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The measurement of actual apparent power and actual reactive power from the instantaneous power signals in single-phase and three-phase systems

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ABSTRACT

The measurement of both electric power and energy, especially in nonsinusoidal conditions, is still an open research problem in the metrology community. Harmonic distortion, noise, transients, overvoltages, and voltage dips have increased the difficulty in achieving accurate measurements. Many nonactive power component definitions have been proposed in the literature, even if their physical interpretation poses some problems. The conventional technique for measuring the apparent power S operates by calculating the product of the root-mean-square (rms) of the voltage and current. This paper investigates the introduction of a novel definition of apparent power S and reactive power Q, starting from the processing of the instantaneous power signal, both in sinusoidal and nonsinusoidal conditions. In particular, the rms value of the instantaneous power waveform is processed to obtain the power parameters. The aim of this study is to contribute to the research concerned with the measurement of apparent power, reactive power, and power factor under nonsinusoidal conditions in single-phase and three-phase systems. Moreover, one benefit of the proposed work is that the signal processing required to implement an electric power and energy meter would be simplified.

1. Introduction

Electric power and energy measurements are required in nearly all research, industrial, and consumer applications. Power measurements are of importance primarily for testing, monitoring, and maintaining energy supply networks and electric equipment (e.g., to measure the efficiency of electric machines). The measurement of electric energy is of primary importance in energy distribution networks because the charge for consumption of energy is computed on this basis. From an economic point of view, it is the most important of all electric measurements.

It is well known that a lack of quality in the electric supply can result in faults, overload, and malfunctions in many electric devices. Therefore, electric power measurements should take into account the quality of the power in terms of distortion from the ideal sinusoidal conditions. It is a common opinion that electric power and energy should be considered in the same way as other consumer goods, by introducing definitions and measurements of quality indexes.

One of most critical problems that must be taken into account during the development and testing of measurement apparatuses is harmonic distortion because it introduces a large uncertainty, especially in the measurement of the reactive power and power factor.

This manuscript is placed in the complex and extensive field concerning the representation of power behavior in electric systems under non-sinusoidal conditions. Many authors have investigated and debated this topic, proposing different definitions for power quantities [1–12]. This work can be considered a small contribution to this field. It is focused on the conventional approach of defining power parameters under non-sinusoidal conditions by adopting instantaneous power waveforms for the definition of apparent power and reactive power, in addition to the well-known definition of active power (average value of the instantaneous power). Although an exhaustive and univocal analysis of power systems under non-sinusoidal conditions can be achieved only with a thorough measurement of a wide set of quantities due to the extremely high number of freedom degrees the systems themselves can assume, the proposed approach could

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List of variables

AD	actual distortion power
AD_t	total actual distortion power
AN	actual nonactive power
APF	actual power factor
APF_t	three-phase actual power factor
AQ	actual reactive power
AQ_t	total actual reactive power
AS	actual apparent power
AS_t	total actual apparent power
D	distortion power (Budeanu)
$i(t)$	instantaneous current
I	rms current
ITHD%	current total harmonic distortion in percent
N	non active power (IEEE)
N_h	total harmonic non active power (IEEE)
$p(t)$	instantaneous power
$p'(t)$	oscillating power
P	average power
PF	power factor
P_h	total harmonic power (IEEE)
P_m	active power
P_{mt}	total mean power
P_0	rms value of the total oscillating power
P_{rms}	rms value of $p(t)$
P_t	total active power
PUF	power unbalance factor
P_1	fundamental active power (IEEE)
Q	reactive power
Q_C	capacitive reactive power (Kunsters and Moore)
Q_{CR}	capacitive reactive power rest (Kunsters and Moore)
Q_L	inductive reactive power (Kunsters and Moore)
Q_{LR}	inductive reactive power rest (Kunsters and Moore)
Q_t	three-phase reactive power
Q_1	fundamental reactive power (IEEE)
S	apparent power
S_C	complementary apparent power
S_c	scatter power (Sharon/Czarnecki)
S_d	distortion apparent power (Shepherd and Zakikhani)
S_h	harmonic apparent power (IEEE)
S_n	non fundamental apparent power (IEEE)
S_q	reactive power (Sharon/Czarnecki)
S_r	active apparent power (Shepherd and Zakikhani)
S_t	three-phase apparent power
S_x	reactive apparent power (Shepherd and Zakikhani)
S_1	fundamental apparent power (IEEE)
T	period
$v(t)$	instantaneous voltage
V	rms voltage
VTHD%	voltage total harmonic distortion in percent
φ_V	voltage phase
φ_I	current phases
ω	pulsation (angular frequency)

be considered as a measurement technique by taking into account the actual shape of the instantaneous power waveforms, without any need for the rms values of voltages and currents. The measurement of both electric power and energy is still an open research problem in the metrology community. Phenomena such as harmonic distortion, noise, transients, over-voltages, and voltage dips have increased the difficulty of achieving accurate measurements, compared with sinusoidal signals [10]. New definitions of electrical quantities in nonstandard situations could be useful in such scenarios [13]. As previously demonstrated [14], there is no direct relationship between the variations in apparent power and instantaneous power fluctuations in the presence of harmonic distortion.

The measurement of the rms value of the instantaneous power under nonsinusoidal conditions as a possible index of harmonic distortion has been analyzed for adoption in low-cost power quality measuring devices [15].