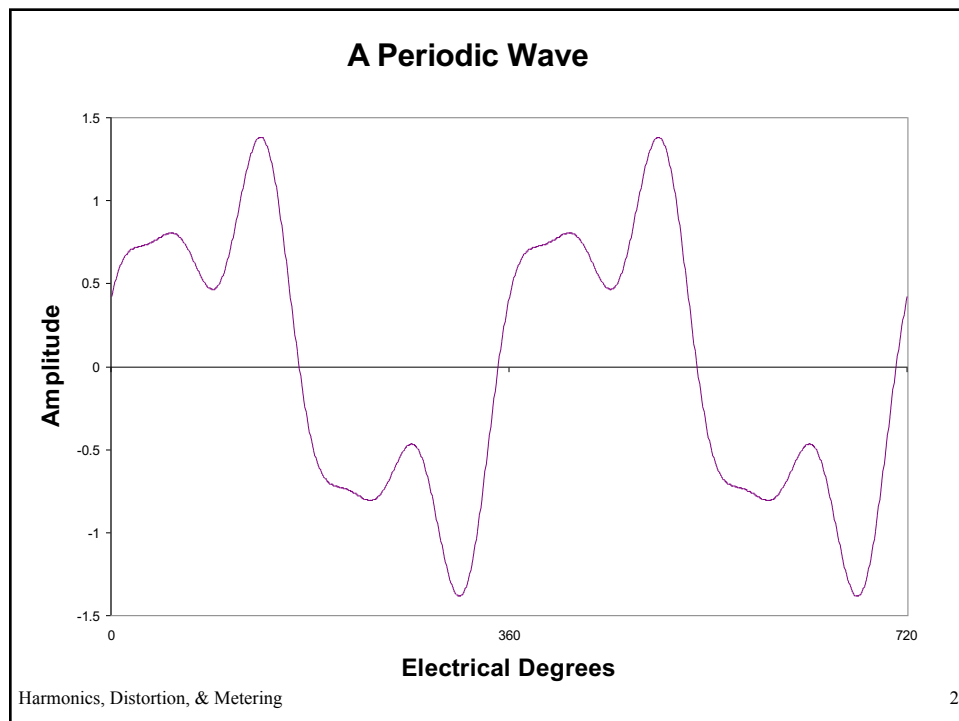
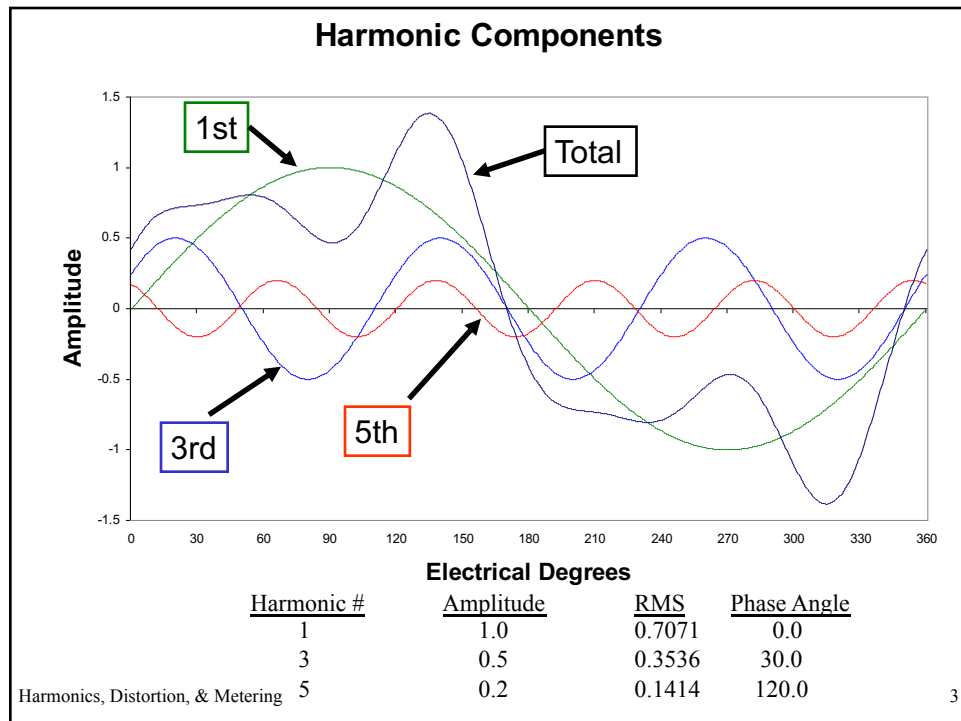


Harmonics, Distortion, and their Effect on Metering

Shahid Mukhtar
ACTARIS / AMC

Mar 2003



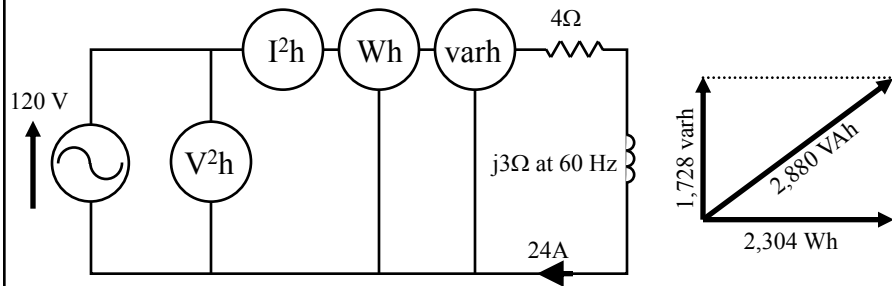


Harmonic Analysis

- Since nonsinusoidal waves can be resolved into harmonically related sinusoidal waves, if you know how to figure the ac powers and power factors for sine waves, you can do it for nonsinusoidal waves. All that you need to add to what you already know is how to combine harmonic powers.
- You could also figure the rms currents and voltages, if you remember how to combine voltages and currents of different frequencies.

60 Hz

Sinusoidal Voltage & Current



After 1 hour:

$$\text{Voltage}^2\text{h} = 120^2 \times 1 = 14400 \text{ V}^2\text{h}$$

$$\text{Current}^2\text{h} = 24^2 \times 1 = 576 \text{ A}^2\text{h}$$

$$\text{Apparent VAh} = \sqrt{14400 \times 576} = 2880 \text{ VAh}$$

$$\text{Energy} = 24^2 \times 4 \times 1 = 2304 \text{ Watthours}$$

$$\text{Quadergy} = 24^2 \times 3 \times 1 = 1728 \text{ varhours}$$

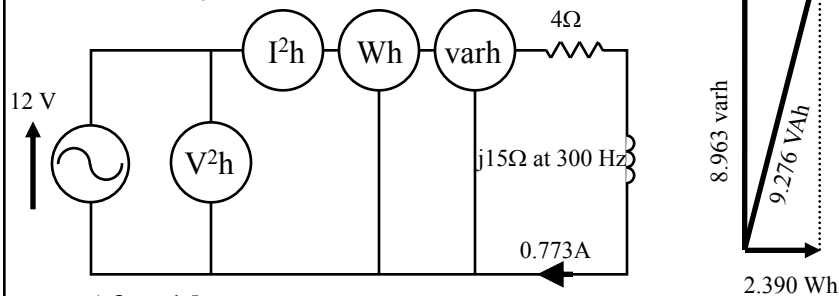
$$\text{Phasor VAh} = \sqrt{\text{Wh}^2 + \text{varh}^2} = \sqrt{2304^2 + 1728^2} = 2880 \text{ VAh}$$

Harmonics, Distortion, & Metering

5

300 Hz

Sinusoidal Voltage & Current



After 1 hour:

$$\text{Voltage}^2\text{h} = 12^2 \times 1 = 144 \text{ V}^2\text{h}$$

$$\text{Current}^2\text{h} = 0.773^2 \times 1 = 0.5975 \text{ A}^2\text{h}$$

$$\text{Apparent VAh} = \sqrt{144 \times 0.5975} = 9.276 \text{ VAh}$$

$$\text{Energy} = 0.773^2 \times 4 \times 1 = 2.390 \text{ Watthours}$$

$$\text{Quadergy} = 0.773^2 \times 15 \times 1 = 8.963 \text{ varhours}$$

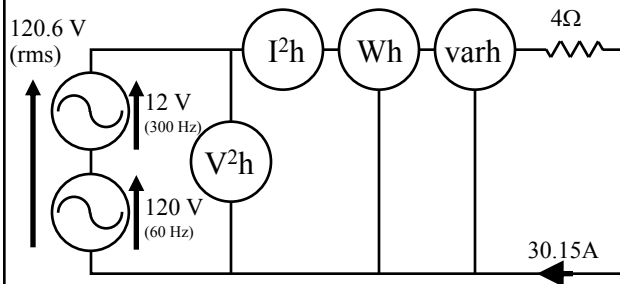
$$\text{Phasor VAh} = \sqrt{\text{Wh}^2 + \text{varh}^2} = \sqrt{2.390^2 + 8.963^2} = 9.276 \text{ VAh}$$

Harmonics, Distortion, & Metering

6

60 Hz & 300 Hz

Non-Sinusoidal Voltage & Current



$$\begin{array}{r} 3,600 + 36 \text{ Wh} \\ \hline 3,636 \text{ App. VAh} \end{array}$$

After 1 hour:

$$\text{Voltage}^2\text{h} = (120^2 + 12^2) \times 1 = 14544 \text{ V}^2\text{h}$$

$$\text{Current}^2\text{h} = (30^2 + 3^2) \times 1 = 909 \text{ A}^2\text{h}$$

$$\text{Apparent VAh} = \sqrt{14544 \times 909} = 3636 \text{ VAh}$$

$$\text{Energy} = (30^2 + 3^2) \times 4 \times 1 = 3636 \text{ Watthours}$$

$$\text{Quadergy} = (30^2 + 3^2) \times 0 \times 1 = 0 \text{ varhours}$$

$$\text{Phasor VAh} = \sqrt{\text{Wh}^2 + \text{varh}^2} = \sqrt{3636^2 + 0^2} = 3636 \text{ VAh}$$

Note:

Distortion VAh=0

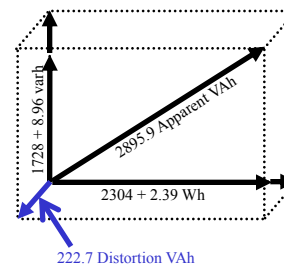
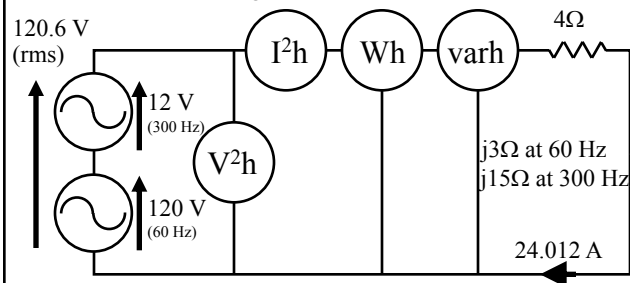
Harmonic Energy=36 Wh

Harmonics, Distortion, & Metering

7

60 Hz & 300 Hz

Non-Sinusoidal Voltage & Current



After 1 hour:

$$\text{Voltage}^2\text{h} = (120^2 + 12^2) \times 1 = 14544 \text{ V}^2\text{h}$$

$$\text{Current}^2\text{h} = (24^2 + 0.7730^2) \times 1 = 576.5975 \text{ A}^2\text{h}$$

$$\text{Apparent VAh} = \sqrt{14544 \times 576.6} = 2895.9 \text{ VAh}$$

$$\text{Energy} = (24^2 + 0.7730^2) \times 4 \times 1 = 2306.4 \text{ Watthours}$$

$$\text{Quadergy} = [(24^2 \times 3) + (0.7730^2 \times 15)] \times 1 = 1737.0 \text{ varhours}$$

$$\text{Phasor VAh} = \sqrt{\text{Wh}^2 + \text{varh}^2} = \sqrt{2306.4^2 + 1737.0^2} = 2887.3 \text{ VAh}$$

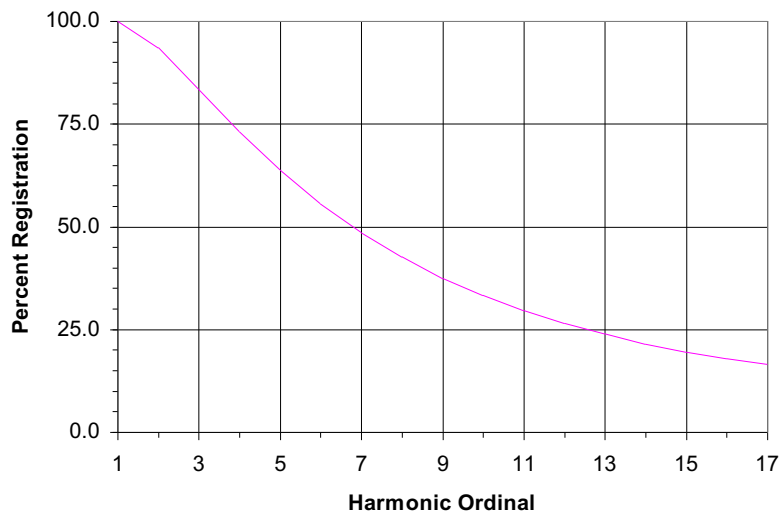
Note:

Apparent VAh > Phasor VAh

Harmonics, Distortion, & Metering

8

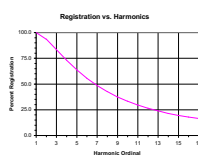
Induction Watthour Meter Response Registration vs. Harmonics



Harmonics, Distortion, & Metering

9

Induction Watthour Meter Response Registration Depends on Sign of Harmonic Power



h	%	Watts		Watts	
		Load	Meter	Load	Meter
1	100.0	1000.00	1000.00	1000.00	1000.00
2	93.6	0.11	0.10	0.11	0.10
3	83.5	0.46	0.38	-0.46	-0.38
4	73.1	0.10	0.07	0.10	0.07
5	63.7	11.90	7.58	-11.90	-7.58
6	55.5	0.10	0.06	0.10	0.06
7	48.5	6.02	2.92	-6.02	-2.92
8	42.6	0.10	0.04	0.10	0.04
9	37.5	3.60	1.35	-3.60	-1.35
10	33.3	0.10	0.03	0.10	0.03
11	29.7	2.38	0.71	-2.38	-0.71
12	26.6	0.10	0.03	0.10	0.03
13	23.9	1.68	0.40	-1.68	-0.40
14	21.5	0.10	0.02	0.10	0.02
15	19.5	1.23	0.24	-1.23	-0.24
16	18.0	0.10	0.02	0.10	0.02
17	16.5	0.94	0.16	-0.94	-0.16
		1029.02	1014.11	972.60	986.64

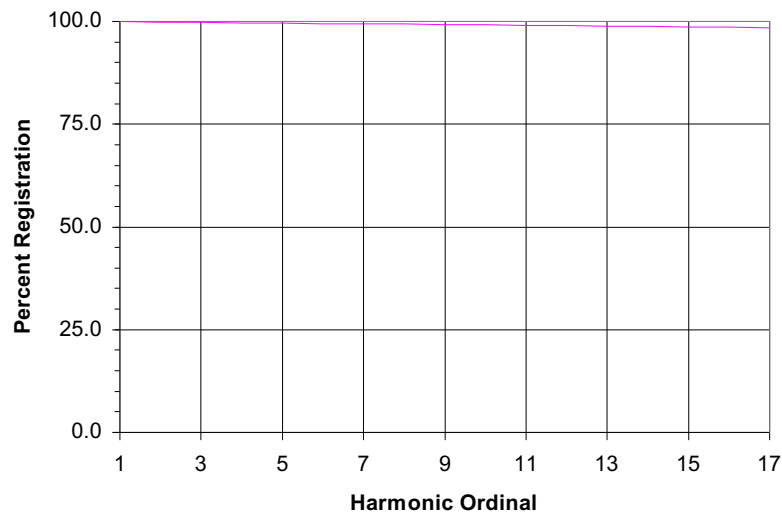
Registration = 98.6% Registration = 101.4%

Harmonics, Distortion, & Metering

10

EV Electronic Watthour Meter Response

Registration vs. Harmonics



Harmonics, Distortion, & Metering

11

EV Electronic Watthour Meter Response

Registration Depends on Sign of Harmonic Power

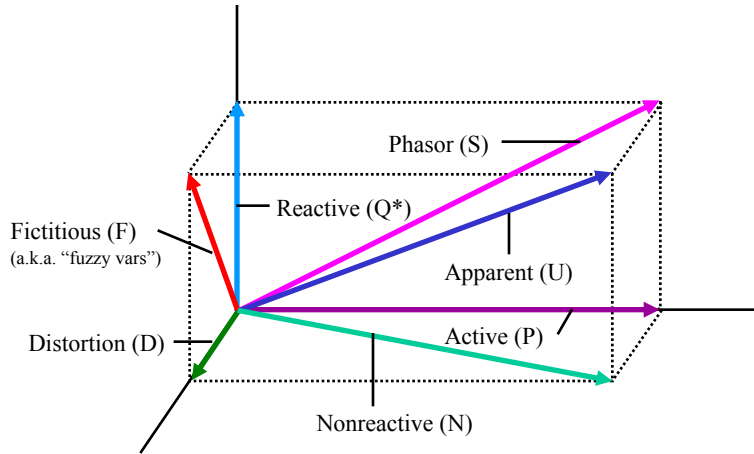
h	%	W a t t s		W a t t s	
		Load	Meter	Load	Meter
1	100.0	1000.00	1000.00	1000.00	1000.00
2	99.9	0.11	0.11	0.11	0.11
3	99.8	0.46	0.46	-0.46	-0.46
4	99.7	0.10	0.10	0.10	0.10
5	99.6	11.90	11.85	-11.90	-11.85
6	99.5	0.10	0.10	0.10	0.10
7	99.5	6.02	5.99	-6.02	-5.99
8	99.4	0.10	0.10	0.10	0.10
9	99.3	3.60	3.57	-3.60	-3.57
10	99.2	0.10	0.10	0.10	0.10
11	99.1	2.38	2.36	-2.38	-2.36
12	99.0	0.10	0.10	0.10	0.10
13	98.9	1.68	1.66	-1.68	-1.66
14	98.8	0.10	0.10	0.10	0.10
15	98.7	1.23	1.21	-1.23	-1.21
16	98.6	0.10	0.10	0.10	0.10
17	98.5	0.94	0.93	-0.94	-0.93
		1029.02	1028.84	972.60	972.77

Registration = 99.98% Registration = 100.02%

Harmonics, Distortion, & Metering

12

Vector Powers



*Not the "Q" of Q-hour metering

Harmonics, Distortion, & Metering

13

Phase "X" Formulae

$$\begin{aligned}
 \text{RMS Potential, } E_X &= \sqrt{\sum_{h=1}^H E_{Xh}^2} & (\text{Volts}) \\
 \text{RMS Current, } I_X &= \sqrt{\sum_{h=1}^H I_{Xh}^2} & (\text{Amperes}) \\
 \text{Apparent Power, } U_X &= E_X I_X & (\text{kVA}) \\
 \text{Active Power, } P_X &= \sum_{h=1}^H E_{Xh} I_{Xh} \cos(\alpha_{Xh} - \beta_{Xh}) & (\text{kW}) \\
 \text{Reactive Power, } Q_X &= \sum_{h=1}^H E_{Xh} I_{Xh} \sin(\alpha_{Xh} - \beta_{Xh}) & (\text{k var}) \\
 \text{Distortion Power, } D_X &= \pm \sqrt{U_X^2 - P_X^2 - Q_X^2} & (\text{kVA}) \\
 \text{Phasor Power, } S_X &= +\sqrt{P_X^2 + Q_X^2} & (\text{kVA}) \\
 \text{Fictitious Power, } F_X &= +\sqrt{U_X^2 - P_X^2} & (\text{kVA}) \text{ (a.k.a. "Fuzzy var s")} \\
 \text{Nonreactive Power, } N_X &= +\sqrt{U_X^2 - Q_X^2} & (\text{kVA})
 \end{aligned}$$

E_{Xh} and I_{Xh} are the RMS voltage and amperage of harmonic h . α_{Xh} and β_{Xh} are the phase angles of the voltage and current of harmonic h with respect to the reference time-frame. H is the highest harmonic ordinal.

Harmonics, Distortion, & Metering

14

Polyphase Vector Powers Formulae

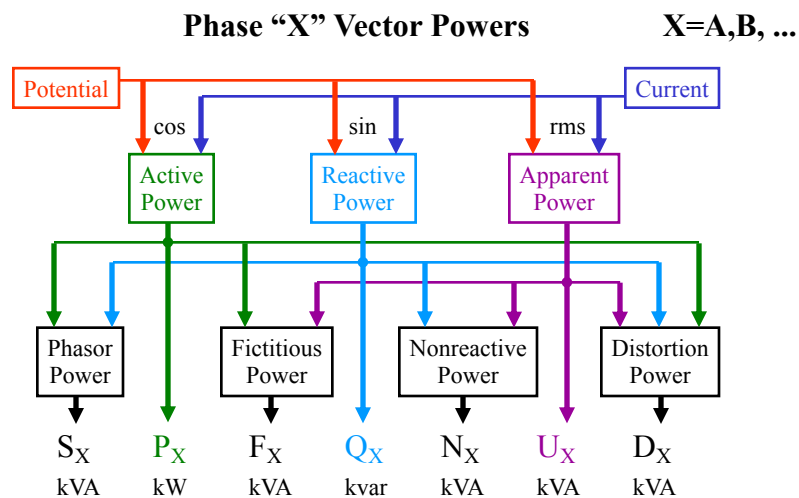
$$\begin{aligned}
 \text{Active Power, } P_{Total} &= P_A + P_B + \dots & (kW) \\
 \text{Reactive Power, } Q_{Total} &= Q_A + Q_B + \dots & (k\text{ var}) \\
 \text{Distortion Power, } D_{Total} &= D_A + D_B + \dots & (kVA) \\
 \text{Apparent Power, } U_{Total} &= +\sqrt{P_T^2 + Q_T^2 + D_T^2} & (kVA) \\
 \text{Phasor Power, } S_{Total} &= +\sqrt{P_T^2 + Q_T^2} & (kVA) \\
 \text{Fictitious Power, } F_{Total} &= +\sqrt{Q_T^2 + D_T^2} & (kVA) \\
 \text{Nonreactive Power, } N_{Total} &= +\sqrt{P_T^2 + D_T^2} & (kVA)
 \end{aligned}$$

Polyphase Scalar Power Formula

$$\text{Arithmetic Apparent Power, } U_{Arithmetic} = U_A + U_B + \dots \quad (kVA)$$

AC Powers: Names, Ingredients, Symbols and Units

Ref: ANSI/IEEE Std. 100-1988; Standard Dictionary of Electrical and Electronic Terms



AC Powers: Names, Ingredients, Symbols and Units

Ref: ANSI/IEEE Std. 100-1988; Standard Dictionary of Electrical and Electronic Terms

Polyphase Vector Powers

