Discussion of “Could Power Properties of Three-Phase Systems Be Described in Terms of the Poynting Vector?”

Francisco de León and José Cohen

The author of the paper [1] should be commended for his continuous efforts and contributions to the controversial topic of power definitions for nonlinear and unbalanced circuits. These discussers agree with the author that there are limitations with the Poynting Vector (PV) and Poynting Theorem (PT) as presented in the paper. Electromagnetic fields are not necessary to describe power phenomena at the electric-circuit level. However, we would appreciate the author’s comments on the following points:

1) PT is not only a “mathematical” tool for calculating energy flow (as the author writes on the first sentence of the abstract). PT has been derived from the experimentally well-supported Maxwell Equations. Therefore, PV and PT are the most physical representations yet available for electrical power and energy phenomena. The author himself on the last paragraph of Section III, states that for certain cases, the PV approach is perhaps “…the only tool for energy flow, storage, and dissipation analysis.” To preserve true physical significance, all power must be in agreement with PV and PT. This comment does not imply that we believe that power phenomena in electric circuits should be described in terms of electric and magnetic fields. We agree with the author that simplicity of calculation and analysis is very important. However, accuracy is more important than simplicity.

2) Is the author suggesting in Section V of the paper that his “Current’s Physical Components (CPCs)” approach to power definitions is the alternative to PV and PT? We will demonstrate in this discussion, with a couple of very simple examples, that the “Current’s Physical Components (CPCs)” proposed by the author [1, ref. 7] do not have a physical existence.

According to the balance of the energy equation for periodical excitation, only two kinds of energy (or power) exist: dissipated/generated and stored/restored. In an electrical load, the former physically represents the active power and the latter represents the reactive power. No other power, such as: apparent, nonactive, deactive, distortion, unbalanced, scattered, generated, and so forth, exist in Maxwell’s terms. They are only “definitions” with physical meaning for special cases. However, since they do not have a true physical existence, they have invariably failed to describe the intended concepts.

The PV theory applied to electrical circuits takes the following instantaneous form [2]:

\[ p(t) = a(t) + r(t) \] (1)

where \( p(t) \) is the instantaneous power delivered to a load, \( a(t) \) represents the instantaneous power consumption, and \( r(t) \) is the instantaneous power that is stored/restored.

The CPCs theory works very nicely for the examples of Figs. 6 and 7 of the paper because the loads are shunt, but this theory fails when...
the loads are series. Consider the case of a balanced three-phase load Y grounded; only one phase is presented in Fig. 1(a).

The instantaneous voltage and current at the load terminals is

\[
v(t) = \sqrt{2} V_{\text{rms}} \cos(\omega t); \quad i(t) = \sqrt{2} \frac{V_{\text{rms}}}{Z} \cos(\omega t + \phi). \tag{2}
\]

For the single-phase linear case, the CPCs model reduces to two currents active \(i_a(t)\) and reactive \(i_r(t)\). From them, one can compute the corresponding “active” and “reactive” powers as

\[
\begin{align*}
    p_a(t) &= v(t) i_a(t) = \frac{P}{\|v\|^2} 2 V_{\text{rms}}^2 \cos^2(\omega t) \\
    p_r(t) &= v(t) i_r(t) = -\frac{Q}{\|v\|^2} 2 V_{\text{rms}}^2 \cos(\omega t) \sin(\omega t).
\end{align*} \tag{3}
\]

The equations in (3) are definitions based on the average quantities \(P\) and \(Q\). The instantaneous “active” and “reactive” powers defined in (3) are not derived from (and do not correspond to) the instantaneous physical energy conversion \(a(t)\) or stored/restored phenomenon \(r(t)\) in the circuit elements. The active power component should be obtained from Joule’s Law, while the reactive power component must be the rate of change of the energy stored in the inductance. Thus, for the circuit of Fig. 1(a), we have that the true physical instantaneous active and reactive powers are

\[
a(t) = R i(t)^2; \quad r(t) = i(t) L \frac{d}{dt} i(t). \tag{4}
\]

Fig. 2 shows the comparison of the physical power components of (4) with the power components derived from the CPCs theory (3). The following values were used \(V_{\text{rms}} = 120 \text{ V}; R = 1 \Omega; L = 3 \text{ mH}, f = 50 \text{ Hz}.\) Thus, we obtain \(Z = 1.372 \Omega; \phi = -43.3^\circ; P = 7.626 \text{ kW};\) and \(Q = -7.187 \text{ kVAR}.

For the linear circuit, the average of the active and reactive powers of the CPCs model and the true (physical) model is the same. Instantaneously, the difference between them is only a phase shift and perhaps inconsequential. However, when the circuit is nonlinear as the one shown in Fig. 1(b), the nonphysical existence of the current (and power) components of the CPCs model creates a serious significance problem. Consider the case of Fig. 1(b) where the conduction angles have been selected such that it produces the current shape of Fig. 3 with \(V_{\text{rms}} = 120 \text{ V}; R = 2 \Omega; f = 50 \text{ Hz}.

The Fourier analysis of the current yields a (peak) fundamental current of 50.29 A, with an angle of \(-32.48^\circ;\) thus, we obtain \(P = 3.6 \text{ kW}; Q = -2.20 \text{ kVAR}.\) Fig. 4(a) shows the power components corresponding to the “active,” “reactive,” and “generated” currents of the CRC model while Fig. 4(b) shows the energetic reality from Maxwell’s viewpoint. For this case, the CPCs model suggests the existence of three currents/powers with “physical meaning.” However, the reactive power \(p_r(t)\) of the CPCs is not related to energy stored/restored since this circuit has no elements capable of storing energy. While the active power \(p_a(t)\) has the same average \(P\) of the load, it is not instantaneously related to the way the energy is consumed by the load. The three nonphysical power components of the CPCs model instantaneously add to the true power consumed because \(p_a(t)\) is mathematically defined to comply with that condition.

The components of the CPCs model are useful concepts, but they do not have the claimed physical meaning. For example, one could compensate with shunt capacitors for the computed \(Q\). Therefore \(p_r(t)\) could be called the “reactive compensable power,” but not reactive power.

The author’s comments would be greatly appreciated.

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