Pacific Northwest
NATIONAL LABORATORY

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Better Measurement:

How four important measurements are being improved

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U.S. DEPARTMENT OF ENERGY BATTELLE

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Motivation

- **Measurements dreamed up for an idealized world are not working well. Distorted signal lead to distorted readings. Measured results are inconsistent**
- *Reactive power* values are not intercomparable between instruments, sometimes vastly different
- *Power* measurements suffer some of the same problems, but for different reasons
- *Power factor* is defined in standard 1459 at least seven different ways, results not intercomparable
- There is now pressure to **change the definition of rms** in order to resolve the interoperability problem!
- The underlying problem is that people think we can “define our way out” of the situation

It is *not possible* to define our way out!

because none of these quantities are pre-existing (i.e. latent) variables, just awaiting a sufficiently clever definition to reveal their value.

There are solutions, however

Overview

What is the situation with

Apparent Power . . . . . 2 slides
Power factor . . . . . 2 slides
Reactive Power . . . . . 2 slides + 2 on Distortion Power
Power . . . . . 1 slide

What will be changed with respect to

Apparent Power +
Power factor . . . . . 1 slide
Reactive Power +
Power . . . . . 1 slide

Overall changes . . . . . 1 slide

12 more slides

Apparent Power

Definition: rms voltage times rms current

This is an *operational* measurement. Rms is an operational measurement: one whose result depends greatly on the operations carried out. These operations cannot be varied without changing the result

This is in contrast to a representational measurement. That kind of measurement usually can be implemented in a few different ways

A great deal of information is lost in *any* measurement, including rms, but operational measurements also have a “many-to-one” characteristic

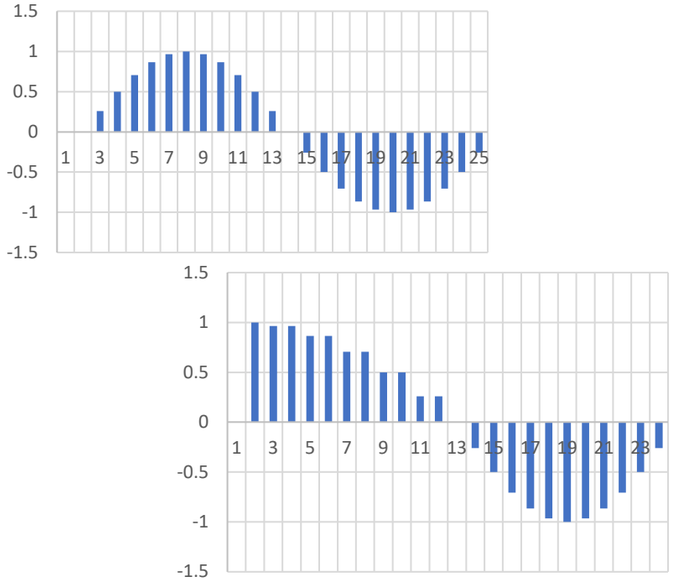
Waveforms for rms are sampled, but samples can be re-ordered without changing the result

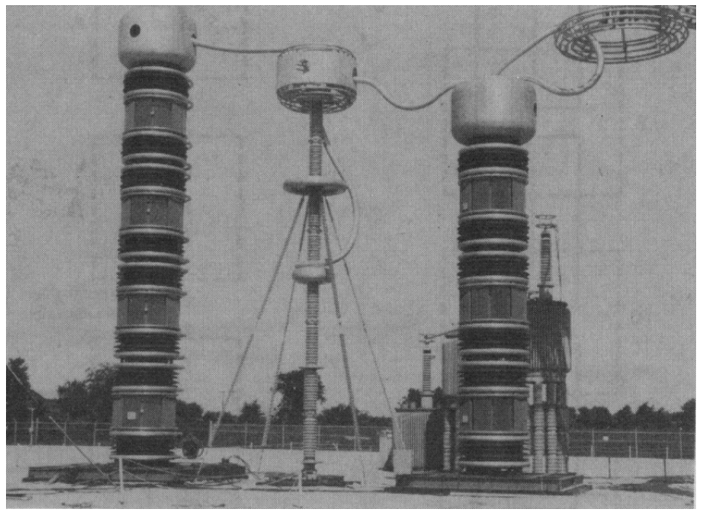
Apparent Power

Many-to-one effect

The rms value of a sine-wave sampled at 24 samples per cycle is the same for 3×10^{32} rearrangements of the same 24 sampled values

And an infinite number that had other values





Design rules

The reason things like transformers of a certain apparent power rating "look" the same is that they are usually built using the same design rules.

A 1200kV transformer rated 1 amp does *not* look like a 1200 kVA distribution transformer

Power Factor

Definition pf=*P/S*, John Fleming 1892 in a paper on transformers

Discovered to be useful as way to recover cost of delivery losses

Utilities found it did not work to give three-phase numbers

In 1919 AIEE and NEMA attempted a solution. Started with a survey

> Over and over again the power companies send in this complaint, “We can find no practical method of metering power factor.” One big western company writes, “We are strictly up against it and welcome suggestions which if followed would give us relief. ”

No single solution was found

Committee gave two definitions. Members added five more

IEEE Std 1459 contains at least seven definitions of power factor

Power Factor

Two problems

(1) If you change the definition you are not measuring the same thing

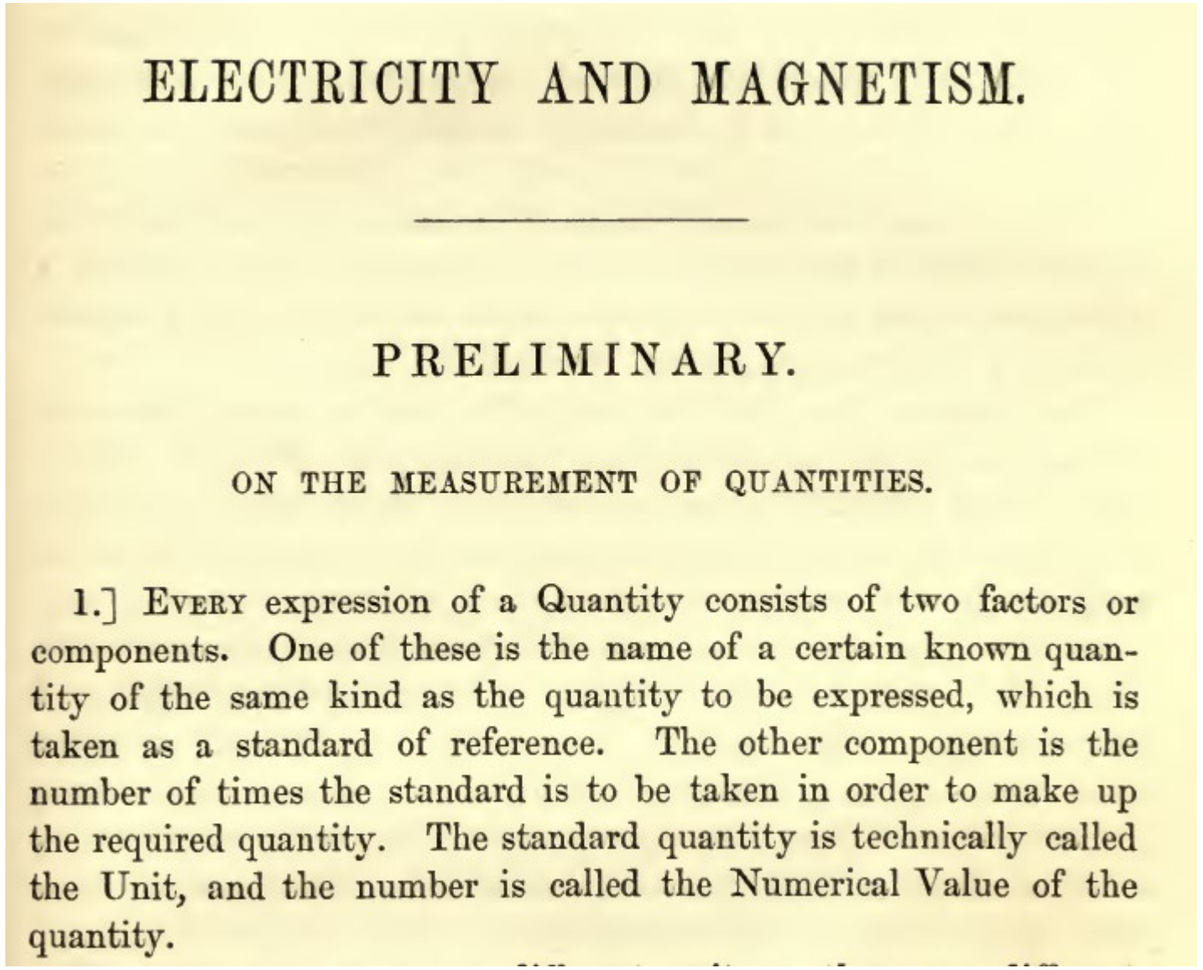
(2) Power factor is *non-extensive*

Maxwell described the process of measurement, and gives requirements, in the first page of his Treatise

(1) the measurand has to have a natural zero, and

(2) the result of the measurement must be linearly related to the quantity

Cauchy's equation as a test



ELECTRICITY AND MAGNETISM.

PRELIMINARY.

ON THE MEASUREMENT OF QUANTITIES.

1.] EVERY expression of a Quantity consists of two factors or components. One of these is the name of a certain known quantity of the same kind as the quantity to be expressed, which is taken as a standard of reference. The other component is the number of times the standard is to be taken in order to make up the required quantity. The standard quantity is technically called the Unit, and the number is called the Numerical Value of the quantity.

Reactive Power

Definition $Q = VI \sin\varphi$

Named by William Hand Browne in 1901 in a letter to the editor of a journal

People had managed to solve all the network problems without it, but expressions like “wattless watts” were used

The name gave something new: a sense of reality to the concept

People think there exists such a things as reactive power. In fact, none of the four things we are considering here have physical existence, they are all descriptions of concepts

Power is the rate of transfer of energy. “Power” as used by power engineers is an average power over some integral number of cycles. It is no more real than the average speed of a bus or a bullet train

Nor is reactive power, though if the reactive power reading is caused by energy going in and out of storage, the movement of real energy (and thus, power) is certainly involved

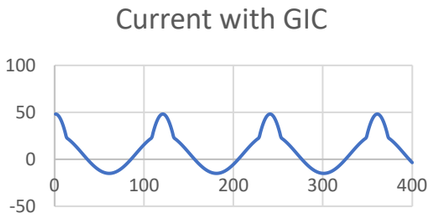
Reactive Power

Reactive power accounts for the observation that sometimes apparent power and real power are not the same

It did not really need to be accounted for

But now it has a name, and gives off a feeling of being something physical, it is observed not to be possible always to hold it accountable

If we have a current waveform like this



most methods of measuring reactive powers say there is reactive. Yet there is no phase lag, no storage

Another operational measurement exposed!

There are at least eleven ways to measure reactive power. I am not aware of a commercial instrument that implements the actual definition, $Q=VI \sin \varphi$.

Distortion Power

Definition: forget it!

Constantin Budeanu (1927) felt that the power triangle should *be*. It evidently bothered him that the values of reactive power, power and apparent power almost never produced a right triangle

(The triangle was wishful thinking, since reactive power depended on how you measured it)

Undaunted, and not greatly influenced by observations, he proposed something he called "*puissance déformante* " to account for the difference

However, the mathematics he invented to go along with this (and reproduced in IEEE Std 1459) do not work, and even Budeanu conceded that the currents and voltages associated with distortion power had no electric or magnetic fields

Distortion Power

We could imagine Budeanu felt the need to account for distortion and nonlinearity

One part of his work suggests he must also have “felt” another kind of solution was feasible

He proposed measuring reactive power harmonic by harmonic and adding up all the numbers

That method works for (real) power

The mathematics works for reactive power. It *can* be done. But the result makes us feel uncomfortable (and it made Budeanu uncomfortable as well, I think)

Can third harmonic power “cancel” fundamental reactive power if they happen to have opposite sign?

But I wonder if Budeanu sensed that by increasing the complexity of the measurement model, he could approach a solution. *More on this later*

Power

Definition $P = \overline{v(t)i(t)}$ Power (as used by power engineers) is the average power over some integral number of cycles

If (and only if) the waveforms involved are all perfectly represented by sinusoids can we write ***P=VI cosφ***

But we don't need to do that

In the world of digital measurements, we can take the sampled values of volts and amps, and multiply them, and then take the average value over the observation interval

But there's still a problem!

IEEE Std 1459 does not give instructions on how to define the measurement interval

What is going to be changed in revised Std 1459

Apparent power

Observation interval and reporting time will be specified

Method likely based on method used in PQ community

Operational nature of measurement will be pointed out

(e.g. averaging AP values does not give AP)

Since the rms will include harmonic effects, optional filtering will be specified to allow fundamental value to be measured. This is a way of decreasing complexity of signal instead of increasing complexity of model

You can think of this in terms of degrees of freedom

Power factor

Observation interval and reporting time will be specified

Warning will be given that the measurement is operational *and* non-extensive

Three-phase results cannot be found from three single-phase numbers

Filtering will be specified to allow fundamental value to be measured

What is going to be changed in revised Std 1459

Reactive Power

Observation interval and reporting time will be specified
Filtering will be specified to allow fundamental value to be measured

Distortion Power

Power

Observation interval and reporting time will be specified
The point-by point method will be given as the recommended method. It is *broadband*
Filtering will be specified to allow fundamental value to be measured

What is going to be changed in revised Std 1459

Overall changes

Standard will be simplified, reducing size by about a factor of two (from 40 pages)

Informative Annexes will be included to explain some of the changes

Cautions about using the conventional names for measurement results will be given

- There really are not eleven ways to measure reactive power, or seven ways to measure power factor—they are all measuring different things
- Please don’t call those results by the names reactive power or power factor: those names are applicable to results from some specifically-defined methods

The work of this standard is not a completed work. The operations to be carried out in operational measurements should be completely specified by standards. Nevertheless there may be a time when the community agrees that adjustment is needed. Examples of this process in other standards will be given

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Thank you for your interest

Are there questions?

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