Measurement of electrical power and energy

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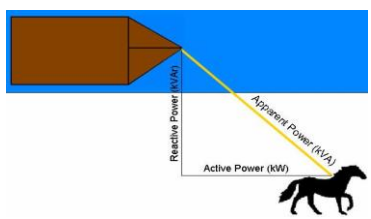
Electrical power = ability to perform work

- Electric power is the rate, per unit time, at which electrical energy is transferred by an electric circuit.
- DC power (DC voltage and current): P=U.I
- AC power (general - non-harmonic waveform):
  - Immediate power $p(t)=u(t).i(t)$
  - Average power $P = \frac{1}{T}\int_0^T u(t)i(t)dt$
  - Harmonic waveform $u(t) = U\cos\omega t\,,\; i(t) = I\cos(\omega t + \phi)$
    - Apparent power: $P_{app}=U.I$ [VA]
    - Active power $P_a=U.I.\cos\phi$ [watt]
    - Reactive power $P_r=U.I.\sin\phi$ [VA$_r$]
    - Power factor: $\cos\phi$
- *Note: according to Parseval theorem the total power is sum of partial power (power of spectral components). Using the theorem idea of active, reactive and apparent power can be generalized for any period waveform.*

Apparent, active and reactive power

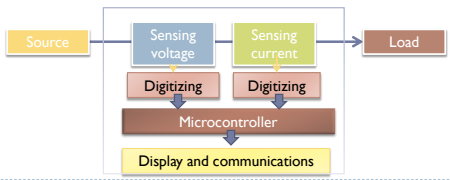


Electrical power measuring instrumentation

- Wattmeters:
  - Transmission – inserted between source of power and load. The own consumption from measured voltage and current should be minimal (close to 0)
    - Most often used at low frequencies (230V, 50/60Hz), energy distribution
      - Quasi harmonic waveforms.
    - Modern wattmeter are wideband measuring distorted sinewaves (higher harmonics are included) or any LF waveforms
  - Absorbing – contain equivalent substitute load abssorbing all measured power from source (conversion to heat)
    - Typical for RF and microwave measurements

LF wattmeters and measurement of energy

- Measured signals are usually about sinewaves (e.g., energetics).
  - Including higher harmonics for distorted waveforms (money ….)
- Principle:



RF wattmeters

- Usually absorbing RF power in matched load .
- Frequency range: from kHz (more often MHz) up to tens of GHz
- Measure peak or averaged power in range typically from -50dBm up to +30dBm on 50ohms
- Typical form: eternal USB modules k PC or spectrum analyzers or desk top instruments
- Except simple measurement of power they offer a variety of additional functions such as statistics, modulation analysis, etc.
- Principle:
  - Conversion of power on head and sensing the final temperature
    - Require reference source and calibration.
  - Fast rectification with nonlinear (squared) conversion characteristics (fast diodes)