Radian Research, Inc.

Distortion Analysis for Energy Measurement Equipment

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Introduction

The purpose of this presentation is to highlight the error behavior of a set of classic energy metrics in the presence of distortion. This evaluation is needed due to the various methods of “similar” calculations performed by different equipment which may be utilized for the same application.

Basic Metrics

$V = \sqrt{\frac{1}{kT}\int_{\tau}^{\tau+kT} v^2 dt}$	$I = \sqrt{\frac{1}{kT}\int_{\tau}^{\tau+kT} i^2 dt}$
$V^2 = \frac{1}{kT}\int_{\tau}^{\tau+kT} v^2 dt$	$I^2 = \frac{1}{kT}\int_{\tau}^{\tau+kT} i^2 dt$
$S_{Arithmetic} = VI$	$S_{\rightarrow} = \sqrt{P^2 + Q^2}$
$P = \frac{1}{kT}\int_{\tau}^{\tau+kT} vidt$	$Q_{\int} = \frac{1}{kT}\int_{\tau}^{\tau+kT} v_{\perp} idt \quad v_{\perp} = \omega\int v^2 dt$
$Q_{rms} = \sqrt{S^2 - P^2}$	$Q_{\pi/2} = \frac{1}{kT}\int_{\tau}^{\tau+kT} v_{\perp} idt \quad v_{\perp} = v(t + \frac{\pi}{2\omega})$

Power Measurements Derived

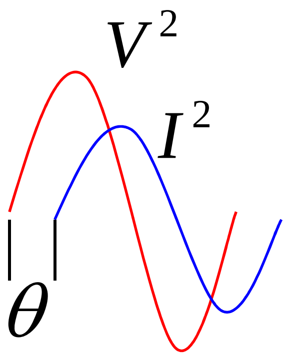
- We assume no prior knowledge concerning the nature of the distortion on the voltage or the current axes. This is accomplished by measuring a set of fundamental metric and then deriving the others from this measurement basis.

Fundamental Metrics & Errors

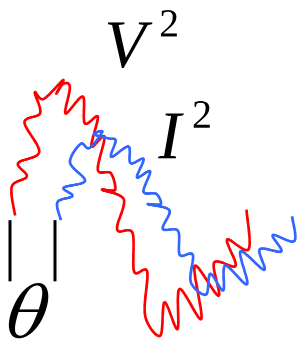
$V^2 = V_0^2\left(1+\xi_{V^2}\right)$	And	$\xi_{V^2} = \dfrac{V^2 - V_0^2}{V_0^2}$
$I^2 = I_0^2\left(1+\xi_{I^2}\right)$	And	$\xi_{I^2} = \dfrac{I^2 - I_0^2}{I_0^2}$
$\theta = \theta_o + 2\pi\xi_\theta$	And	$\xi_\theta = \dfrac{\theta - \theta_o}{2\pi}$

Performance Evaluation

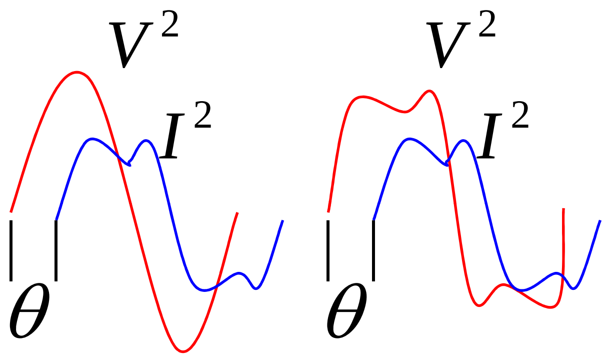
- To evaluate the performance of each metric (P-watt, S-va, Q-var) we introduced a particular type of distortion and evaluated if it met our expectations and/or matched the predicted value.



Pure



Zero-mean additive Gaussian noise



m^{th} order on voltage and a n^{th} order on current

Error Sources

- There are errors associated with each of the waveforms beyond the calibration of V, I or Ø measurements.
  - In a pure waveform error may exist due to RMS squaring during calculations. Error amount depends on how clean the V&I supply delivers during test.
  - A zero-mean additive Gaussian noise waveform has error cause by the noise density. The more noise present will increase the error.
  - In a m^{th} order on voltage and a n^{th} order on current waveform there is error caused by the total harmonic distortion.

Comparison of Integration vs. RMS

- For Real, Apparent and **Reactive Power** you can comprise the metric by deriving the measurement using RMS Voltage and Current or by integrating (2) the Voltage and Current for several samples.

$$VAR_i = \sqrt{VA_i^2 - WATT_i^2}$$

$$VAR_i = \| \tilde{V}i \| \cdot \| \tilde{I}_i \| \sin(\theta_i)$$

$$VAR_i = \frac{\omega}{kT} \int_{\tau}^{\tau+kT} I_i \left[\int V_i \, dt \right] dt$$

$$VAR_i = \frac{1}{kT} \int_{\tau}^{\tau+kT} \left(I_i V_i \left(t + 90^\circ \right) \right) dt$$

Conclusions – Gaussian Noise

- A measurement device cannot avoid including noise density error into RMS Voltage and RMS Current measurements.

- If the integration does not involve the noise density, ie: the noise is NOT squared in the measurement process, and the noise is zero mean, the noise integration will vanish.

Conclusion – Gaussian Noise (cont)

- Metrics derived from RMS voltage and RMS current inherits noise power density components, thereby adding error to these derived metrics. We see that arithmetic VA, RMS VAR and arithmetic PF inherit errors from RMS Voltage and RMS Current.
- Vector VA or PF that are derived from Watt and Integral or shifted VAR, have no inherent error assuming Watt or VAR are true.
- Identifies the importance of “low noise” during testing.

Conclusion – Harmonics

- Just as in the case of zero-mean additive Gaussian noise, a harmonic on the current or voltage axis will force the measurement device to include the harmonic magnitude in its RMS voltage and current measurement

- It is recognized that a orthogonal relationship exists between the fundamental and harmonic components: If the harmonic order on the voltage and current axis are not equal, the resulting metric estimates are analogous to that obtain for zero-mean additive Gaussian noise.

Conclusion – Harmonics (cont)

- If the harmonic order on the voltage and current axis are equal, then a harmonic error componet will appear on the active power estimat (watt) and the reactive power estimate (var).

- Identifies concern on which method each equipment calculate metrics

Thank You!

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