Fundamentals of Power Measurement

Unit Relationships

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>Volts</td>
<td>Voltage</td>
</tr>
<tr>
<td>I</td>
<td>Amps</td>
<td>Current</td>
</tr>
<tr>
<td>P</td>
<td>Watts</td>
<td>Power</td>
</tr>
<tr>
<td>R</td>
<td>Ohms</td>
<td>Resistance</td>
</tr>
</tbody>
</table>

**Average, RMS, Peak, Peak-to-Peak Conversation**

<table>
<thead>
<tr>
<th>Known Value</th>
<th>Average</th>
<th>RMS</th>
<th>Peak</th>
<th>Peak-to-Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>1.0</td>
<td>1.11</td>
<td>1.37</td>
<td>3.14</td>
</tr>
<tr>
<td>RMS</td>
<td>0.9</td>
<td>1.0</td>
<td>1.44</td>
<td>2.83</td>
</tr>
<tr>
<td>Peak</td>
<td>0.637</td>
<td>0.707</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Peak-to-Peak</td>
<td>0.30</td>
<td>0.035</td>
<td>0.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**Mechanical Power**

\[ P_m = \frac{2 \pi \times \text{Rotating Speed}}{60 \text{ (Sec/Min)}} \times \text{Torque} \]

**Synchronous Speed**

\[ \text{Synchronous Speed} = \frac{120 \times \text{Frequency}}{\text{Number of Poles}} \]

**Electrical Power**

**DC Power Measurement**

\[ P = V \times I \]

**AC Power Measurement**

\[ P = V_{rms} \times I_{rms} \times \cos \phi \]

**Power Relationships**

\[ V \times I = \text{Watts} \]

**VOLT-AMPS**

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

**Efficiency**

\[ \text{Efficiency} = \frac{\text{Output Power}}{\text{Input Power}} = \frac{P_{out}}{P_{in}} \]

**Blondel Transformation**

Blondel theory states that total power is measured with ONE LESS wattmeter than the number of Wires.

1. **1-Wattmeter Method**
   \[ P_f = W_1 \]
   \[ PF_f = \frac{W_1}{V_A} \]
2. **2-Wattmeter Method**
   \[ P_f = W_1 + W_2 \]
   \[ PF_f = \frac{W_1 + W_2}{V_A + V_B} \]
3. **3-Wattmeter Method**
   \[ P_f = W_1 + W_2 + W_3 \]
   \[ PF_f = \frac{W_1 + W_2 + W_3}{V_A + V_B + V_C} \]

**A WORD OF CAUTION**

NEVER Open circuit the secondary side of a current transformer while it is energized!

This could cause serious damage to the CT and could possibly be harmful to equipment operators.

**The Precision Makers**

YOKOGAWA

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**Distorted AC Waveforms**

Harmonics are defined as voltages, currents or power at frequencies that are multiples of the fundamental frequency. Total Power of the Distorted Waveform is calculated as:

\[ P_T = \sum_{k=1}^{\infty} \left( \frac{1}{k} \right)^2 \times P_k \]

Typical UL and CSA Method

\[ P_T = \sum_{k=1}^{\infty} \left( \frac{1}{(k-1)} \right)^2 \times P_k \]

Typical IEC Method

Normal Mode

\[ P_T = \sum_{k=1}^{\infty} \left( \frac{1}{k} \right)^2 \times P_k \]

Harmonics Mode

\[ P_T = \sum_{k=1}^{\infty} \left( \frac{1}{(k-1)} \right)^2 \times P_k \]

**Power Analyzer vs Oscilloscope**

<table>
<thead>
<tr>
<th>Function</th>
<th>WT1000 Power Analyzer</th>
<th>DLM2020 Oscilloscope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>DC – MHz</td>
<td>DC – 500MHz</td>
</tr>
<tr>
<td>Accuracy</td>
<td>±0.05% of Full Scale range</td>
<td>±0.05% of Full Scale range</td>
</tr>
<tr>
<td>Input Method</td>
<td>Direct Coupled</td>
<td>Direct Coupled</td>
</tr>
<tr>
<td>Resolution</td>
<td>±0.05% of Full Scale range</td>
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**Test & Measurement**
Fundamentals of Power Measurement

**Unit Relationships**

\[
\begin{align*}
\text{WATTS} & = PV = \text{Power} \\
\text{AMPS} & = I = \text{Current} \\
\text{VOLTS} & = V = \text{Voltage} \\
\text{OHMS} & = R = \text{Resistance}
\end{align*}
\]

**Average, RMS, Peak, Peak-to-Peak Conversation**

- **Known Value**
  - **Average**: 1.0
  - **RMS**: 0.9
  - **Peak**: 0.637
  - **Peak-to-Peak**: 0.32

**Electrical Power**

- **DC Power Measurement**
  - Watts \( W = V \times I \)

- **AC Power Measurement**
  - \( V_{x} = V_{rms} \times A_{rms} \times \cos \phi \)

- **Apparent Power**
  - \( S = V_{rms} \times I_{rms} \)

- **Displacement Power Factor**
  - \( PF = \cos \phi \)

- **True Power Factor**
  - \( PF = \frac{W}{VA} \)

- **Efficiency**
  - \( \eta = \frac{\text{Output Power}}{\text{Input Power}} = \frac{P_{out}}{P_{in}} \)

**Harmonic Measurements**

- **Blondel Transformation**
  - Blondel theory states that total power is measured with One LESS wattmeter than the number of Wires.

  - 1-Wattmeter Method
    - \( P_{1} = W_{1} \)
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  - 2-Wattmeter Method
    - \( P_{2} = W_{1} + W_{2} \)
    - \( PF_{2} = \frac{W_{1} + W_{2}}{VA_{1} + VA_{2}} \)

  - 3-Wattmeter Method
    - \( P_{3} = W_{1} + W_{2} + W_{3} \)
    - \( PF_{3} = \frac{W_{1} + W_{2} + W_{3}}{VA_{1} + VA_{2} + VA_{3}} \)

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**Energy, Power, and Efficiency**

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