International Conference
On Harmonics and Quality of Power, ICHQP
Ljubljana 2018

# Why the Power Theory has a Limited Contribution to Studies on the Supply and Loading Quality ?

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Louisiana State University, USA

Harmonics were born
in 1822

**in Jean Baptist FOURIER**
**mind.**

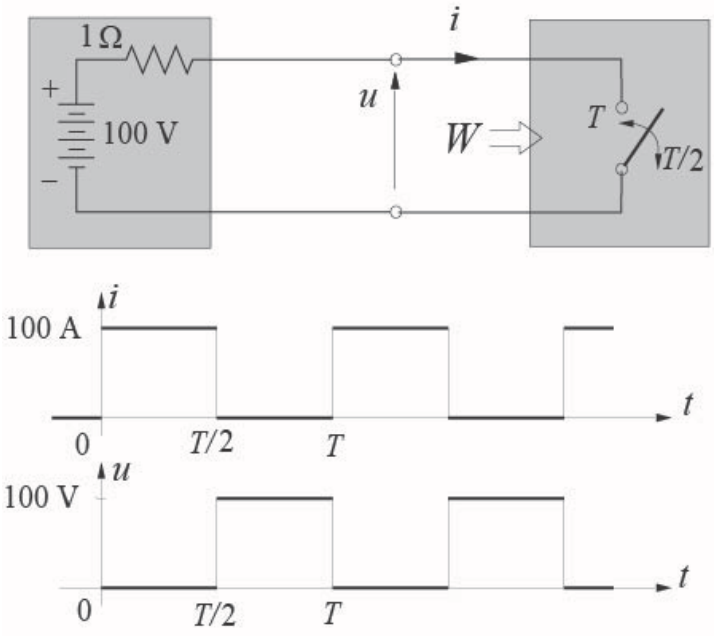
Fourier used them for a description of the heat transfer

**Harmonics do not exist**
**as physical entities**

“a harmonic”
is only a mathematical concept

When a harmonic leaves our mind and attempts
to live
as a physical entity

**it can cause**
**major misconceptions on power phenomena**




$$u(t) = U_0 + \sqrt{2}\sum_{n=1}^{\infty} U_n \cos(n\omega_1 t + \alpha_n) = \sum_{n=0}^{\infty} u_n \qquad i(t) = I_0 + \sqrt{2}\sum_{n=1}^{\infty} I_n \cos(n\omega_1 t + \beta_n) = \sum_{n=0}^{\infty} i_n.$$

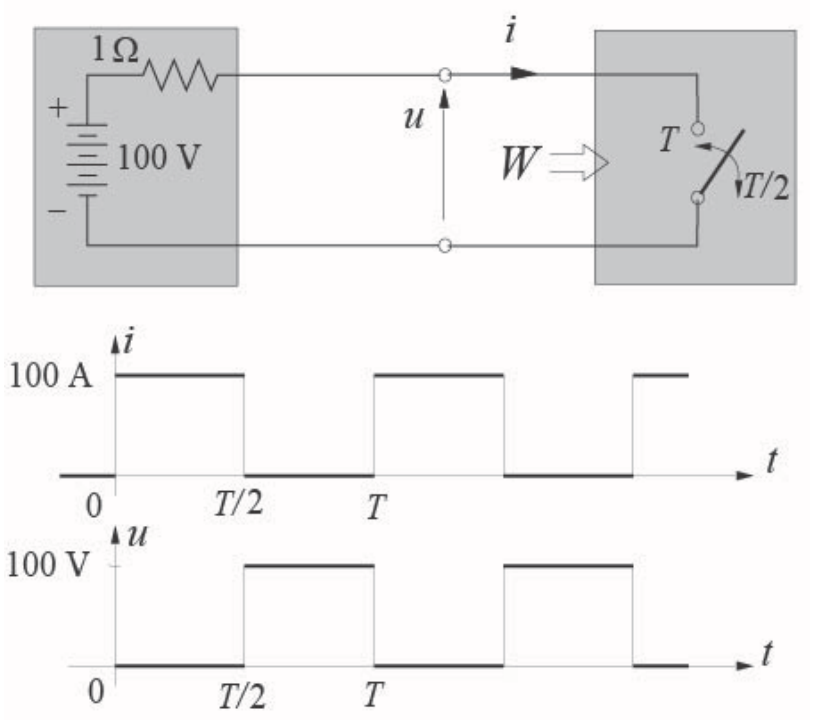
If harmonics do exist as physical entities,
than the rate of the energy flow

$$p(t) = \frac{dW}{dt} = u(t)\,i(t) = \sum_{r=0}^{\infty} u_r \sum_{s=0}^{\infty} i_s = \sum_{n=0}^{\infty} S_n \cos(n\omega_1 t + \psi_n)$$

**is an infinite sum of oscillating components**

$$p(t) = u(t)\,i(t) = \sum_{r=0}^{\infty} u_r \sum_{s=0}^{\infty} i_s = \sum_{n=0}^{\infty} S_n \cos(n\omega_1 t + \psi_n)$$

If harmonics are physical quantities, the energy flows even in an open circuit




$$p(t) = \frac{dW}{dt} = u(t)\,i(t) = 0$$

It is not clear, who used for the first time
the phrase:
**“power quality”**

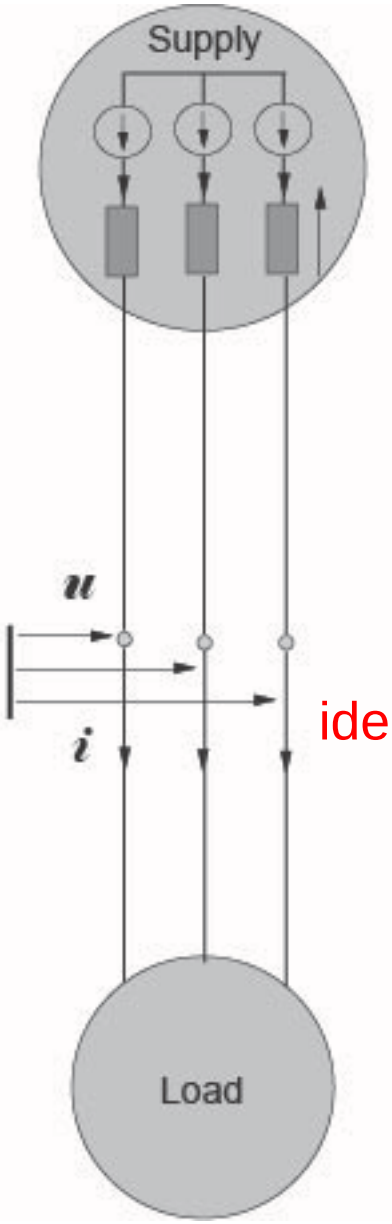
Taking into account that
**the power**
**does not have quality**

the career of this phrase
into papers, journals, conferences, company names

**is really astonishing**

**“Power Quality Meter”:**

Voltage & current asymmetry
Voltage & current harmonics
Transients
High frequency noise
Rms value variance



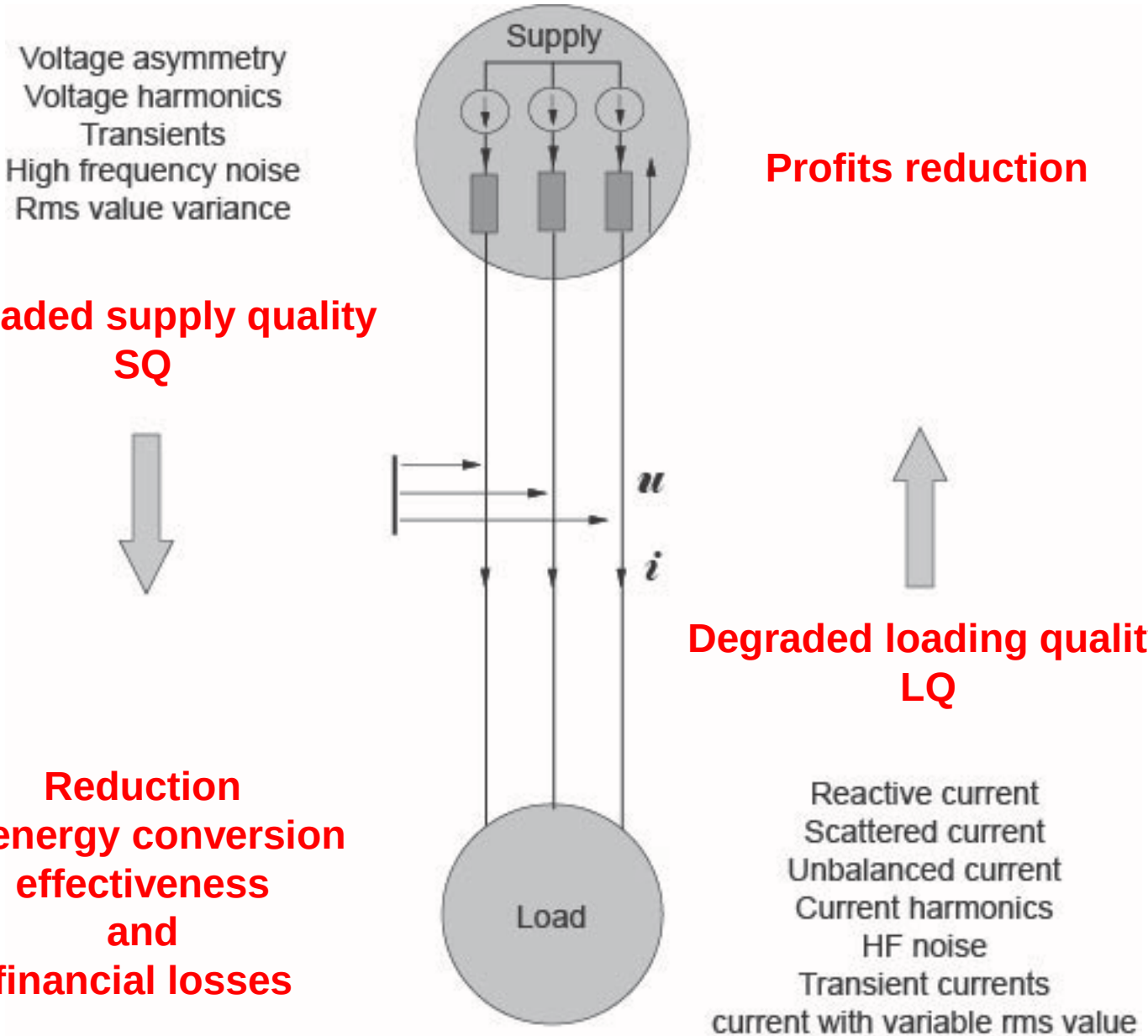

?

Where are
sources of deviation
from
ideal voltages and currents

?

Voltage asymmetry
Voltage harmonics
Transients
High frequency noise
Rms value variance

**Degraded supply quality**
**SQ**



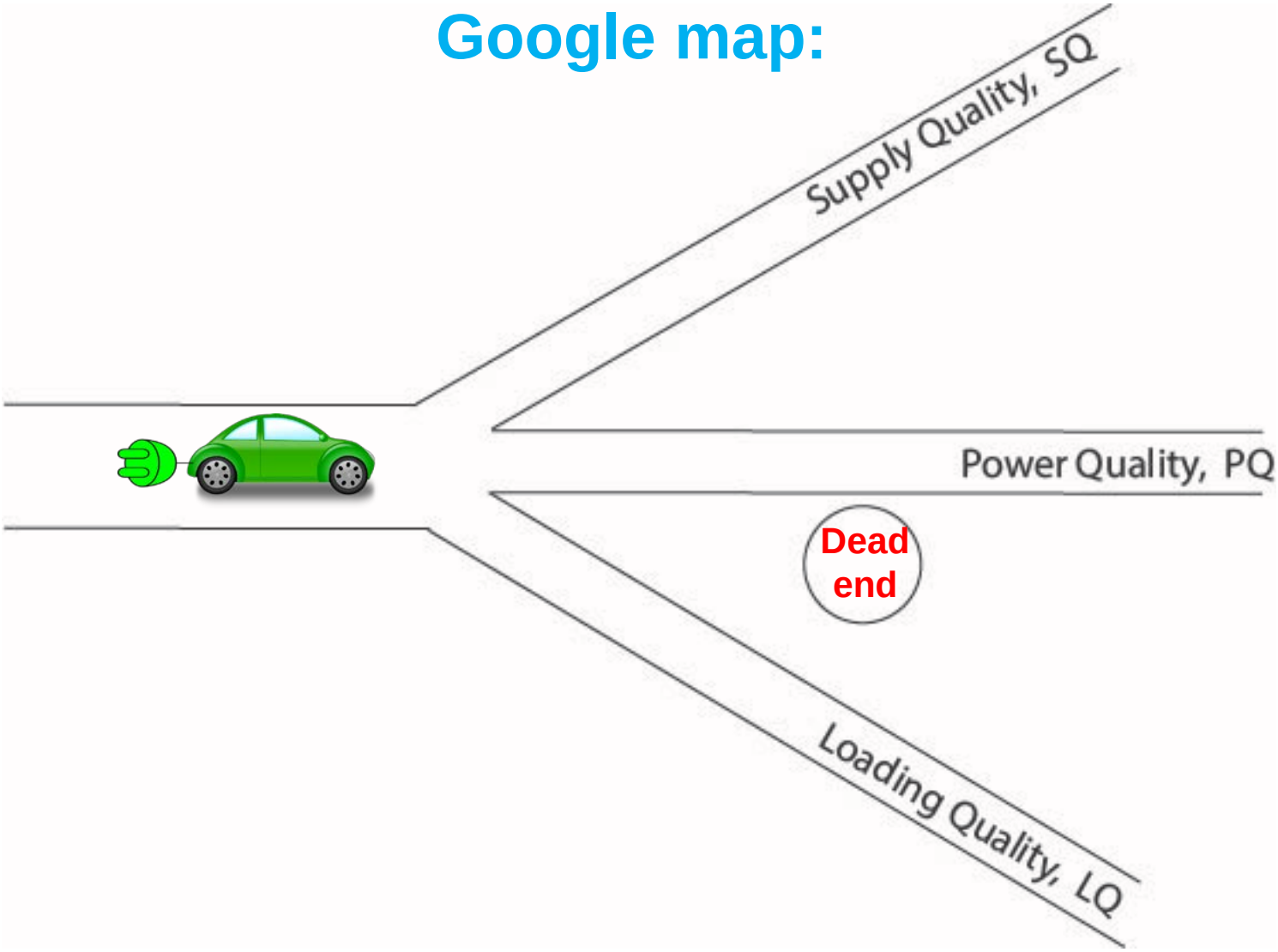

**Profits reduction**

**Degraded loading quality**
**LQ**

**Reduction**
**of energy conversion**
**effectiveness**
**and**
**financial losses**

Reactive current
Scattered current
Unbalanced current
Current harmonics
HF noise
Transient currents
current with variable rms value

# Google map:


Supply Quality, SQ
Power Quality, PQ
Dead end
Loading Quality, LQ

Power properties of a load,
its powers, power factor, generated distortion, asymmetry,
current RMS variation
are a components
of the Loading Quality (LQ)

Components of a degraded
Supply Quality (SQ),
meaning
the supply voltage distortion, variation of the RMS value, asymmetry, transients

affect
power properties of the load

Therefore,

studies on the Loading Quality (LQ), on the Supply Quality (SQ)

and studies on Power Properties (Power Theory)
of electrical systems

**cannot be separated.**

Why the Power Theory has a Limited Contribution to Studies on the Supply and Loading Quality

?

There are two reasons for that:

**The first reason:**

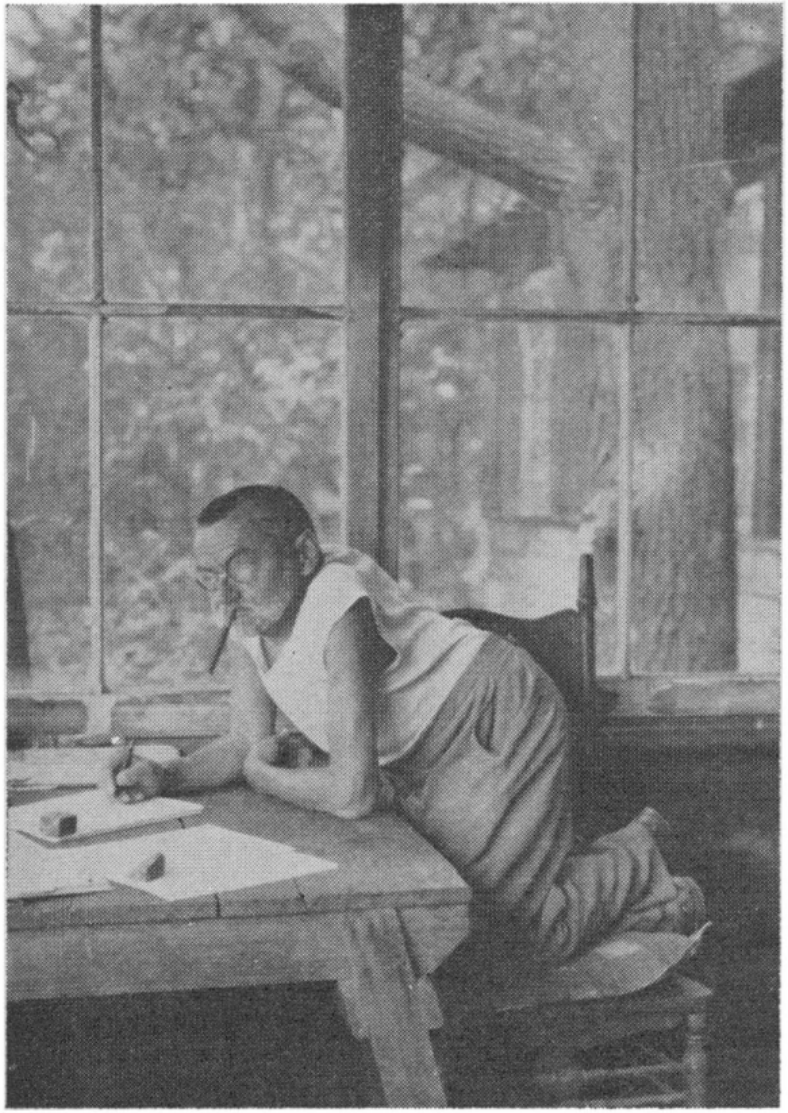
Explenation of power phenomena
in systems with nonsinusoidal voltages and currents
has occured to be

one of the most difficult problems
of the electrical engineering

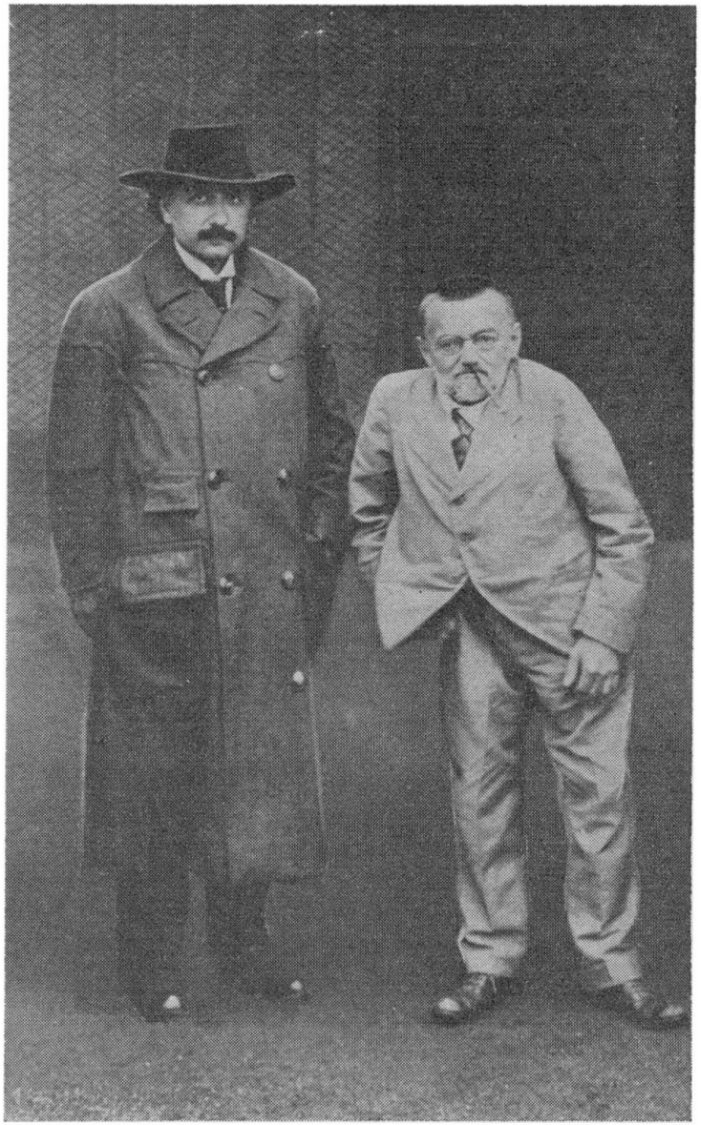
**The second reason:**

# A Misconceptions Defence System (MDS)

has evolved in the Electrical Engineering community
to defend various misconceptions
ofen trusted
with a sort of a religious zeal



**Charles Proteus Steinmetz**



Einstein and Steinmetz.

**In Einstain's company…**

Hundreds scientists worked on it
and hundreds papers over the whole XIX century
were published.

A lot of mutually conflicting concepts and misinterpretations
were dissaminated in the electrical engineering

The most advanced results
of studies
on power properties of electrical systems and compensation

were obtained in the frame of

the Currents' Physical Components (CPC) – based Power Theory

The very core of CPC is the load current decomposition

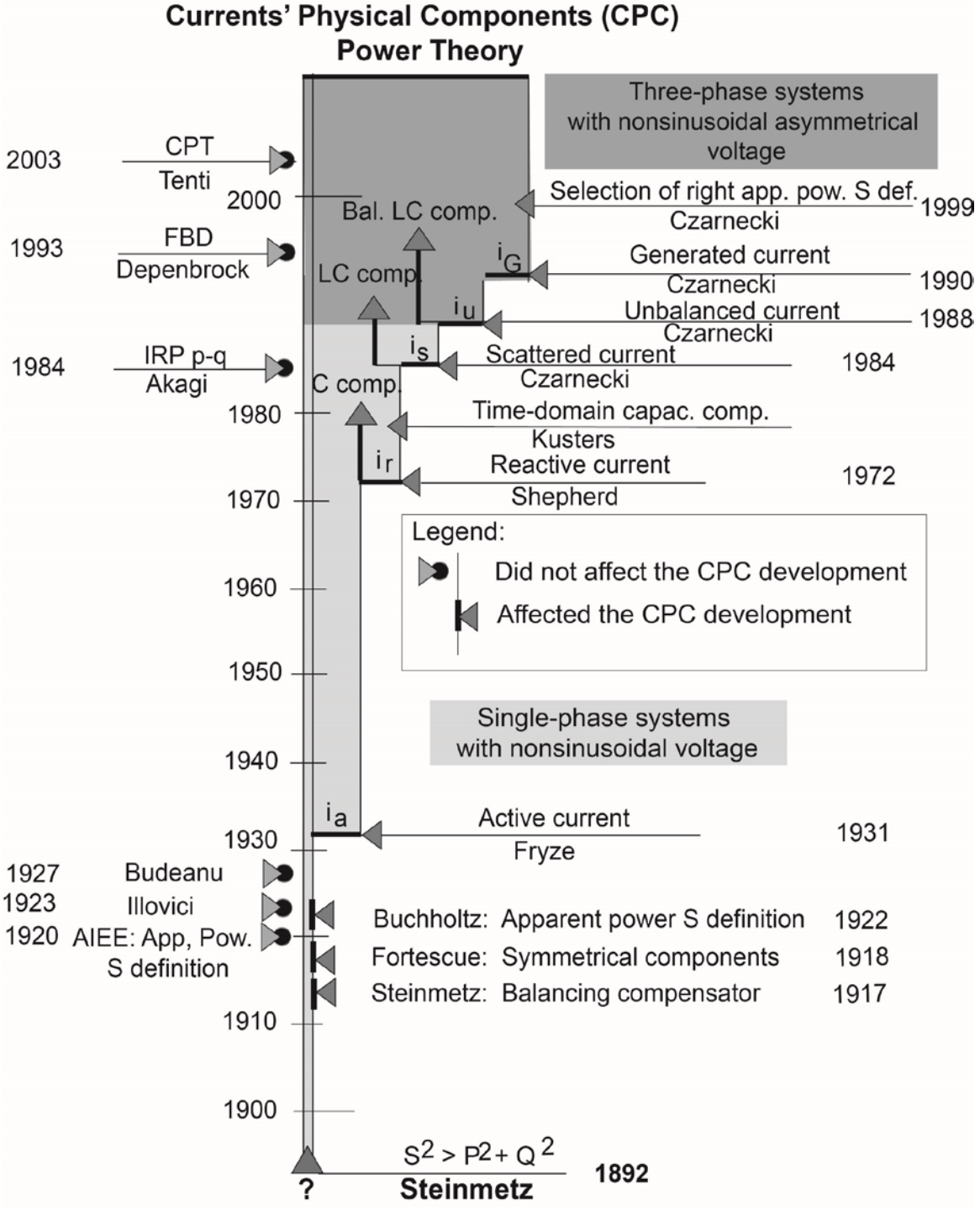
$$i(t) = i_a(t) + i_r(t) + i_s(t) + i_u^n(t) + i_u^p(t) + i_u^z(t) + i_G(t)$$

All, seven, current components
are associated
with distinctive physical phenomena in the load

This decomposition
is valid
for electrical systems of any complexity and any load

All currents in CPC decomposition
are mutually orthogonal
so that their three-phase RMS values ||.||
satisfy the relationship

$$\|\boldsymbol{i}\|^2 = \|\boldsymbol{i}_\mathrm{a}\|^2 + \|\boldsymbol{i}_\mathrm{r}\|^2 + \|\boldsymbol{i}_\mathrm{s}\|^2 + \|\boldsymbol{i}_\mathrm{u}^\mathrm{n}\|^2 + \|\boldsymbol{i}_\mathrm{u}^\mathrm{p}\|^2 + \|\boldsymbol{i}_\mathrm{u}^\mathrm{z}\|^2 + \|\boldsymbol{i}_\mathrm{G}\|^2$$


Currents' Physical Components (CPC)
Power Theory
Three-phase systems
with nonsinusoidal asymmetrical
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2003
CPT
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Selection of right app. pow. S def.
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AIEE: App, Pow.
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$S^2 > P^2 + Q^2$
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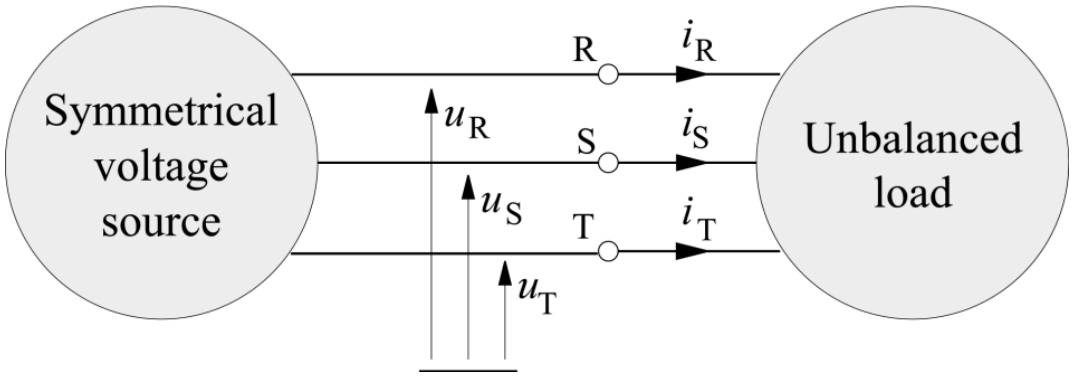
Steinmetz
1892



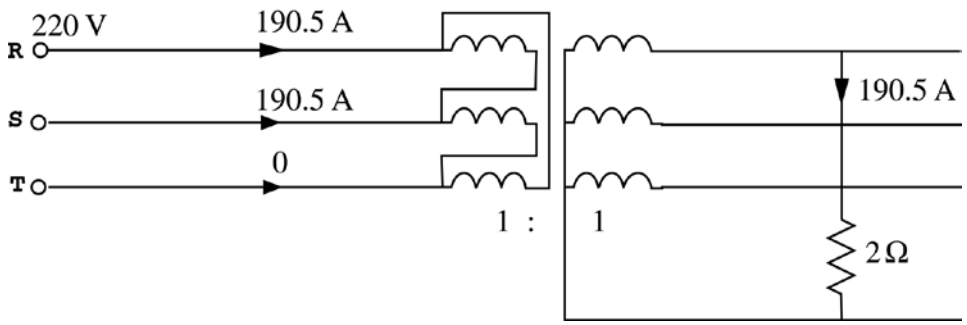

Apparent power definitions:

$$S = S_A = U_R I_R + U_S I_S + U_T I_T$$

$$S = S_G = \sqrt{P^2 + Q^2}$$

$$S = S_B = \sqrt{U_R^2 + U_S^2 + U_T^2}\,\sqrt{I_R^2 + I_S^2 + I_T^2}$$

Which of these three definitions is right?




$P = 72.3\ \text{kW}$

$$S = S_A = U_R I_R + U_S I_S + U_T I_T = 83.8\ \text{kVA}$$

$$S = S_G = \sqrt{P^2 + Q^2} = 72.3\ \text{kVA}$$

$$S = S_B = \sqrt{U_R^2 + U_S^2 + U_T^2}\ \sqrt{I_R^2 + I_S^2 + I_T^2} = 102.7\ \text{kVA}$$

$$\lambda_A = \frac{P}{S_A} = 0.86 \qquad \lambda_G = \frac{P}{S_G} = 1 \qquad \lambda_B = \frac{P}{S_B} = 0.71$$

Which is the right value of the power factor?

I demonstrated that the energy loss at its delivery
is related to the power factor $\lambda = P/S$
only if
the apparent power $S$ is calculated
from definition

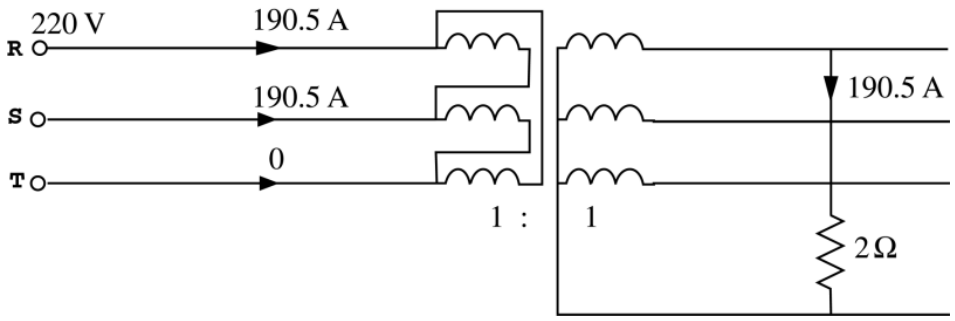
$$S = \sqrt{U_{\mathrm{R}}^2 + U_{\mathrm{S}}^2 + U_{\mathrm{T}}^2}\ \sqrt{I_{\mathrm{R}}^2 + I_{\mathrm{S}}^2 + I_{\mathrm{T}}^2}$$

Apparent power definitions:

$$S = U_{\mathrm{R}} I_{\mathrm{R}} + U_{\mathrm{S}} I_{\mathrm{S}} + U_{\mathrm{T}} I_{\mathrm{T}}$$

$$S = \sqrt{P^2 + Q^2}$$

result in a wrong value of the power factor $\lambda$




$$S = \sqrt{U_R^2 + U_S^2 + U_T^2}\,\sqrt{I_R^2 + I_S^2 + I_T^2} = 102.7 \text{ kVA}$$

$$P = 72.6 \text{ kW}, \quad Q = 0$$

A common power equation has the form:

$$S^2 = P^2 + Q^2$$

$$102.7^{\,2} = 72.6^{\,2} + ????$$

I have never met a power system engineer
who was able to write a power equation for a three-phase system

## Misconceptions Defense System (MDS) in action:

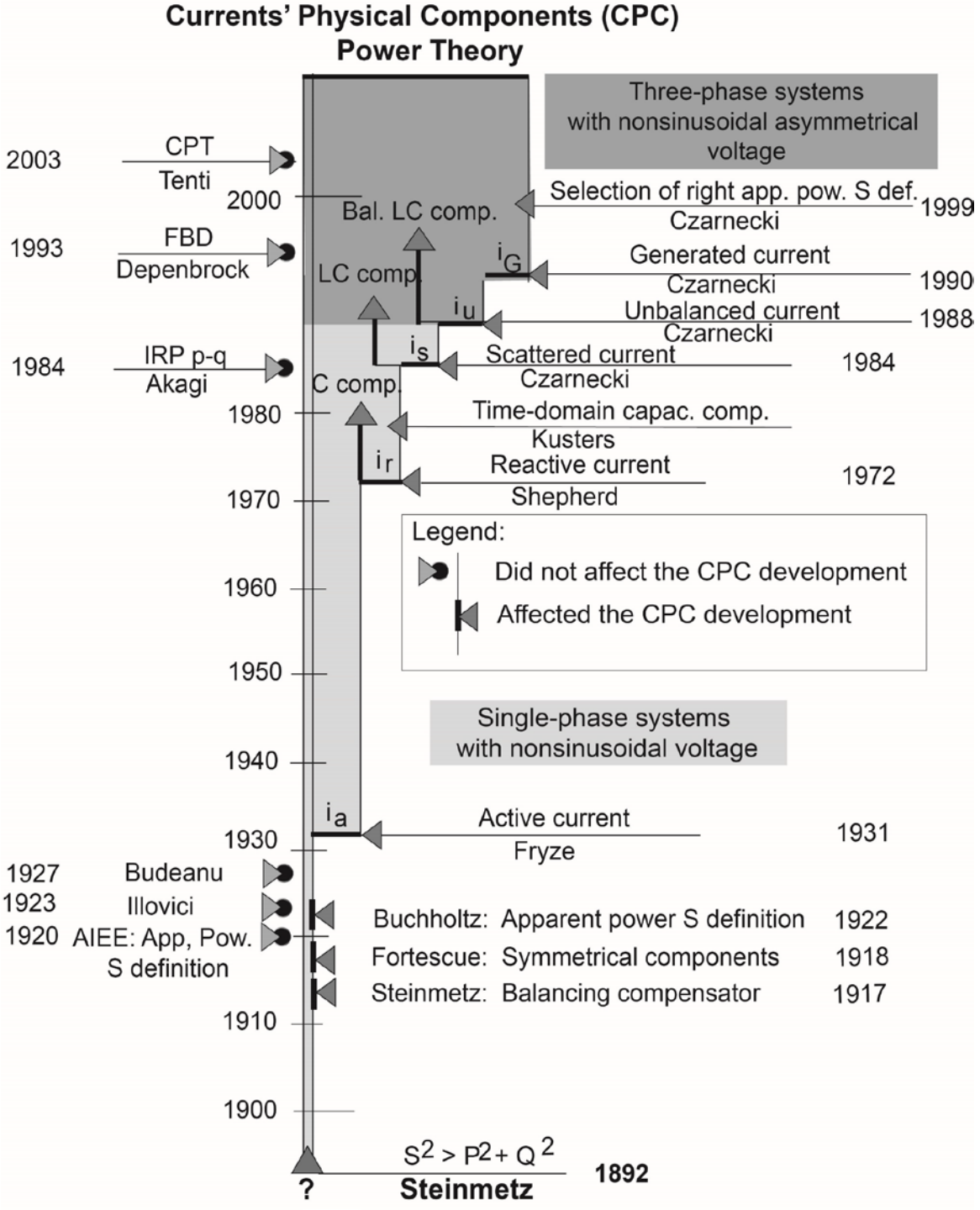
According to reviewers and the editor:

Apparent power definitions and power factor are not sufficiently important to publish the described above problem in IEEE Trans. on Power Delivery

It was published in German journal Archiv fur Elektrotechnik:

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

The EE community is well protected, however:
This paper cannot be found on the IEEE Xplore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## 1927: C.I. Budeanu:

Reactive power:

$$Q = \sum_{n=1}^{\infty} U_n I_n \sin\varphi_n$$

Distortion power:

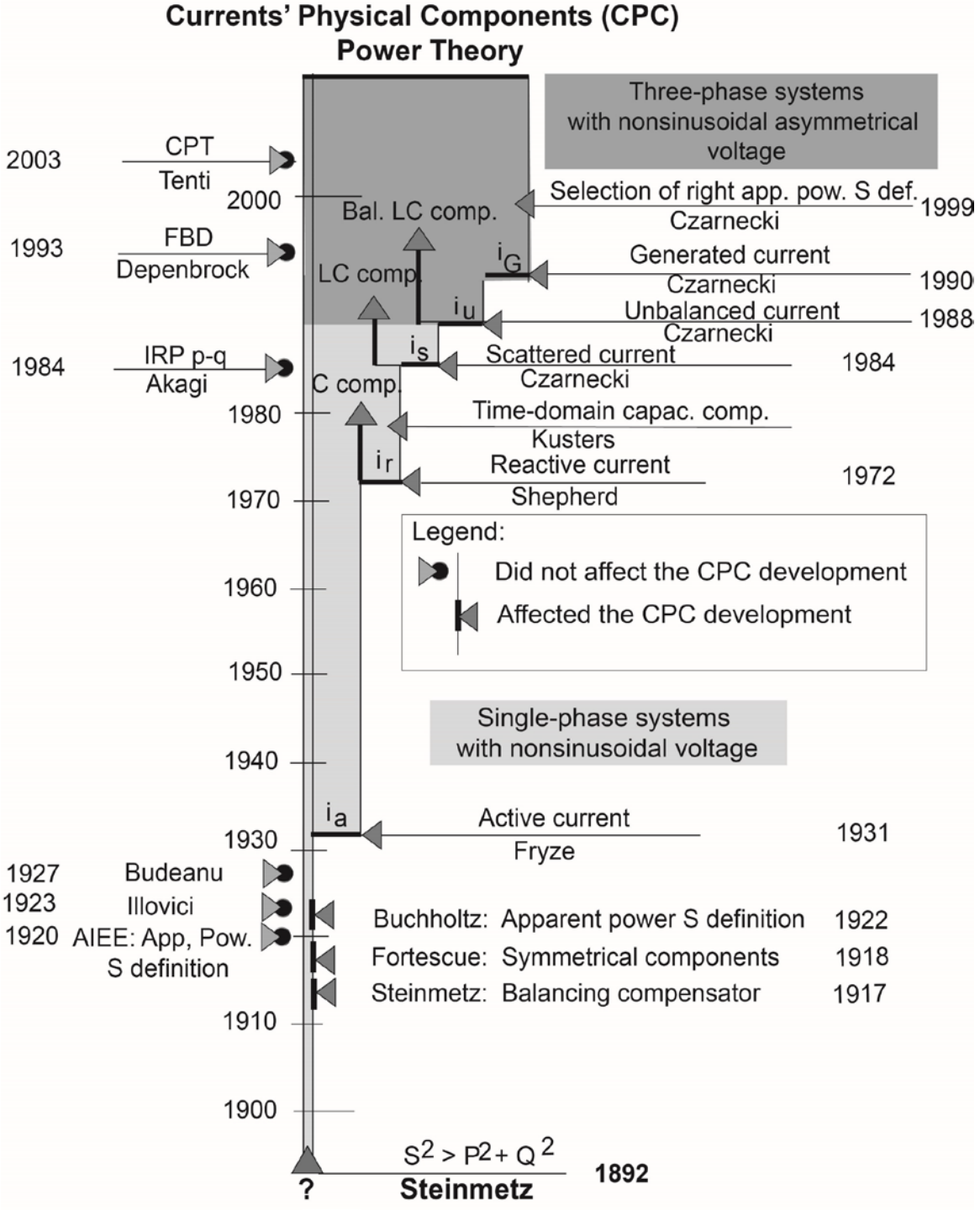
$$D = \sqrt{S^2 - (P^2 + Q^2)}$$

## 1987: L.S. Czarnecki:

What is wrong with the Budeanu's concept of reactive and distortion powers and why it should be abandoned,
IEEE Trans. on Instrumentation and Measurements

**2000: – The Misconceptions Defense System in action:**

The IEEE Standard 1459
adopted, by a poll (!!),
Budeanu's definitions of the reactive and distortion powers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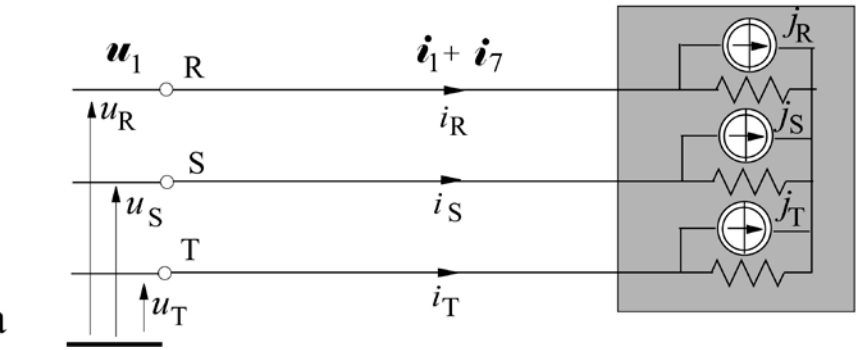
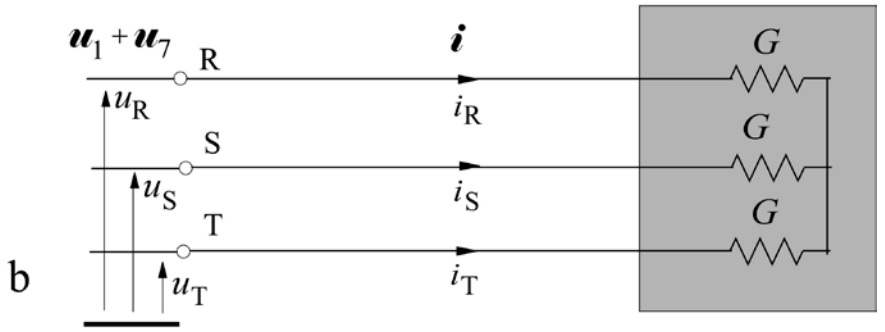
# Instantaneous Reactive Power pq Theory

$$u_R = \sqrt{2}\,U_1 \cos \omega_1 t + \sqrt{2}\,U_7 \cos 7\omega_1 t$$

$$i_R = \sqrt{2}\,I_1 \cos \omega_1 t + \sqrt{2}\,I_7 \cos 7\omega_1 t$$

$$\boldsymbol{i} = G\,\boldsymbol{u}$$




$$p = \overline{p} + \tilde{p} = 3U_1 I_1 + 3U_1 I_7 \cos 6\omega_1 t$$

$$q = 0$$

$$p = \overline{p} + \tilde{p} = P + 6GU_1 U_7 \cos 6\omega_1$$

$$q = 0$$

These two circuits,
substantially different with respect to properties
are identical in terms of IRP p-q Theory

# The Instantaneous Reactive Power pq Theory misinterprates power phenomena

2000: – The Misconceptions Defense System
in action:

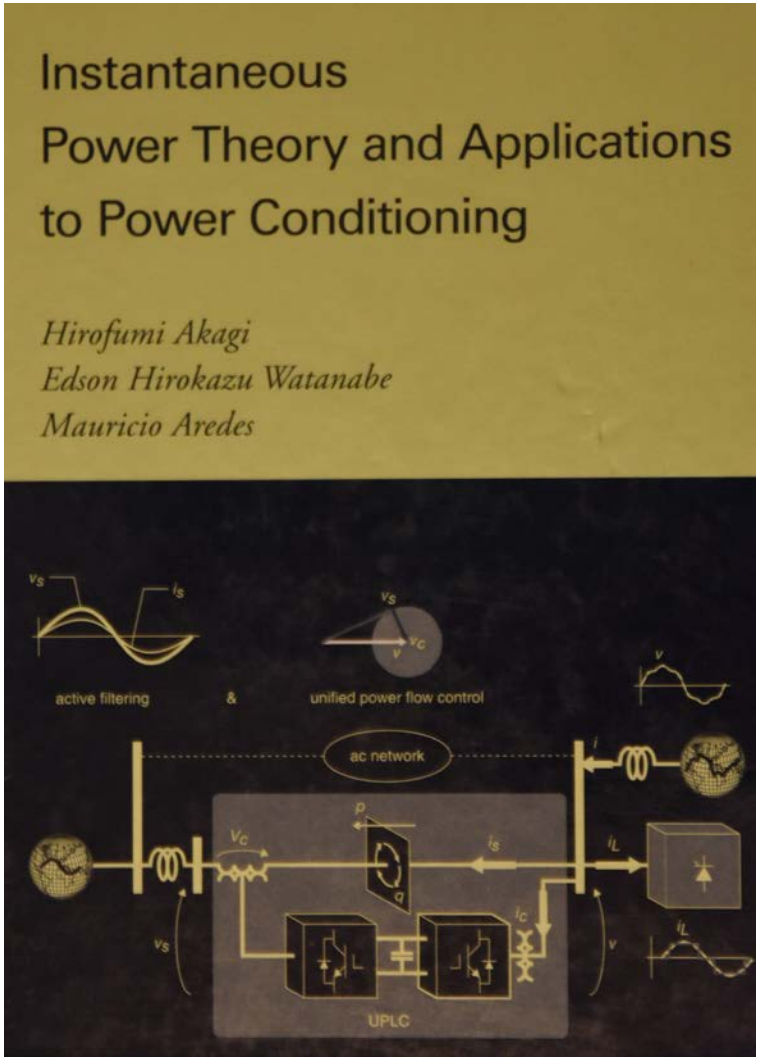
A reviewer of IEEE Transactions on Power Electronics:

"Everybody in EE community knows that
The Instantaneous Reactive Power pq Theory
is perfectly right:
– reject the paper".

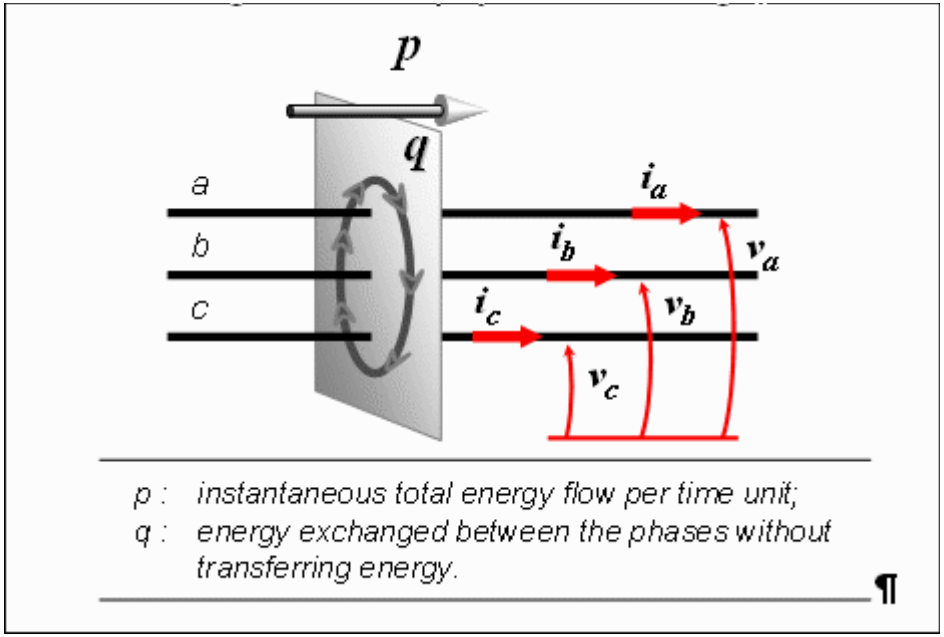
In the original paper on IRP pq
published in 1983
the physical meaning
of the Instantaneous Reactive Power q
was not provided

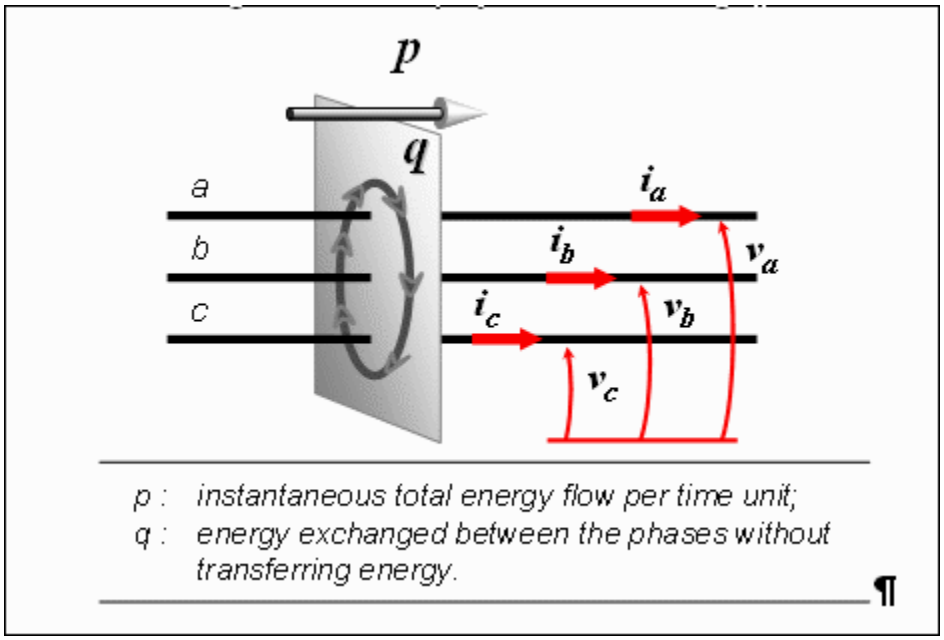
This physical meaning
was for years
a subject of studies and debates

The physical meaning of q was provided
24 years later, in 2007,
in the book:




*"…the imaginary power q is proportional to the quantity of energy that is being exchanged between the phases of the system…" "Figure"..." summarizes the above explanations about the real and imaginary powers."*





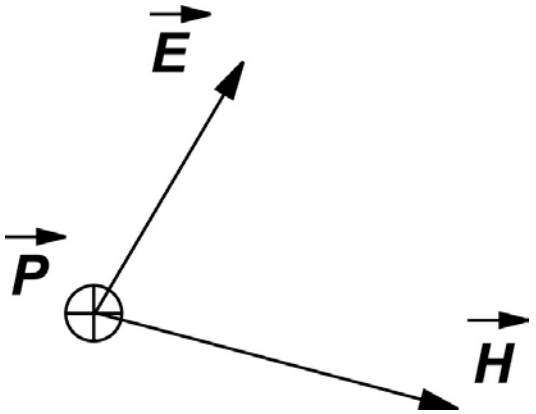

The phrase:

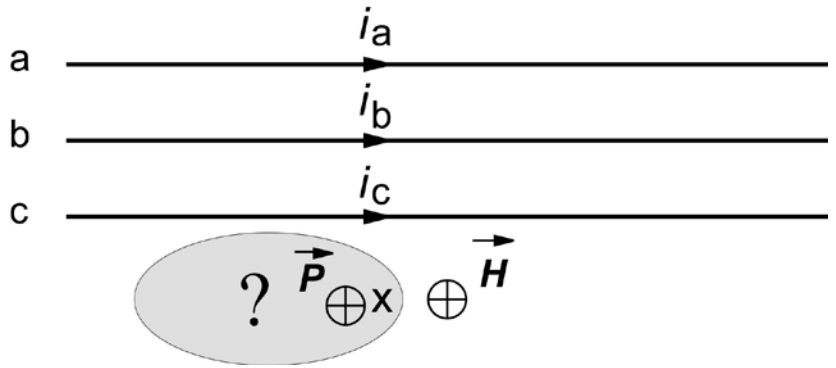
"*q*: energy exchange between the phases without transferring energy"

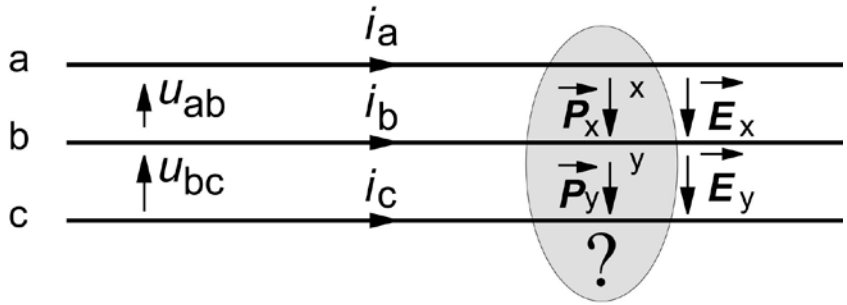
It seems
it was supported
by the Misinterpretations Defense System

# The energy flows in the direction of the Poynting Vector

$$\vec{P} = \vec{E} \times \vec{H}$$



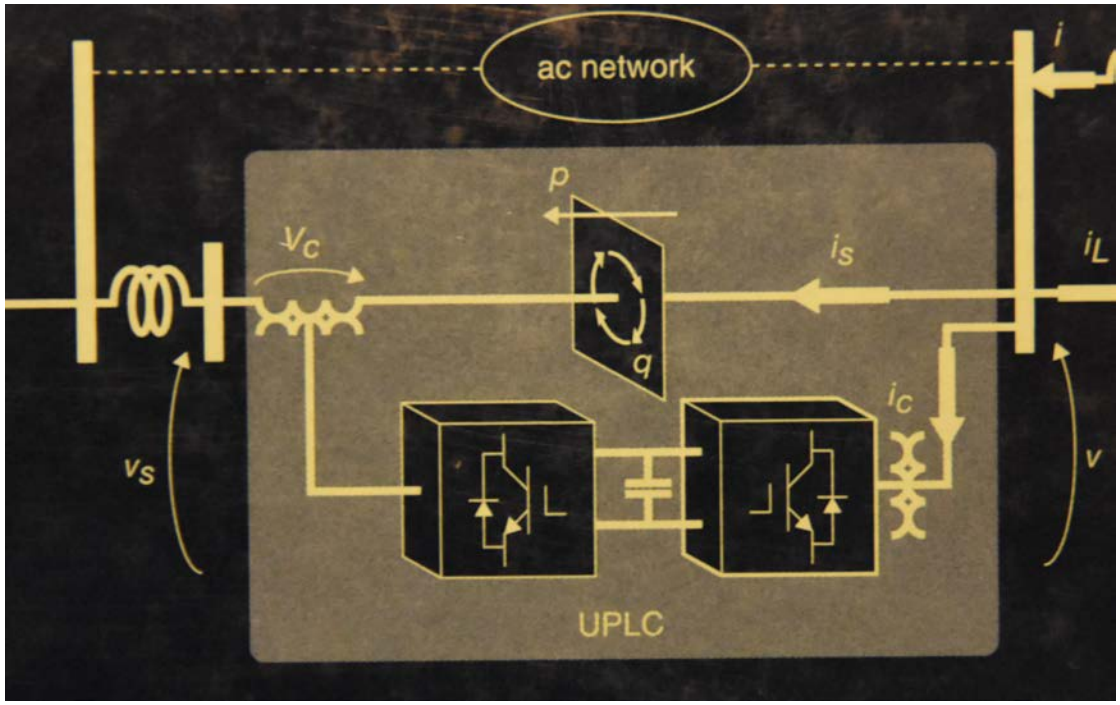



## The MDS in action:

A reviewer for IEEE Trans. on Power Electronics:

"The author should provide with the manuscript the result of a poll run over the EE community,
that this picture indeed suggests the energy rotation around supply lines"



2001: Z. Cekarski, A.E. Emanuel:
"Poynting Vector and the Power Quality of Electric Energy"
*European Transactions on Electric Power*

They suggested
that power properties of electrical systems
and the power quality
should be described only in terms of the Poynting Vector

$$\vec{P} = \vec{E} \times \vec{H}$$

Several papers followed this suggestion

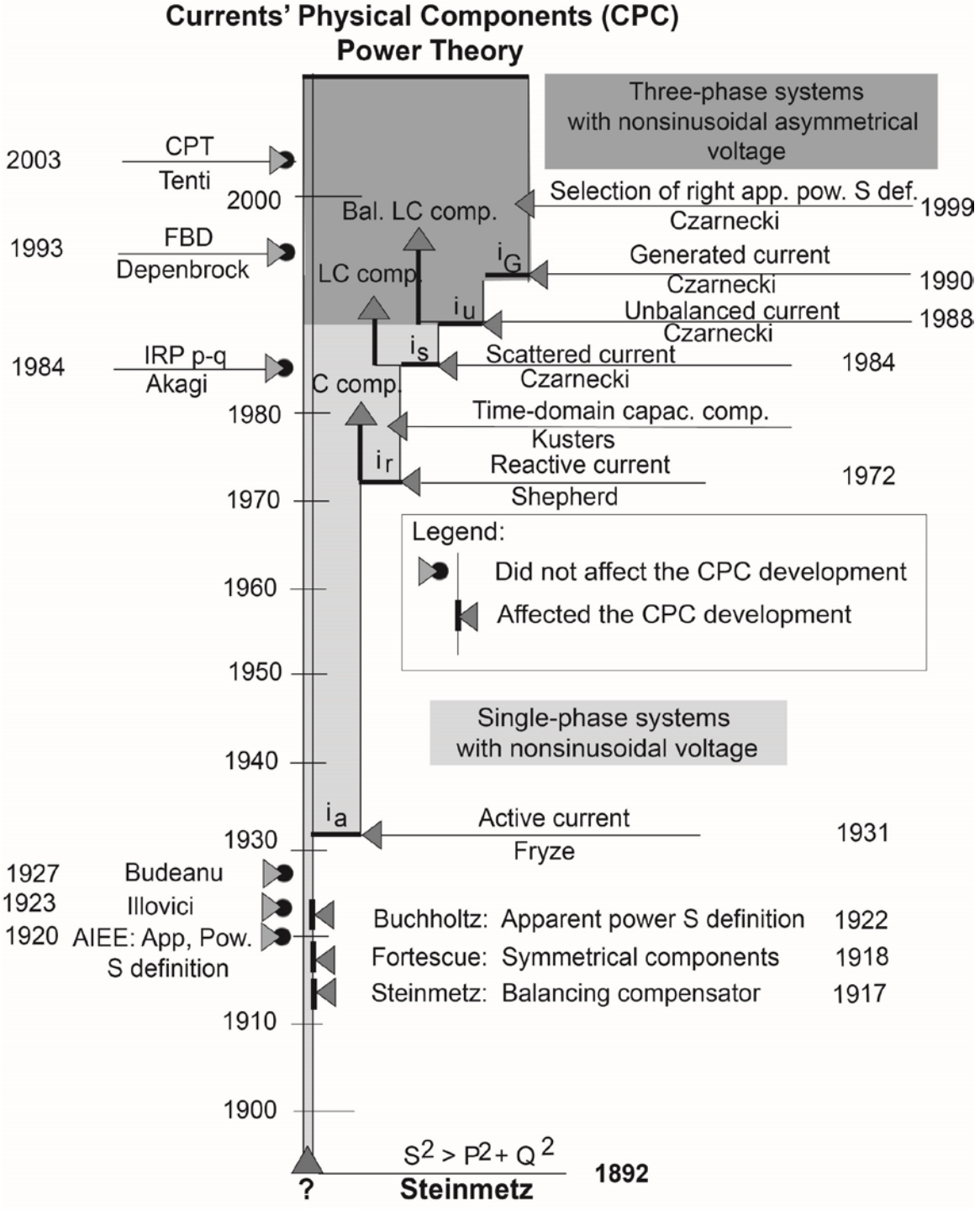
The Misconceptions Defense System
has failed
to defense this idea, however

In the paper:

L.S. Czarnecki, “Could power properties of three-phase systems be described in terms of the Poynting Vector?”
*IEEE Transactions on Power Delivery, 2006*

***It was shown that this idea has no sense***

We do not see papers
on powers in terms of the Poynting Vector
any more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Conservative Power Theory (CPT)
developed in 2003 by P. Tenti

This a sort of the time-domain version
of the Budeanu's power theory

**CPT:**

in the time-domain

$$S^2 = P^2 + Q_{\mathrm{T}}^2 + D_{\mathrm{T}}^2$$

**Budeanu:**

in the frequency-domain

$$S^2 = P^2 + Q_{\mathrm{B}}^2 + D_{\mathrm{B}}^2$$

**CPT:**

in the time-domain

$$S^2 = P^2 + Q_{\mathrm{T}}^2 + D_{\mathrm{T}}^2$$

**Budeanu:**

in the frequency-domain

$$S^2 = P^2 + Q_{\mathrm{B}}^2 + D_{\mathrm{B}}^2$$

## Analogy:

There are no physical phenomena associated with the reactive and distortion powers

They do not provide right fundamentals for compensation

The reactive power in CPT is conservative in the same sense as the reactive power in Budeanu

There is a major difference, however.

In 1987, the paper:

L.S. Czarnecki, "What is wrong with the Budeanu's concept of the reactive and distortion powers and why it should be abandoned,"
sent to
*IEEE Transactions on Instrumentation and Measurements*
was published

30 years later, the paper:

L.S. Czarnecki, "Critical comments on the Conservative Power Theory,"
sent to
*IEEE Transactions on Power Delivery*
was rejected

The effects of this difference:

We do not see papers on Budeanu's power theory
and its applications, now,

while
on the IEEE Xplore we can find
more than 250 papers, including seven in the IEEE Transactions
on
applications of the Conservative Power Theory
!

There are, of course, major errors in these papers,
but perfectly protected by the Misconceptions Defense System

# Summary

Even if

power properties
of electrical systems are not the main subject of studies
on
the Loading Quality (LQ)
&
the Supply Quality (SQ)

these properties are very important for such studies

# Summary

The Power Theory,
which should be able to describe these properties
cannot do help in these studies very much
because of

numerous misconceptions on power properties
of electrical systems

protected by sort of

a Misconceptions Defense System

# Summary

The Misconceptions Defense System

is nothing else than
an exemplification the very fundamental Law of the Nature.

Sir Isaak Newton
called

The Action and Reaction Principle

# Summary

Fortunately, this Principle does not stop
the forward movement
and eventually

The Currents' Physical Components (CPC) – based Power Theory
shall be taught in power programs

# Summary

The current decomposition into Physical Components

$$\boldsymbol{i}(t) = \boldsymbol{i}_{\mathrm{a}}(t) + \boldsymbol{i}_{\mathrm{r}}(t) + \boldsymbol{i}_{\mathrm{s}}(t) + \boldsymbol{i}_{\mathrm{u}}^{\mathrm{n}}(t) + \boldsymbol{i}_{\mathrm{u}}^{\mathrm{p}}(t) + \boldsymbol{i}_{\mathrm{u}}^{\mathrm{z}}(t) + \boldsymbol{i}_{\mathrm{G}}(t)$$

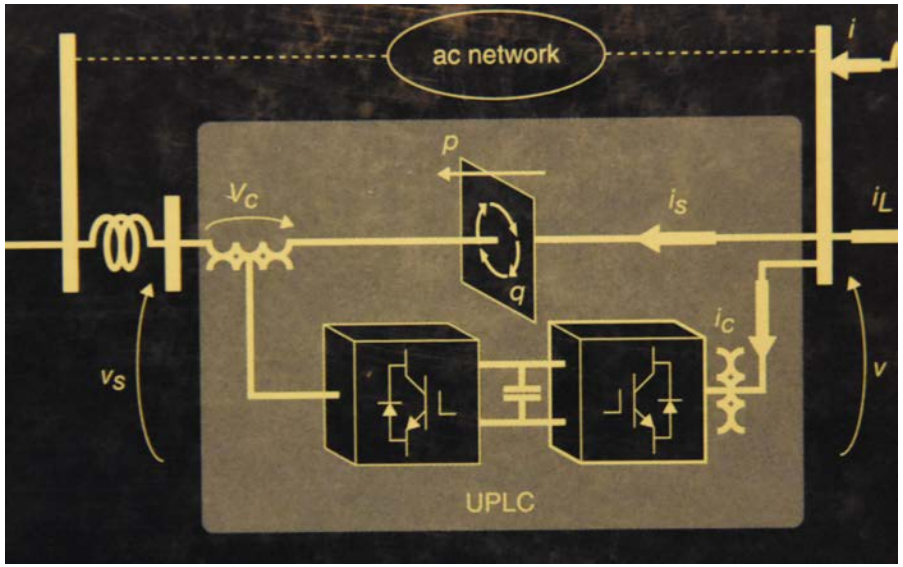
- Explains the energy flow related phenomena in systems of any complexity, linear, non-linear, and with periodic switching.
- Provides fundamentals for reactive compensator design.
- Provides fundamentals for switching compensator control.
- It was never challenged as incorrect.

# Summary

The CPC – based Power Theory
provides
a powerful tool for studies on SQ and LQ

# Summary

The activity
of the Misconceptions Defense System
makes the research on power properties of electrical systems
even more exciting,
it provides new challenges
and a bit of fun,
like this:




A reviewer for IEEE Trans. on Power Electronics:

"The author should provide with the manuscript the result of a poll, run over the EE community, that this picture indeed suggests the energy rotation around supply lines"

Thanks for your attantion!!