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Closure on "Instantaneous Reactive Power p-q Theory and Power Properties of Three-Phase Systems"

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The author appreciates the interest of Francisco de León, Jose Cohen and Seong-Jeub Jeon in my paper [1] and their discussions.

1) I fully agree with León and Cohen's opinion that the current physical components in the CPC power theory, such as active, reactive, scattered and unbalanced currents and generated currents, are only mathematical, but not physical entities, and this is strongly emphasized in my paper [4]. They do not have any physical existence in electrical circuits, but occur only as an effect of an artificial decomposition of the current. However, this decomposition in the CPC Power Theory has a particular property. Namely, each component of the load current depends on a different and observable physical phenomenon in the circuit. Calling them *Currents' Physical Components* (CPC), I did not suggested their physical existence. I coined this name only because each of these currents is ***associated*** with a distinctive physical phenomenon in the circuit. The component called the *active current* occurs only when there is permanent flow of energy to the load. The *reactive current* occurs only when there is a phase-shift between the voltage and current. The *scattered current* occurs only when the load conductance for harmonics is scattered around some equivalent value of this conductance. The *unbalanced current* occurs only when the supply currents are asymmetrical due to the three-phase load imbalance. The *generated current* occurs only when, due to non-linearity or periodic time-variance of the load parameters, the load generates harmonics.

2) In their discussion F. de Leon and J. Cohen states that "*CPC power theory does not properly explain the instantaneous properties of power.*" Unfortunately, the Authors do not explain what the term "*instantaneous properties*" of power mean. Powers in systems with periodic quantities are not defined as instantaneous quantities but they are defined for a time interval not shorter than a single period T. Only the instantaneous power is defined as an instanttaneous quantity, meaning the instantaneous rate of energy flow from the source to the load, $p(t) = dW/dt$. However, we cannot associate any "*instantaneous properties*" with this power, because an infinite number of loads with entirely different power properties can have at the same instant of time the same instantaneous power $p(t)$. Consequently, the statement that "*CPC power theory does not properly explain the instantaneous properties of power*" has no sense.

3) The Authors are wrong in their conclusions on properties of the active current because the definition of this current was totally neglected. Prof. Fryze introduced the concept of the active current $i_a(t)$ in 1931 as the current of an equivalent resistive load that at the same voltage $u(t)$ has the same active power P as the original load. Unfortunately, this current in the Discussion by de Leon and Cohen is not used according to Fryze's definition. It has nothing in common with the instantaneous power $p(t)$ and just such was Fryze's intention. Moreover, the Authors seem to criticize some concepts of the CPC Power Theory that in fact do not exist in this theory. For example, they write "*To compensate for the difference between the true active current (and power) and the defined active current (and power), the CPCs theory proposes several other mathematically obtained components.*" They did not observe that there is no such quantity as "*the true active current*" in the CPC power theory. Also, there are no such quantities as "*a true active power*" and "*a defined active power*". It is difficult to guess what the Authors are talking about. This discussion would be more fruitful if, before writing their comments, the Authors would have acquainted themselves at least with the terms used in the CPC Power Theory, as presented in [2] and [5]. Moreover, the conclusion from my cited sentence "*Any decomposition may lead to misinterpretation…*" that all decompositions have to lead to misinterpretations is wrong. Decompositions are major tools in mathematics, physics and technology, even if the components cancel each other.

4) Among numerous doubts raised by de León and Cohen with respect to the CPC Power Theory is their surprise that according to this Theory "*one could calculate a reactive current even if the circuit has no elements capable of storing energy.*" In fact, this Theory reveals one of the major misinterpretations of power phenomena. Namely, it undermines a very common opinion that the reactive current and reactive power are caused by energy oscillation between the source and a load that has capability of energy storage. As demonstrated in paper [4] this opinion is erroneous. The reactive power Q is not caused by energy oscillation, but by a phase-shift between the load voltage and current. Such a phase-shift can occur even in a purely resistive load with time-variant parameters, for example, in a purely resistive circuit with a periodic switch, thus in a circuit without any oscillation of energy.

5) The Authors' state "*To preserve true physical significance power components must be in agreement with the Poynying Theorem….*" Observe however,

that only the instantaneous power $p(t)$ and its average value over a period, meaning the active power satisfy such a requirement. All other powers used in electrical engineering fail to satisfy it. The Authors are right that the Instantaneous Reactive power p-q Theory "*fail to give a sensible physical meaning…*" However, the same conclusion with respect to the *CPC* Power Theory is wrong. Each power in the CPC Power Theory is associated with a distinctive physical phenomenon. In particular, *the reactive power Q* is a measure of the effect of the phase-shift between the voltage and current harmonics on the apparent power S; *the scattered power* D_s is a measure of the effect of the change of the load conductance with harmonic order n on the apparent power; *the unbalanced power* D_u is a measure of the effect of the load imbalance on the apparent power and *the harmonic generated power* D_g is a measure of effect of harmonics generated in the load on the apparent power. Therefore, the power equation of three-phase loads with a non-sinusoidal supply voltage can be written in the form

$$S^2 = P^2 + Q^2 + D_s^2 + D_u^2 + D_g^2$$

These powers and the power equation provide clear information how circuits features and phenomena, such a phase-shift, change of the load conductance with harmonic order, the load imbalance and generation of current harmonics in the load due to its nonlinearity or periodic time-variance affect the load apparent power S and its power factor, λ. Moreover, the CPC Power Theory provides fundamentals for compensation of each of harmful powers, meaning powers Q, D_s, D_u and D_g. Observe that these powers are not defined in terms of (as recommended by the Authors) the Poynting Theorem. By the way, Eq. (2) in the Discussion written by de León and Cohen

$$p(t) = a(t) + r(t)$$

provides an excellent illustration on how useless this Theorem is in explaining power properties of electrical loads. When this equation is applied to loads in Figure 1 (a) and (b) in the Discussion then, due to the lack of energy storage capability of both loads, the power $r(t) = 0$, meaning the instantaneous power $p(t)$ of both loads has no components. Consequently, this equation does not provide an answer even for such a simple question: *why the load in Fig. 1(a) has power factor $\lambda = 1$, while that in Fig. 1(b) has power factor equal only to $\lambda = 1/\sqrt{2}$?* To be accurate, using only the Poynting Theorem, the concept of the power factor, $\lambda = P/S$, cannot be introduced because this Theorem does not make possible to calculate the apparent power S. This is not a physical quantity related to the Poynting Vector.

6) In his Discussion on the CPC, S-J Jeon wrote:"*The decomposition seems to be meaningful only under strictly restricted conditions…*", which sounds like a rebuke. After that, the Author stated that "*A theory based on a restricted condition should not be used as a standard to criticize other theory.*" These conclusions are wrong due to points 7, 8 and 9.

7) Each scientific statement, in particular theory, can be valid only under strictly defined conditions. The CPC Power Theory, as presented in the discussed paper [1] was developed under the condition that the supply voltage is sinusoidal and symmetrical. The CPC Power Theory of linear, time-invariant loads with asymmetrical, but sinusoidal supply voltage is presented in my paper [6].

8) The Instantaneous Reactive Power (IRP) p-q Theory has been formulated for very wide set electrical systems, meaning set of conditions, including nonsinusoidal and asymmetrical voltages and currents. Any theory valid for a set of conditions {C} has to be valid for any sub-set of the set {C}. To show that such a theory is not valid is enough to prove that it is not valid for some sub-set of the set {C}. If, as was proven in paper [1], the IRP p-q Theory is not capable of identifying power properties of a load at a symmetrical supply voltage instantaneously, it is not capable, of course, to do it when the voltage is asymmetrical. If it is not able to identify these properties, as it was proven, when the voltage is sinusoidal, then it is not able to do it when this voltage is nonsinusoidal.

9) The CPC Power Theory in my paper was not used as any "*standard to criticize other theory*…", but only as a tool that enables identification of power properties of three-phase systems. The objective of my papers was not to "*criticize other theory*," but to show that a pair of p and q powers calculated at some instant of time does not provide information on power properties of three-phase loads. No conclusions can be drawn with respect to the load power properties. The knowledge of these two powers does not allow us to answer the question: *is this load active, reactive, balanced or unbalanced?*

REFERENCES

[1] 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, pp. 362-367, 2006.

[2] L.S. Czarnecki, "Currents' Physical Components (CPC) in circuits with nonsinusoidal voltages and currents. Part 1: Single-phase linear circuits," *Electrical Power Quality and Utilization Journal,* Vol. XI, No. 2, pp. 3-14, 2005.

[3] L.S. Czarnecki, "Energy flow and power phenomena in electrical circuits: illusions and reality," *Archiv fur Elektrotechnik,* (82), No. 4, pp. 10-15, 1999.

[4] L.S. Czarnecki, "Physical interpretation of the reactive power in terms of the CPC power theory," *7th Int. Workshop on Power Definitions and Meas. under Non-Sinusoidal Conditions,* Cagliari, 2006.

[5] L.S. Czarnecki, "Currents' Physical Components (CPC) in circuits with nonsinusoidal voltages and currents. Part 2: Three-phase linear circuits," *Electrical Power Quality and Utilization Journal,* Vol. XII, No. 1, pp. 3-14, 2006.

[6] L.S. Czarnecki, "Powers of asymmetrically supplied loads in terms of the CPC power theory," *7th Int. Workshop on Power Definitions and Meas. under Non-Sinusoidal Conditions,* Cagliari, 2006.