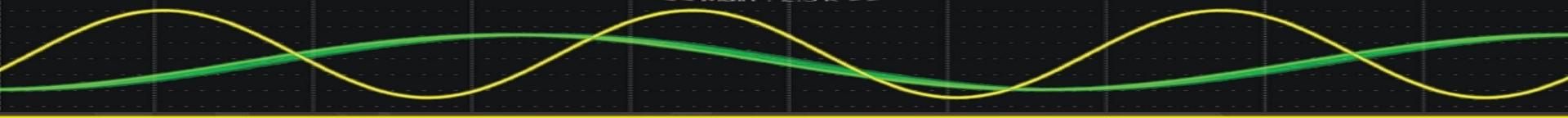




# Fundamentals of Electrical Power Measurement

Bill Gatheridge  
Product Manager



# Fundamentals of Electrical Power Measurements



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# Yokogawa Webinar – Housekeeping Issues



## Teleconference Information

**Call-in toll-free number (US/Canada): 1-877-668-4490**

**Call-in toll number (US/Canada): 1-408-792-6300**

**Access Code – 754 756 534**



## PC's Speakers - Audio Broadcast

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## Recorded Presentation

**A recording of this presentation will be posted under our technical library of our web page.**



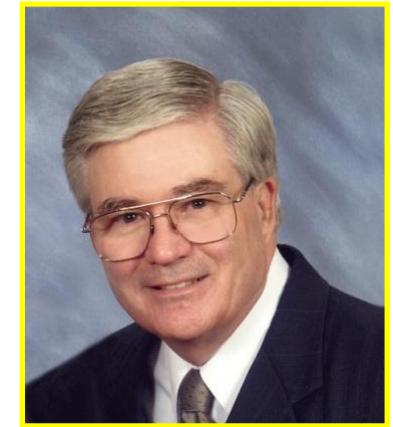
## Poll Questions

**Please take a few minutes to answer the 5 poll questions presented later in the presentation.**

# Presenter

**Bill Gatheridge**

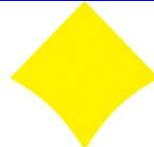
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**YOKOGAWA**



**Providing Solutions  
and  
Education  
for  
Electrical Power Measurements**

# Overview - What We Plan To Do

- **Part I: Electrical Power Measurements**
  - **Review Some Basics**
  - **Power Measurements Using a Precision Power Analyzer**
    - **Single-Phase Power Measurements**
    - **Current Sensors**
    - **Three-Phase Power Measurements**
    - **2 & 3 Wattmeter Method**

# Overview - What We Plan To Do

- **Part II: Power Factor Measurement**
  - **Displacement Power Factor**
  - **True Power Factor**
  - **Power Factor Measurements in Single-Phase & Three-Phase Circuits**
  - **Practical Power Factor Measurement Applications**

# Overview - What We Plan to Do

## ➤ **Part III: Power Measurements using a Digital Oscilloscope**

- **How to properly use a Digital Oscilloscope to make Electrical Power Measurements**
- **Some “Do’s” and “Don’ts”**
- **Measurement Examples**
- **Comparison of a DSO and a Power Analyzer**

## ➤ **Answer your questions concerning Electrical Power Measurements**

# Yokogawa Corporate History

1930 Vintage  
Standard AC Voltmeter  
0.2% Accuracy Class



- **Founded in 1915.**
- **First to produce and sell electric meters in Japan.**
- **North American operation established in 1957**
- **World wide sales in excess of \$4.3 Billion**
- **84 companies world wide**
- **Over 19,000 employees worldwide**
- **Operations in 33 Countries**



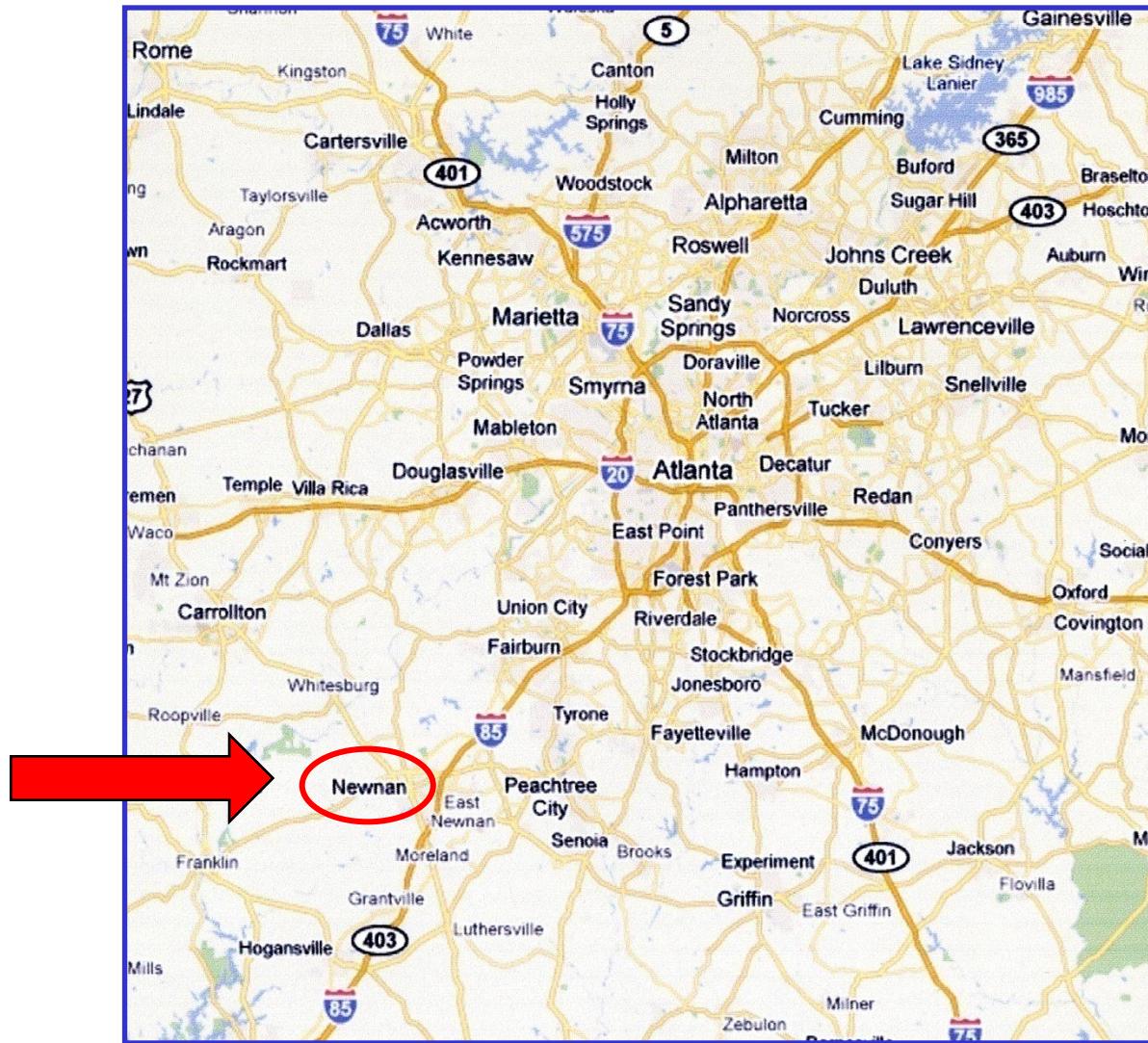
**WT3000**  
**Precision Power Analyzer**

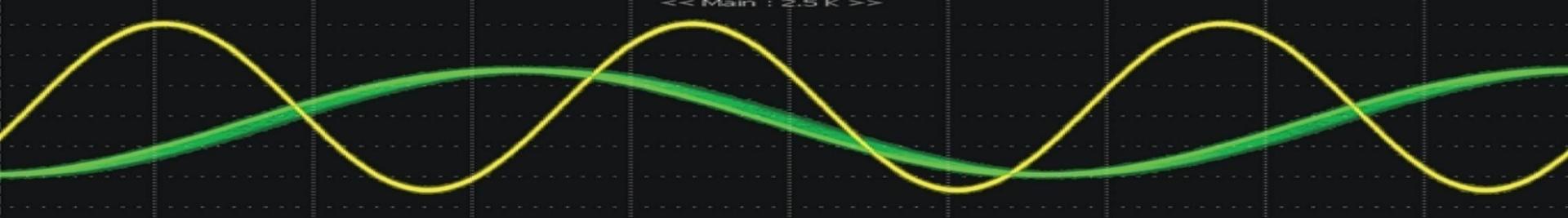
# Yokogawa Corporation of America



**Yokogawa Corporation of America  
Newnan, GA**

# Yokogawa Corporation of America

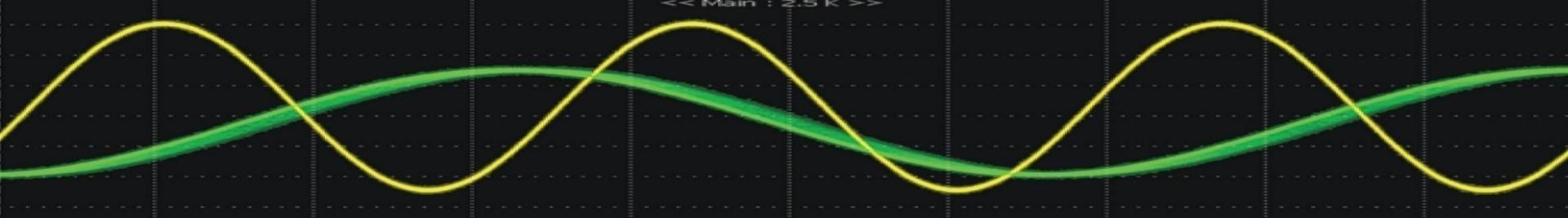




# PART I

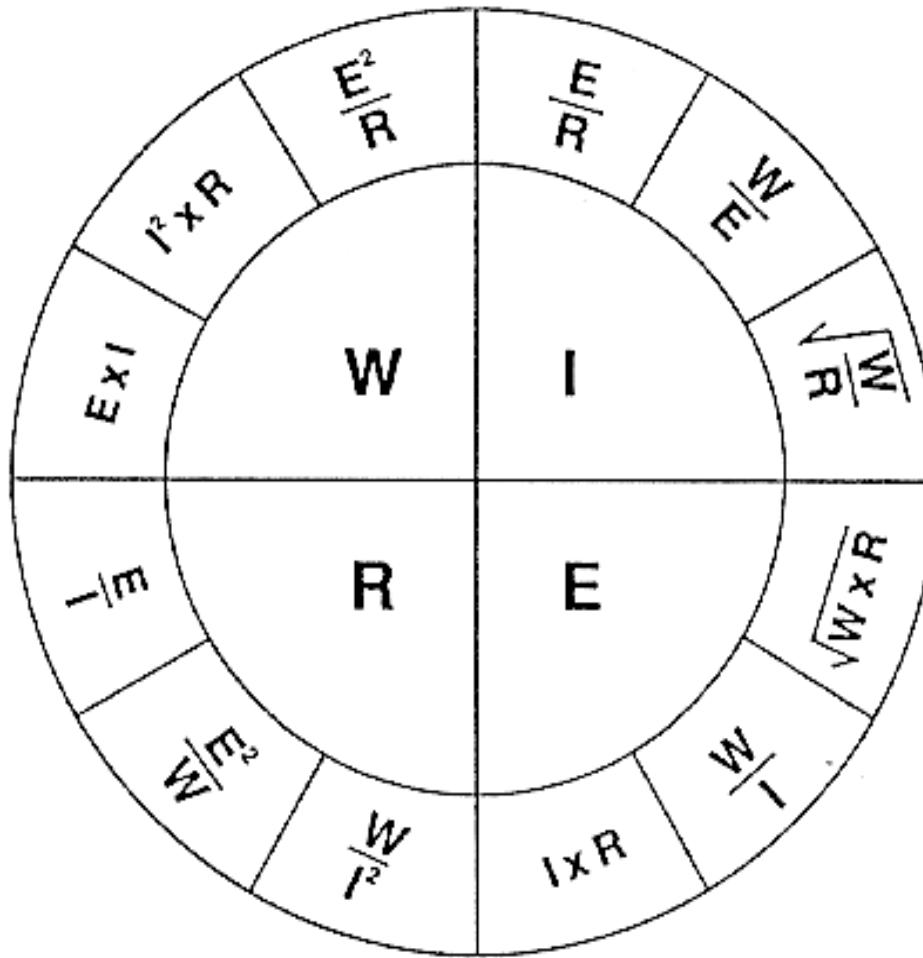
# ELECTRICAL POWER

# MEASUREMENTS



## First let's Review some Basics

# Review OHM'S LAW



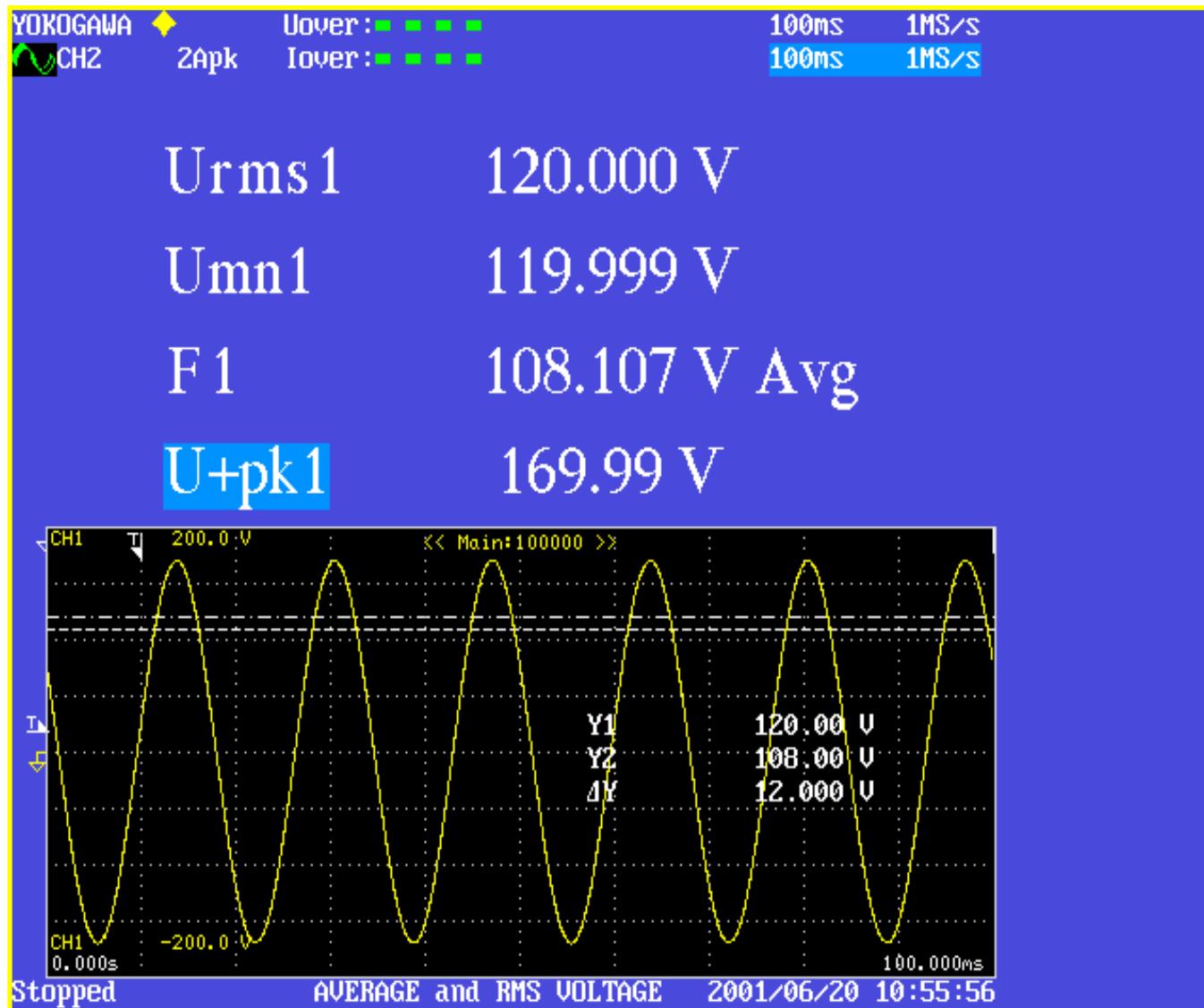
# Average and RMS Values

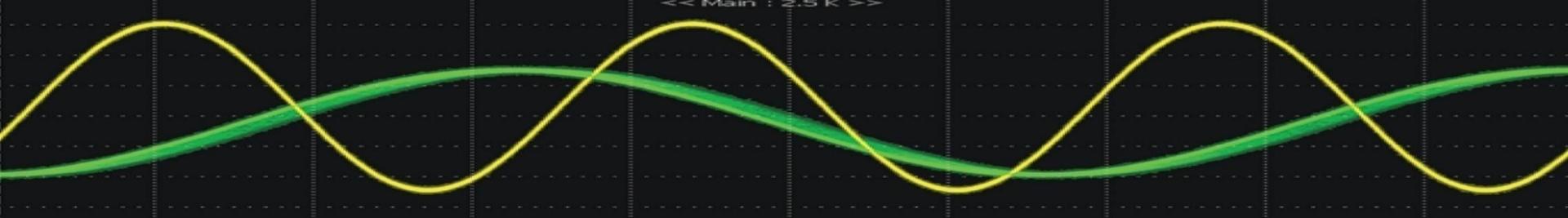
## Average, RMS, Peak-to-Peak Value Conversion for Sinusoidal Wave

*(multiplication factor to find)*

Known Value	Average	RMS	Peak	Peak-to-Peak
Average	1.0	1.11	1.57	3.14
RMS	0.9	1.0	1.414	2.828
Peak	0.637	0.707	1.0	2.0
Peak-to-Peak	0.32	0.3535	0.5	1.0

# Average and RMS Values





# Electrical Power Measurements

## What's A Watt ?

A unit of Power equal to one Joule of Energy per Second

DC Source:  $W = V \times A$

AC Source:  $W = V \times A \times PF$

# Measurement of Power

## AC Power Measurement

### ■ Active Power:

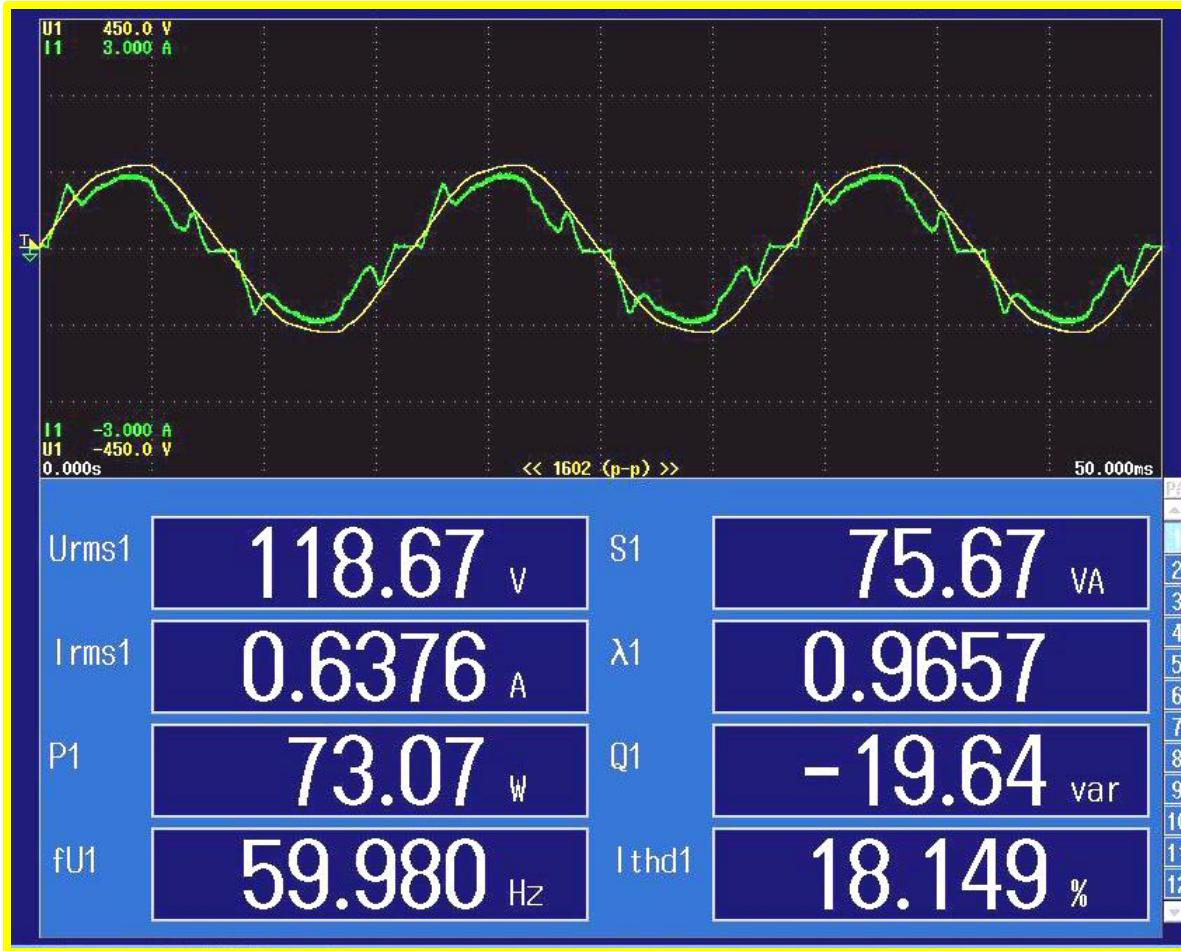
$$\text{Watts } P = V_{\text{rms}} \times A_{\text{rms}} \times PF$$

- Also sometimes referred to as True Power or Real Power

### ■ Apparent Power:

$$\text{Volt-Amps } S = V_{\text{rms}} \times A_{\text{rms}}$$

# Measurement of AC Power



$$\text{Watts } P = V_{\text{rms}} \times A_{\text{rms}} \times \text{PF} = Urms1 \times Irms1 \times \lambda1$$

$$\text{Volt-Amps } S = V_{\text{rms}} \times A_{\text{rms}} = Urms1 \times Irms1$$

# Measurement of Power

- Digital Power Analyzers are entirely electronic and use some form of DIGITIZING TECHNIQUE to convert analog signals to digital form.
  - higher end analyzers use DIGITAL SIGNAL PROCESSING techniques to determine values
- Digital Power Oscilloscopes use SPECIAL FIRMWARE to make true power measurements
- Digitizing instruments are somewhat RESTRICTED because it is a sampled data technique
- Many Power Analyzers and Power Scopes apply FFT algorithms for additional power and harmonic analysis

# Measurement of Power

- **Yokogawa Digital Power Analyzers and Digital Power Scopes use the following method to calculate power:**
  - $P_{avg} = 1/T \int_0^T v(t) * I(t) dt$
- **Using digitizing techniques, the INSTANTANEOUS VOLTAGE is multiplied by the INSTANTANEOUS CURRENT and then INTEGRATED over some time period.**

# True RMS Measurements

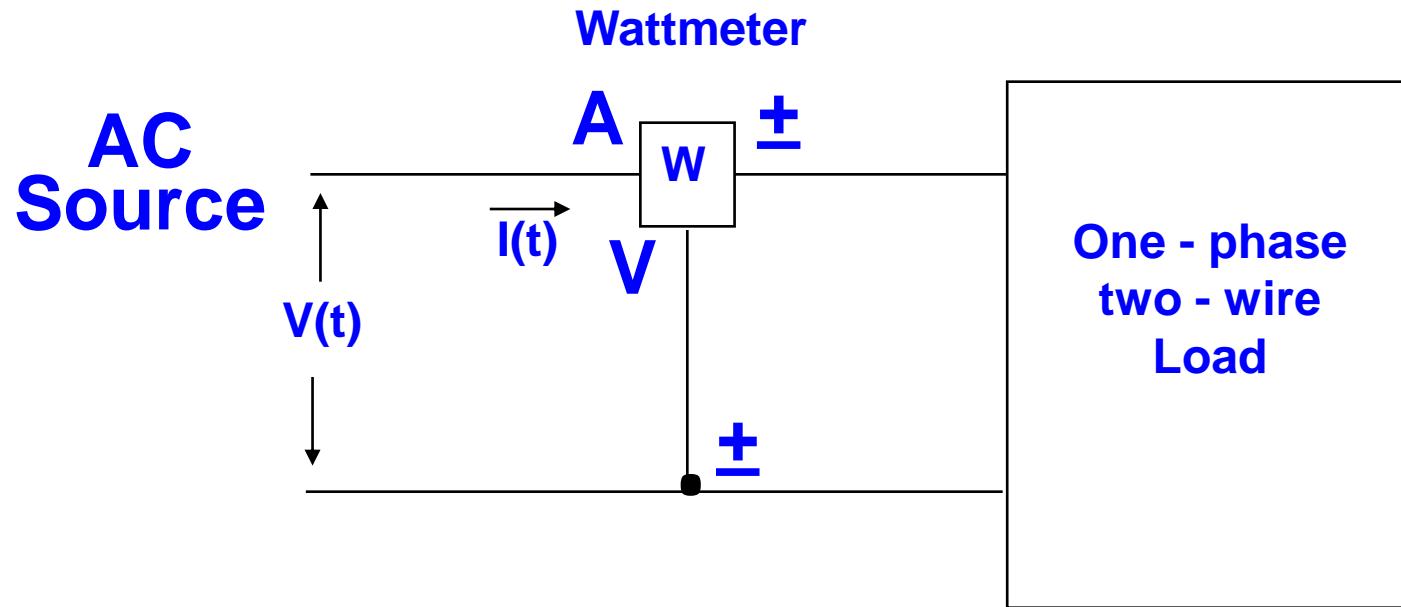
$$P_{\text{total}} = 1/T \int_0^T v(t) * I(t) dt$$

$$U_{\text{RMS}} = \sqrt{1/T \int_0^T v(t)^2 dt}$$

$$I_{\text{RMS}} = \sqrt{1/T \int_0^T i(t)^2 dt}$$

These calculation methods provide a True Power Measurement and True RMS Measurement on any type of waveform, including all the harmonic content, up to the bandwidth of the instrument.

# Single Phase Power Measurement

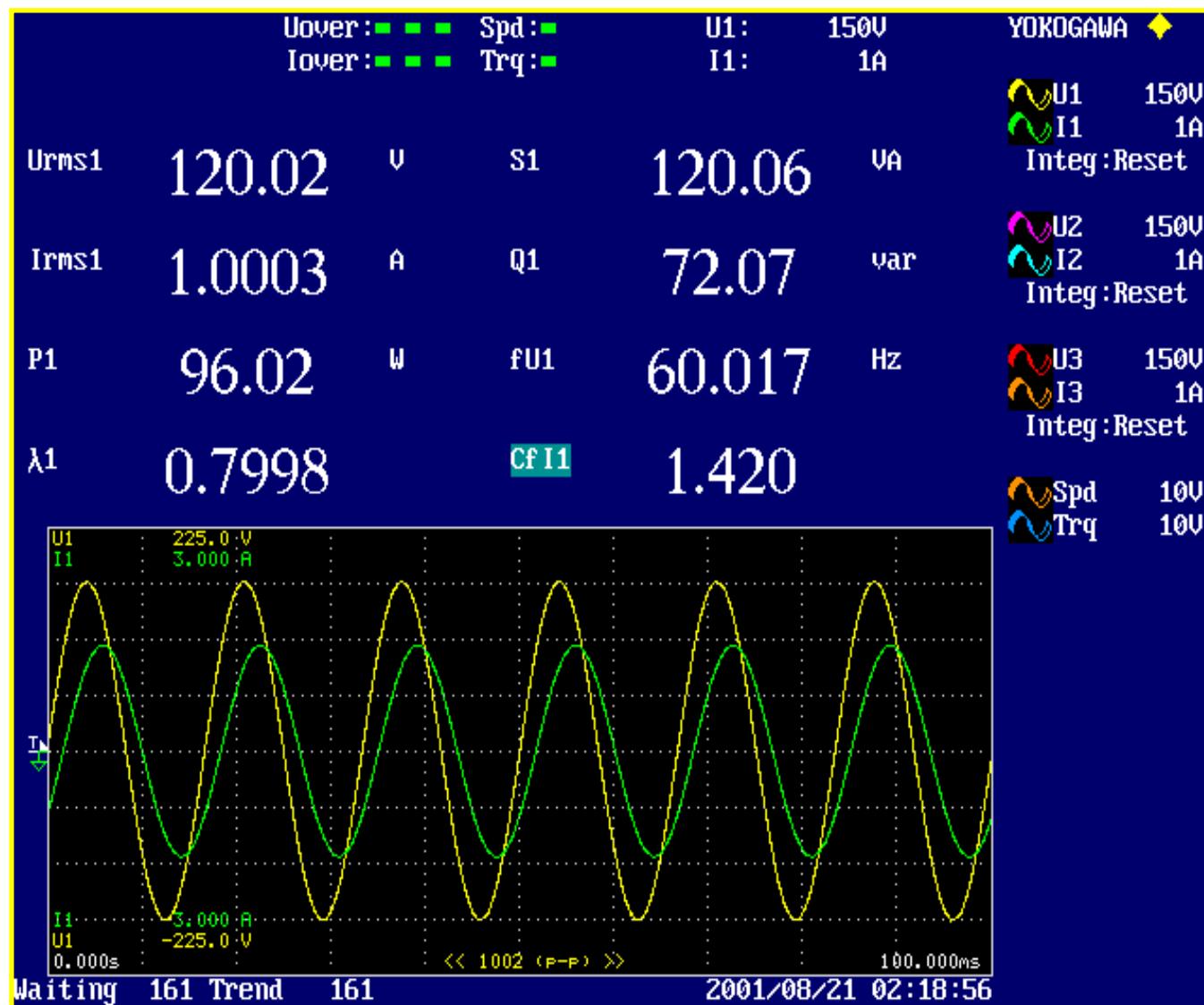


Single Wattmeter  
Method

## Single-Phase Two-Wire System

- The voltage and current detected by the **METER** are the voltage and current applied directly to the Load.
- The indication on the Meter is the **POWER** being dissipated by the load.

# Measurement Results Single-Phase Two-Wire System



# Current Sensors

AEMC



Yokogawa  
Scope  
Probes



Yokogawa  
CT's

Yokogawa/GMW-  
LEM/Danfysik CT System



Pearson  
Electronics



Ram Meter  
Shunts

## SELECTION CONSIDERATIONS

- Accuracy, CT Turns Ratio Accuracy
- Phase Shift
  - 1 or 2 Degrees Maximum: Cosine 2 Deg = 0.9994
- Frequency Range
  - DC to line frequency, sine waves: DC Shunts
  - DC & AC: Hall Effect or Active type CT
  - AC Approximately 30 Hz and higher: Various types of CT's

## SELECTION CONSIDERATIONS

- **Instrument Compatibility**
  - **Output: Millivolts/Amp, Millamps/Amp; or Amps**
  - **Impedance and Load, Burden**
  - **Scope Probes - - *CAUTION!* Use on Scopes, NOT Power Analyzers**
- **Physical Requirements**
  - **Size**
  - **Connections: Clamp-On or Donut type**
  - **Distance from Load to Instrument**

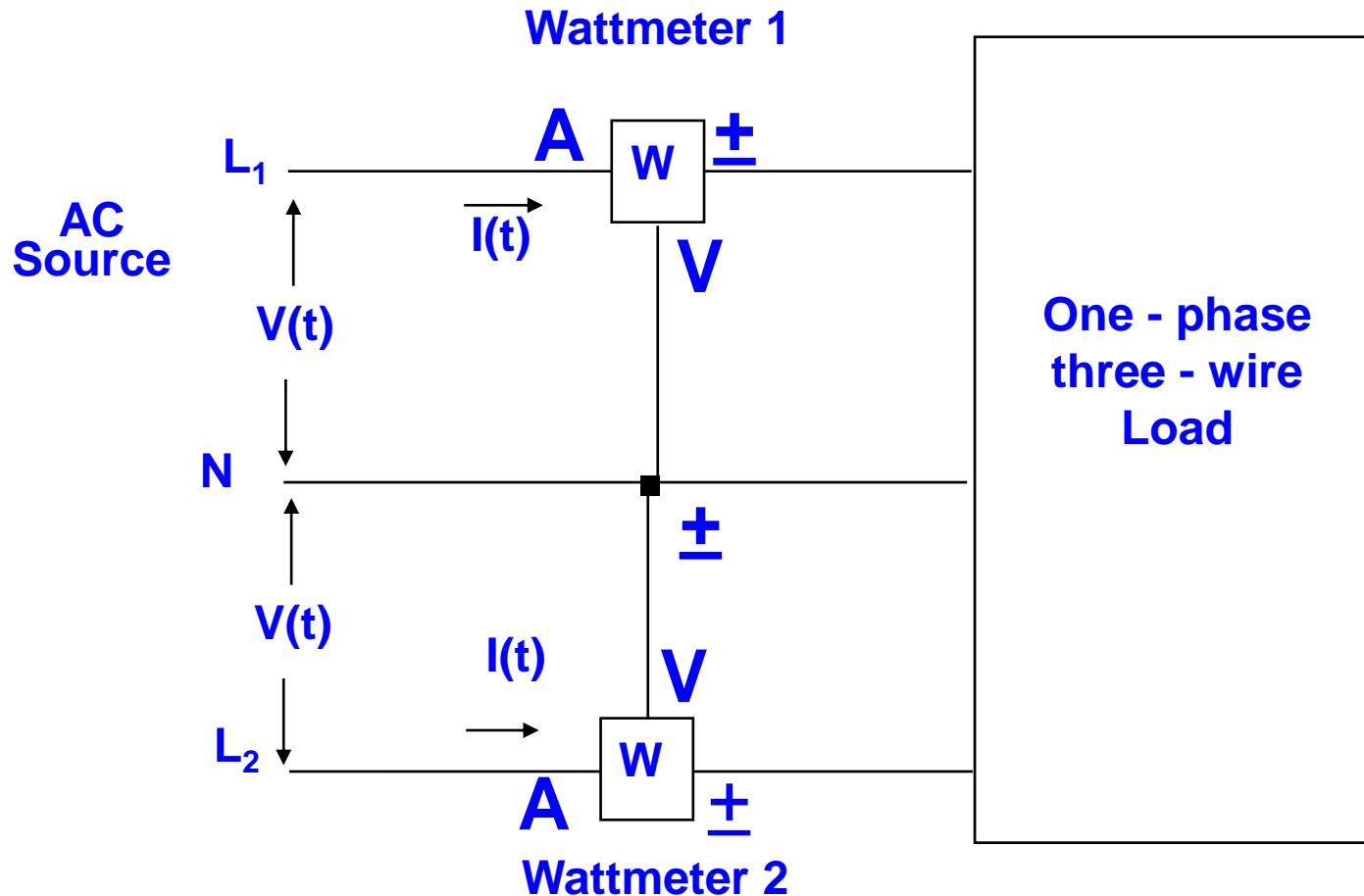
# Current Sensors

## 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.
- A CT is a Current Source.
  - By Ohm's Law  $E = I \times R$
  - When R is very large, E becomes very high
    - The High Voltage generated inside the CT will cause a magnetic saturation of the core, winding damage, or other damage which could destroy the CT.

# Single-Phase Three-Wire Power Measurement



Two Wattmeter  
Method

$$P_T = W_1 + W_2$$

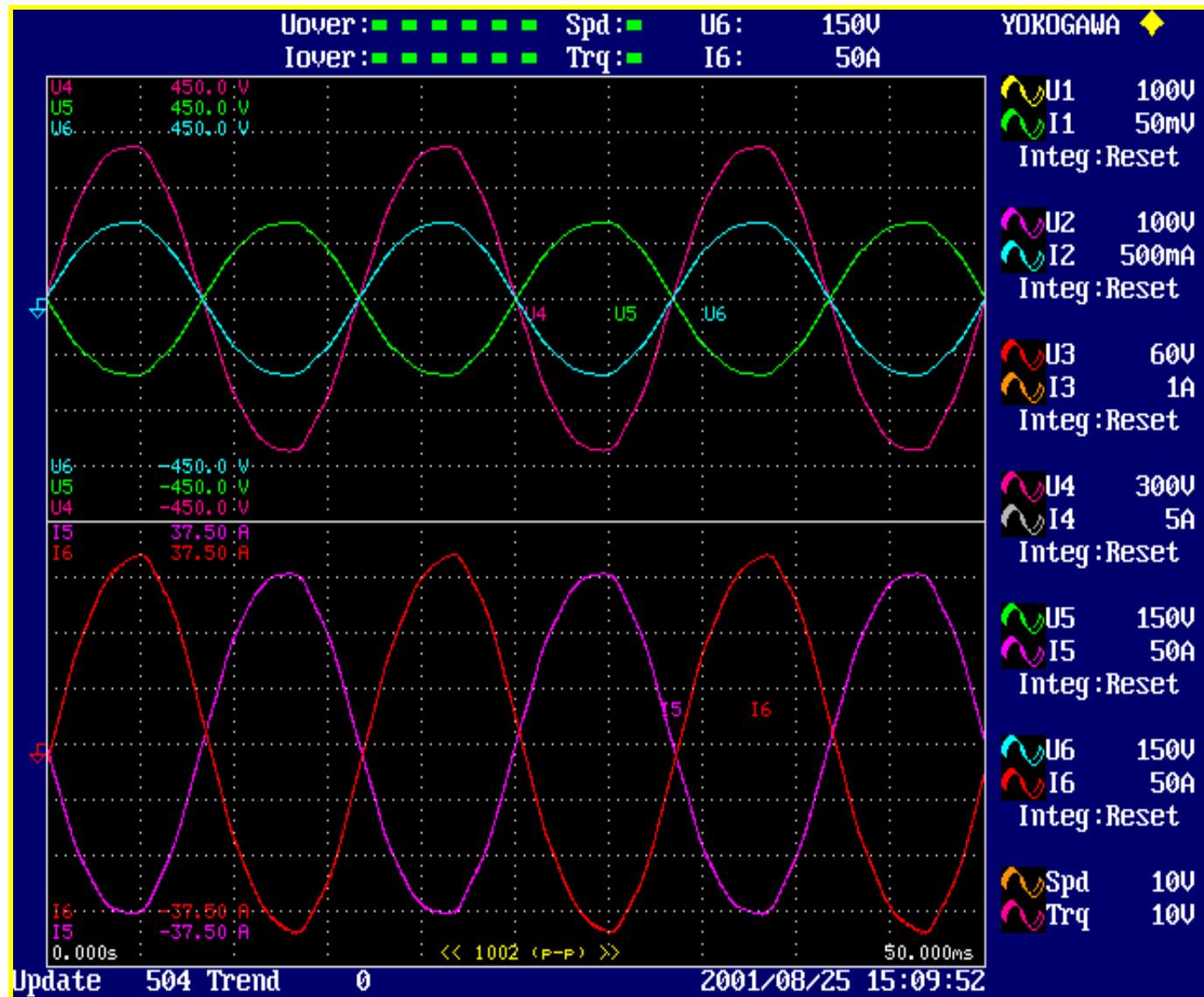
## Single-Phase Three-Wire System (Split Phase)

- The voltage and current detected by the **METERS** are the voltage and current applied directly to the Load.
- The indication on **EACH METER** is the power being delivered by the **LINE** to which the meter is connected.
- The total power dissipated by the load is the **ALGEBRAIC SUM** of the two indications.

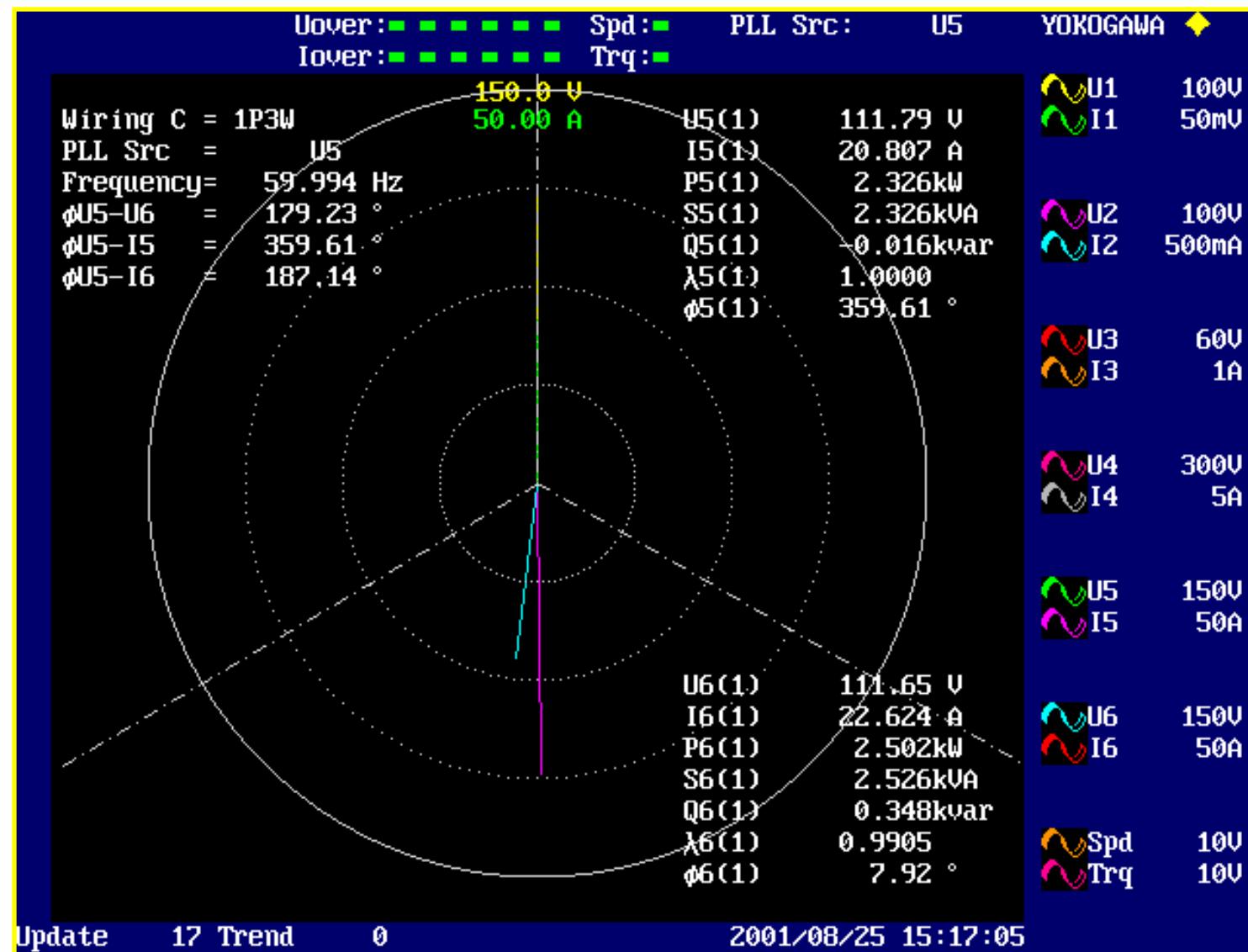
# Measurement Results Single-Phase Three-Wire System

	Uover:	Spd :	U6:	150V	YOKOGAWA
	Iover:	Trq :	I6:	50A	
Urms5	111.86	V	Urms4	223.25	V
Irms5	20.796	A	S6C	4.8462	kVA
Urms6	111.44	V	S5	2.326	kVA
Irms6	22.613	A	S6	2.520	kVA
P5	2.326	kW	λ5	1.0000	
P6	2.496	kW	λ6	0.9905	
PΣC	4.8221	kW	λΣC	0.9950	
fU5	59.995	Hz	---	---	
U1	100V		I1	50mV	
Integ:Reset			U2	100V	
			I2	500mA	
Integ:Reset			U3	60V	
			I3	1A	
Integ:Reset			U4	300V	
			I4	5A	
Integ:Reset			U5	150V	
			I5	50A	
Integ:Reset			U6	150V	
			I6	50A	
Integ:Reset			Spd	100	
			Trq	100	

# Measurement Results Single-Phase Three-Wire System



# Measurement Results Single-Phase Three-Wire System



## Blondel Transformation

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

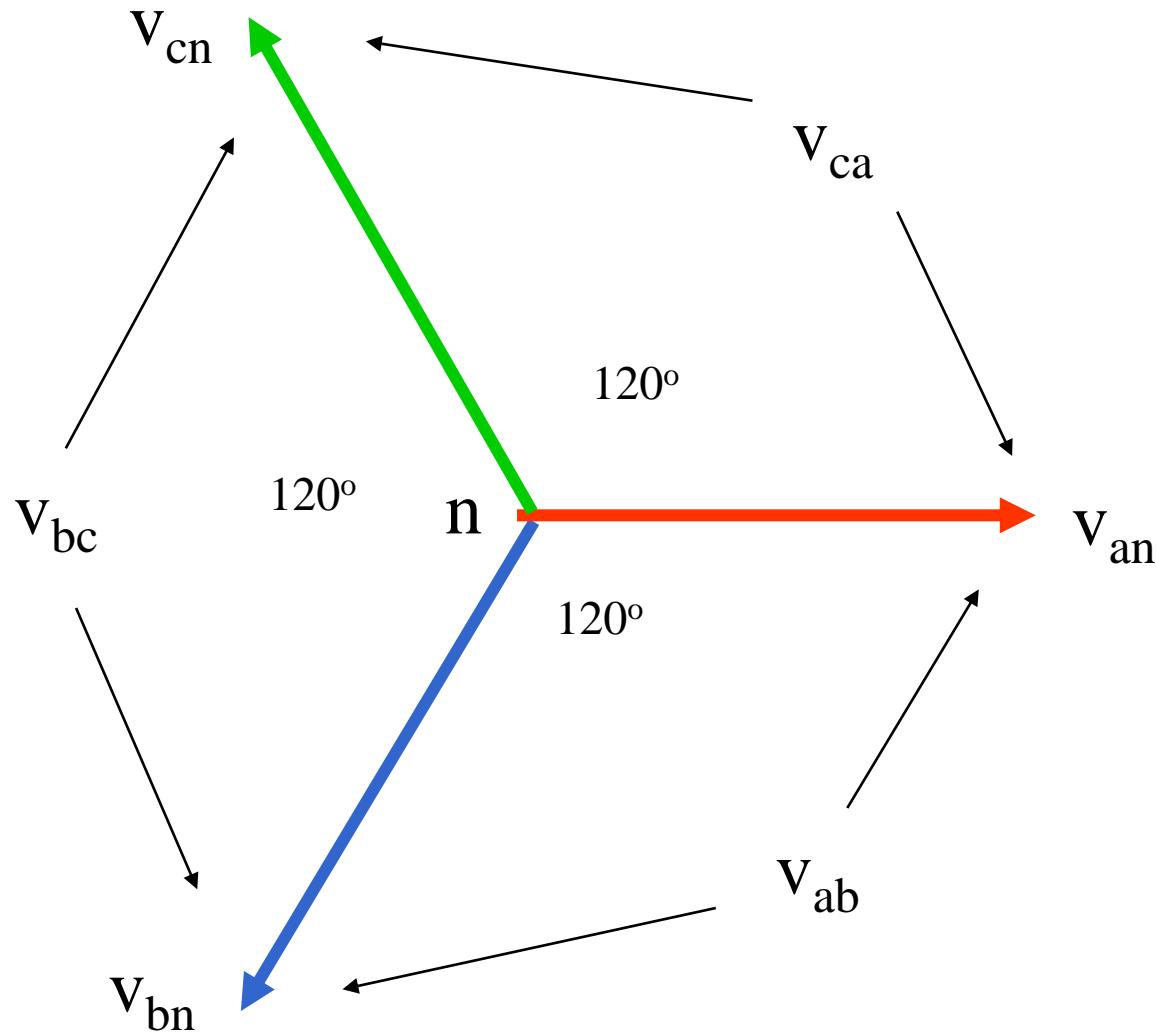
**1-P 2-W      1 Wattmeter**

**1-P 3-W      2 Wattmeters**

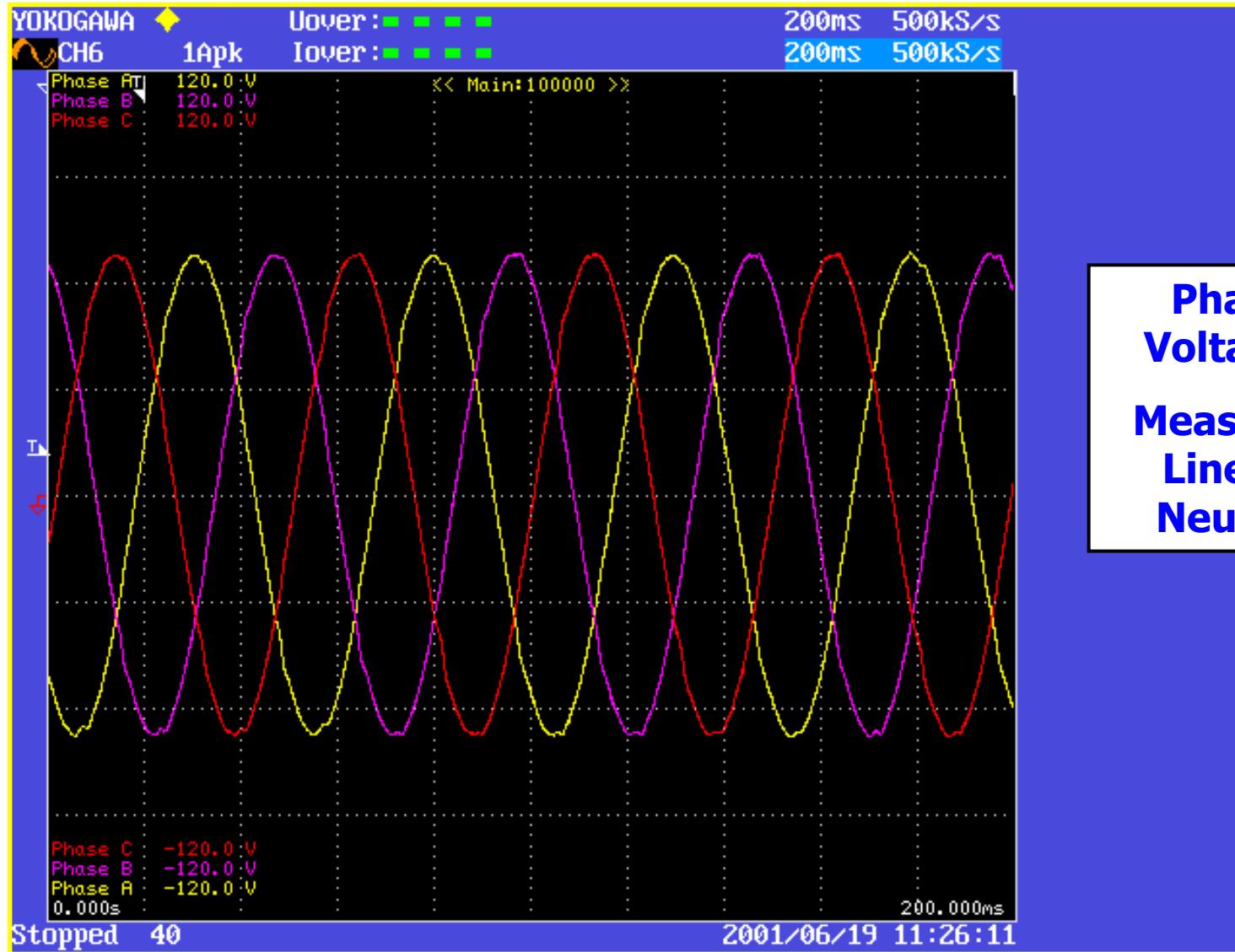
**3-P 3-W      2 Wattmeters**

**3-P 4-W      3 Wattmeters**

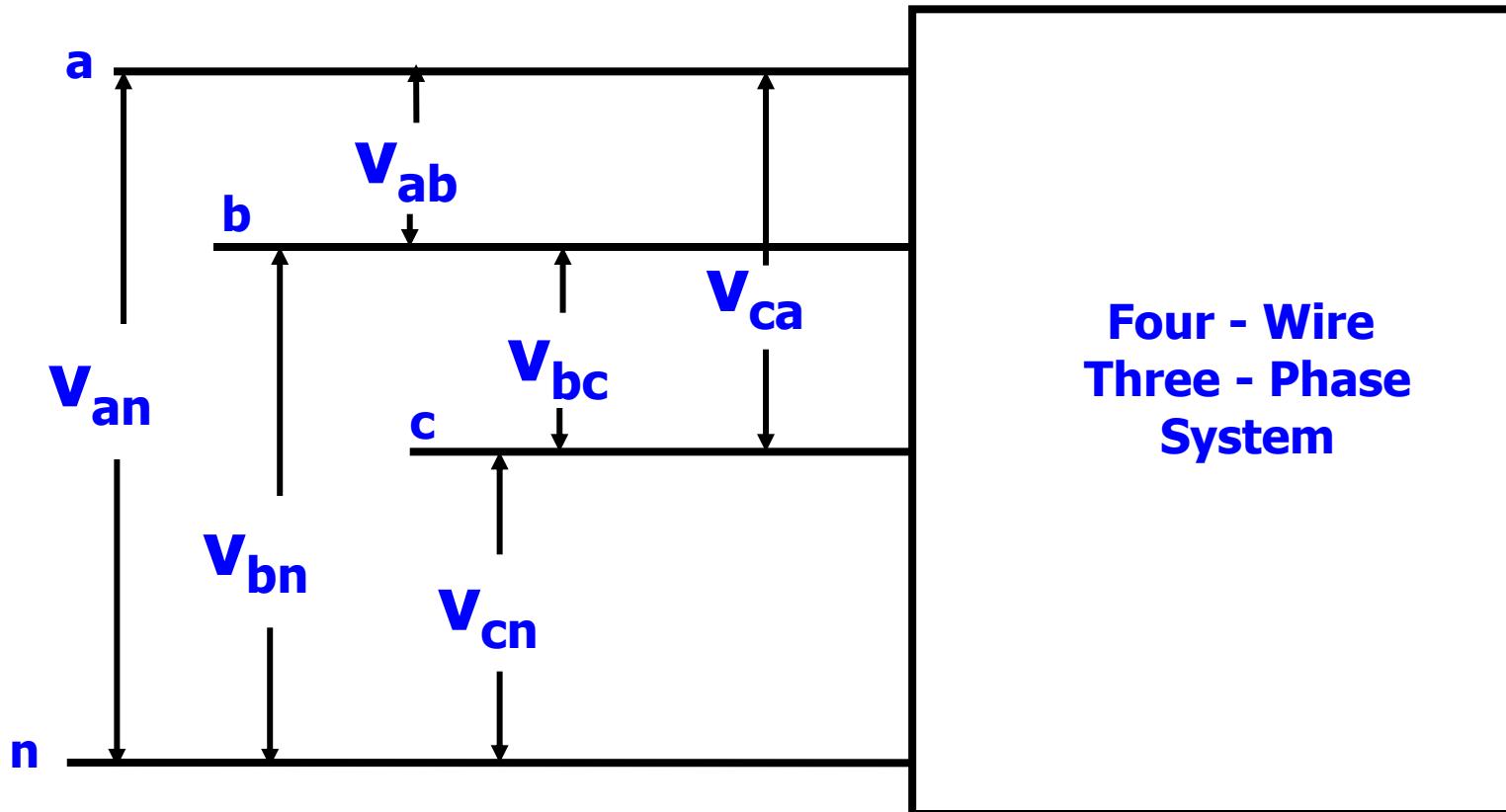
# Three - Phase Systems



# Three - Phase Systems



# Three - Phase Systems



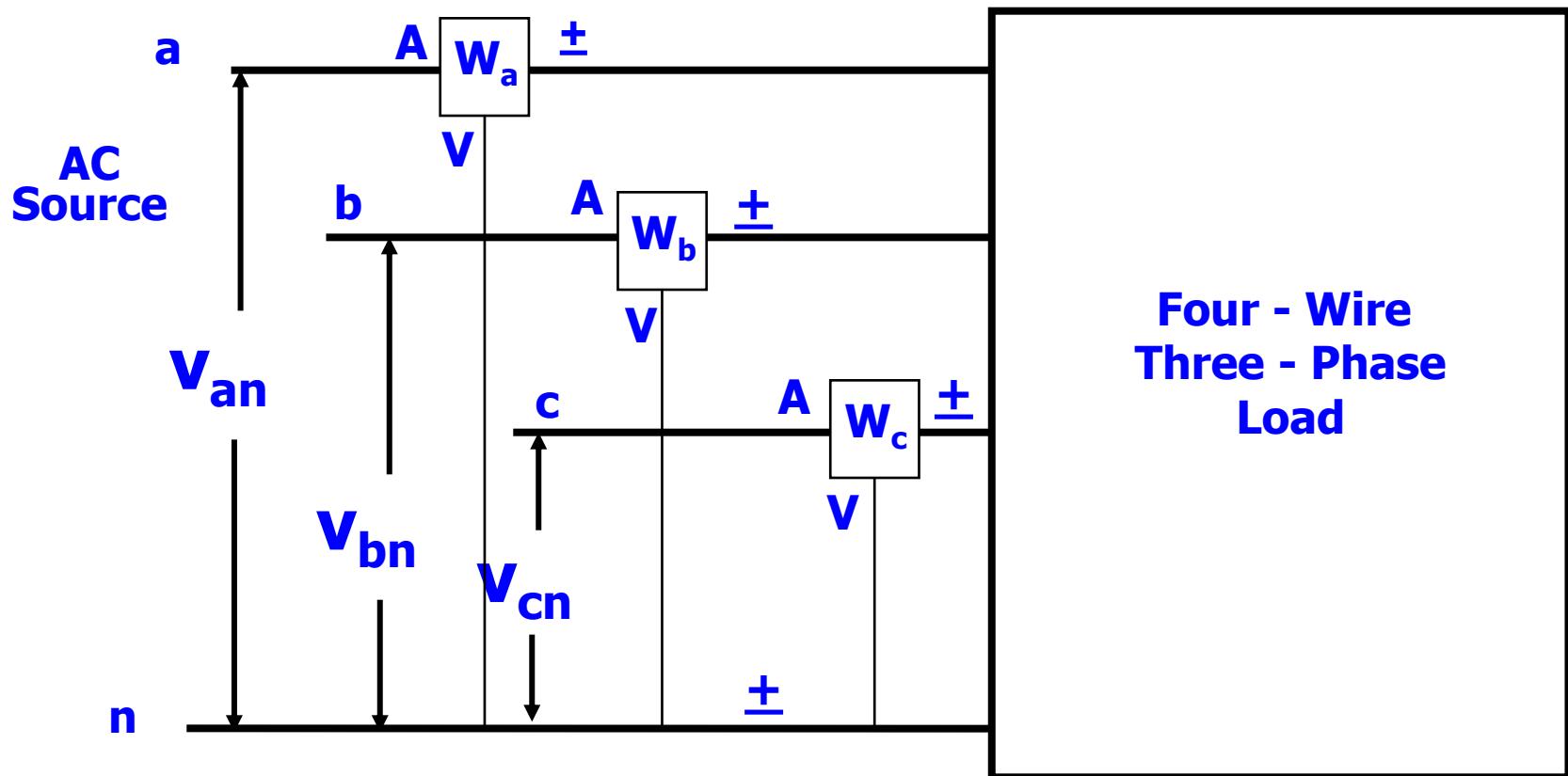
$$V_{I-n} = 120 / 277 \text{ Volts}$$



$$V_{I-I} = 208 / 480 \text{ Volts}$$

$$V_{I-I} = \sqrt{3} * V_{I-n}$$

# Measurement of Power



**Three Wattmeter  
Method**

$$P_T = \sum W_a + W_b + W_c$$

# Measurement of Power

## Three-Phase Four-Wire System

- The three meters use the FOURTH wire as the common voltage REFERENCE.
- Each meter indicates the PHASE power.
- The TOTAL POWER for the three phases is the ALGEBRAIC SUM of the three meters.
- In essence, each meter measures a SINGLE PHASE of the three phase system.

# Measurement Results

# Three-Phase Four-Wire System

**Phase Power**

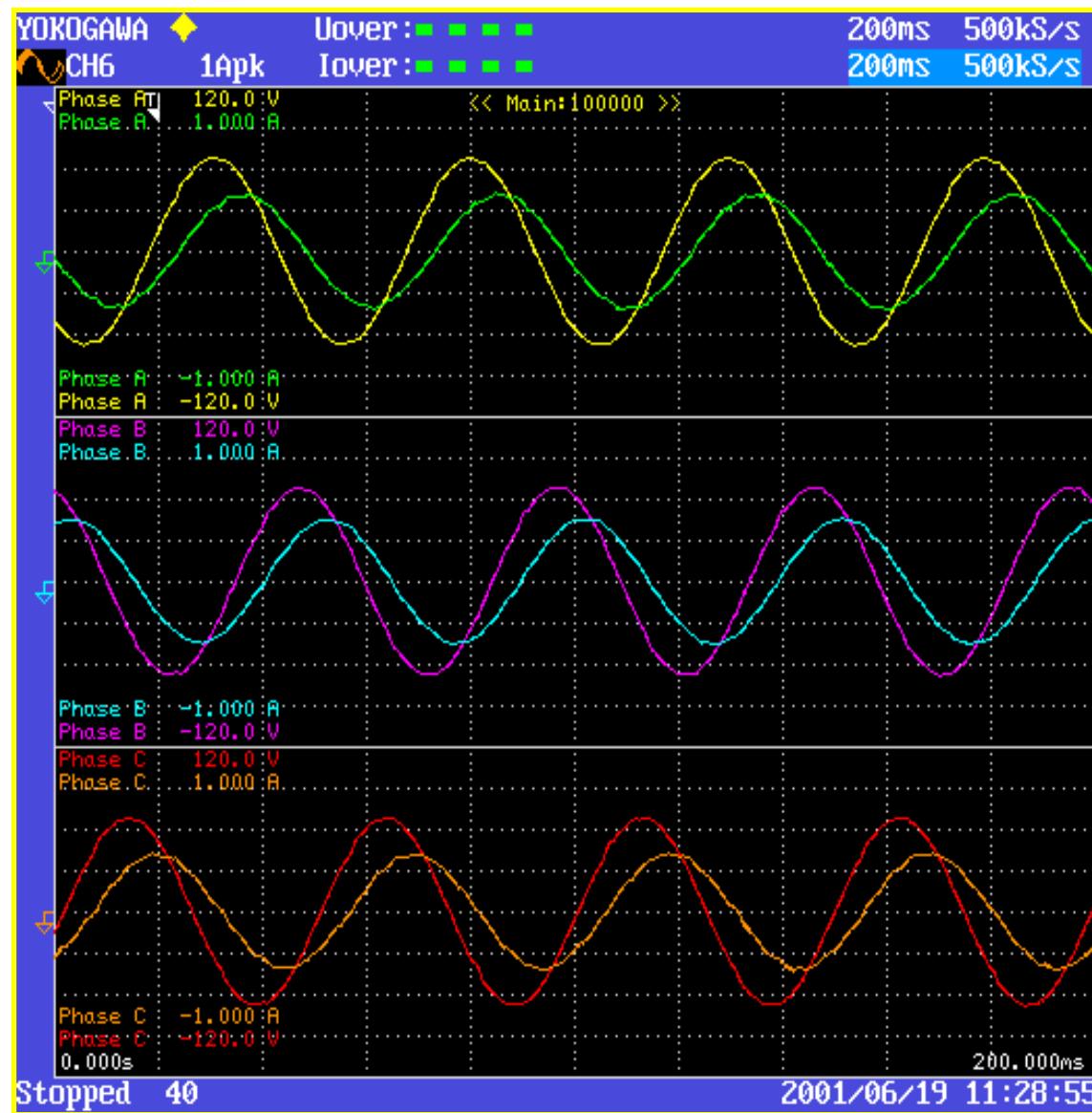
**Phase Power Factor**

**Phase Current & Voltage**

	Uover:	Spd:	Iover:	Trq:	Rate:	1sec	YOKOGAWA
P1	22.07	W			λ1	0.8714	U1 150V I1 1A Integ:Reset
P2	22.21	W			λ2	0.8721	U2 150V I2 1A Integ:Reset
P3	22.09	W			λ3	0.8708	U3 150V I3 1A Integ:Reset
PΣA	66.37	W			Irms1	0.3637	A Spd 10V Trq 10V
SEA	76.17	VA			Irms2	0.3648	A
λΣA	0.8714				Irms3	0.3644	A
Urms1	69.65	V			Urms2	69.81	V
fU1	30.434	Hz			Urms3	69.61	V
Update	1516	Trend	1503				2001/08/23 04:02:11

# Measurement Results

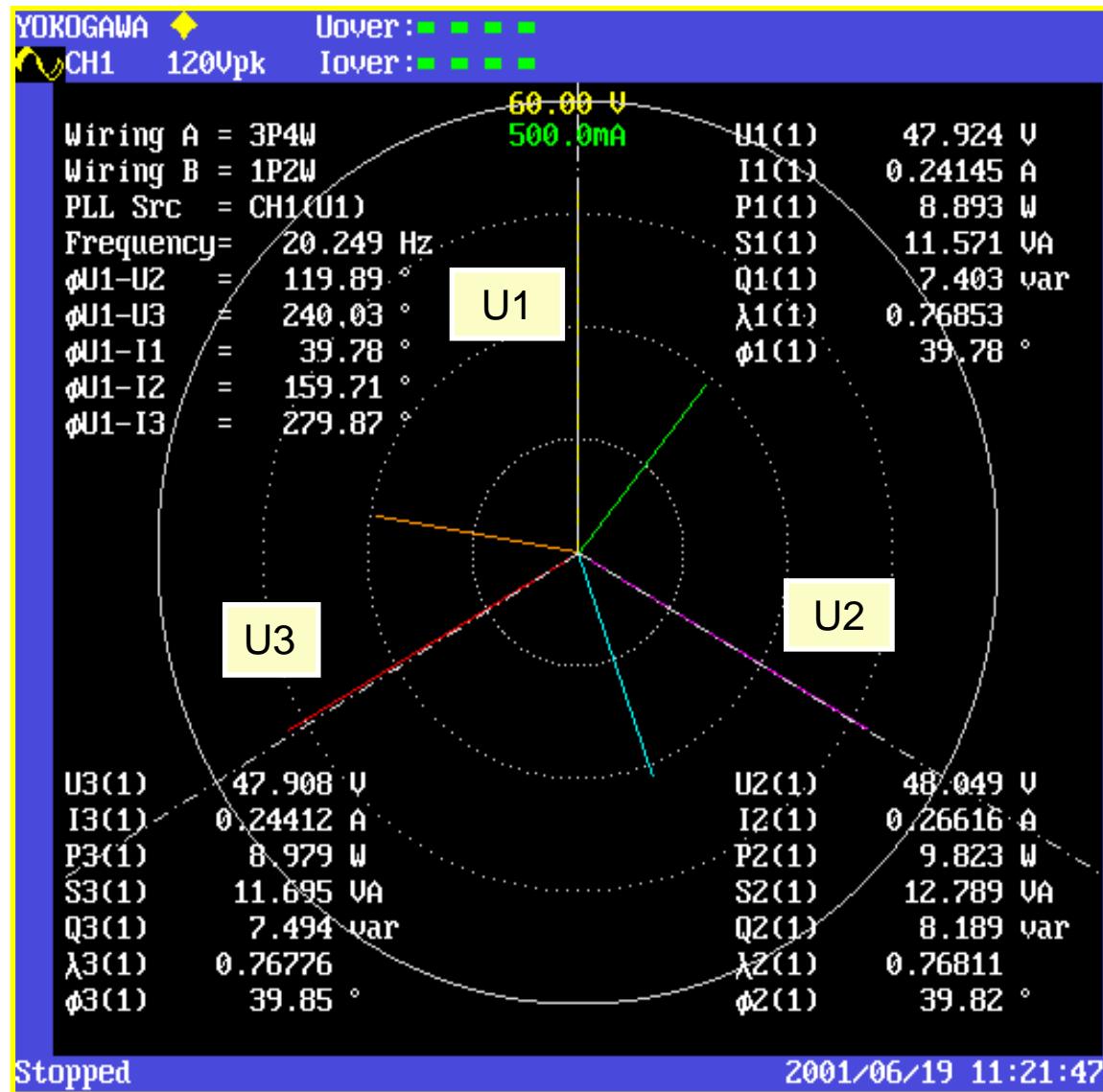
# Three-Phase Four-Wire System



Phase Voltages  
Measured Line to Neutral

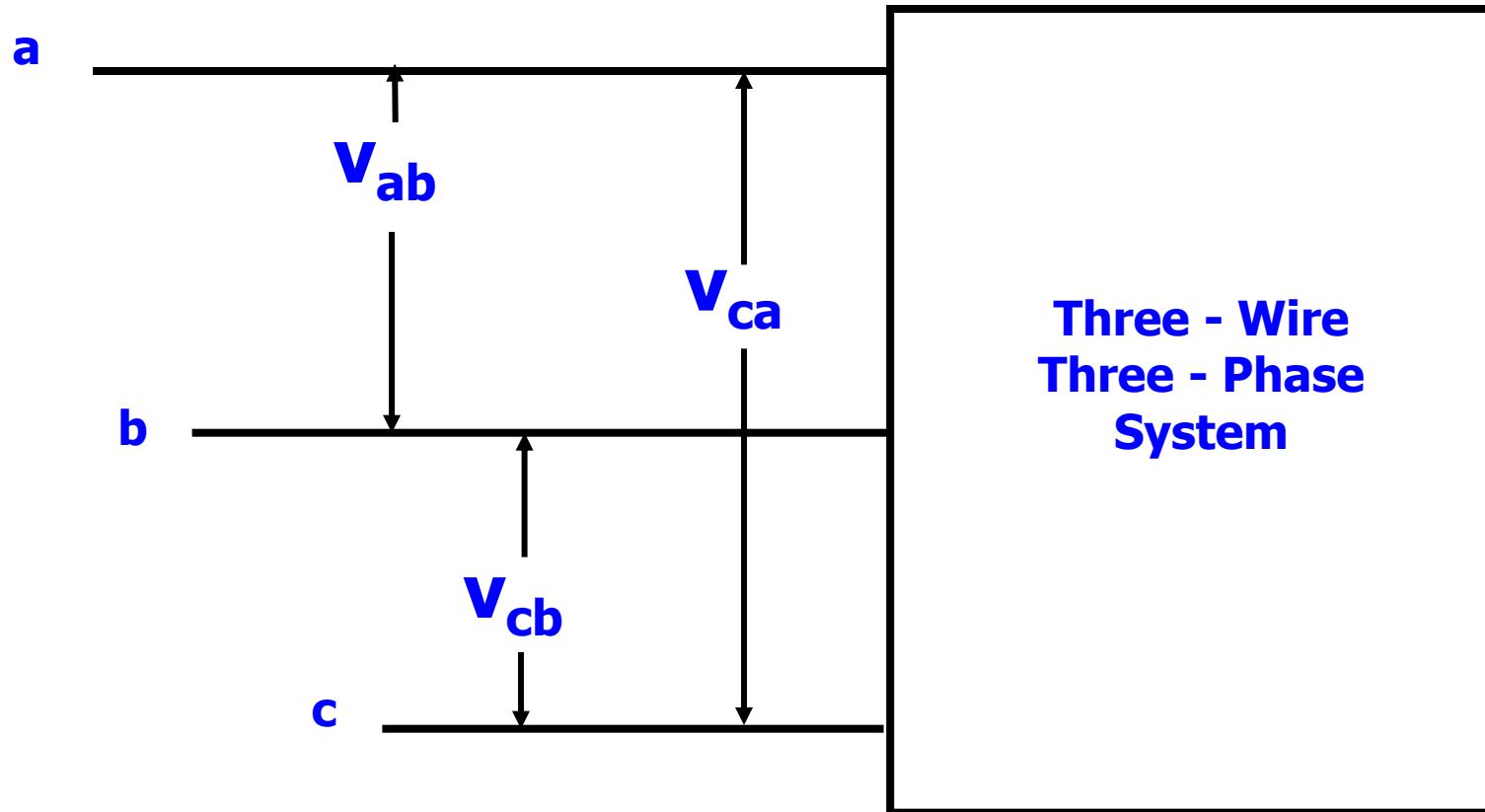
Phase Currents

# Three-Phase Four-Wire Vector Diagram



Phase Voltages  
Measured Line to Neutral

# Three-Phase Three-Wire Systems



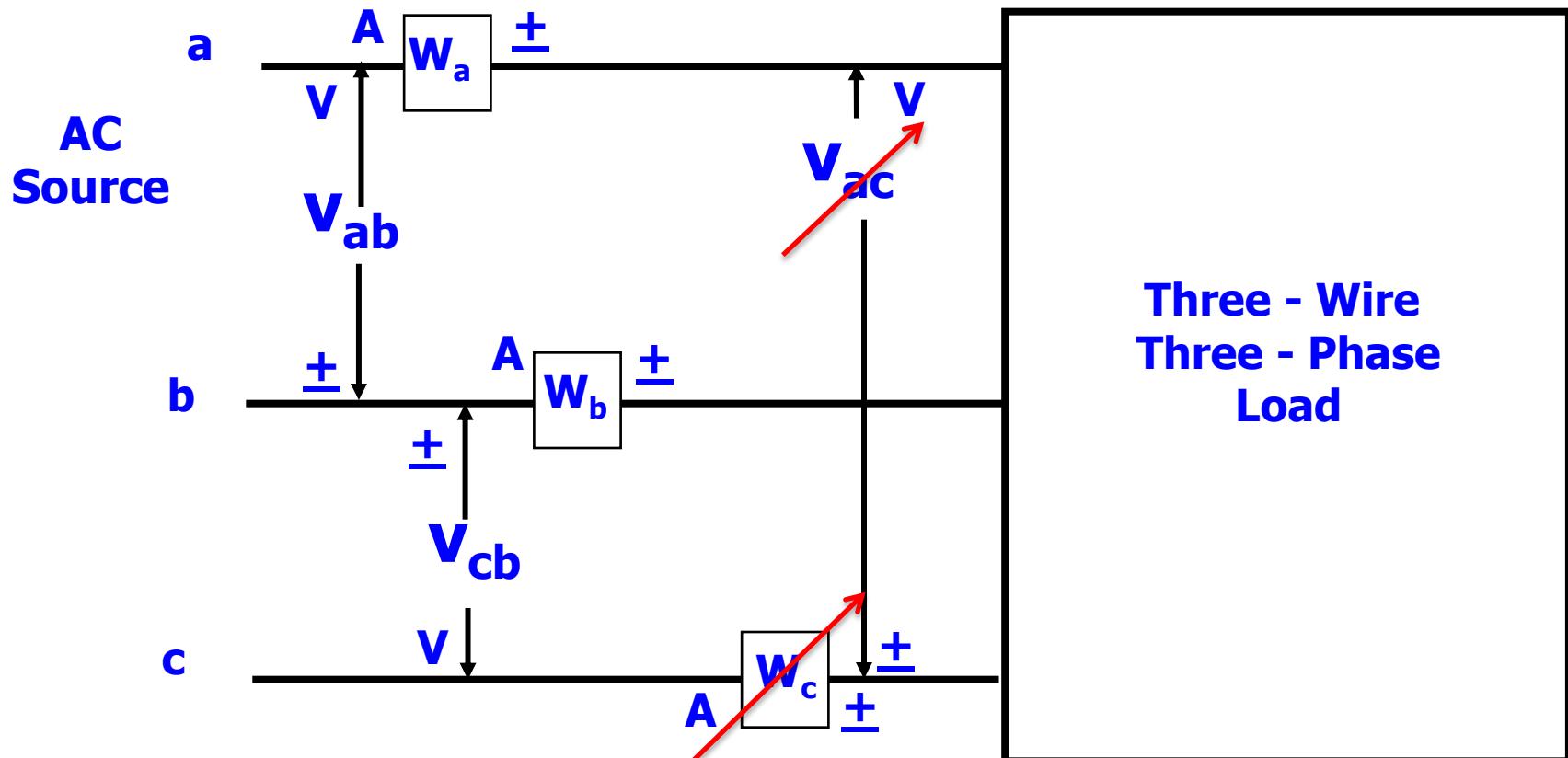
## Remember

### Blondel's Transformation

. . . total power is measured with ONE LESS wattmeter than the number of WIRES.

# Measurement of Power 3P-3W System

## Three - Phase Three - Wire System With Two Meters



**Two Wattmeter  
Method**

$$P_T = \sum W_a + W_b$$

## Three-Phase Three-Wire System

The wattmeters used for this connection each measure the PHASE CURRENTS

The measured voltages are the LINE-TO-LINE values, NOT Phase Voltage.

Thus the indications on each of the meters IS NOT the power delivered by the PHASE of the measured current.

This configuration is a very NON-INTUITIVE connection!

# Three-Phase Three-Wire System



The method yields the Total Power as the Sum of the **TWO METERS** in Phase 1 and 2. Note that **NONE** of the meters is indicating the correct **PHASE POWER**.

# Electrical Power Measurements

- The Two Wattmeter technique tends to cause less confusion than the three meter technique since there is no expectation that a meter will give an accurate phase indication.
- However, with the Yokogawa Power Analyzers, on a 3-Phase 3-Wire System, use the 3V-3A wiring method. This method will give all three Voltages and Currents, and correct Total Power, Total Power Factor and VA Measurements on either Balanced or Unbalanced 3-Wire system.

# Three-Phase Three-Wire System With Three Meters

Uover :				YOKOGAWA	
Iover :				U1 150V	1A
Urms1	84.92	V	P1	22.49	W
Urms2	85.07	V	P2	8.31	W
Urms3	85.09	V	P3	14.42	W
Irms1	0.2682	A	PΣA	30.80	W
Irms2	0.2689	A	S1	22.77	VA
Irms3	0.2694	A	S2	22.88	VA
λΣA	0.7780		S3	22.92	VA
fU1	20.744	Hz	SΣA	39.59	VA
Update	21	Trend	0	2008/11/19 04:01:41	

The method yields the Total Power as the Sum of the **TWO METERS** in Phase 1 and 2. Note that **NONE** of the meters is indicating the correct **PHASE POWER**.

# Delta Measurements

**3P3W (3V3A) Connection**

$$P_{3P3W} = P_{3P4W}$$

**L-L  
Voltage**



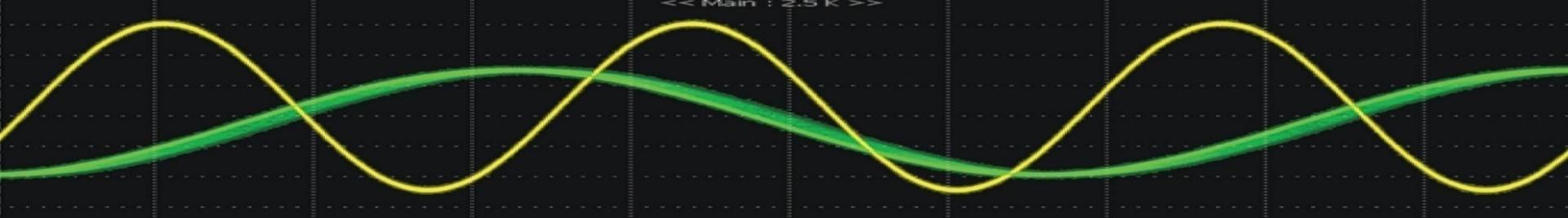
**Phase Power Measurement Solution on 3P3W (3V3A) Connection**

# 3P-3W and 3P-4W Power Measurements

$$P_{3P3W} = P_{3P4W}$$

	Uover: Iover:	U3: I3:	YOKOGAWA
Urms1	<b>3P-3W</b> 95.40	Urms4 55.06	U1 150V I1 1A Integ :Reset
Urms2	95.60	Urms5 55.20	U2 150V I2 1A Integ :Reset
Urms3	95.44	Urms6 55.15	U3 150V I3 1A Integ :Reset
Irms1	0.2981	Irms4 0.2984	U4 100V I4 1A Integ :Reset
Irms2	0.2986	Irms5 0.2986	U5 100V I5 1A Integ :Reset
Irms3	0.3011	Irms6 0.3011	U6 100V I6 1A Integ :Reset
PΣA	40.87	PΣB 40.89	
λΣA	0.8258	λΣB 0.8259	
Update	2201 Trend	0	2009/01/15 06:27:49

$$U_{L-N} \times \sqrt{3} = U_{L-L} \quad 55.20 \times \sqrt{3} = 95.60$$

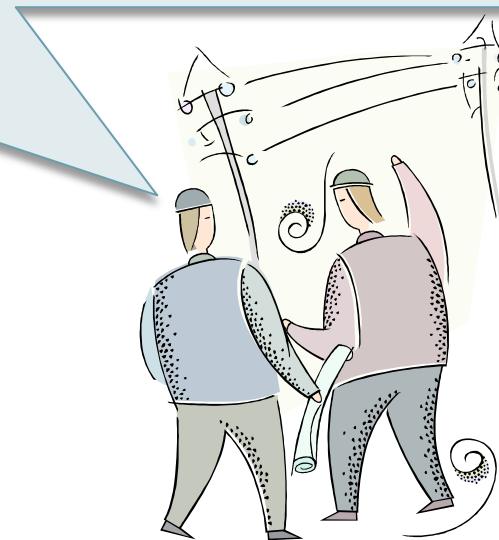


## PART II

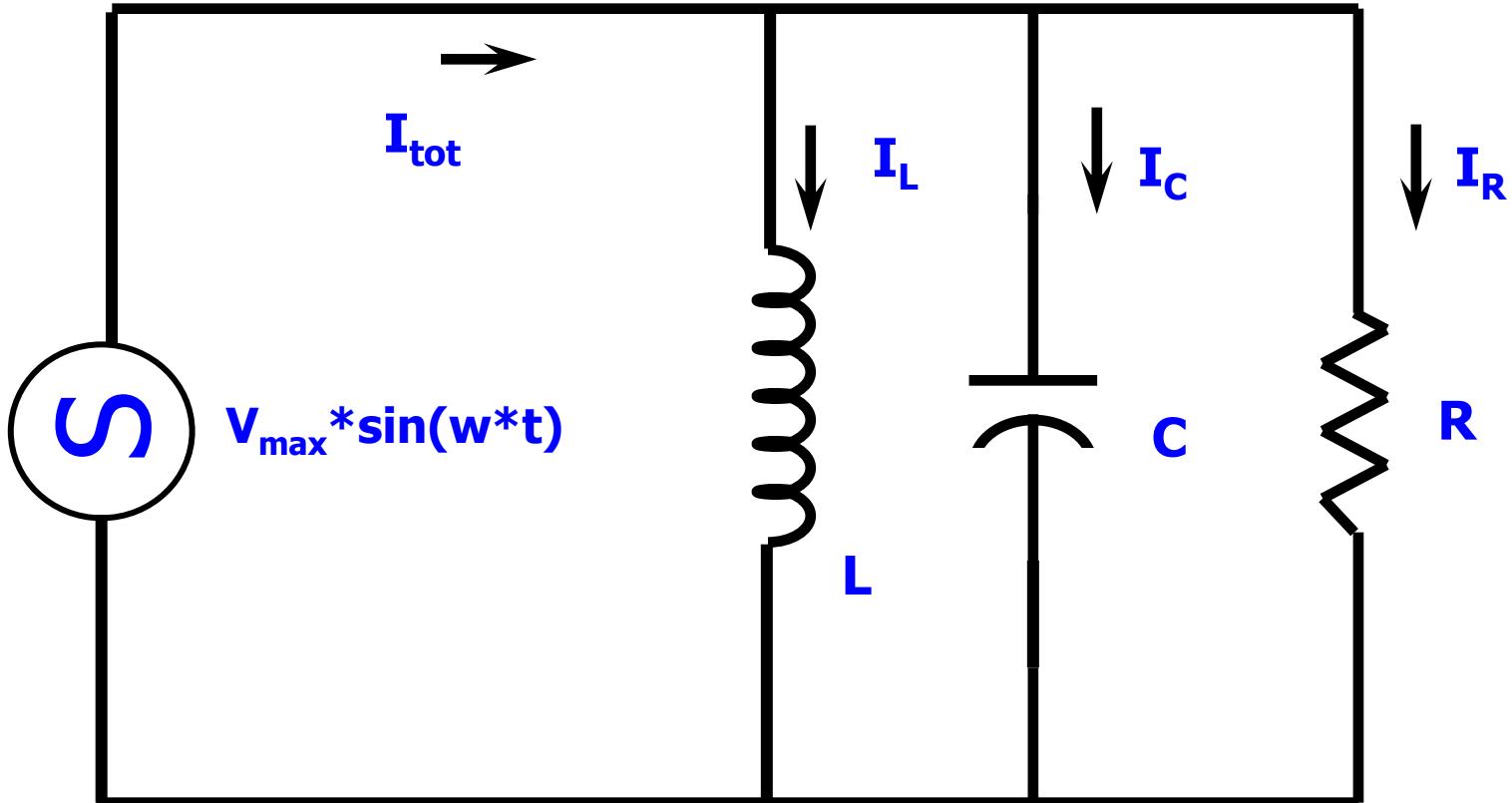
# POWER FACTOR MEASUREMENTS

# Power Factor Measurement

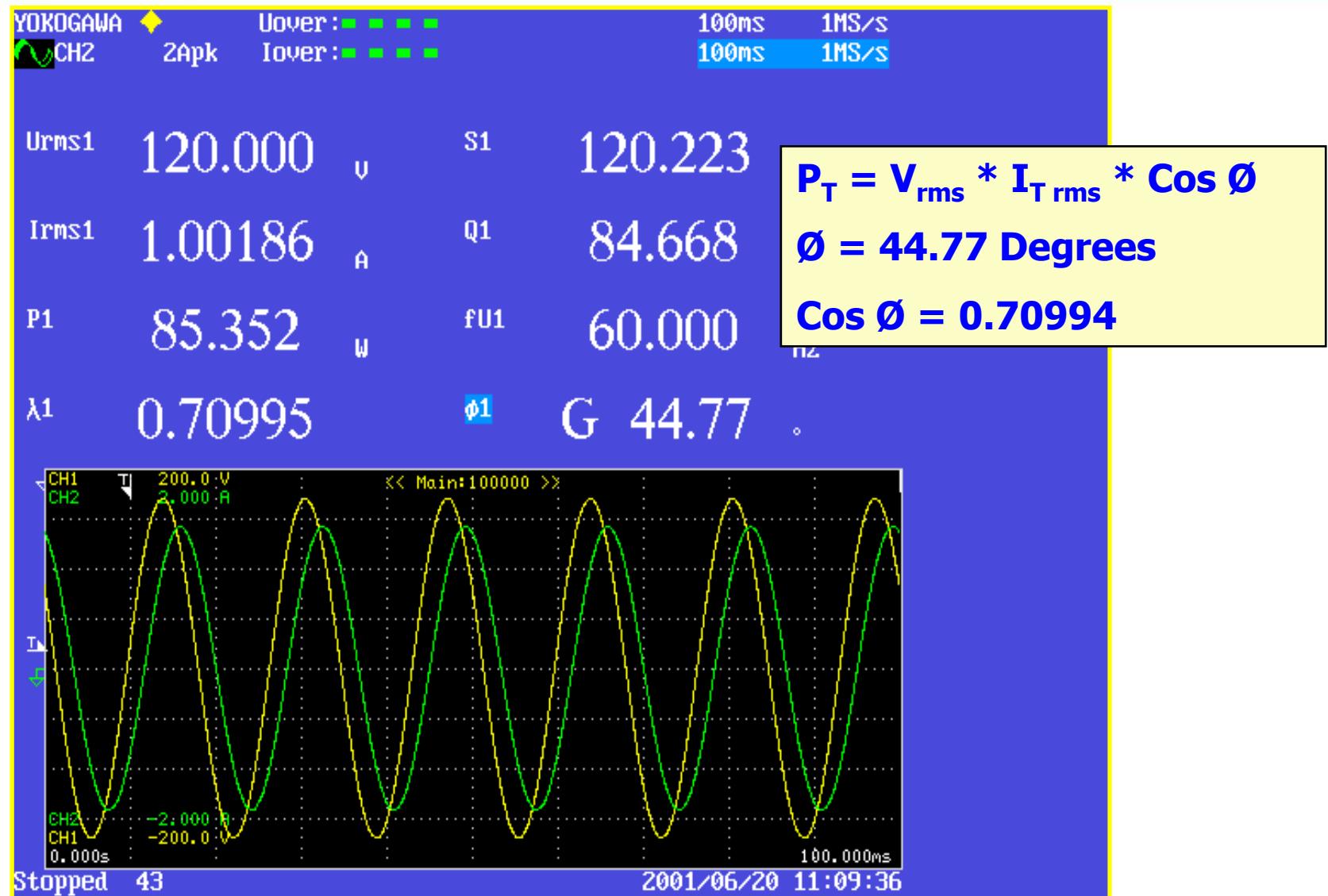
If Power Factor is the Cosine of the Angle between Voltage and Current, then how do we measure Power Factor on a Three Phase Circuit?



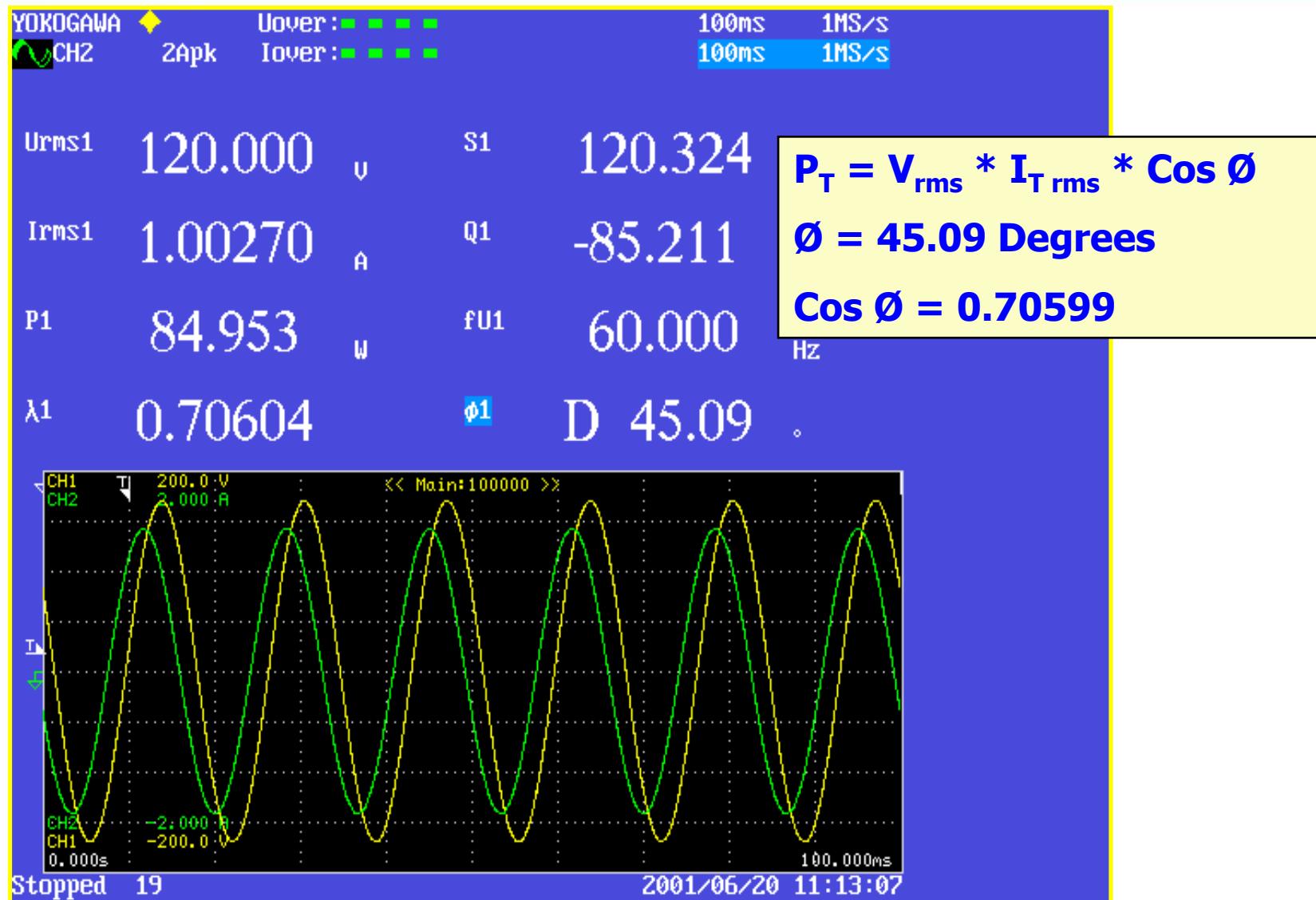
# R - L - C Circuit



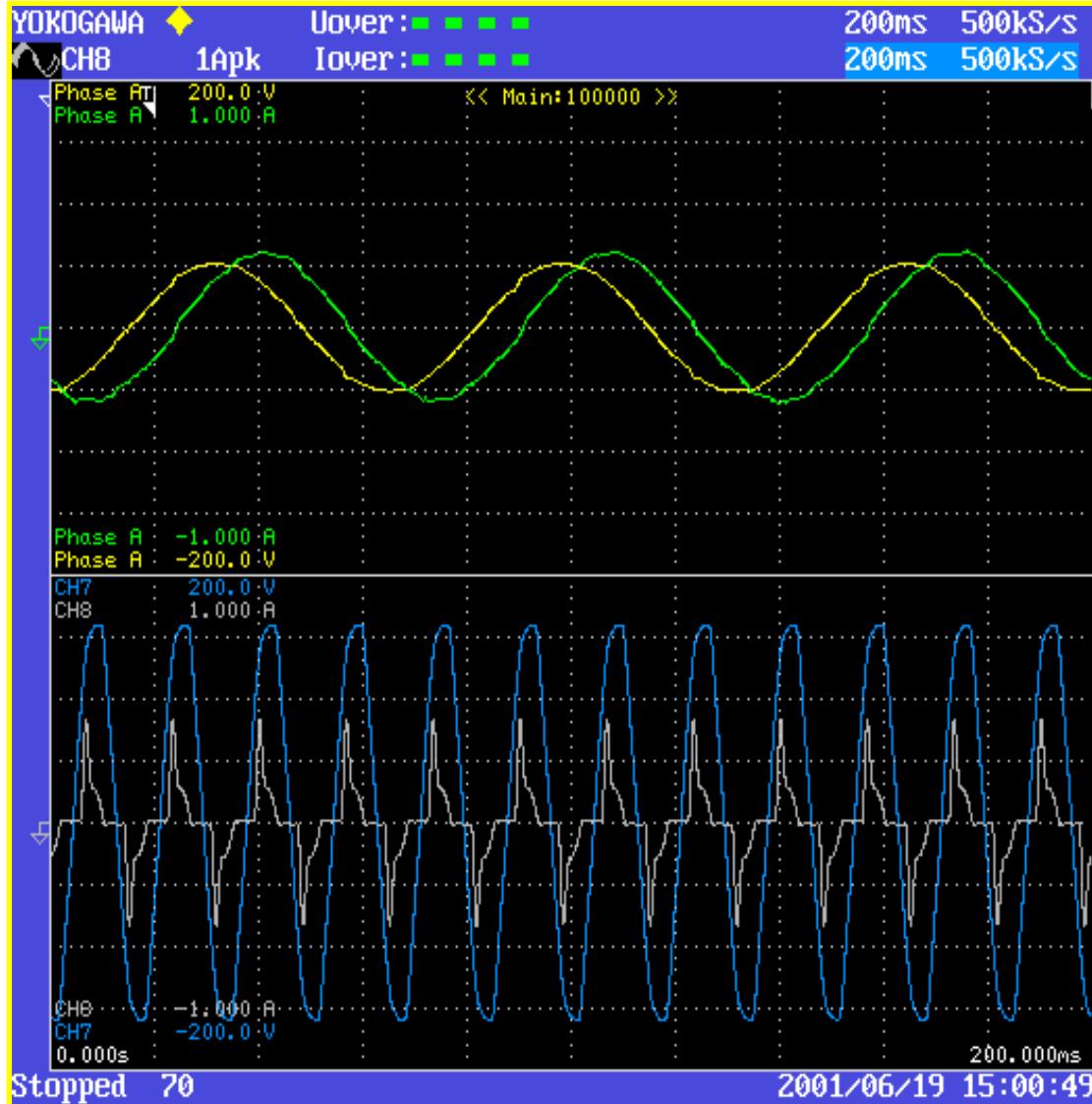
# Current LAGS Voltage in an Inductor



# Current LEADS Voltage in a Capacitor



# Real World Examples



**Inductive Load**

**AC Motor**

**Current LAGS  
Voltage in an  
Inductor**

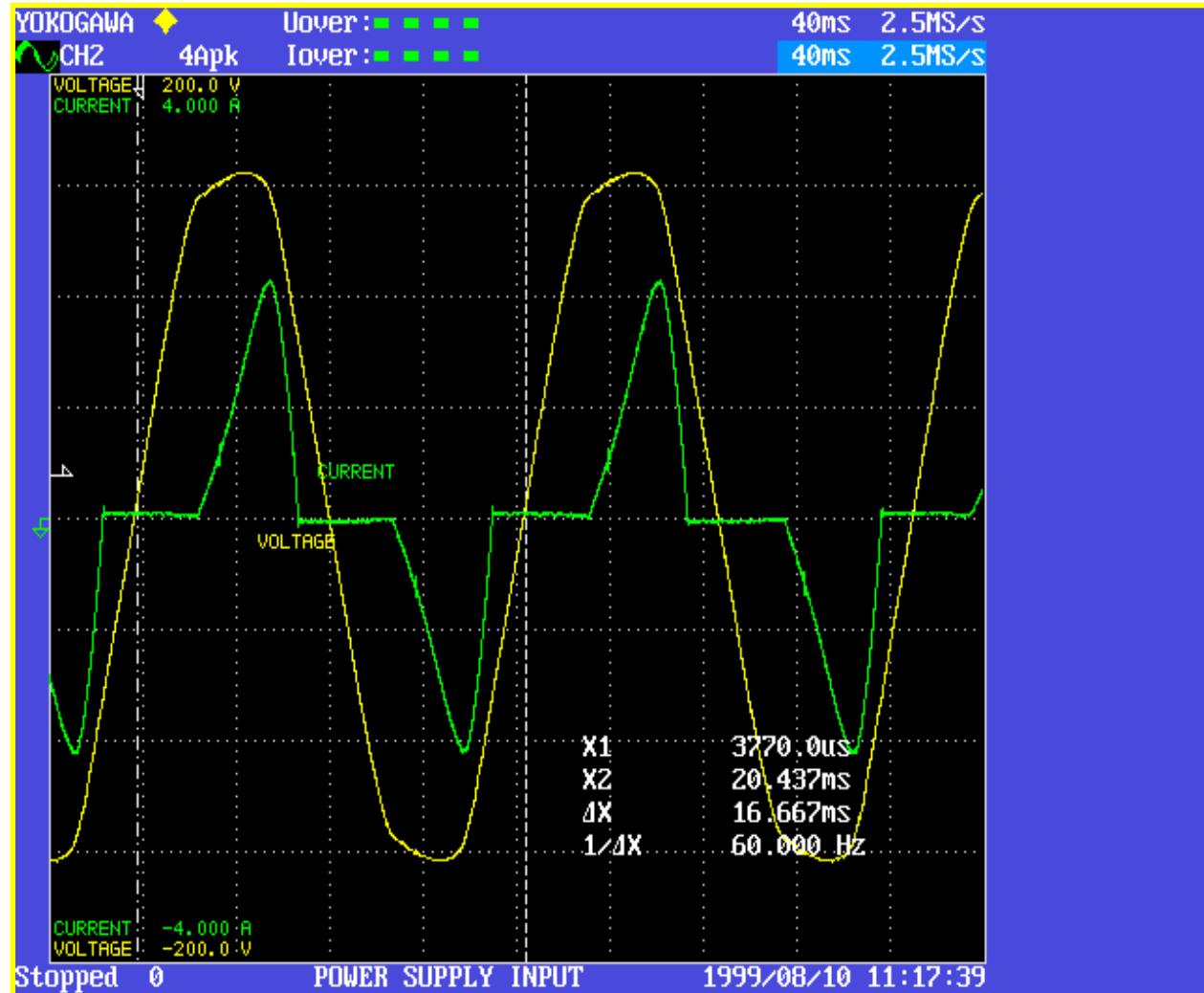
**Capacitive Load**

**Compact Fluorescent  
Lamp**

**Current LEADS  
Voltage in a  
Capacitor**

# Power Factor Measurement

- $\text{PF} = \cos \theta$
- Where is the Zero Crossing for the Current Waveform?
- How do we accurately measure  $\theta$  between these two waveforms?



# Power Factor Measurement

For SINE WAVES ONLY

$$\text{PF} = \cos \theta$$

This is defined as the DISPLACEMENT  
Power Factor

---

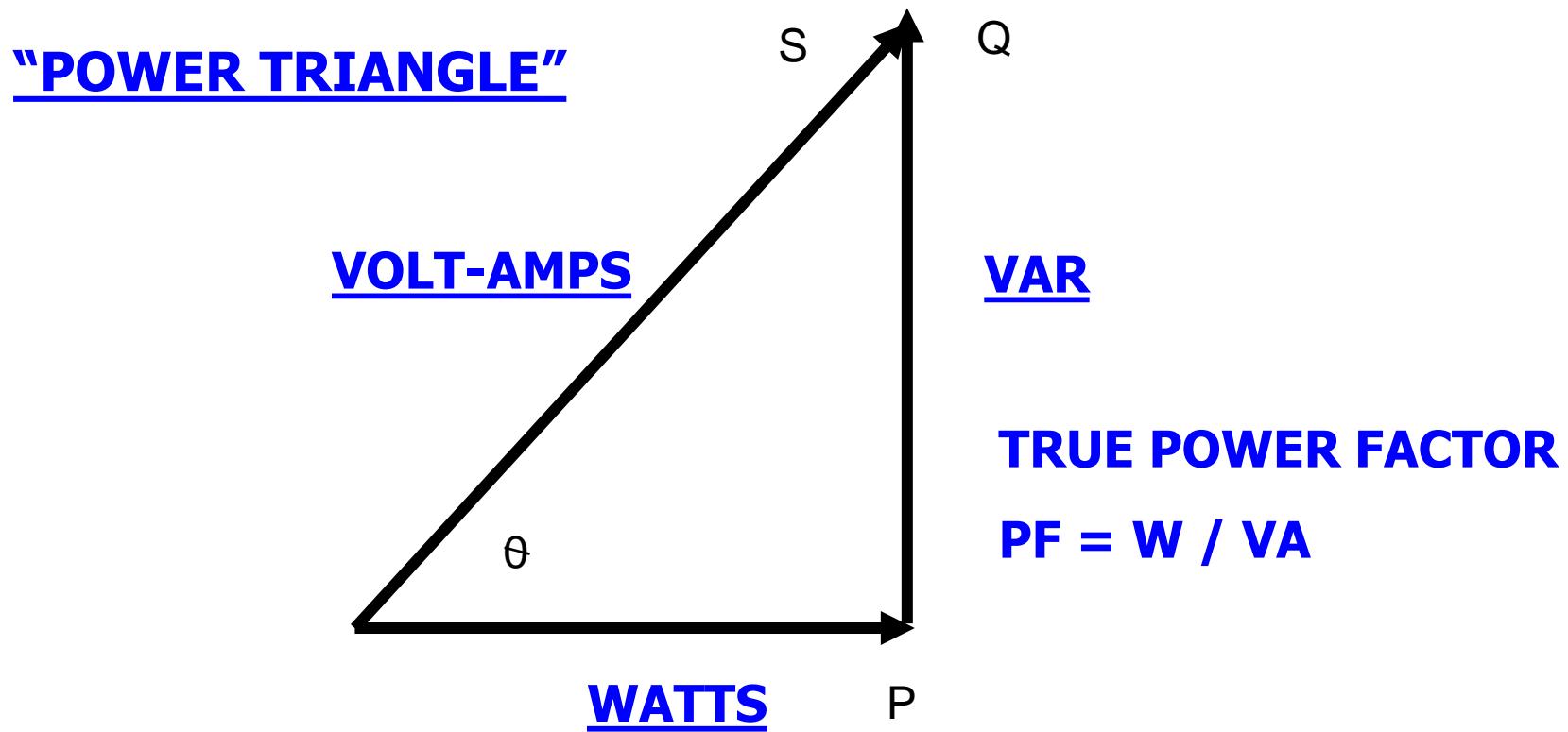
For All Waveforms

$$\text{PF} = \text{W/VA}$$

This is defined as TRUE Power Factor

# Phasor Form of Power

## Phasor Diagram of Power for R - L Circuit



# Power Factor Measurement

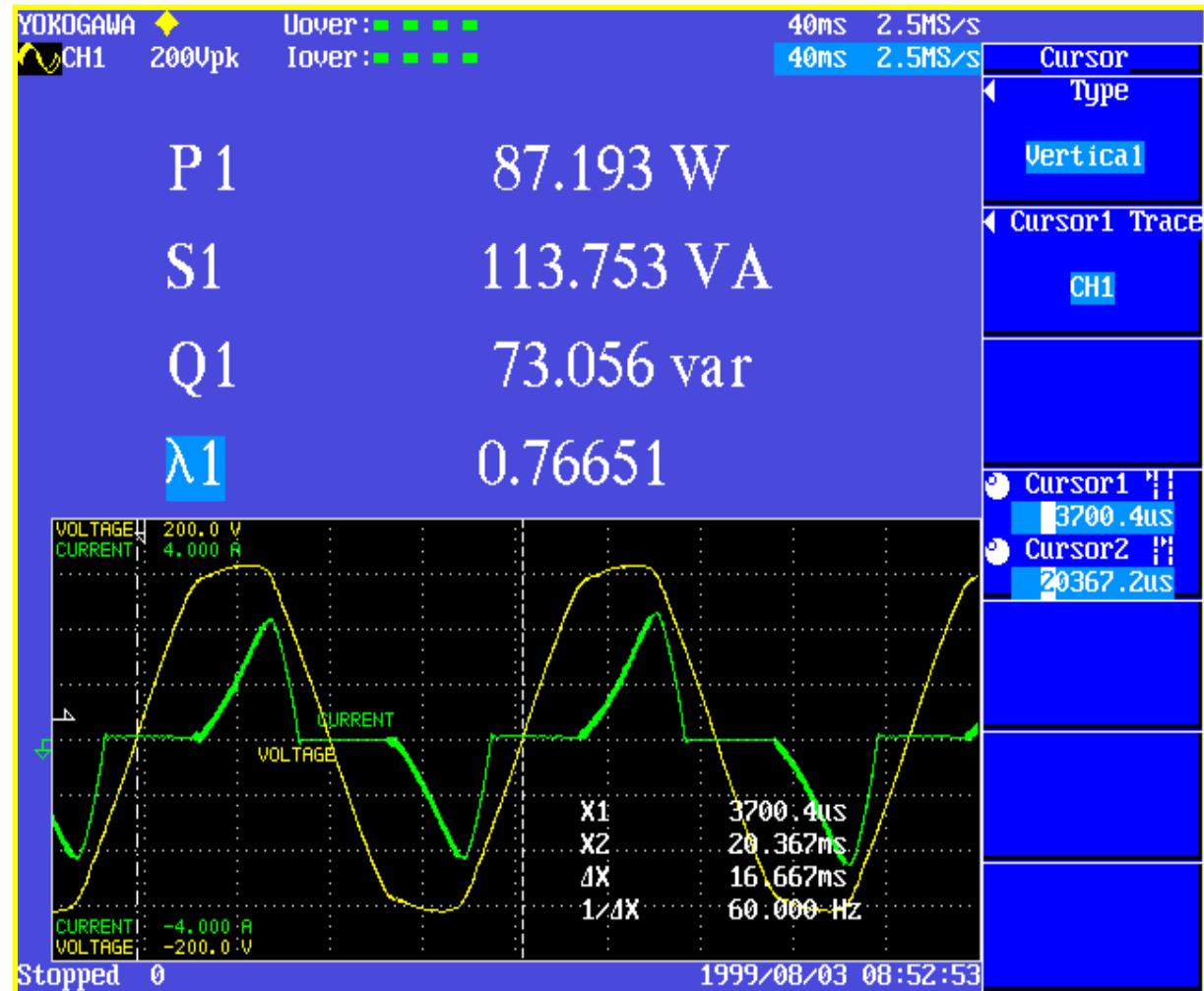
## True Power Factor

$$PF = W / VA$$

$$PF = \\frac{W}{VA}$$
  
**87.193/113.753**

$$PF = 0.76651$$

Power Supply Input



# Power Factor Measurement

## Displacement Power Factor

**PF = Cos Ø  
Between  
Fundamental  
Waveforms**

**PF = Cos 21.06**

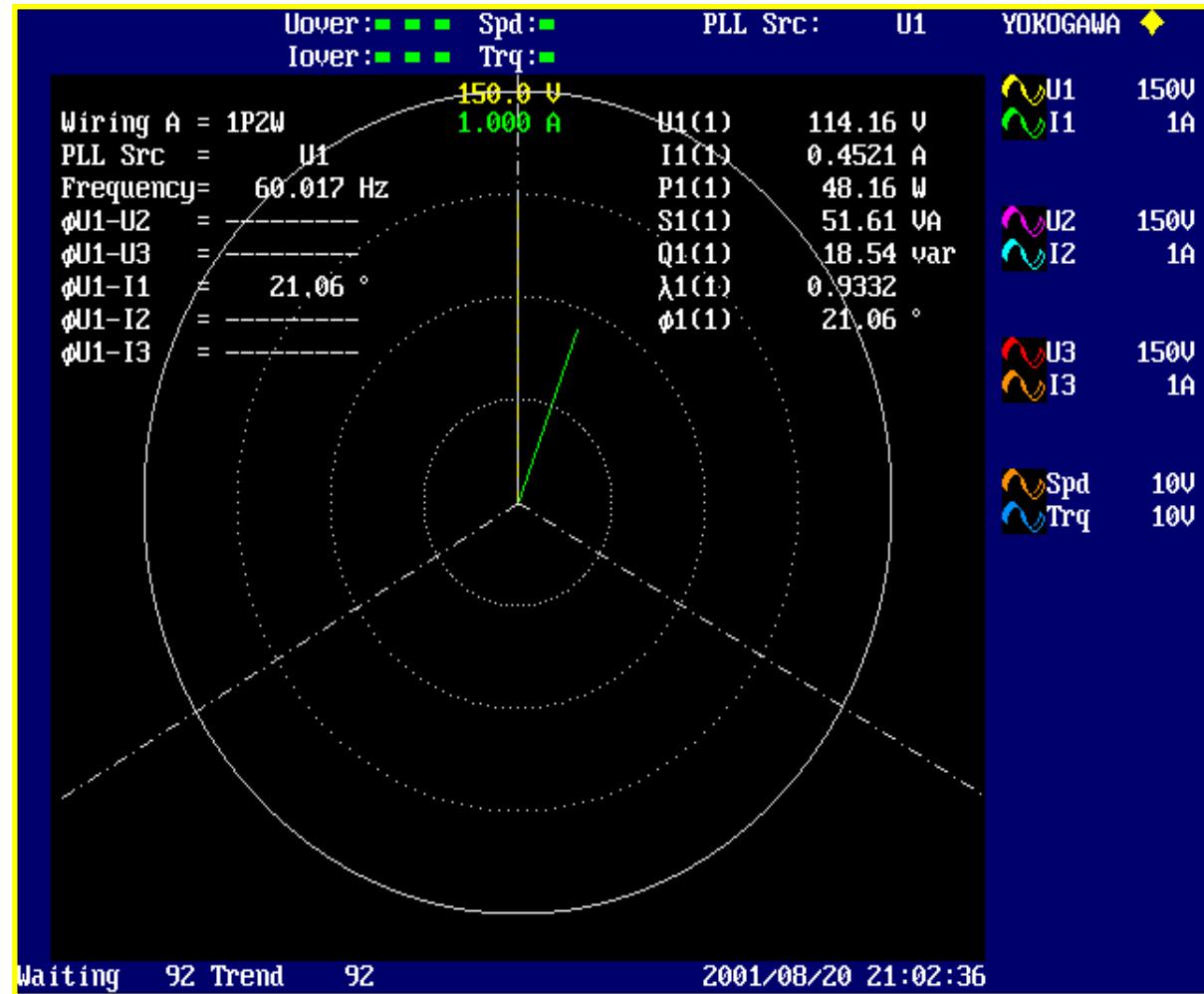
**PF = 0.9332**

**PF = P1 / S1**

**PF = 48.16 / 51.61**

**PF = 0.9332**

**Power Supply Input**



**Current LAGS Voltage by 21.06 Degrees**

## 3-Phase 4-Wire System

$$\mathbf{PF}_{\text{Total}} = \sum \mathbf{W} / \sum \mathbf{VA}$$

$$\mathbf{PF}_{\text{Total}} = ( \mathbf{W}_1 + \mathbf{W}_2 + \mathbf{W}_3 ) / ( \mathbf{VA}_1 + \mathbf{VA}_2 + \mathbf{VA}_3 )$$

## Using 2 Wattmeter Method

$$PF_{Total} = \Sigma W / \Sigma VA$$

$$PF_{Total} = (W_1 + W_2) / (\sqrt{3}/2)(VA_1 + VA_2)$$

- If the load is Unbalanced, that is the Phase Currents are different, this method could result in an error in calculating total Power Factor since only two VA measurements are used in the calculation.

## Using 3 Wattmeter Method

$$PF_{Total} = \sum W / \sum VA$$

$$PF_{Total} = (W_1 + W_2) / (\sqrt{3}/3)(VA_1 + VA_2 + VA_3)$$

- This method will give correct Power Factor calculation on either Balanced or Unbalanced 3-Wire system. Note that all three VA measurements are used in the calculation. This calculation is performed in the Yokogawa Power Analyzers when using the 3V-3A wiring method.

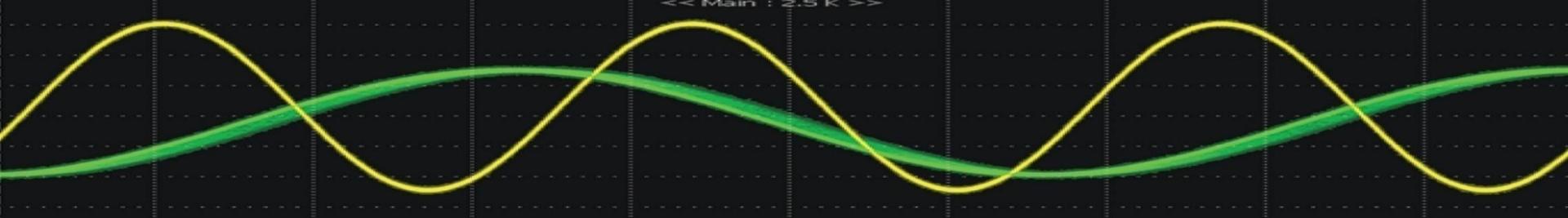
# 3-Phase 3-Wire Power Factor Measurement

**3V 3A**

## Measurement Method

- $\Sigma P = P1 + P2$
- $\Sigma PF = \Sigma P / \Sigma VA$
- $\Sigma PF = 49.466 / 93.060$
- $\Sigma PF = 0.53155$
- How is  $\Sigma VA$  calculated?

YOKOGAWA		Uover :	Iover :	200ms	500kS/s
CH6	1Apk	---	---	200ms	500kS/s
P1	15.477 W		$\lambda_1$	0.28578	
P2	33.989 W		$\lambda_2$	0.64245	
$P_{\Sigma A}$	49.466 W		$\lambda_3$	-0.35395	
---	-----		$\lambda_{\Sigma A}$	0.53155	
---	-----		$S_1$	54.157 VA	
---	-----		$S_2$	52.905 VA	
---	-----		$S_3$	54.122 VA	
---	-----		$S_{\Sigma A}$	93.060 VA	
Stopped 0		1999/08/20 10:02:31			



## POWER MEASUREMENT APPLICATIONS



**Standby Power**

**Energy Star®**

**&**

**IEC62301 Testing**

- ◆ **International Standard IEC62301**
- ◆ **Household Electrical Appliances – Measurement of Standby Power**
- ◆ **Hardware and Software Measurement Solution**

# Scope

- This International Standard specifies methods of measurement of electrical power consumption in Standby Mode. It is applicable to mains powered electrical household appliances.
- The objective of this standard is to provide a standard method of test to determine the power consumption of a range of appliances and equipment in standby mode.

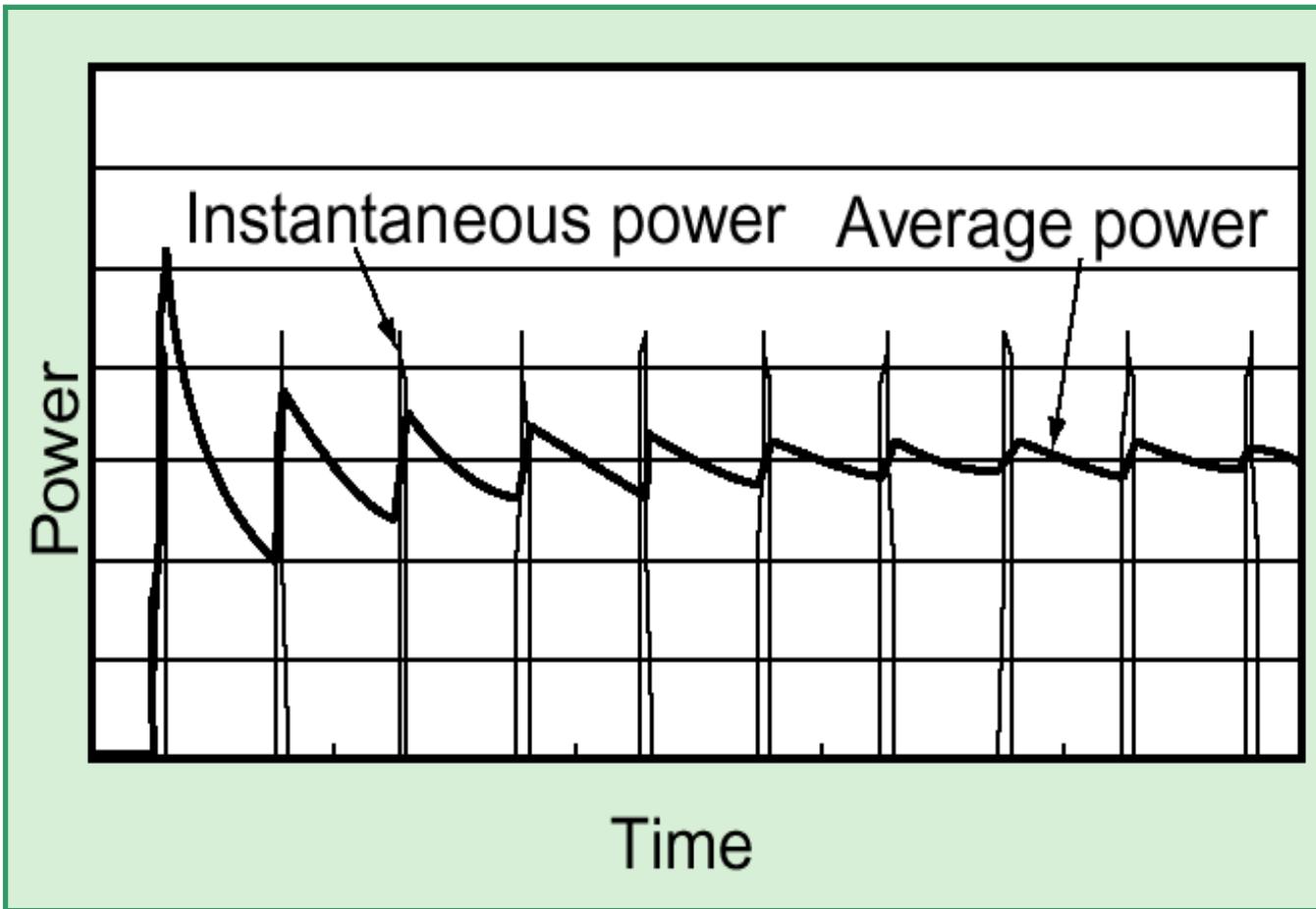
# Terms and Definitions

- The Standard also references Twenty Five (25) IEC Standards for various Household electrical appliances.
- These standards define the various test parameters with the limits for items such as THD, Power and other items for the appropriate product.
- In the US and North America, the Energy Star® standard is typically used for the testing limits.

# Appliance Type

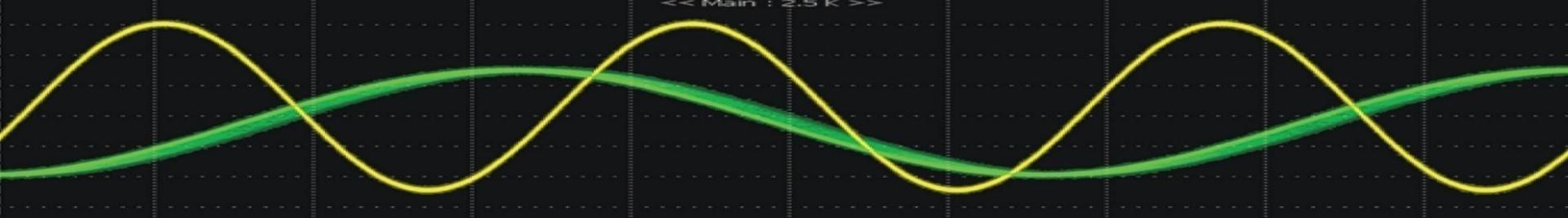
## Pulse Power Mode

Example: Laser Printer or Copy Machine with Heaters



## ■ Yokogawa's Standby Power Measurement:

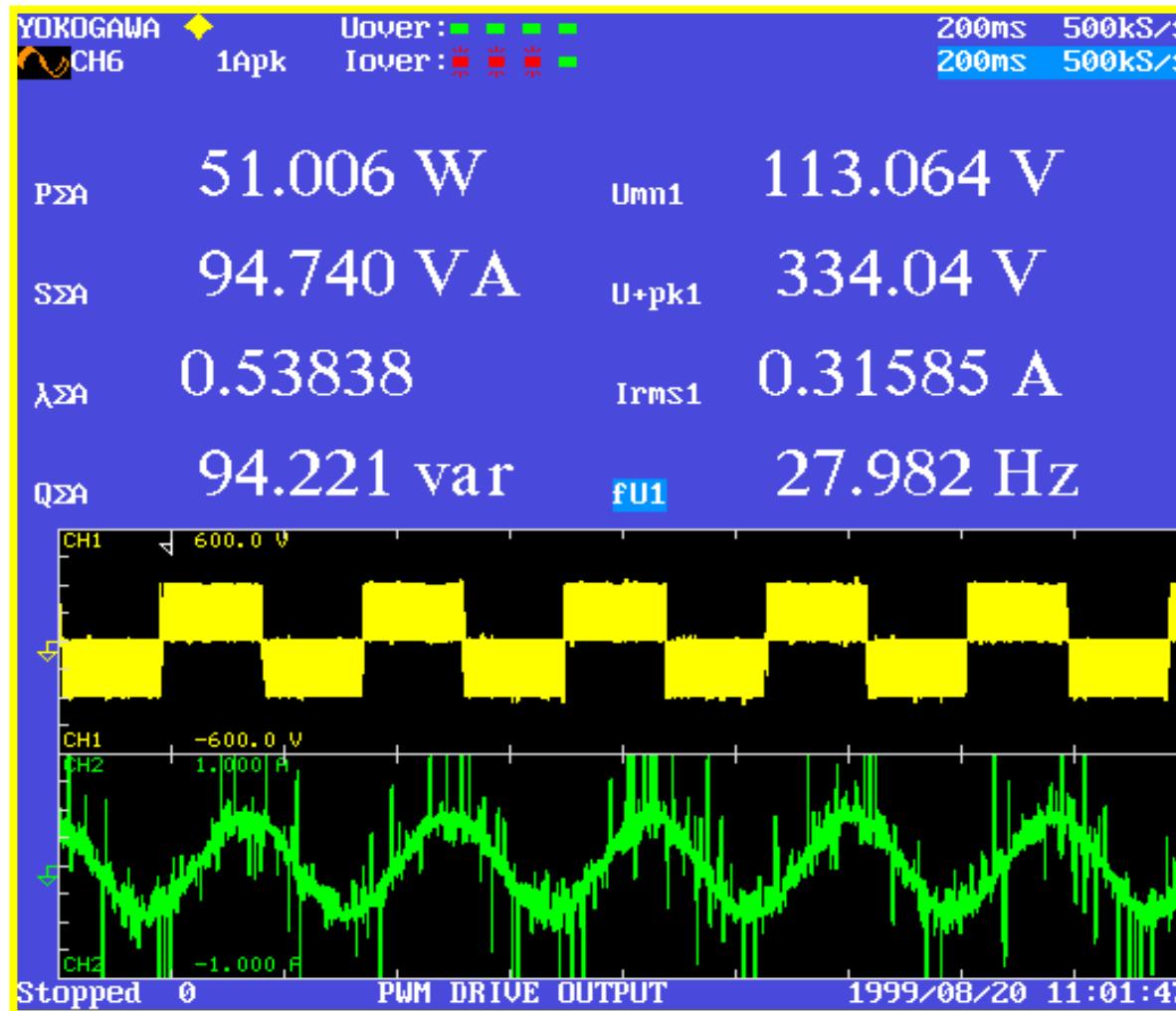
- Energy divided by Time > Watt-Hour/Time.
- This is the Average Active Power measurement mode.
- This is the preferred method as it works on both steady and fluctuating power sources and is the most accurate method.
- Yokogawa pioneered this method with the Model WT200 introduced in 2000.



## OTHER APPLICATIONS

# Power Measurement Application

## 3-P 3-W PWM Motor Drive Power Measurement



**3V 3A**

**Measurement Method**

**Drive voltage is typically measured using the Mean value scaled to rms.**

- DC Bus Voltage is measured as  $U+pk$**

# Device Efficiency Measurement

- Device Efficiency is Calculated as Output Power Divided by Input Power
  - Usually expressed as a percentage
- Use Two Power Meters to Measure the Input and Output Power
  - Calculate the Efficiency from the readings of the two Power Meters
  - Problem – Input and Output Readings may not be made Simultaneously. Possible error due to Time Skew
- Use a Multi-Element Power Analyzer to Measure Input and Output Power
  - Calculate the Efficiency in a Single Power Analyzer
  - Eliminates any Error due to Time Skew of Measurements

# Device Efficiency Measurements

Device  
Efficiency:  
Output P  
Input P

Normal Mode      Uover: [ ] Spd: [ ] Update: 500msec EAMP  
Iover: [ ] Trq: [ ] Integ: Reset

YOKOGAWA ▶

Wiring

Wiring Settings

η Formula

Compensation

Element Independent OFF ON

Δ Measure

Urms1 Element [ 1 ] [ 2 ] [ 3 ] [ 4 ]  
Irms2 [ 3P3W(3V3A):Σ A ] [ 1P2W ]  
Irms3

η1 =  $\frac{P_{\Sigma A}}{P_4} * 100[\%]$    η2 =  $\frac{OFF}{1} * 100[\%]$

η3 =  $\frac{OFF}{1} * 100[\%]$    η4 =  $\frac{OFF}{1} * 100[\%]$

Irms1 Idef1 = P1 + None + None + None  
Irms2 Idef2 = P1 + None + None + None

SΣA 32.248 VA | λ3 0.70811  
QΣA 22.831 var | λΣA 0.71255

Update 38      2007/10/09 14:52:02

9 ▾

Power Analyzer Setup Menu

# Device Efficiency & Power Loss

Normal Mode		Uover:   Spd:   I4 : 1Arms	Iover:   Trq:   Integ:Reset	YOKOGAWA
& change items				
Urms1	150.685	v	Urms4	119.617 v
Urms2	150.642	v	Irms4	0.80193 A
Urms3	149.955	v	P4	54.987 W
Irms1	0.27227	A	λ4	0.57323
Irms2	0.27239	A	η1	56.019 %
Irms3	0.27225	A	F10	24.1836 Hz
PΣA	30.803	W	fU3	20.496 Hz
λΣA	0.43417			
<div style="float: right; border: 1px solid black; padding: 2px;">         PAGE  1  2  3  4  5  6  7  8  9  10  11  12  13  14  15  16  17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  42  43  44  45  46  47  48  49  50  51  52  53  54  55  56  57  58  59  60  61  62  63  64  65  66  67  68  69  70  71  72  73  74  75  76  77  78  79  80  81  82  83  84  85  86  87  88  89  90  91  92  93  94  95  96  97  98  99  100  101  102  103  104  105  106  107  108  109  110  111  112  113  114  115  116  117  118  119  120  121  122  123  124  125  126  127  128  129  130  131  132  133  134  135  136  137  138  139  140  141  142  143  144  145  146  147  148  149  150  151  152  153  154  155  156  157  158  159  160  161  162  163  164  165  166  167  168  169  170  171  172  173  174  175  176  177  178  179  180  181  182  183  184  185  186  187  188  189  190  191  192  193  194  195  196  197  198  199  200  201  202  203  204  205  206  207  208  209  210  211  212  213  214  215  216  217  218  219  220  221  222  223  224  225  226  227  228  229  230  231  232  233  234  235  236  237  238  239  240  241  242  243  244  245  246  247  248  249  250  251  252  253  254  255  256  257  258  259  260  261  262  263  264  265  266  267  268  269  270  271  272  273  274  275  276  277  278  279  280  281  282  283  284  285  286  287  288  289  290  291  292  293  294  295  296  297  298  299  300  301  302  303  304  305  306  307  308  309  310  311  312  313  314  315  316  317  318  319  320  321  322  323  324  325  326  327  328  329  330  331  332  333  334  335  336  337  338  339  340  341  342  343  344  345  346  347  348  349  350  351  352  353  354  355  356  357  358  359  360  361  362  363  364  365  366  367  368  369  370  371  372  373  374  375  376  377  378  379  380  381  382  383  384  385  386  387  388  389  390  391  392  393  394  395  396  397  398  399  400  401  402  403  404  405  406  407  408  409  410  411  412  413  414  415  416  417  418  419  420  421  422  423  424  425  426  427  428  429  430  431  432  433  434  435  436  437  438  439  440  441  442  443  444  445  446  447  448  449  450  451  452  453  454  455  456  457  458  459  460  461  462  463  464  465  466  467  468  469  470  471  472  473  474  475  476  477  478  479  480  481  482  483  484  485  486  487  488  489  490  491  492  493  494  495  496  497  498  499  500  501  502  503  504  505  506  507  508  509  510  511  512  513  514  515  516  517  518  519  520  521  522  523  524  525  526  527  528  529  530  531  532  533  534  535  536  537  538  539  540  541  542  543  544  545  546  547  548  549  550  551  552  553  554  555  556  557  558  559  560  561  562  563  564  565  566  567  568  569  570  571  572  573  574  575  576  577  578  579  580  581  582  583  584  585  586  587  588  589  590  591  592  593  594  595  596  597  598  599  600  601  602  603  604  605  606  607  608  609  610  611  612  613  614  615  616  617  618  619  620  621  622  623  624  625  626  627  628  629  630  631  632  633  634  635  636  637  638  639  640  641  642  643  644  645  646  647  648  649  650  651  652  653  654  655  656  657  658  659  660  661  662  663  664  665  666  667  668  669  670  671  672  673  674  675  676  677  678  679  680  681  682  683  684  685  686  687  688  689  690  691  692  693  694  695  696  697  698  699  700  701  702  703  704  705  706  707  708  709  710  711  712  713  714  715  716  717  718  719  720  721  722  723  724  725  726  727  728  729  730  731  732  733  734  735  736  737  738  739  740  741  742  743  744  745  746  747  748  749  750  751  752  753  754  755  756  757  758  759  760  761  762  763  764  765  766  767  768  769  770  771  772  773  774  775  776  777  778  779  780  781  782  783  784  785  786  787  788  789  790  791  792  793  794  795  796  797  798  799  800  801  802  803  804  805  806  807  808  809  810  811  812  813  814  815  816  817  818  819  820  821  822  823  824  825  826  827  828  829  830  831  832  833  834  835  836  837  838  839  840  841  842  843  844  845  846  847  848  849  850  851  852  853  854  855  856  857  858  859  860  861  862  863  864  865  866  867  868  869  870  871  872  873  874  875  876  877  878  879  880  881  882  883  884  885  886  887  888  889  890  891  892  893  894  895  896  897  898  899  900  901  902  903  904  905  906  907  908  909  910  911  912  913  914  915  916  917  918  919  920  921  922  923  924  925  926  927  928  929  930  931  932  933  934  935  936  937  938  939  940  941  942  94</div>				

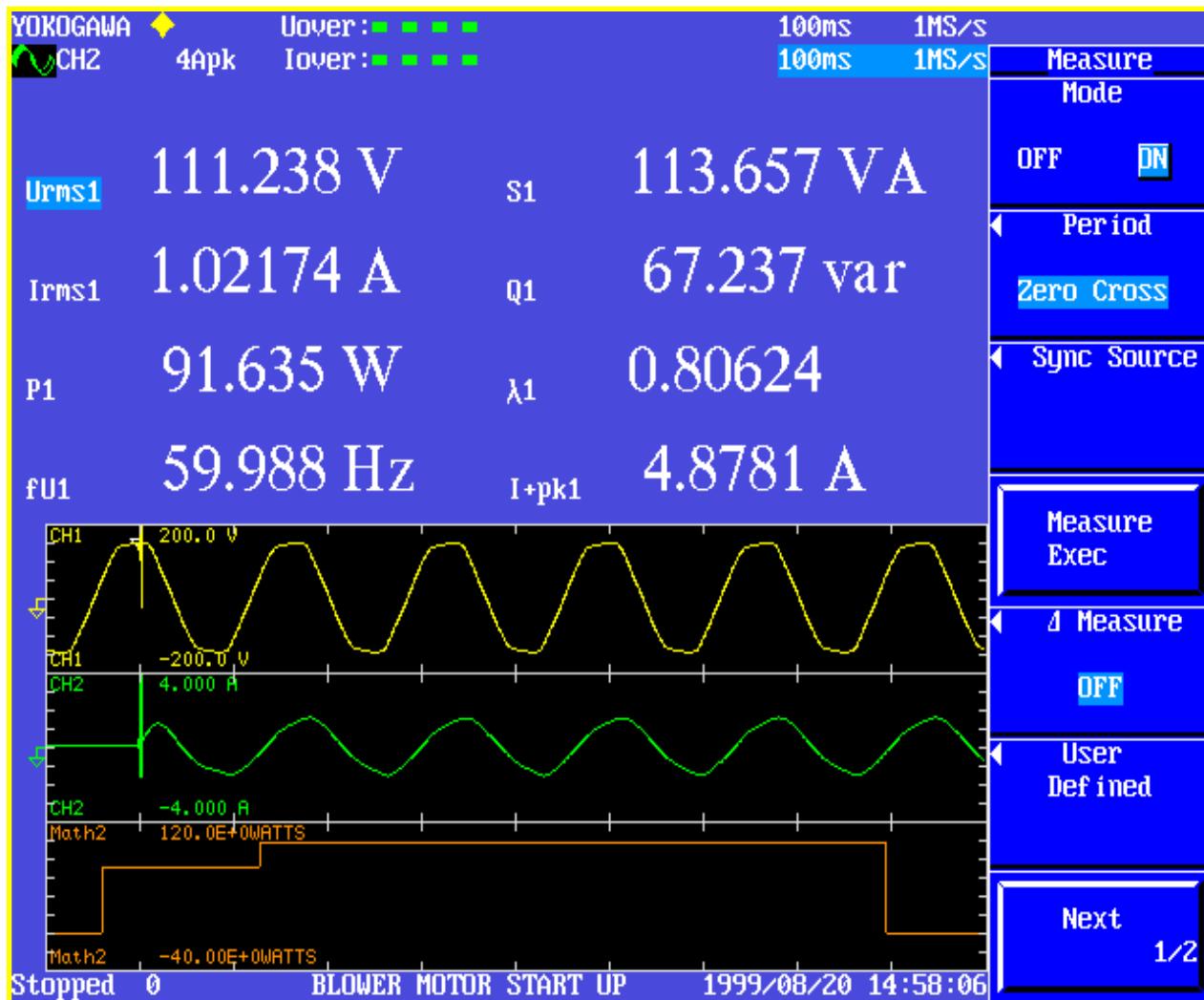
# Power Measurement Application

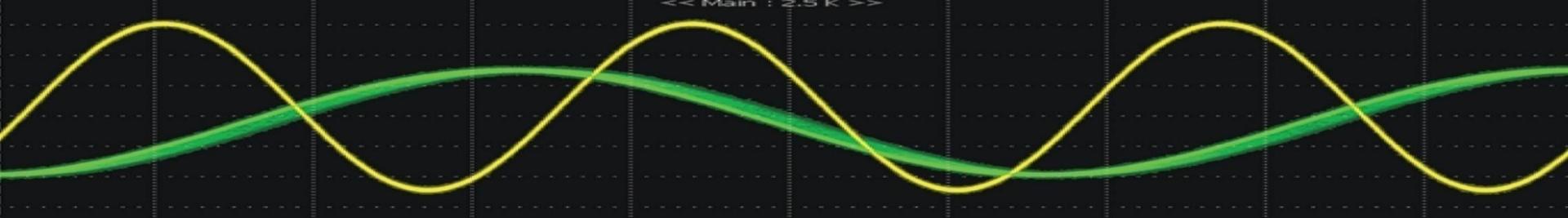
## Device Start Up Analysis

## Device Voltage

## Device Current

## Cycle-by-Cycle Start Up Power





**PART III**  
**BASIC POWER MEASUREMENTS**  
**using a**  
**DIGITAL OSCILLOSCOPE**

## Why use a Digital Oscilloscope for Electrical Power Measurements?

- We have a “Comfort Level” using an Oscilloscope
- Dedicated Probes & Ease of Connections
- Power Analysis Math Capabilities
- High-frequency Bandwidth
- Waveform Display & Analysis
- Harmonic Analysis to IEC Standards

# Measurement of Power

## ➤ Special Note:

**When using an oscilloscope, AC Power is not just connecting a voltage probe to Ch1 and a current probe to Ch2 and then multiplying Ch1 x Ch2.**

**This will give an AC measurement of VA, not AC Watts.**

# Measurement of Power

## Remember - AC Power Measurement

### ■ Active Power:

$$\text{Watts } P = V_{\text{rms}} \times A_{\text{rms}} \times PF$$

- Also sometimes referred to as True Power or Real Power

### ■ Apparent Power:

$$\text{Volt-Amps } S = V_{\text{rms}} \times A_{\text{rms}}$$

# Measurement of Power

- Yokogawa Digital Power Scopes use the following method to calculate power:

$$\bullet P_{\text{avg}} = 1/T \int_0^T v(t) * I(t) dt$$

- Taking advantage of digitizing techniques, the INSTANTANEOUS VOLTAGE is multiplied by the INSTANTANEOUS CURRENT and then INTEGRATED over some time period.

# Power Analyzer vs. DSO

## Function

Bandwidth

## Power Analyzer

DC – 2MHz

## DSO

DC – 500 MHz

Accuracy

0.1 to 0.02%

1.5% at input terminals, at DC

Calibrated Traceable Measurement System

Power approx 3.5%  
Based on Probes  
DC Accuracy

Ranges

Direct connection  
High Voltage &  
High Currents

Probes for high frequency & small currents

Digitizers

Typical 16-Bit  
65,536 levels

Typical 8-Bit  
256 Levels

# Measurement Challenge: SKEW



## Current clamp

e.g. 30 A, 100 MHz  
model 701932



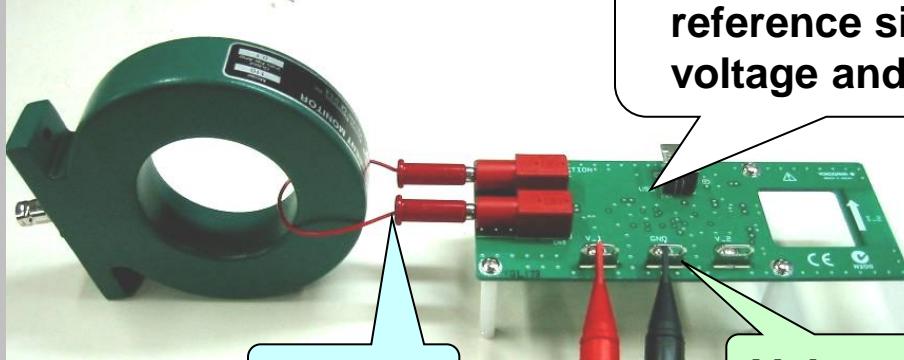
## Differential probe

e.g. 1400 V, 100 MHz  
model 700924



**Skew = Propagation Delay Difference**

## Deskew Source - model 701936



**Synchronous reference signal for voltage and current**

**Auto Deskew function**



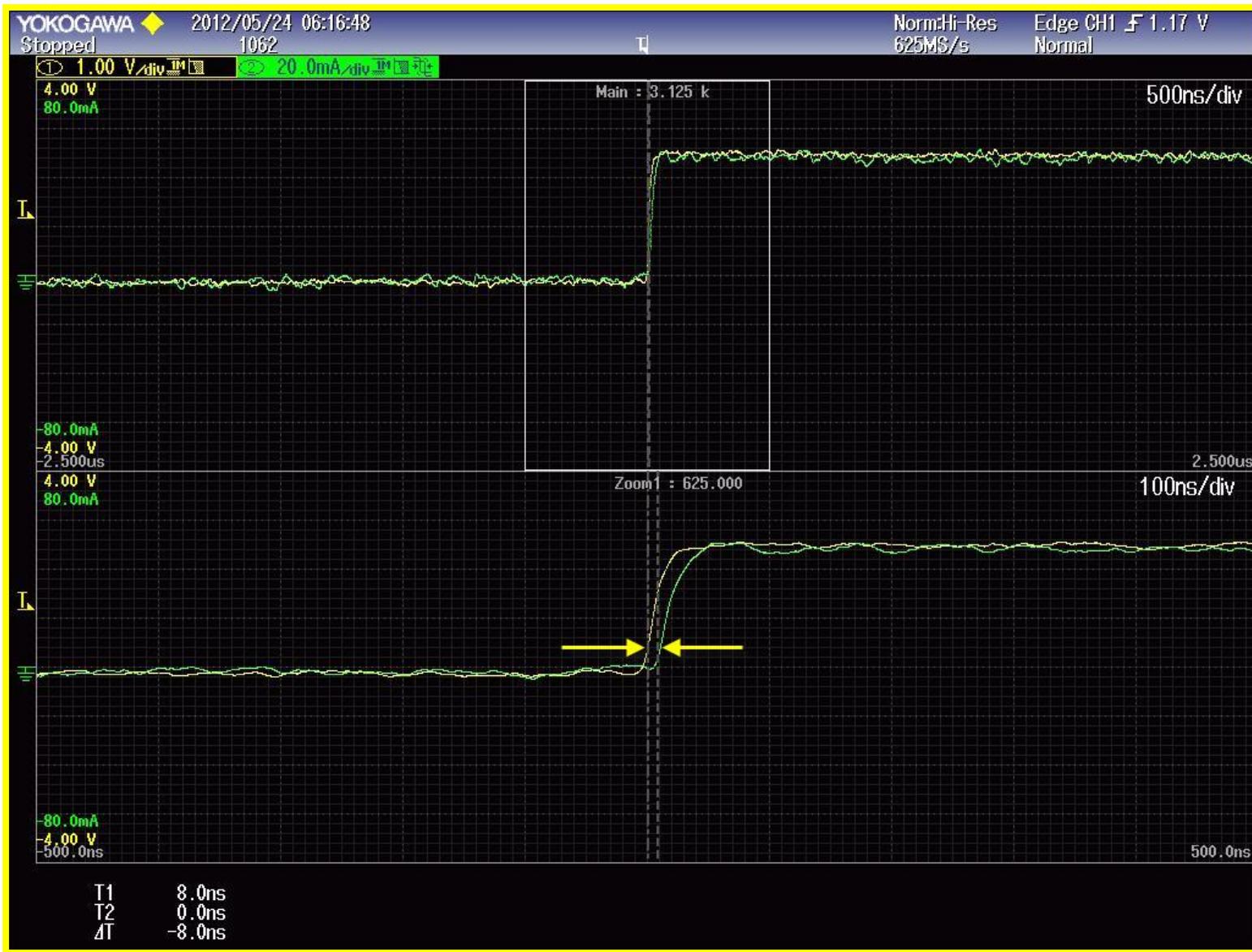
**Successful de-skew!**

# Deskew Calibration

- Signal source used for adjusting the skew between a voltage probe and a current probe.
  - Many different kinds of probes can be used for power measurements. Each probe has a different signal path length.
  - Signal source generates time-coincident voltage and current signals. This allows you to adjust for skew between voltage and current probes.



# BEFORE DE-SKEW

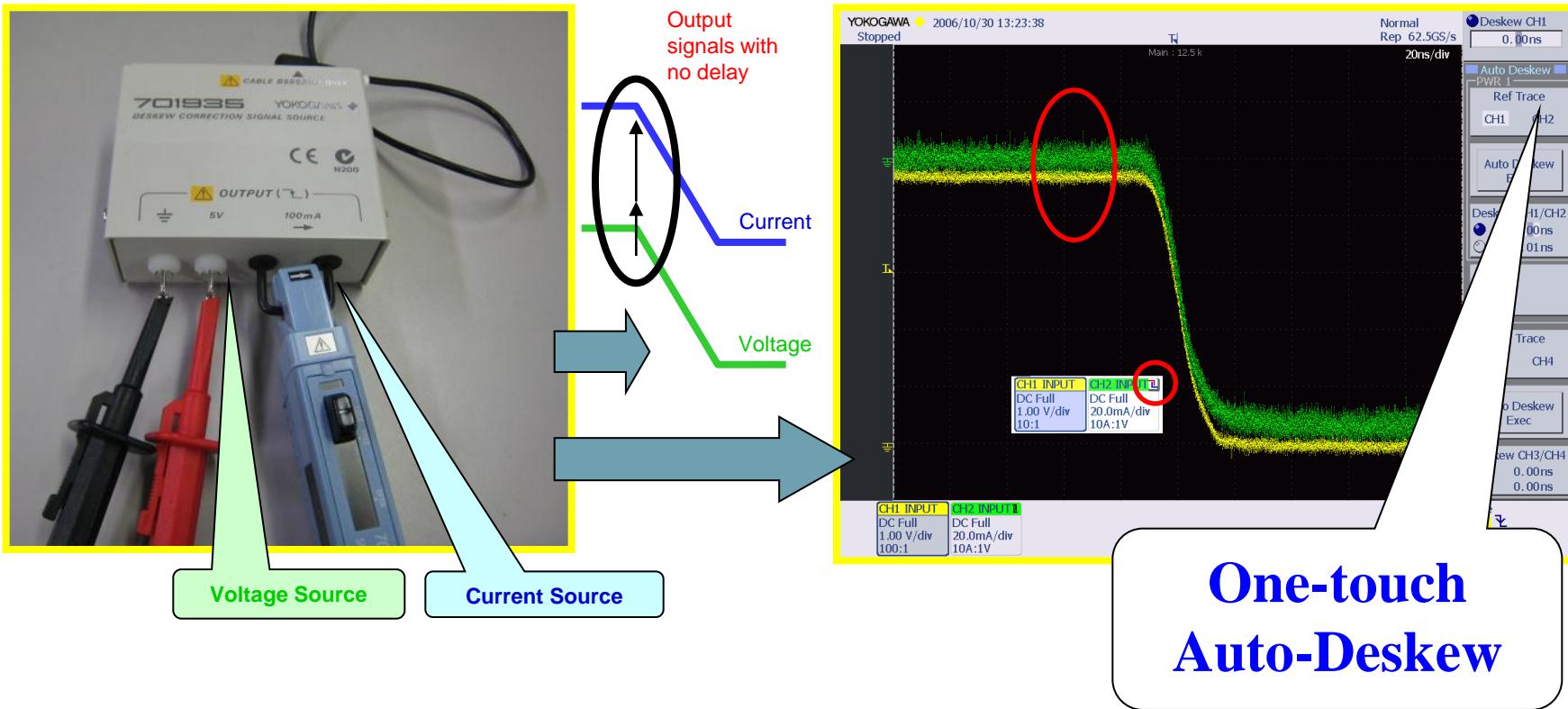


# AFTER DE-SKEW



# Yokogawa Solution: Auto De-skew

To correctly measure the analysis parameters such as power, impedance, power factor, watt hour, and ampere hour from the voltage and current under analysis, the voltage and current signals must be applied to the Vertical Input channels of the Oscilloscope while preserving the phase relationship which exists between U & I in the DUT.

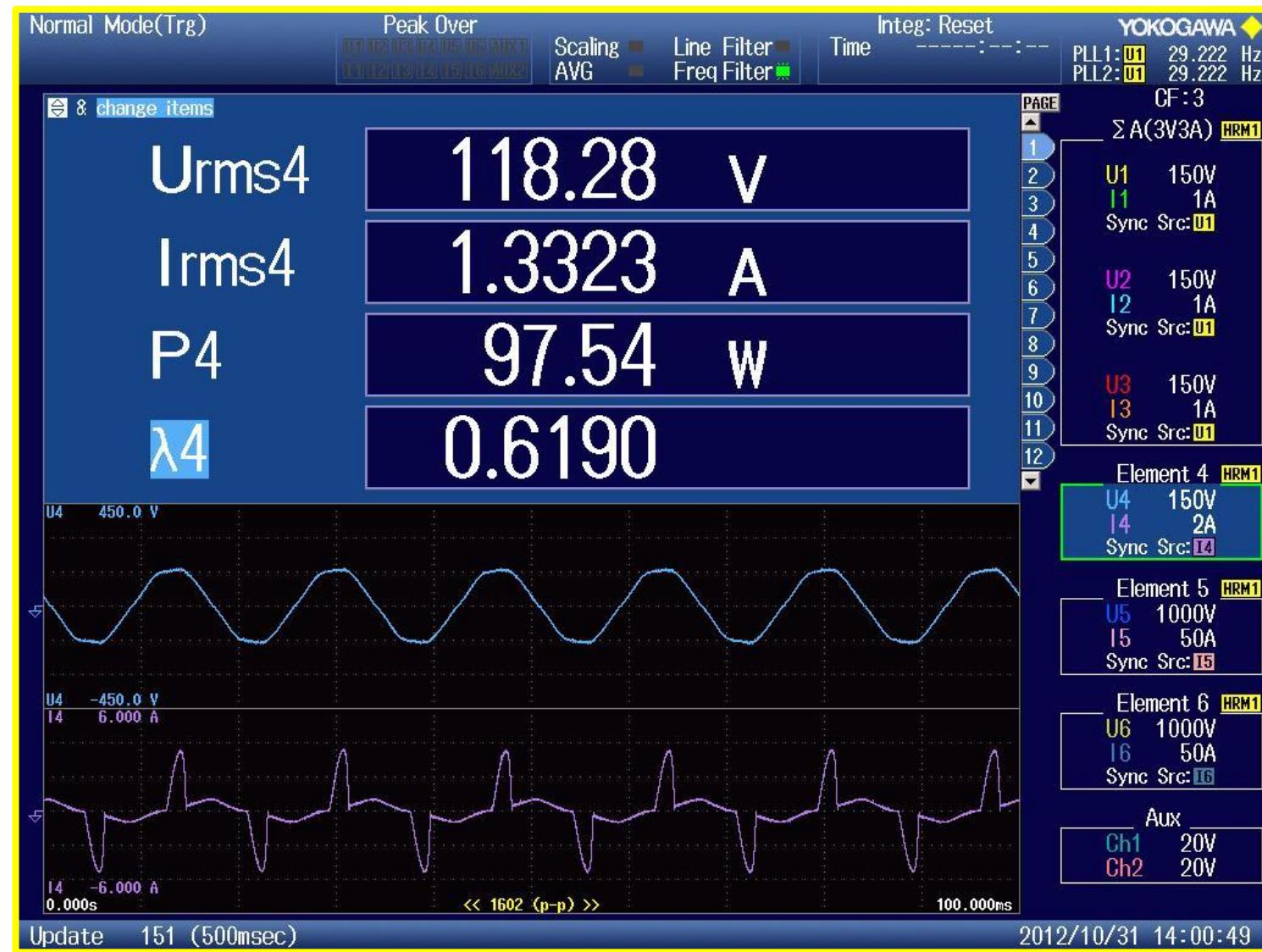


**Deskew - The difference in the current probe and voltage probe signal propagation time (skew) is automatically corrected.**

## Typical Measurements

- **Board Level Power Measurements**
- **Switching Power Loss**
- **Device Power Consumption**
- **Switching Noise Level**
- **Harmonics**
- **Waveform Display & Analysis**
- **Inrush & Transients**

# Power Supply Input with Power Analyzer



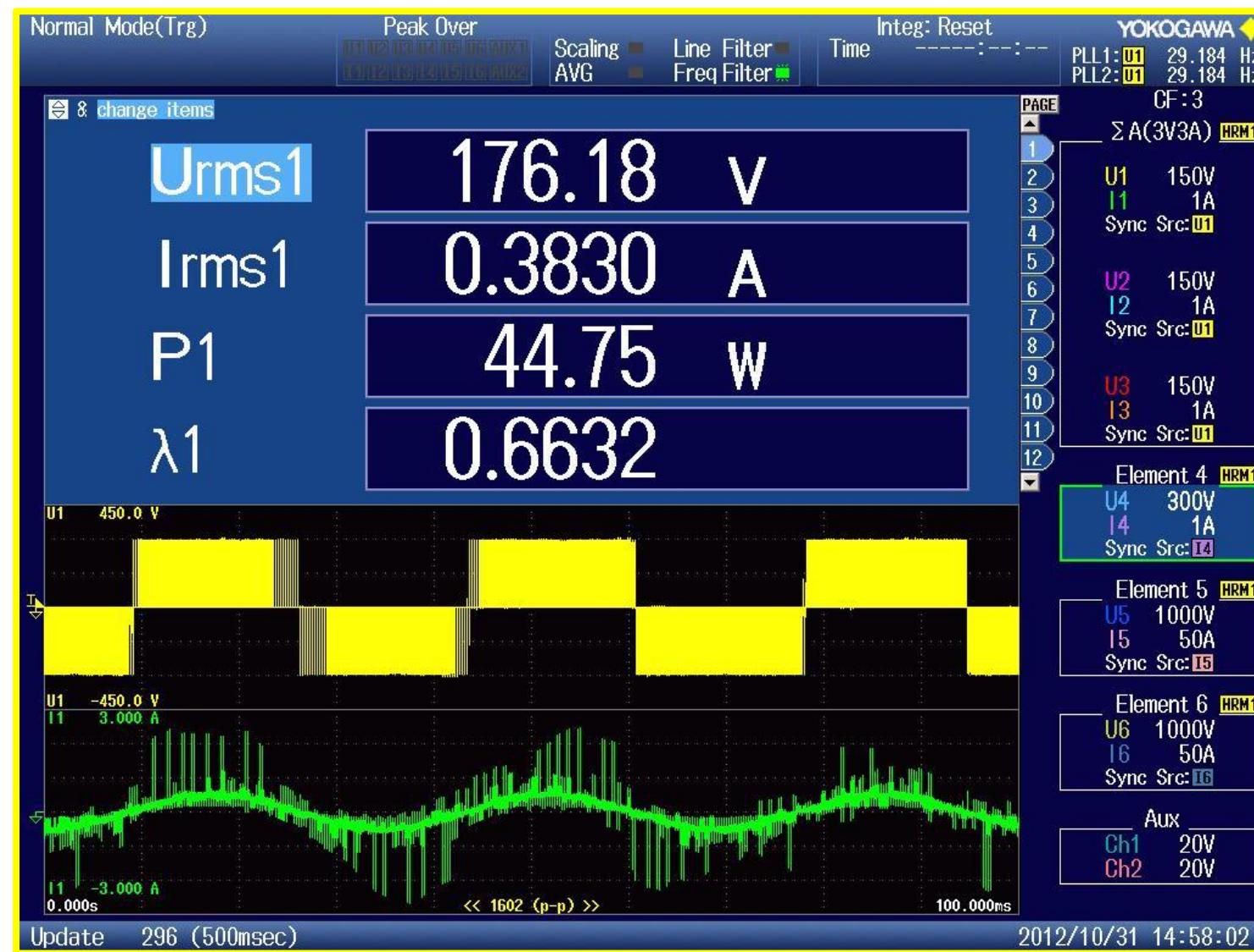
# Power Supply Input with DSO



# Power Supply Input Summary

Measurement Comparison		
Measurement Item	Power Analyzer	Power DSO
Voltage RMS	<b>118.28 V</b>	<b>117.27 V</b>
Current RMS	<b>1.3323 A</b>	<b>1.3321 A</b>
Watts	<b>97.54 W</b>	<b>96.49 W</b>
Power Factor	<b>0.619</b>	<b>0.617</b>

# PWM Inverter Output with Power Analyzer



# PWM Inverter Output with Power DSO



# PWM Inverter Output Summary

Measurement Comparison		
Measurement Item	Power Analyzer	Power DSO
Voltage RMS	176.18 V	178.56 V
Current RMS	0.3830 A	0.3950 A
Watts	44.75 W	46.37 W
Power Factor	0.6632	0.6602

# DSO Power Calculation

Calc

	Name	Expression	Unit
<input checked="" type="checkbox"/> Calc 1	S	RMS(C3)*RMS(C2)	VA
<input checked="" type="checkbox"/> Calc 2	P	(1/DeltaT(C3))*IntegTY(M1)	W
<input checked="" type="checkbox"/> Calc 3	Q	SQRT(P2(RMS(C3)*RMS(c2))-P2((1/Del	VAR
<input checked="" type="checkbox"/> Calc 4	PF	((1/DeltaT(C3))*IntegTY(M1))/(RMS(C3))	

# What You Will Need

## • Power Measurements with a DSO

- Oscilloscope
- Options – power analysis, probe power
- Probes
  - Differential Voltage Probe
  - Current probe
  - High Voltage Probe
- Other
  - Isolation line-transformer for non-isolated designs (safety).
  - Deskew Device



# **Yokogawa's Power Measuring Solutions**

- **Yokogawa offers the Most Complete Line of Power Measurement Products to meet the customers Application and Budget.**
- **Product, Application and Software support provided from a network of Field Sales Reps, Factory Regional Sales Managers and Factory Support Engineers.**
- **NIST Traceable Calibration provided by Factory Trained technicians in Newnan, GA.**

# Yokogawa's Power Measuring Solutions

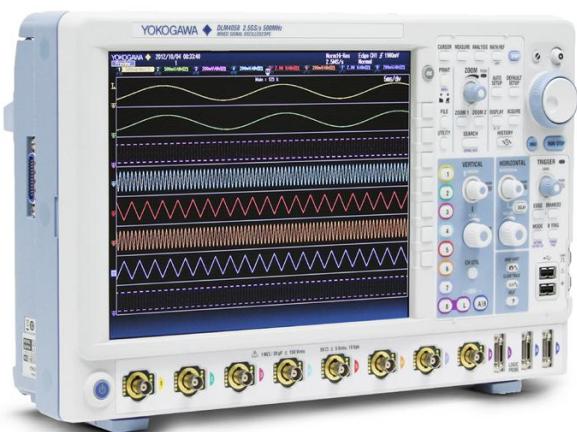
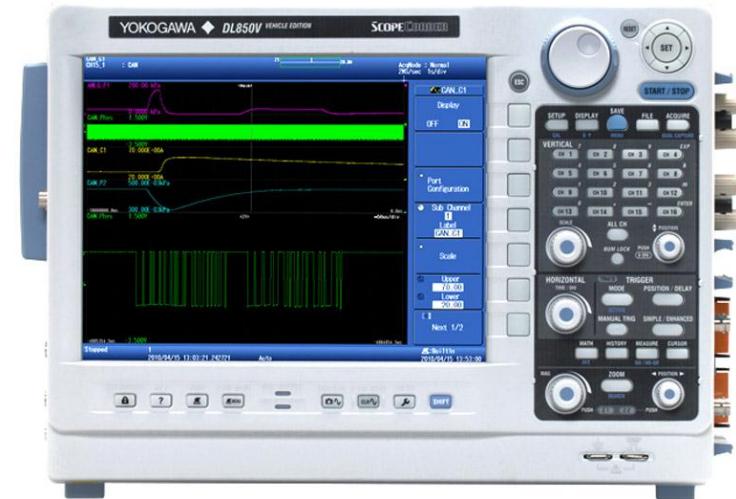


Precision Power  
Analyzers



# Yokogawa's Power Measuring Solutions

## Digital Oscilloscopes with Power Analysis



# Yokogawa's Power Measuring Solutions

## Portable Power Test Instruments



# Yokogawa's Power Measuring Solutions

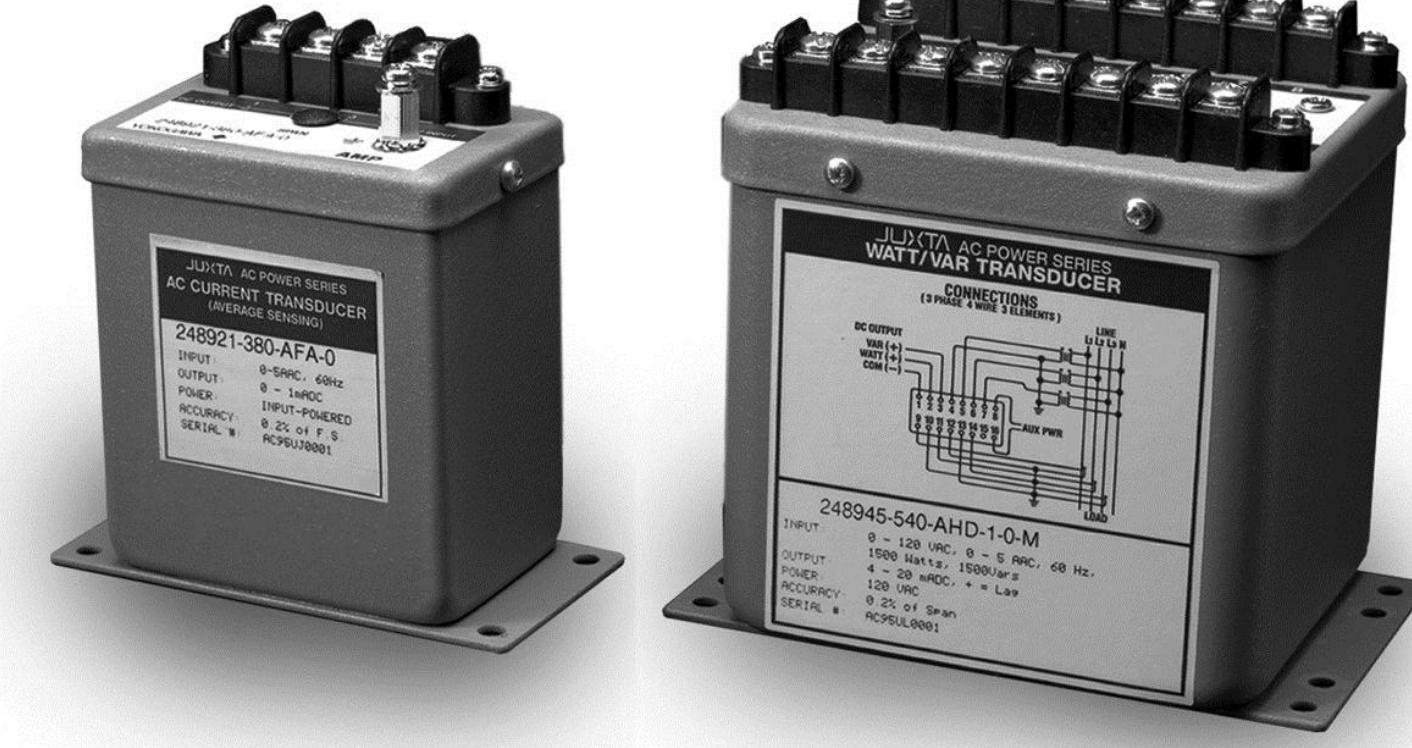


## Panel and Switchboard Analog Meters



# Yokogawa's Power Measuring Solutions

## Power Transducers



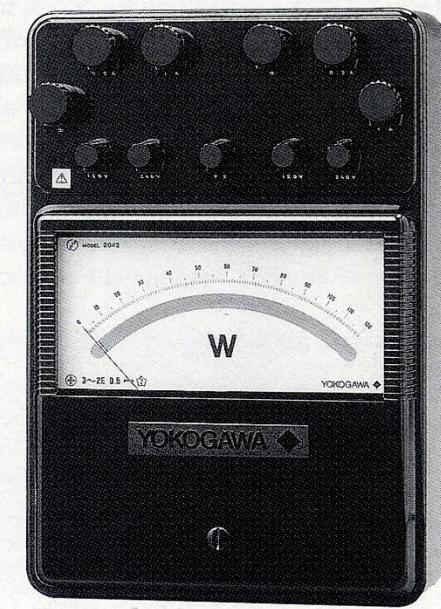
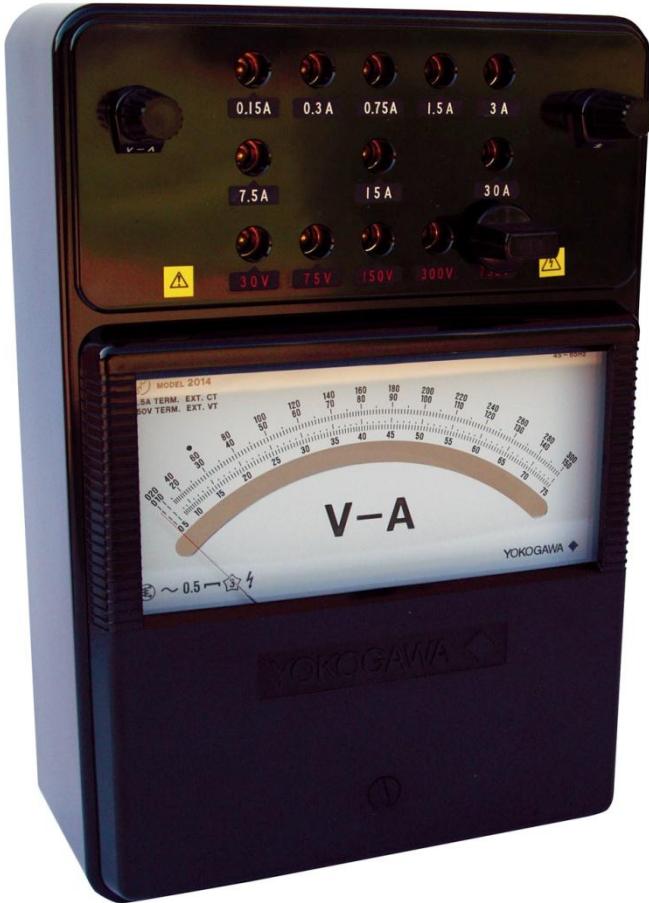
# Yokogawa's Power Measuring Solutions

## Multi Function Digital Meters



# Yokogawa's Power Measuring Solutions

## Portable Instruments



# Overview - What We Hope You Learned

- **Helped You With a Better Understanding of Electrical Power Measurements**
- **Review of Some of the Basics**
- **Power Measurements Using a Precision Power Analyzer and Digital Oscilloscope**
  - **Single-Phase Power Measurements**
  - **Current Sensors**
  - **Three-Phase Power Measurements**
  - **2 & 3 Wattmeter Method**

- **Part II: Power Factor Measurements**
  - **Displacement Power Factor**
  - **True Power Factor**
  - **Power Factor Measurements in Single-Phase & Three-Phase Circuits**
  - **Practical Power Factor Measurement Applications**

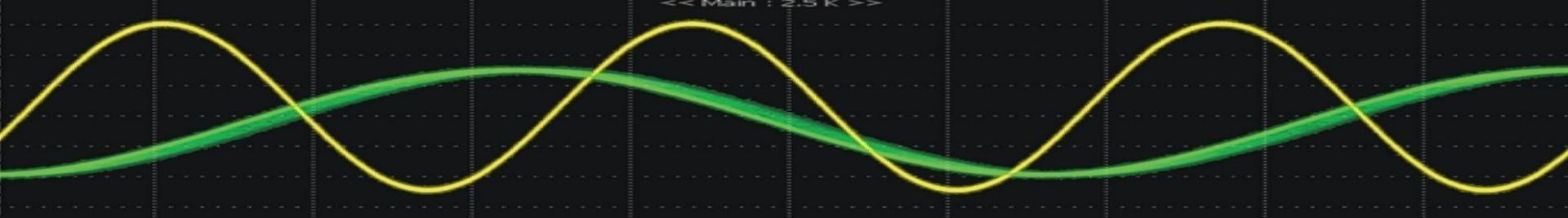
# Overview - What We Hope You Learned

## ➤ Part III: Power Measurements using a Digital Oscilloscope

- How to properly use a Digital Oscilloscope to make Electrical Power Measurements
- De Skew Operation
- Measurement Examples on a Power Supply Input and a PWM Inverter Output
- Measurement Comparison between the DSO and a Power Analyzer

## ➤ Answer your questions concerning Electrical Power Measurements

***Thank You  
For  
Attending***



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