this conclusion not because they get different values of apparent powerfrom those calculated relationships (5) and (26) but because they get different values of the apparent power of active filter. For example, in the last case study it is obtained that:
   - the apparent power of the load by IEEE recommended relation (3), $S_{IEE} = 746,75VA$;
   - the apparent power of active filter by (2), $SFA_{IEE}=692,57VA$;
   - the active filter current by (28) and the apparent power of active filter by (3), SFA_{IEECAL}=789,57VA; the two values differ by 14%.
5. In these conditions the relation (3) must be replaced or to specify that it is valid for balanced loads.
6. Excepting apparent power definitions in p-q theory (21), (26) and apparent power of active filter calculation by two methods, these conclusions are found in several works of Prof. Czarnecki.
7. It should be emphasized that using relations (5) and (26) the same value is obtained by the two calculation methods.
8. The relation (26) can be used for apparent power calculation in p-q theory.

REFERENCE

[1] **L. S. Czarnecki,** *What is Wrong with the Budeanu Concept of Reactive and Distortion Power and why It Should Be Abandoned.* IEEE Trans. Instr. Meas., Vol. 36, pp. 834-837, 1987.

[2] **L.S. Czarnecki**, *Scattered and Reactive Current, Voltage, and Power in Circuits with Nonsinusoidal Waveforms and Their Compensation,* IEEE Transactions on Instrumentation and Measurement, Vol. 40, No. 3, June 1991, pp. 563-567.

[3] **L.S. Czarnecki**, *Instantaneous Reactive Power p-q Theory and Power Properties of Three-phase Systems* , IEEE Trans. on Power Delivery, Vol.21, No 1, Jan. 2006, pp. 362-367.

[4] **M. Depenbrock**, *The FBD Method, a Generalz Applicable Tool for Analzzing Power Relations,* IEEE Trans. Power Systems, Vol. 8, May 1993.

[5] Ferrero A., *Definitions of Electrical Quantities Commonly Used in Non-Sinusoidal Conditions*, ETEP, Vol.8, No.4, 1998, pp. 235-240.

[6] E. H. Watanabe, R. M. Stephan, M. Aredes, *New Concept of Instantaneous Active and Reactive Powers in Electrical Systems with Generic Load,* IEEE Transaction on Power Delivery, Vol. 8, No. 2, April 1993, pp. 697-703.

[7] A.E. Emanuel. *Apparent and Reactive Powers in Three-Phase Systems: in Search of a Physical Meaning and a Better Resolution*. ETEP, Vol. 3, n. 1, 1993, pp. 7-14.

[8] Czarnecki L.S., *Distortion Power in Systems with Nonsinusoidal Voltage,* IEE Proceedings-B, Vol.139, No.3, May 1992, pp.276-280.

[9] Emanuel A.E., *On the Definition of Power Factor and Apparent Power in Unbalanced Polyphase Circuits with Sinusoidal Voltage and Currents*, IEEE Trans. on Power Del., No. 3, 1993.

[10] Emanuel A.E., *New Concepts of Instantaneous Active and Reactive Powers in Electrical Systems with Generic Loads*, IEEE Trans. on Power Del., No. 2, 1993.

[11] Emanuel A.E., *The Oscillatory Nature of the Power in Single-and Polyphase Circuits*, ETEP Eur. Electr. Power 6, No. 5, 1996, pp.315-320.

[12] Emanuel A.E., Czarnecki L.S., *Power components in a system with sinusoidal and nonsinusoidal voltages and/or currents*, Proc. IEE, 1990, 137.

[13] Ferrero A., *Definitions of Electrical Quantities Commonly Used in Non-Sinusoidal Conditions*, ETEP Vol.8, No.4, 1998, pp. 235-240.

[14] Ferrero A., Superti Furga G., *A new approach to the definition of power components in tree-phase systems under nonsinusoidal conditions,* IEEE Trans. on Instrumentat. a Meas., IM-40, No.3, 1991, pp.567-577.

[15] H. Akagi, A. Nabae, *The p-q Theory in Three-Phase Systems Under Non-Sinusoidal Conditions*, ETEP, Vol.3, No.1, 1993, pp.27-31.

[16] PENG F.Y., LAI J.S., *Generalized Instantaneous Reactive Power Theory for Three-Phase Power Systems,* IEEE Trans. Instrum. Meas., vol. 45, no. 1, Feb. 1996.

[17] AKAGI H., *New Trends in Active Filters for Power Conditioning*, IEEE Trans. Ind. Appl. 1996, 32, (6), pp. 1312-1322.

[18] H. Akagi, "*Active harmonic filters," Proceedings of the* IEEE, vol. 93, No. 12, Dec. 2005, pp. 2128-2141.

[19] L.S. Czarnecki, *Limitations of the IRP p-q Theory as Control Algorithm of Switching Compensators*, Proceedings of 9th Conference Electrical Power Quality and Utilisation, Barcelona, 9-11 October, 2007.

[20] The IEEE Standard Dictionary of Electrical and Electronics Terms, 6th, IEEE Standards Office New York, NY, USA ©1997, ISBN:1559378336.

[21] F. Buchholz, *"Die Drehstrom-Scheinleistung ein ungleichmeßiger Belas-tung drei Zweige*," Licht und Kraft, No. 2, January 1922, pp. 9-11.

[22] V.N. Nedelcu, *"Die einheitliche leistungstheorie der unsymetrischen und mehrwelligen mehrphasensysteme,"* ETZ-A, 84, 5, p9. 153-157, 1963.

[23] V.N. Nedelcu, *Electromechanical conversion theory,* Technical Ed., Bucharest, 1978. (In Romanian).

[24] A. Bitoleanu, Mihaela Popescu, *How can the IRP p-q theory be applied for active filtering under nonsinusoidal voltage operation?*, Przegląd Elektrotechniczny, Nr. 1, 2011, ISSN PL 0033-2097, pp. 67-71.