
Code: 27.002

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Semiconductor Revolution

- New manufacturing technologies
- Daily tasks facilitated
- Raise in the concern about quality of electric power
Power Quality

- Deviations that result in an equipment malfunction
- Measurement methodologies
- Legislation
- Definitions of the nonsinusoidal powers and power factor
• Definitions under nonsinusoidal conditions
• Harmonic terms
• Purely sinusoidal system
Learning tool

- LabVIEW Virtual instrument (VI)
- Phase-controlled single-phase AC voltage controller
- Waveforms
- Nonsinusoidal powers
- Power factor
- Harmonic distortion
- Reactive power compensation
- Filtering of the current third harmonic
Power Quantities – Nonsinusoidal Condition

- Standards defined by IEEE in Std 1459-2010
Power Quantities – Nonsinusoidal Condition

\[ v(t) = v_1(t) + v_H(t) \]

\[ v_1(t) = \sqrt{2} V_{1\text{rms}} \, \text{sen}(\omega t - \alpha_1) \]

\[ v_H(t) = V_0 + \sqrt{2} \sum_{h \neq 1} V_{hrms} \, \text{sen}(h\omega t - \alpha_h) \]

\[ V_{rms}^2 = V_{1\text{rms}}^2 + V_{H\text{rms}}^2 \]

\[ V_{H\text{rms}}^2 = V_0^2 + \sum_{h \neq 1} V_{hrms}^2 \]
Power Quantities – Nonsinusoidal Condition

\[ i(t) = i_1(t) + i_H(t) \]

\[ i_1(t) = \sqrt{2} I_{1\text{rms}} \sin(\omega t - \beta_1) \]

\[ i_H(t) = I_0 + \sqrt{2} \sum_{h \neq 1} I_{hrms} \sin(h \omega t - \beta_h) \]

\[ I_{rms}^2 = I_{1\text{rms}}^2 + I_{H\text{rms}}^2 \]

\[ I_{H\text{rms}}^2 = I_0^2 + \sum_{h \neq 1} I_{hrms}^2 \]
Power Quantities – Nonsinusoidal Condition

• Total Harmonic Distortion

\[
THD_V = \frac{V_{Hrms}}{V_{1rms}} = \sqrt{\left(\frac{V_{rms}}{V_{1rms}}\right)^2} - 1
\]

\[
THD_I = \frac{I_{Hrms}}{I_{1rms}} = \sqrt{\left(\frac{I_{rms}}{I_{1rms}}\right)^2} - 1
\]
Power Quantities – Nonsinusoidal Condition

- Active Power

\[
P = \frac{1}{T} \int_{0}^{T} v(t) i(t) \, dt
\]

\[
P_{ns} = \sum_{h=1}^{\infty} V_{hrms} I_{hrms} \cos \phi_{h} = P_{1} + P_{H}
\]

\[
P_{1} = \frac{1}{kT} \int_{\tau}^{\tau+kT} v_{1}(t) i_{1}(t) \, dt = V_{1rms} I_{1rms} \cos \phi_{1}
\]

\[
P_{H} = V_{0} I_{0} + \sum_{h \neq 1} V_{hrms} I_{hrms} \cos \phi_{h}
\]
Power Quantities – Nonsinusoidal Condition

• Reactive Power

\[ Q_{ns} = \sum_{h=1}^{\infty} V_{hrms} I_{hrms} \sin \phi_h \]

\[ Q_1 = \frac{\omega}{kT} \int_{\tau}^{\tau+kT} i_1(t) \left[ \int_{\tau} v_1(t) dt \right] dt = V_{1rms} I_{1rms} \sin \phi_1 \]
Power Quantities – Nonsinusoidal Condition

• Apparent Power

\[ S = V_{\text{rms}} I_{\text{rms}} \]

\[ S^2 = S_1^2 + S_N^2 \]

\[ S_1 = V_{1\text{rms}} I_{1\text{rms}} = \sqrt{P_1^2 + Q_1^2} \]

\[ S_N^2 = D_I^2 + D_V^2 + S_H^2 \]

\[ S_H = V_{H\text{rms}} I_{H\text{rms}} = S_1 (THD_V)(THD_I) \]
Power Quantities – Nonsinusoidal Condition

- Distortion Power

\[ D_I = V_{1rms} I_{Hrms} = S_1(THD_I) \]

\[ D_V = V_{Hrms} I_{1rms} = S_1(THD_V) \]

\[ D_H = \sqrt{S_H^2 - P_H^2} \]
Power Quantities – Nonsinusoidal Condition

• Power Factor

\[ FP = \frac{P}{S} \]
Voltage Controller

• Phase-Controlled Single-phase AC Voltage Controller

Figure 1. Phase-controlled single-phase AC voltage controller – triac.

Figure 2. Phase-controlled single-phase AC voltage controller – antiparallel thyristors.
Voltage Controller

- Phase-Controlled Single-phase AC Voltage Controller

\[ v_s(t) = \sqrt{2} V_s \text{sen}(\omega t) \]

\[ V_{Rrms} = \sqrt{\frac{1}{T} \int_0^T [v_R(t)]^2 \, dt} \]

\[ V_{Rrms} = \frac{V_s}{\sqrt{\pi}} \sqrt{(\pi - \alpha) + \frac{\text{sen} 2\alpha}{2}} \]

\[ \alpha = \pi \frac{V_C}{V_M} \]
Voltage Controller

- Phase-Controlled Single-phase AC Voltage Controller

\[ i_R(t) = \frac{v_R(t)}{R} \]

\[ I_{Rms} = \frac{V_S}{\sqrt{\pi} R} \sqrt{(\pi - \alpha) + \frac{\text{sen} 2\alpha}{2}} \]
Voltage Controller

• Phase-Controlled Single-phase AC Voltage Controller

\[
a_k = \frac{\sqrt{2V_0}}{\pi R} \begin{cases}
\cos[(k + 1)\alpha] - \cos[(k + 1)\pi] \\
\cos[(k - 1)\alpha] - \cos[(k - 1)\pi]
\end{cases}
\]

\[
\frac{1}{(k + 1)} - \frac{1}{(k - 1)}
\]
**Voltage Controller**

- Phase-Controlled Single-phase AC Voltage Controller

\[ b_k = \frac{\sqrt{2} V_0}{\pi R} \left\{ \frac{\text{sen}[(k + 1)\alpha]}{(k + 1)} - \frac{\text{sen}[(k - 1)\alpha]}{(k - 1)} \right\} \]
Reactive Power Compensation

\[ X_c = \frac{1}{\omega C} = \frac{1}{2\pi fC} \]

\[ Q_C = V_S I_{Crms} \sin \phi \]

\[ I_{Crms} = \frac{V_S}{X_c} = 2\pi fC V_S \]

\[ Q_C = -2\pi fC V_S^2 \]
• Reduce the production of harmonic currents
• Add filters to drain the currents, to block them or to provide current harmonics locally
• Modify the frequency response of the system
Harmonic Filtering

- LC resonant circuit
- Shunt filters
- Series filters
Methodology

- LabVIEW (National Instruments)
- Programming language: G
Figure 3. Front panel – waveforms and voltage harmonic composition.
Figure 4. Front panel – control signals and current harmonic composition.
Results
Figure 5. Results without reactive power compensation and without filtering – 90° firing angle.
Figure 6. Results with reactive power compensation and without filtering – 90° firing angle.
Figure 7. Results with reactive power compensation and with filtering – 90° firing angle.
Conclusions

• Measurement of distortion indexes
• Power theory for nonsinusoidal electrical circuits
• Virtual Instrument to illustrate a nonsinusoidal system operation that considerably facilitate the understanding of the nonsinusoidal powers
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