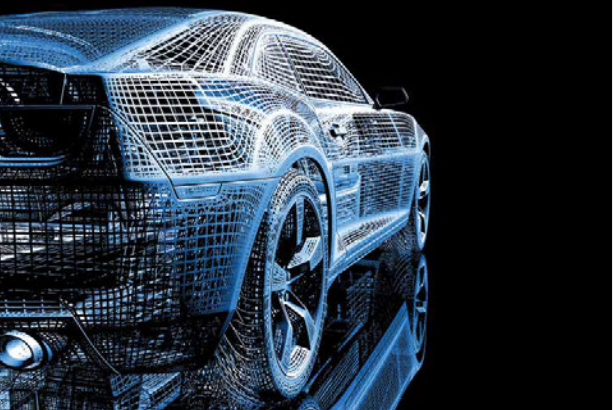




# High Current Measurement Application Guide



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# Introduction

Designing an instrumentation system for high current measurement requires careful consideration of the trade-offs associated with each type of sensing device. The purpose of this guide is to help engineers understand the sensing choices available and the corresponding trade-offs with each technology.

## What is Electrical Current?

Electricity is the movement of negatively charged electrons in a conductor from a region of high electron density to a region of low electron density. The difference in electric potential between these regions is known as Voltage (measured in Volts). It provides the electromotive force to move electrons. The rate of charge flow carried by these electrons per second is what we know as electric current – measured in Amperes while the opposition to this current flow is known as resistance, measured in Ohms.

Electric current is by convention said to flow from a region of high electric potential to a region of low electric potential i.e. opposite to the direction of electron flow.

## Measuring Current

As shown in figure 1; current measurement is a series measurement of electron flow. There are currently 2 ways to make this measurement with a current sensor:

- Direct measurement by passing the current directly through a sensing device itself (shunt type measurement)
- Indirect measurement by passing a current carrying conductor through the aperture of a current sensing devices (clamp, current transformer).

This application guide is focused on indirect technologies as they apply to the measurement of measurement of electrical power. The devices in this application guide are targeted toward the measurement of the inputs and outputs of electromechanical systems such as grid-tied inverters, variable speed motor drives, motors, chargers, generators, appliances and transformers. The required bandwidth of such systems is typically below 1MHz; if higher bandwidths are required please see Yokogawa's offering of high bandwidth oscilloscope probes.

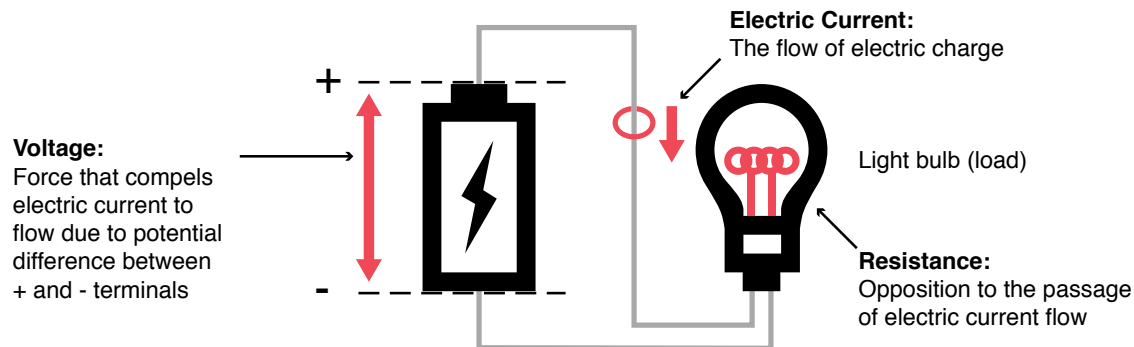


Figure 1 - Basic components of electrical circuit

# Key Specifications

The use of a current clamp or current transformer greatly simplifies measuring high currents (>50A) where physical constraints (conductor sizes, insertion losses, safety) make a direct measurement through the precision internal shunt of a power analyzer, DMM, or external shunt into a data acquisition impractical. This convenience comes with a cost, and system designers must educate themselves on these trade-offs in order to make the best practical engineering decision. The following key specifications for each device must be considered when selecting a current measurement device for your design.

## Key System Design Specifications:

- Define the purpose of the measurement
- Budget constraint
- Physical constraint
- Accuracy
- Frequency response
- Phase shift
- Maximum current to be measured (Peak/RMS)
- Minimum current to be measured (Peak/RMS)
- Output signal (voltage/current)

Once the specifications for the measurement system have been defined, the sensor technology that can be used for current measurement will be determined. Perhaps the most important specification to consider is the purpose of the measurement; this will often set the rest of the specifications.

For example, if a high current measurement is needed for the purpose of benchmarking power, energy consumption, and efficiency, then the accuracy specification will drive the appropriate technology.

Likewise, if a high current measurement is needed for the purpose of getting a general idea of current consumption, waveform shape, and event capture, then a different technology would likely be appropriate.

Performance vs Technology									
	High Accuracy	Simple Installation	AC Current	DC Current	High Frequency	Low Phase Shift	Low Cost	Wide Measurement Range	Voltage Output*
Hall-effect clamp		X	X	X			X		X
Rogowski Coil		X	X		X		X		X
AC Transformer Clamp		X	X				X		X
AC Transformer	X		X		X	X			
Fluxgate Transformer	X		X	X	X	X		X	

\*All other technologies are current output

# Choosing a Sensor

Indirect current measurement relies upon sensing the magnetic field generated by a current carrying conductor. Sensing this field can be done with a variety of technologies such as AC current transformers, Hall-effect sensors, Rogowski coils, and fluxgate sensors. Each one of these technologies will have associated trade-offs to be compared with the system design specifications in order to make the appropriate choice.

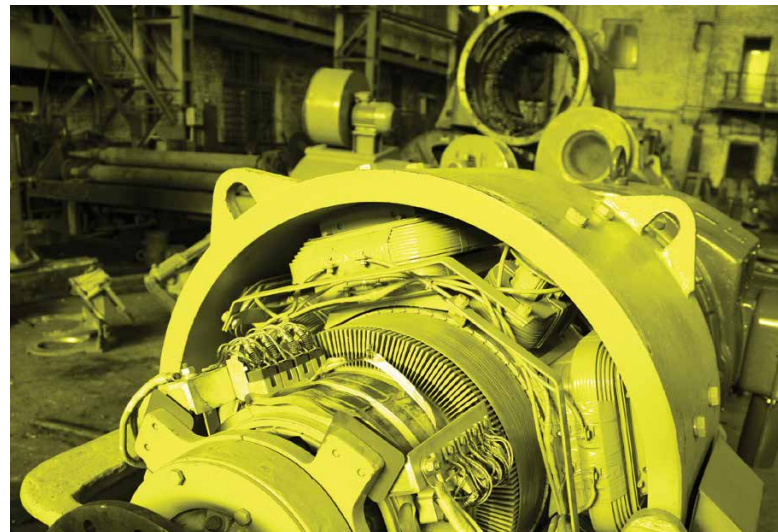
Below are some general selection guidelines by technology and application:

## Closed Aperture vs Clamp

- A “donut” style or “fully closed aperture” current transformer design will generally perform better than an “open clamp” or “split core” type solution. This is due to the split core’s lack of symmetry and necessary discontinuity of the magnetic core and associated windings. A split core makes the closed loop zero flux design impossible to construct, especially if multiple cores and windings are needed for accuracy (e.g. fluxgate sensing with closed loop compensation).

## AC Transformers

- Purely AC current transformers are typically used in line power or constant frequency applications where the voltage waveform is of a static frequency and DC components or transient phenomena are not of concern. Many current transformer manufacturers target power line frequencies specifically (50/60Hz, 400Hz) and therefore the performance specifications around those frequencies are generally acceptable (error  $\leq 1\%$ ). These come in clamp or donut style designs.



## Rogowski Coils

- Rogowski coils are typically used when convenience is the deciding factor, obtaining a general wave shape for an AC or pulsed signal is desired, and accuracy is not of utmost importance. Rogowski coils are very sensitive to conductor position; this error alone can contribute up to 2% of total error excluding other sources (error  $>1\%$ ).

## Hall-effect AC/DC Clamp

- Hall-effect current clamps are typically used when convenience is important, obtaining a general wave shape for any type of AC or DC signal is desired, and high accuracy is not a concern (error  $\Rightarrow 1\%$ ).

## Fluxgate Closed Loop

- Fluxgate based, closed loop zero flux current transformer designs benefit from the combination of sensing technologies (fluxgate sensor, AC transformer, zero flux compensation). They are capable of making measurements on very complex AC/DC waveforms. This design will generally provide the best linearity, accuracy, stability, and frequency response. These devices are typically used for benchmarking power measurements where switching waveforms are present (inverters) and errors must be minimal across a wide operating bandwidth (error  $\leq 1\%$ ).

# Sensor Technologies

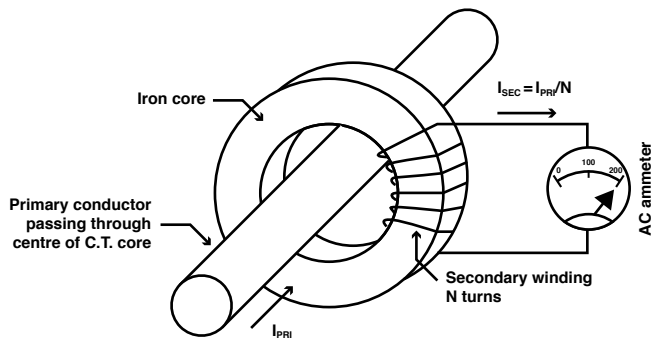


Figure 2 - AC current transformer

## AC Current Transformers

AC current transformers rely upon Faraday's law which states that an electromotive force is generated in a coil when it is placed in a time-varying electromagnetic field. The operation of a current transformer is similar to that of a voltage transformer, the secondary output current is proportional to the turn ratio. In some cases, the current transformer can be a direct (series) measurement or an indirect measurement (through CT opening). Because they require a changing magnetic field, they cannot be used for DC measurements. Like voltage transformers, these sensing devices are passive and do not require excitation, consisting of wire wrapped around a magnetic core.

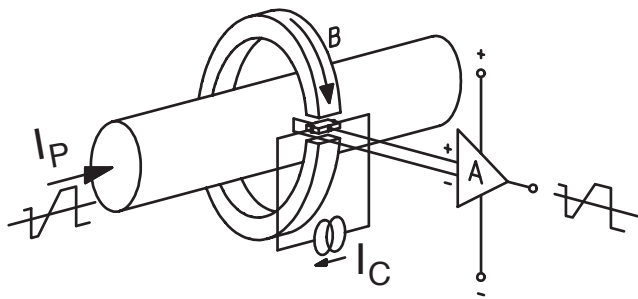


Figure 3 - Hall-effect sensor

## Hall-effect Sensors

The Hall-effect utilizes a conductive sensing material carrying a current and placed perpendicular to a magnetic field. The magnetic field produces a Lorentz force, pushing the charge carriers to one side of the material. The resulting voltage difference across the material is proportional to the flow of the current generating the magnetic field. In a current sensor, the magnetic field is generated by the primary conductor that is oriented 90 degrees from a Hall sensor placed inside an airgap in the iron core. The gap in the core concentrates the magnetic field around the sensor. The resulting differential voltage across the sensing material is then amplified and conditioned to an appropriate output signal (voltage or current). The Hall-effect principle applies for both AC and DC signals. Hall-effect current clamps usually have mV/A or mA/A output signal and may have a range switch.

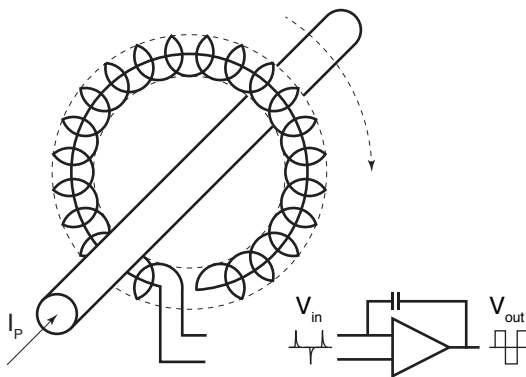


Figure 4 - Rogowski coils

## Rogowski Coils

Rogowski coils consist of a helical coil of wire with a center return lead wrapped around a straight primary conductor. The change in current (derivative) through the primary conductor induces a proportional voltage in the coil. This voltage is then integrated via signal conditioning electronics to produce a voltage that is proportional to the primary current. This is why Rogowski coils require a continuously changing (AC) or pulsed current in order to produce an output. The coils typically have an air core (no solid core) and therefore are flexible; also the coil wiring (center return lead) means the construction is typically a flexible loop with an open end.

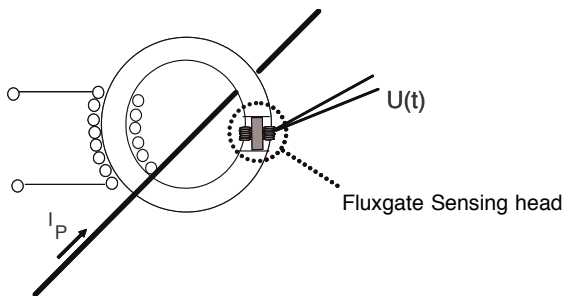


Figure 5 - Fluxgate sensor

## Fluxgate Sensors

Fluxgate sensors are a saturable inductor constructed of a magnetic core and wound coil. The sensor is excited by a periodic square wave signal, sweeping the inductor across the B-H curve in and out of saturation resulting in a symmetric current waveform. When an external magnetic field is introduced (primary current through an aperture of the CT) the flux density is changed and the current waveform becomes asymmetric due to the change in time to reach saturation. This asymmetry can be measured via a change in duty cycle or via harmonic analysis, producing a linear output with respect to the primary current. Fluxgate sensors are capable of sensing both AC and DC currents and typically offer greater stability, resolution and accuracy when compared to Hall sensors. Similar to a Hall clamp, a fluxgate sensor can be placed inside an airgap or can be constructed out of a second magnetic core placed inside of the current transformer itself.

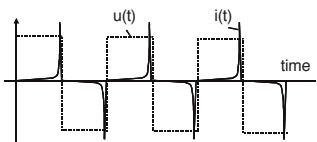


Figure 6 - Fluxgate sensor no primary current

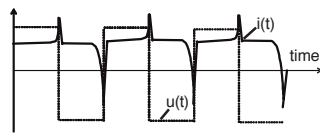


Figure 7 - Fluxgate sensor with primary current

## Errors

All of these technologies will have measurement error attributed to factors such as linearity, offset, temperature and noise.

- Errors in AC current transformers can be a function of manufacturing quality or residual flux.
- Hall-effect sensors are vulnerable to errors arising from the necessity of sensing and amplifying very small voltages and the properties of the Hall sensing material (offset, temperature drift, noise).
- Rogowski coils are prone to positioning, droop/offset, and phase delay errors.
- Linearity error is a concern for any type of sensor, and is a function of the technology, construction, and temperature characteristics.
- Fluxgate sensors provide more robust measurement due to a time-based measurement (duty or spectral analysis), low magnetic offsets due to the cyclic excitation, and a low temperature drift.

## Zero Flux Technique

Linearity errors can be compensated by operating the sensing technology in a “zero flux” condition where the magnetic field being measured by the sensor is essentially zero. This is accomplished through the use of a compensation winding inside of the current transformer that generates an equal yet opposing magnetic field to that of the primary field. This winding is driven in a closed loop circuit formed by the sensor (fluxgate or Hall) and associated amplification circuitry as shown in figure 8. This allows the sensor to essentially operate around a zero sensing condition (a single point), minimizing any gain errors. Offset errors can further be eliminated by applying a zero offset or a “nulling function” in the sensing instrument that the current transformer is connected to (data acquisition, oscilloscope, or power analyzer).

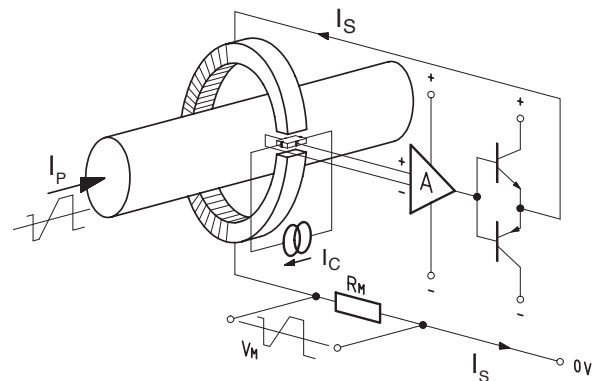


Figure 8 - Closed loop Hall-effect zero flux CT

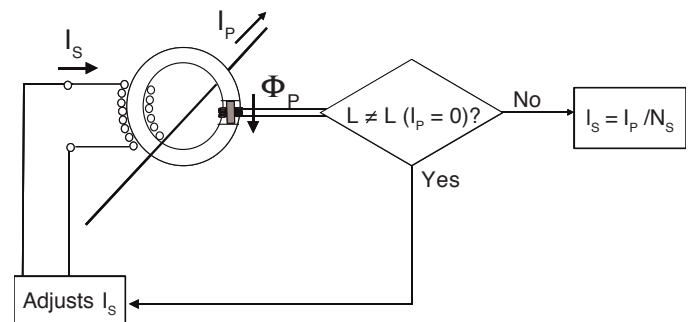


Figure 9 - Closed loop fluxgate zero flux CT





## Frequency Response

Current sensing technology and its associated electronics will always have limited bandwidth; however, an additional advantage to the closed loop zero flux configuration is at higher frequencies the compensation winding acts as an AC current transformer. This significantly extends the bandwidth and reducing the response time of the transducer. This means that a zero flux (closed loop) current transformer design essentially incorporates multiple current sensing techniques, the AC current transformer technology as well as Hall-effect or fluxgate technologies. Thus zero flux designs can be capable of measuring AC, DC and complex waveforms of any shape.

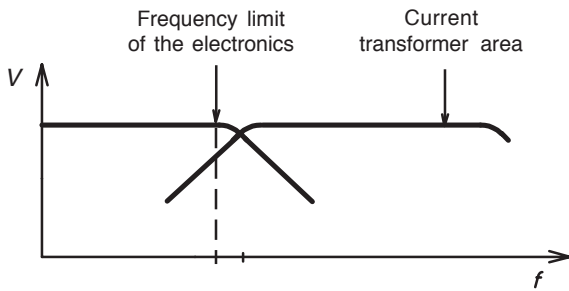


Figure 10 - Frequency response of closed loop design

## Output

Another advantage of the closed loop design is that the output signal is current based, providing a more robust signal in high noise environments. It is also the preferred signal for power analyzers which can directly measure current with high accuracy.

When dealing with any current transformer the output is considered a constant current source. This means as current flows through the primary conductor, the secondary must never be left as an open circuit. An open circuit produces an essentially infinite resistance, by Ohm's law  $V = I \cdot R$ , resulting a very high voltage that will damage the current transformer and present a significant safety hazard. Therefore, systems should be designed with caution so that the current transformer cannot be disconnected while performing a measurement.

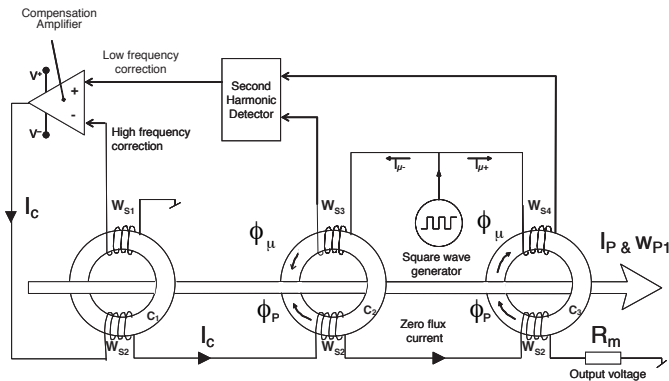


Figure 11 - Multi-core closed loop fluxgate design

# Product Selection

Once the system design specifications have been established, and the key trade-offs of each technology is understood, a product can be selected. The following pages highlight Yokogawa current measurement products and technologies for use with test and measurement equipment including Power Analyzers, Power Scopes, Oscilloscopes and ScopeCorders.

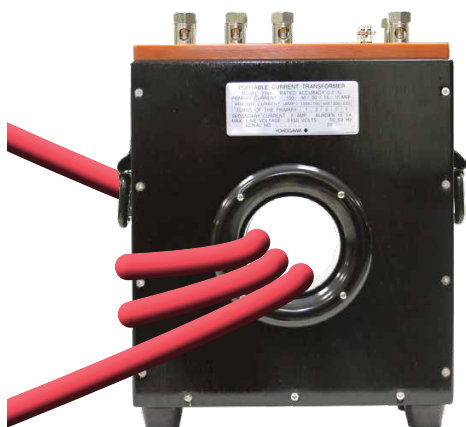


## AC Current Transformers

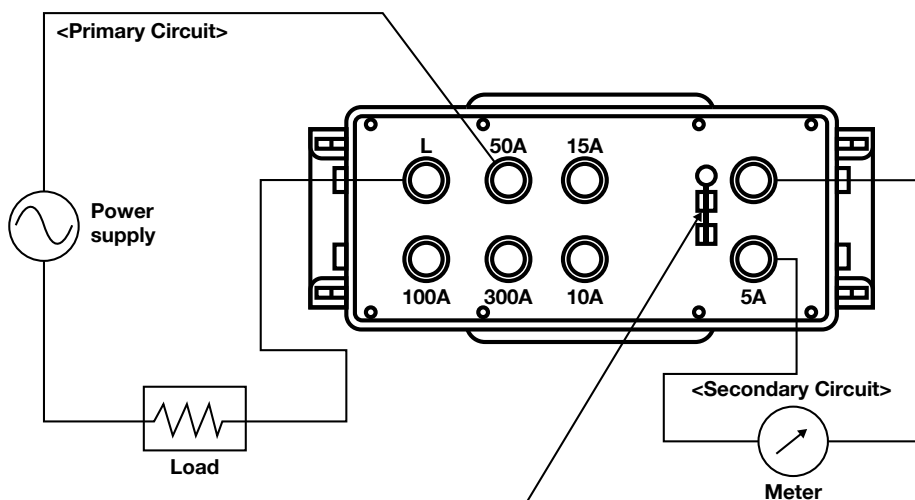
**Ideal For:** High voltage, high current 50/60HZ AC systems

The Yokogawa 2241 and 2242 AC transformers serve to convert a very wide range of AC currents to levels that are suitable for measurement while offering isolation from the instrument. These transformers are capable of handling very large currents from high power systems, however have multiple taps offering measurement ranges from 1500A to 10A (taps located on top of the CT). Currents less than 100A are wired in series, while larger currents are passed through the aperture.

Yokogawa AC Current Transformers		
Model	2241	2242
Primary Current Rating	10/15/30/50/100/250/ 300/500/750/1500A	10/15/30/50/100/250/ 300/500/750/1500A
Secondary Current Rating	5A	5A
Rated Burden	15VA	15VA
Relative Error	0.2% (50/60Hz) 0.7% (3kHz)	0.2% (50/60Hz) 0.7% (3kHz)
Max Phase Displacement	± 10 minutes	± 10 minutes
Max Line Voltage	3450V	6900V
Frequency Response	50/60Hz (rated) 3kHz (reference)	50/60Hz (rated) 3kHz (reference)
Dimensions	12.5"x9.75"x5"	13.75"x10.5"x6"
Weight	19.8lbs	23.4lbs



Example of wiring connection for 50A input as primary current



**Knife switch**  
**Short:** If the secondary circuit is open, it must be shorted.  
**Open:** It should be opened at measurement.

## AC Current Clamps

**Ideal For:** Taking convenient AC measurements

AC transformer clamps are a convenient option for taking AC current measurements. Voltage and current output options are available for connections to oscilloscopes, data acquisition, or power analyzers when a portable waveform capture or an approximate power measurement is needed.



Yokogawa AC Current Clamps

Model	SR651	SR661	SR701	JM813
<b>Measurement Range</b>	0.1 to 1000A	0.1 to 1200A (12/120/1200A)	1mA to 1000A	1 to 3000A
<b>Output Signal</b>	Voltage	Voltage	Current	Current
<b>Transformation Ratio</b>	1mV/A (1V@1000A)	(3 ranges) 100mV/A: 0.1A to 12A 10mV/A: 0.1A to 120A 1mV/A: 1A to 1200A	1000:1 1mA/A (1A@1000A)	3000:3 1mA/A (3A@3000A)
<b>Accuracy (% of reading)*</b>	0.75% (200A), 0.5% (1000A)	3% / 2% / 1%	3%(1mA), 0.5%(10A), 0.3%(1000A)	1.5% (150A) to 0.5% (3000A)
<b>Phase Shift*</b>	0.75° (200A) to 0.5° (1000A)	15° / 5° / 1°	2° (1A) to 0.7° (1000A)	1.5° (150A) to 0.5° (3000A)
<b>Frequency Range</b>	30Hz to 5kHz	1Hz to 100kHz	30Hz to 5kHz	30Hz to 5kHz
<b>Load Impedance</b>	100kΩ min	1MΩ @ 47 pF (oscilloscope)	5Ω max	≤0.6Ω
<b>Common Mode Voltage</b>	600 V Cat. III	600 V Cat. III	600 V Cat. III	600 V Cat. III
<b>Output Connection</b>	Banana Jack	6.5ft BNC	Banana Jack	Banana Jack

\* Rated at 45-65Hz. Frequency deratings apply, see mfg user manual for full set of specifications.

## AC/DC Hall-effect Current Clamps

**Ideal For:** AC/DC waveform capture and basic measurement

Hall-effect clamps are a convenient option for making both AC and DC current measurements. These units provide a voltage output for connections to oscilloscopes or data acquisition and provide a quick and portable means for capturing complex waveforms and making approximate AC/DC measurements where accuracies >1% are acceptable.



Hall-effect Clamps				
Model	SL261	MH60	MR410	CPC - xxxx
Measurement Range	0.05 to 100A(DC) 0.035 to 70A(AC) (10A/100ADC)	0.5 to 100A (AC/DC) (hall/transformer)	1 to 600A(DC) 1 to 400A(AC)	(AC/DC) 1 to 250A 1 to 500A 1 to 1100A 1 to 2200A
Output Signal	(2 ranges) 10ADC (7AAC): 100mV/A 100ADC (70AAC): 10mV/A	10mV/A	600ADC (400AAC): 1mV/A	8mV/A 4mV/A 2mV/A 1mV/A
Accuracy (% of reading)*	3%±50mA (10ADC), 12%±50mA (40ADC), 15% (100ADC)	1.5%±0.1mV (64A), 4%±1A (90A), 5% (100A) **	1.5%±1A (100ADC), 2% (400ADC), 2.5% (600ADC)	1% (full scale)
Phase Shift*	1.5° (7AAC) 1° (70AAC)	1°	2.5° (200AAC) 2° (400AAC)	1°
Frequency Range	DC to 100kHz	DC to 1kHz (3kHz/30kHz ranges)	DC to 10kHz	DC to 75kHz
Load Impedance	>1MΩ/100pF	1MΩ/100pF	>100kΩ/100pF	10-15Ω/>1nF
Common Mode Voltage	600 V Cat. III	600 V Cat. II 300 V Cat. III	600 V Cat. III	NA
Power Source	9V battery (55hrs)	rechargeable battery (8 hrs) w/USB power	9V battery (100hrs)	USB powered
Output Connection	6.5ft BNC	6.5ft BNC (signal) μUSB type B (power)	5ft Banana	4.9ft BNC (signal) USB type A (power)

\* Rated at 45-65Hz (\*\*400Hz). Frequency deratings apply, see mfg user manual for full set of specifications.

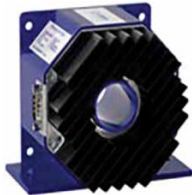
## Closed Loop Fluxgate Current Transformers

**Ideal For:** Benchmarking measurements with a power analyzer

Closed-loop compensated, fluxgate sensor based current transformers employ advanced technology for providing highly accurate measurements on AC and DC waveforms. These units have a current output that is ideal for noise immunity and interface to the direct current inputs of a power analyzer. Precise high current measurements can be made on complex current waveforms often encountered in switching power electronic systems such as inverter-based motor drives and power conversion systems.



IT-60,200,400,700-S



IT-1000-S



IN 1000-S



IN 2000-S

Closed Loop Fluxgate Transformers								
Model	IT 60-S	IT 200-S	IT 400-S	IT 700-S	IT 1000-S	IN 1000-S	IN 2000-S	ITZ 5000-S
<b>Measurement Range</b>	0-60Apk 0-42Arms	0-200Apk 0-141Arms	0-400Apk 0-282Arms	0-700Apk 0-495Arms	0-1000Apk 0-707Arms	0-1500Apk 0-1000Arms	0-3000Apk 0-2000Arms	0-5000Apk 0-3535Arms
<b>Transformation Ratio</b>	600:1 100mApk 707mA Arms	1000:1 200mApk 141mA Arms	2000:1 200mApk 141mA Arms	1750:1 400mApk 283mA Arms	1050:1 1Apk 707mA Arms	1500:1 1Apk 667mA Arms	2000:1 1.5Apk 1Arms	2500:1 2Apk 1.41Arms
<b>Accuracy (% of reading)*</b>	0.05% + 30µA to 100kHz	0.05% + 30µA to 30kHz	0.05%*	0.05%*	0.05% + 30µA to 4kHz	0.05%*	0.05% + 30µA to 40kHz	0.02%* (full scale)
<b>Phase Shift*</b>	<1° to 100kHz	<1° to 100kHz	<1°*	<1°*	<1° to 10kHz	<1°*	<1° to 5kHz	<1°*
<b>Frequency Range</b>	DC to 800kHz	DC to 500kHz	DC to 500kHz*	DC to 500kHz*	DC to 300kHz	DC to 230kHz*	DC to 40kHz	DC to 80kHz*
<b>Common Mode Voltage</b>	2350V Cat. III**	2350V Cat. III**	2350V Cat. III**	1950V Cat. III**	650V Cat. III**	1000V Cat. III** (4200V)	1000V Cat. III (6000V)	4000V Cat. III
<b>Power Source</b>	IST Ultrastab (6ch) or /PD2 (4-6ch)	IST Ultrastab (6ch) or /PD2 (4-6ch)	IST Ultrastab (6ch) or /PD2 (4-6ch)	IST Ultrastab (6ch) or /PD2 (4-6ch)	IST Ultrastab (6ch) or /PD2 (4-6ch)	IST Ultrastab (6ch) or /PD2 (4-6ch)	IST Ultrastab (6ch) or /PD2 (4-6ch)	ITZ Ultrastab (1ch)
<b>Output Connection</b>	Banana Jack (IST) A1628WL (PD2)	Banana Jack (IST) A1628WL (PD2)	Banana Jack (IST) A1628WL (PD2)	Banana Jack (IST) A1628WL (PD2)	Banana Jack (IST) A1589WL (PD2)	Banana Jack (IST) A1628WL (PD2)	Banana Jack (IST) A1628WL (PD2)	Banana Jack (ITZ)
<b>Aperture Size</b>	26mm	26mm	26mm	30mm	30mm	38mm	70mm	140mm

\* Not all models have been fully characterized by Yokogawa. Range and error information can also be obtained from OEM

\*\* HAR07 Cable

# High Current Power Measurement Configuratoin Examples

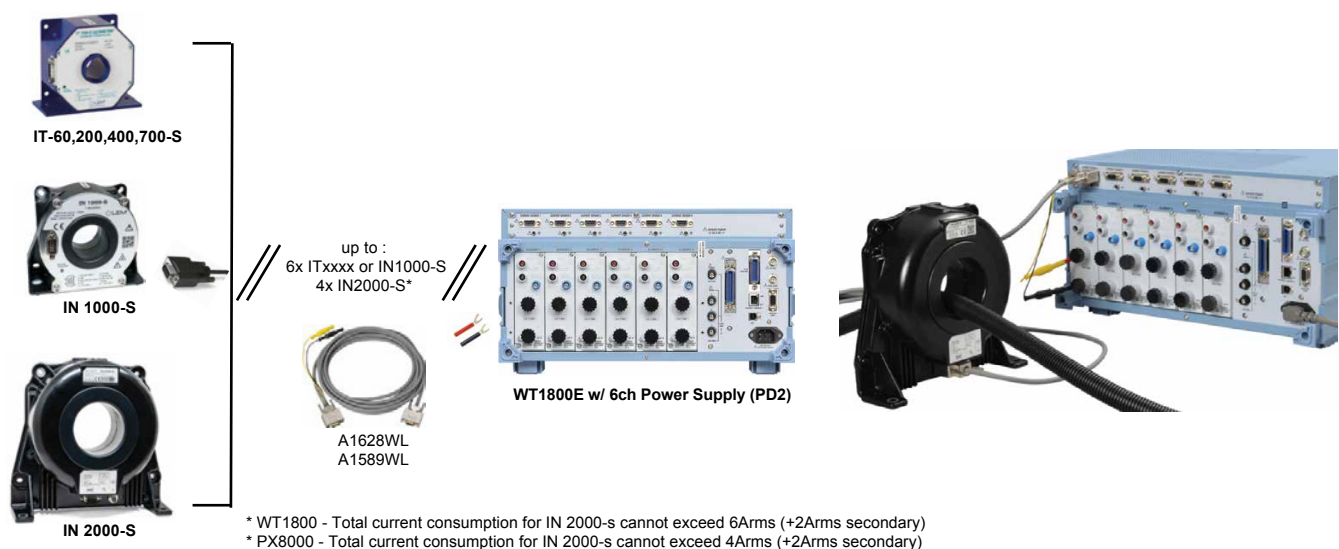


Figure 12 - Power analyzer with built-in power supply

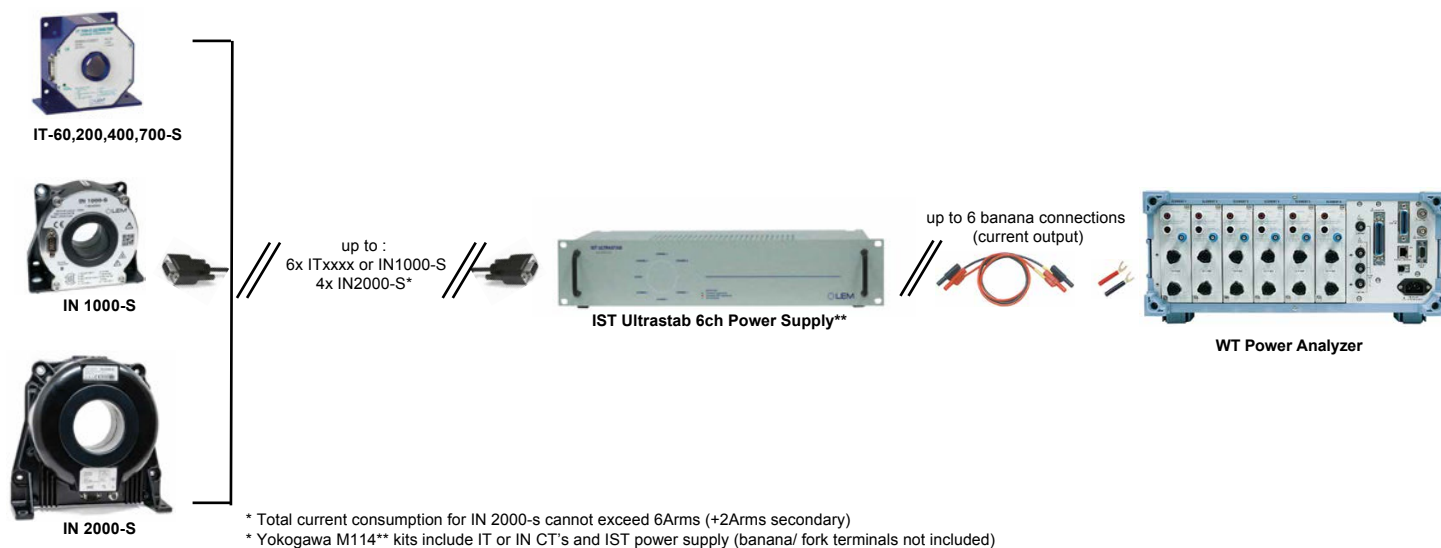


Figure 13 - Power analyzer with external power supply kit

# Integration Considerations

Once a current sensing product has been selected, integration of the device into the measurement system must be carefully engineered. The output signal types, accuracy, measurement range and interconnections must all be evaluated appropriately.



## Example Use Cases

### Case 1

A manufacturer of UPS systems is engineering an instrumentation system to monitor and make measurements on 6 phases of AC voltage, current, power and one DC phase (480Vrms, 75Arms). Power and harmonic monitoring is important, however capturing distorted waveshapes during changeover events is critical. The instrumentation system is data acquisition based and must have the ability to easily move to different installations.

In this case, the engineer has selected a Hall based clamp style sensor. The Hall-effect is valid for any type of waveshape (AC/DC); data acquisition systems typically take voltage type signals, ease of installation is of concern, accuracy is not critical. Data acquisition systems are not typically highly accurate when making power measurements, so it makes little sense to select a highly accurate current device.

### Engineering Considerations:

- The output voltages from Hall-effect clamps are often in mV/A, where the maximum output voltage is less than 1V. The data acquisition system should have a comparable full-scale input range, e.g. utilizing a 10V input range would result in poor resolution measurement. The proper scaling for the instrument must also be considered when using clamps that have multiple range switches (400A/40A); changing range on the clamp requires a range change on the instrument.
- Hall-effect clamps must be powered, usually this is supplied by a small 9V or AA batteries, USB power, or a wall style AC to DC plug.
- Many Hall-effect clamps have a BNC style interconnection, the data acquisition system should have the same or an adapter may be needed if banana jacks are used.
- Hall-effects are prone to offset drift; and because of this the nulling (zero offset) function of the probe itself and/or the data acquisition should be used before making critical measurements.

Figure 14 is an example of a system configuration using Yokogawa Instrumentation.



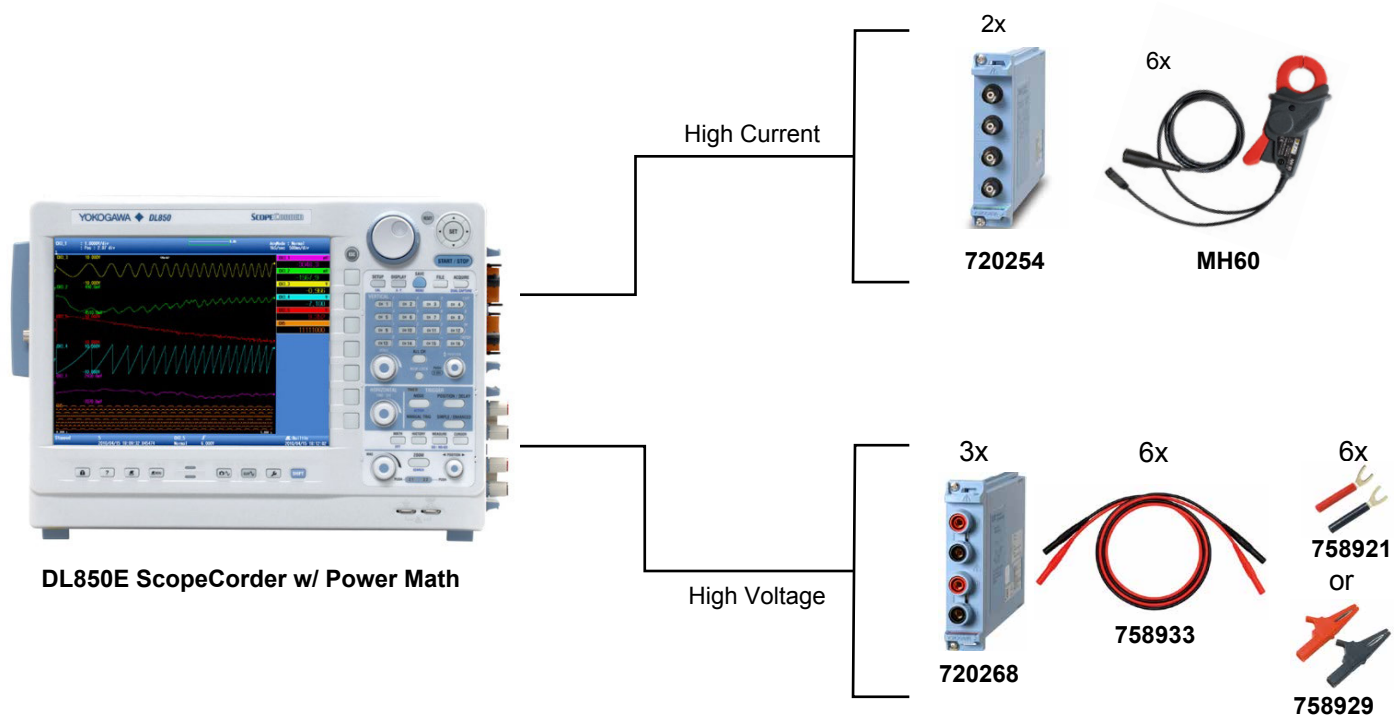


Figure 14 - 6-phase high power monitoring system

Yokogawa DL850E ScopeCorder with Real-Time Power		
QTY	Part Number	Description
1	DL850E-D-HE/M1/HD1/G2/G5	DL850E ScopeCorder Chassis with power math
3	720268 1MS/s 16bit 2ch analog input module	High voltage module, isolation to 1000Vrms, 3 modules for 6 phases of voltage
2	720254 1MS/s 16bit 4ch analog input module	4 channel module 16bit resolution to handle 6 phases of current clamps
6	MH60 current probe 100 AC/DC	Hall-effect current clamps with rechargeable battery, BNC connection
6	758933 measurement lead set	Connects to 720286 for voltage measurement, 1000V
6	758929 large alligator clip leads	Connects to 758933 for voltage measurement, 1000V (alligator clip)
6	758921 fork terminal adapter	Connects to 758933, for voltage measurement, 1000V (screw terminal)

### Case 2

A manufacturer of inverter based motor drives is engineering an instrumentation system for benchmarking power measurements on 3 phases of PWM based AC voltage, current, power and one DC input phase (800Vrms, 1100Arms). Waveforms are of interest; however, capturing the most accurate power measurements is most critical as the efficiencies of new inverter designs are over 90%. The instrumentation system is power analyzer based and must provide highly accurate power, energy, and harmonic measurements.

In this case, the engineer has selected a fluxgate based zero flux current transformer. The fluxgate is valid for any type of waveshape (AC/DC) and will provide the highest accuracy solution for PWM application requiring high bandwidths. Power analyzers are highly accurate devices, and therefore the most precise current measurement is required to keep errors to a minimum. A low accuracy clamp or fixed frequency current measurement device would not be a good selection.

### Engineering Considerations:

- This is a “donut style” design, therefore the primary cable must be able to pass through the center aperture (check diameter). In some cases a bus bar or smaller cable with smaller diameter insulation may be needed.
- This is a powered device and requires a power supply with the appropriate voltage and current capacities and a location for mounting (rack).
- Combining the fluxgate AC current transformer technologies in a closed loop method; there is always a constant current output on the secondary when the primary has current flow. The current transformer cannot be disconnected when a measurement is being performed. Appropriate labels or design considerations should be made for safety and to avoid damage to the device.
- The closed loop sensor will provide a current based output which is less susceptible to noise. Also, this is the preferred signal type for high bandwidth power analyzer which employs a unique shunt design that has the proper impedance, drift, and conditioning electronics for precision current measurement.
- The full scale output of the secondary current must be sized appropriately in relation to the power analyzer. For example, a 2000:1 ratio for a 280Arms transformer will result in a 140mA full scale output. The power analyzer should have comparable low current measurement ranges. A power analyzer with a 40A input and a 500mA minimum full scale range would be far too large. A better choice would be a power analyzer with a 5A range and a 5mA minimum full scale range.
- While closed loop sensor designs are less prone to offset drift, the nulling (zero offset) function of the power analyzer can be used to further reduce offset error.

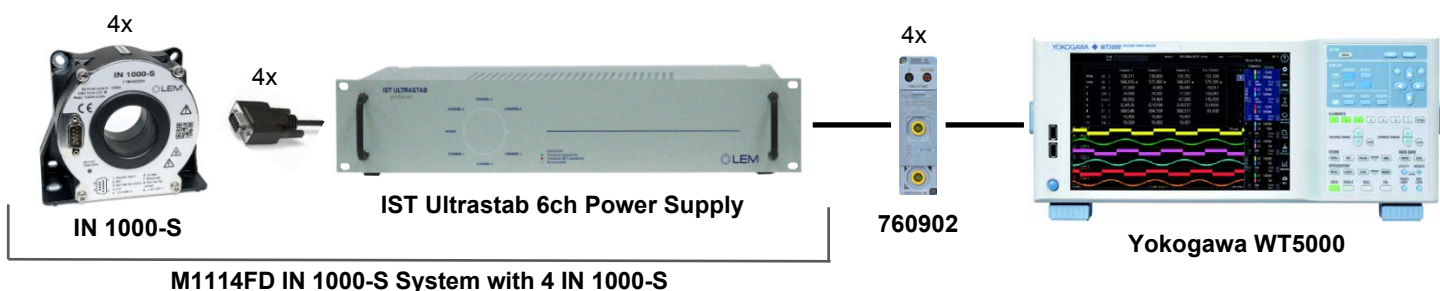


Figure 15 - WT5000 example configuration

Yokogawa WT5000 Power Analysis System		
QTY	Part Number	Description
1	WT5000/MTR1/US-HE-D	High performance power analyzer chassis, motor option
4	760902 5A High accuracy element	4x 5A high accuracy input elements for WT5000 (voltage and current connectors included)
1	M1114FD IN 1000-S System with 4 IN 1000-S	4x 1000Arms high accuracy AC/DC current transformers, fluxgate, zero-flux design 0.6A output w/ rack mounted power supply



Figure 16 - WT1800E example configuration

Yokogawa WT1800E Power Analysis System		
QTY	Part Number	Description
1	WT1804E-5A4-50A0-HE-D/G6/PD2/MTR	Mid-range power analyzer, 4x 5A elements, integrated current transformer power, motor eval
4	90.N6.60.000.0 LEM IN-1000 Current Transducer	1000Arms high accuracy AC/DC current transformers, fluxgate, zero-flux design 0.6A output
4	A1628WL direct current input cable	Cable powering IN-1000's, and providing signal to WT1800E (plug into fork terminal )
4	758921 Fork Terminal Adapter	Connect to A1628WL and WT1800E binding post for current

**Cable Length Considerations**

When it is necessary to lengthen the cables of the IT or IN series current transformers, the voltage drop in power supply lines and total burden resistance seen by the transformer needs to be considered.

- The voltage drop across the power supply cables must be <%5 of the +15V lines.
- The total resistance seen by the secondary of the current transformer must be less than the transformers RM (burden resistance) specification. This is specified as curve of primary current vs resistance with multiple operating temperatures. It is important to consider the resistance of the entire signal length from transformer to power analyzer as well as the internal resistance of the power analyzer.

Example:

- IN 2000-s Current transformer
- WT5000 Power analyzer w/ 760902 5A element
- Maximum operating current 3000Apk

The specifications for the 5A 760902 WT5000 module state the internal resistance is 0.11Ω at >500mA and 0.5Ω at <200mA. The IN 2000-S specifications show the maximum burden resistance at 3000Apk is approximately 1 Ω @ 25C, with a transformation ratio of 2000:1 (NS), and an overhead current consumption of about 200mA (IC).

- Power supply cables must be sized to maintain <0.75V drop when operating at 3000Apk primary current or 1Apk of secondary current ~1.2Apk total supply current.
- At 2000Apk primary current (1Apk secondary) the total resistance of the signal cables from the current transformer to the power analyzer must be <0.89 Ω @ 25 (1Ω-0.11Ω).

Recommendations on wire types and shielding for the power supply cables are found in the IST power supply user manual. For long runs, twisting of the signal wires from the power supply to the power analyzer is recommended to reduce the influence of noise; however this will increase the total length of these wires.

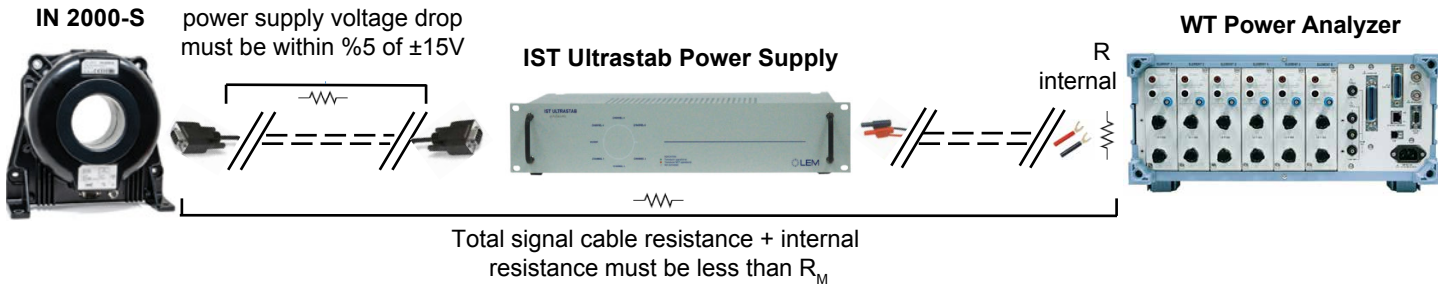


Figure 17 - Lengthening IN/IT transformer cables

<b>Input Impedence</b>	Voltage	10 MΩ ±1% // approx. 15 pF			
	Current	Direct Input: 0.5 Ω ±10% + approx. 0.3 μH (200 mA or lower) 0.11 Ω ±10% + approx. 0.3 μH (500 mA or higher)			
<b># of Secondary turns</b>	$N_s$		2000		
<b>Positive Current Consumption</b>	$+I_c$	mA	180	200	225
<b>Negative Current Consumption</b>	$-I_c$		80	89	100
					Add $I_s$ for total current consumption

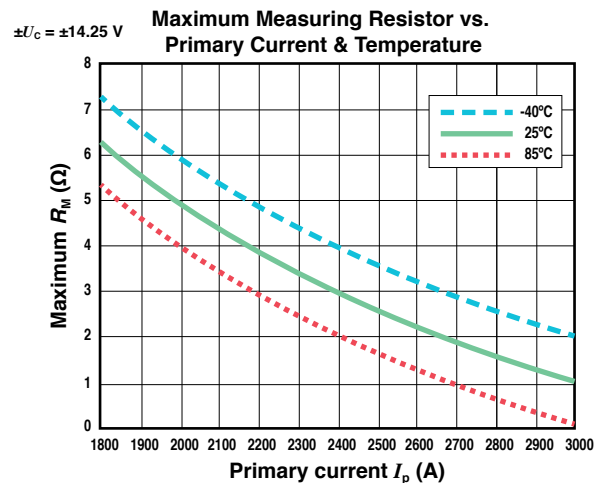


Figure 18 - WT5000 and IN 2000-S specifications

### Combining Uncertainty for Power Measurements

Power analyzer uncertainty is stated as % of reading + % of range error. Current transformers are often stated as a % of reading + offset. The following examples show methods for estimating the total uncertainty in a power analyzer and current transformer system.

#### Example (sum of errors, worst case):

Input conditions:	200V, 100A, power factor: 1, effective power: 20kW
Range settings:	300V/500A, (150kW effective range, internal current range 0.5A)
Current transformer rating:	200A, 1000:1 ratio (0.2A)
Power analyzer uncertainty:	0.05% of reading + 0.05% of range
Current transformer uncertainty:	0.05% of reading + 30 $\mu$ A(30 $\mu$ A@0.2A = 0.015% range)

Total power error can be estimated by:

$$\text{Power Error}_{\text{worst case}} = (\text{effective power} * \sum \text{reading error}) + (\text{effective range} * \sum \text{range error})$$

Where:

$$\sum \text{range error} = \% \text{ range power analyzer} + \% \text{ range current transformer}$$

$$\sum \text{reading error} = \% \text{ reading power analyzer} + \% \text{ reading current transformer}$$

Reading Error = 20kW \* (0.05% + 0.05%) = 0.02kW  
 Range Error = 150kW \* (0.05% + 0.015%) = 0.0975kW  
 Total Power Error = 0.1175kW (0.5875% of reading)

## Choose the Right Solution



IT-60,200,400,700-S



IT-1000-S



IN 1000-S



IN 2000-S



Current Clamps



WT5000

## About Us

Since its foundation in 1915, Yokogawa has been recognized as a technology leader. Annually, Yokogawa reinvests nearly a quarter billion dollars in research and development, much of it aimed at core technologies like test and measurement. As a result, Yokogawa's annual corporate revenues have grown to nearly \$4 Billion while amassing more than 6,000 patents and registrations. All of us within the Test and Measurement Division recognize it as our mission to continuously develop and supply the best possible solutions with optimum quality and value to customers and society, thereby contributing to our customer's growth.