# RCTi, RCTi-3ph and RCT1A:
A comparison with instrument (metering) class current transformers *IEC60044-1*

These technical notes should be read in conjunction with the RCT1A and RCTi technical notes and short-form datasheets. This document is intended to draw an analogy between instrument (metering) class CTs and flexible, clip-around, Rogowski current transducers so that the user can make an informed choice about the suitability of using our RCTi, RCTi-3ph or RCT1A in place of an instrument (metering) class CT.
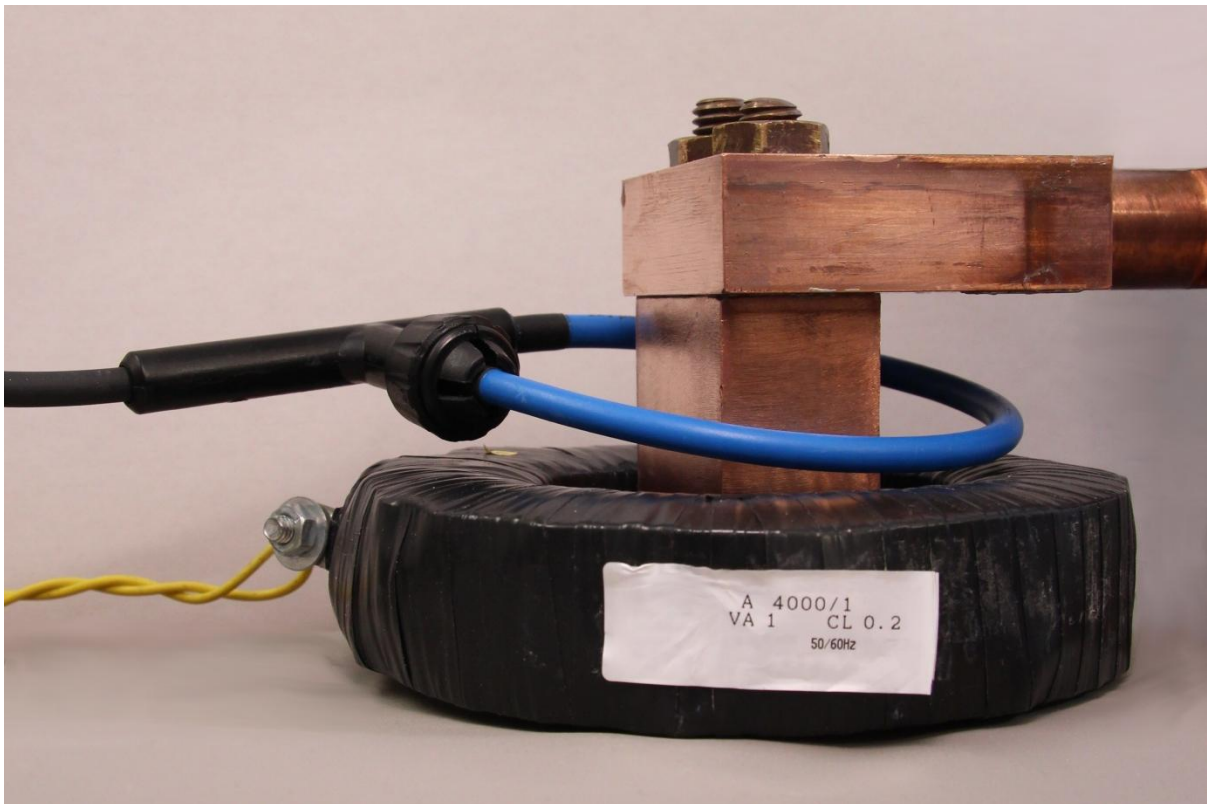
(RCT1A) Patent pending application no. PCT/EP2012/053893

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1. A summary of IEC60044-1 defining the phase and accuracy requirements for instrument (metering) current transformers.

Industrial standard IEC60044-1 relates to instrument (metering) current transformers (CTs). The standard defines the performance of a CT based on a number of accuracy classes from 0.1 to 5, 0.1 being the most accurate class. Each class defines;

- a maximum current ratio error.
- and a maximum phase displacement.

at a given percentage of rated current.

Current Ratio Error
An instrument CT has a primary rated current corresponding to a secondary output of 1A or 5A, the current ratio error is the accuracy of the ratio (Rated primary current (A): 1A or 5A).

Phase Displacement
The phase displacement is the phase shift between the actual current and the secondary current output of the CT.

Class
The 'class' of the current transformer provides a simple indication of the accuracy of the current measurement and hence whether the current transformer is suitable for a certain application. For example class 0.1 to 0.5 CTs are used for tariff (kWh) metering. Class 1, or greater, CTs are used for general purpose energy monitoring. The CT class is often specified for current monitoring apparatus used in LV equipment and is an important requirement for CTs used in conjunction with a power meter to ensure rated accuracy.

The values for current ratio error and phase displacement listed in Table 1. are defined for a given:

- **Rated frequency** (this is usually a single frequency typically 50 or 60Hz).
- **100% to 25% rated burden** (where the burden is the load to the secondary output of the CT which is additionally defined in terms of its power factor).

Accuracy Class	±Percentage current (ratio) Max. error at percentage of rated current shown below				±Phase displacement (°) at Max. percentage of rated current shown below			
	5%	20%	100%	120%	5%	20%	100%	120%
0.2	0.75	0.35	0.2	0.2	0.5	0.25	0.17	0.17
0.5	1.5	0.75	0.5	0.5	1.5	0.75	0.5	0.5
1.0	3.0	1.5	1.0	1.0	3.0	1.5	1.0	1.0

Table 1. Accuracy and phase displacement

2. The advantages of the RCT compared with current transformers

Like current transformers Rogowski current transducers only measure ac currents only. They can often be used as replacements for current transformers and have a number of benefits over conventional CTs, which are:

✓ **…are very easy to use** - the coil is thin, flexible, clip-around and easy to insert around a current carrying device. Ideal for retrofit applications.

✓ **…are intrinsically safe devices.** There is no danger from an open circuit secondary.

✓ **… in the case of voltage output versions, can take large current overloads without damage**

✓ **…do not suffer from magnetic saturation so are very linear**

✓ **… the size of the Rogowski coil can be chosen independently of the current magnitude.** This is unlike other current transducers which become bulkier as the current magnitude increases. For currents of several kA's or more there is no better alternative than the Rogowski transducer!

✓ **…are non-intrusive**. They draw no power from the main circuit carrying the current to be measured. The impedance injected into the main circuit due to the presence of the transducer is only a few pico-Henrys!

✓ **…have a wide (-3dB) bandwidth**, and are therefore suitable for a wide range of frequencies or measuring higher order harmonics.

✓ **…have a small, known, phase error, for power measurements at 45/65Hz and higher order harmonics.** Ideal for power measurement or power quality monitoring.

✓ **…can measure AC signals superimposed on large DC**. The transducer is not affected by direct currents - as a result it can measure small AC currents in the presence of a large DC component

Rogowski current transducers do have a number of differences and limitations compared with CTs. It is important to understand that the specification IEC60044-1 was written for CTs and not Rogowski current transducers.

This document is intended to draw an analogy between instrument (metering) class CTs and Rogowski current transducers so that the user can make an informed choice about the suitability of using our RCTi, RCTi-3ph or RCT1A in place of an instrument (metering) class CT.

3. Rated burden

The RCT1A has a rated burden of 5VA power factor 1.

Like a current transformer, the **RCT1A** is a current output device. It is designed to be compatible with equipment traditionally connected to instrument current transformers.

Unlike a current transformer, the **RCTi and RCTi-3ph** require a load impedance of 10kΩ for rated accuracy (further detail is in <u>RCTi –technical notes -001.pdf.)</u>. The **RCTi and RCTi-3ph** are generally not suitable for use with energy meters that require a current input.

3.1 Practical burden (load) for the RCT1A

To operate within rated conditions (accuracy and phase displacement) the overall resistance of the load attached to the RCT1A needs to be between 5Ω and 1.25Ω. It is important to note that the cabling between the Rogowski current transducer and the subsequent recording device (e.g. energy meter) forms part of the load.

Generally it is sensible to locate the RCT1A electronics (integrator) near to the recording device since both require external power. The RCT1A is powered from +24Vdc.

It is also sensible to keep the burden to a minimum (close to 1.25Ω) as this reduces the power consumption of the RCT1A and hence the power rating of the supply.

If the distance between the conductor under test and the metering equipment is large then the RCT1A should be specified with a longer cable between the Rogowski coil and the DIN rail mount electronics. PEM can supply cable lengths up to 50m.

The cable length from the RCT1A output to the metering equipment should not be more than 2m. Longer cable lengths can cause instability in the electronics.

Two example installations are shown below:

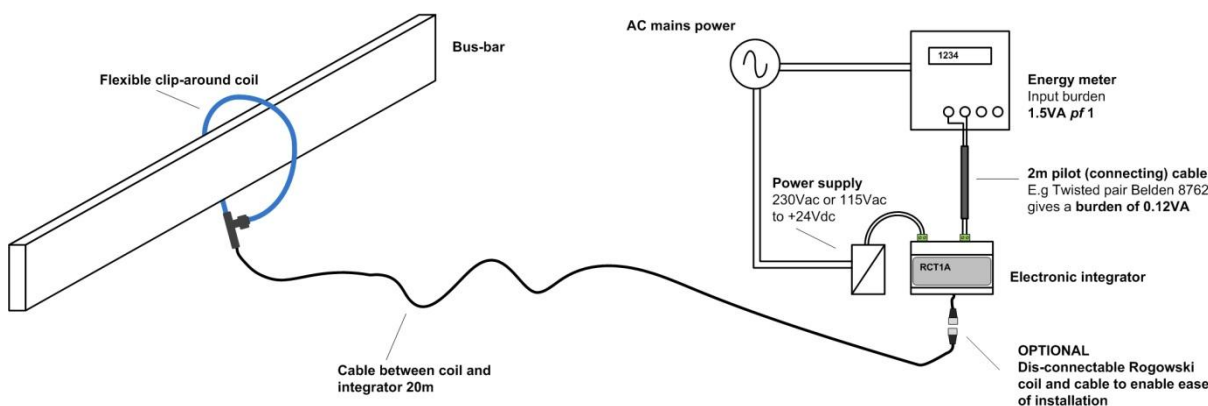*Figure 2. An example installation 1.*

Total burden =   2.5VA (energy meter) + 0.12VA (cable)   =   2.62VA which is within rated conditions

Power dissipated in the load at rated current is = $(1A)^2$ x 2.62Ω =   2.62W (@ 24Vdc)

Efficiency of the RCT1A is approximately 60%
Power supply needs to be rated for   =   4.4W (@ 24Vdc)

Where the energy or power meter has a burden of less than 1.25Ω the customer can fit an additional small resistor in series with the input of the recording device e.g. if the power meter has a burden of 0.33VA then a 1 ohm resistor in series with the input will enable the RCT1A to operate with rated accuracy. For example the installation below:
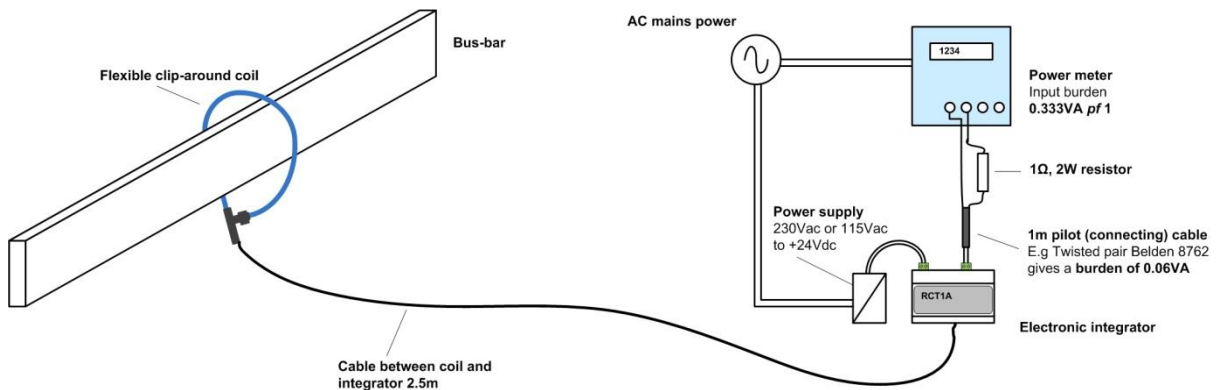

Figure 3. An example installation 2.

Total burden =   0.33VA (power meter) + 1VA (series resistor) + 0.06VA (cable)

=   1.39VA which is within rated conditions

Power dissipated in the load at rated current is = $(1A)^2$ x 2.62Ω=   1.39W (@24Vdc/rated primary current)

Efficiency of the RCT1A is approximately 60%
Power supply needs to be rated for   =   2.3W (@24Vdc/rated primary current)

Where the requirement is for a burden with a power factor (pf) < 1, PEM can supply custom designs.

4. Rated current

4.1   Rated current (primary current), I_p

The 'Rated current' or 'Rated primary current' for the RCT range is defined as the rms of a sinusoidal current.

The **RCT1A** can operate at 120% of its rated current, continuously and with no loss of performance.

The **RCTi and RCTi-3ph** can operate at 150% of their rated current, continuously and with no loss of performance.

4.2   Rated output (secondary current for RCT1A, I_s)

The 'Rated output' of the **RCT1A** is a current 0 to 1Arms where 1A corresponds to the rated primary current.

The 'Rated output' of the **RCTi and RCTi-3ph** is a voltage 0 to 5Vrms where 5V corresponds to the rated primary current.

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5. Rated frequency

The 'Rated frequency' for the RCT1A and the RCTi is chosen to be 50 to 60Hz.

This does not mean the RCT only operates at these frequencies! One of the key benefits of all PEM's Rogowski current transducers is their wide-band operation. However most CTs are specified in terms of accuracy and phase shift at 50/60Hz which is why the RCT is specified and calibrated at these frequencies.

5.1 Operation above rated frequency and higher order harmonics

Unlike conventional CTs the **RCT1A** has an excellent high frequency (hf) performance. The high frequency performance of the RCT1A is determined by the burden (load). The plot below shows the high frequency performance from 45Hz to 1kHz for the RCT1A for two different load conditions, 5Ω and 1.25Ω.
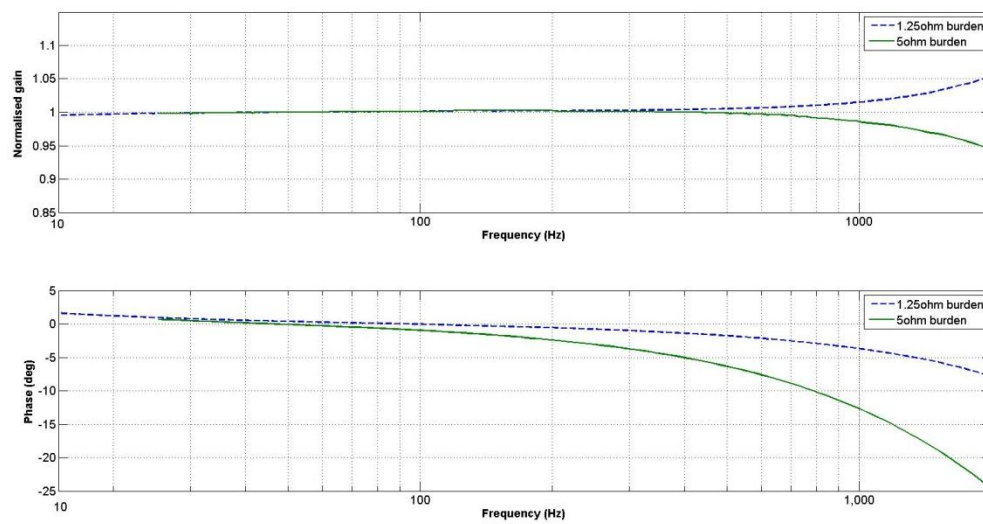
Figure 4. Frequency response from 15Hz to 2kHz for an RCT1A rated at 500A

For any value of burden between 25% and 100% rated burden the (-3dB) bandwidth will be greater than 5kHz.

If you require the RCT1A with a higher rated frequency or with a wider bandwidth please contact PEM.

The **RCTi and RCTi-3ph** high frequency performance is several orders of magnitude better than the RCT1A, with high frequency (-3dB) capability up to 1MHz. For more details see - RCTi-technical notes -001.pdf.

5.2   De-rating the 'Rated current' or 'Rated burden' at frequencies < 45Hz

The RCT1A can operate at frequencies below 45Hz however either the rated current or the rated burden must be reduced to prevent damage to the internal isolated power supply. Figure 5. shows the appropriate de-rating curve for both current and burden at low frequency.
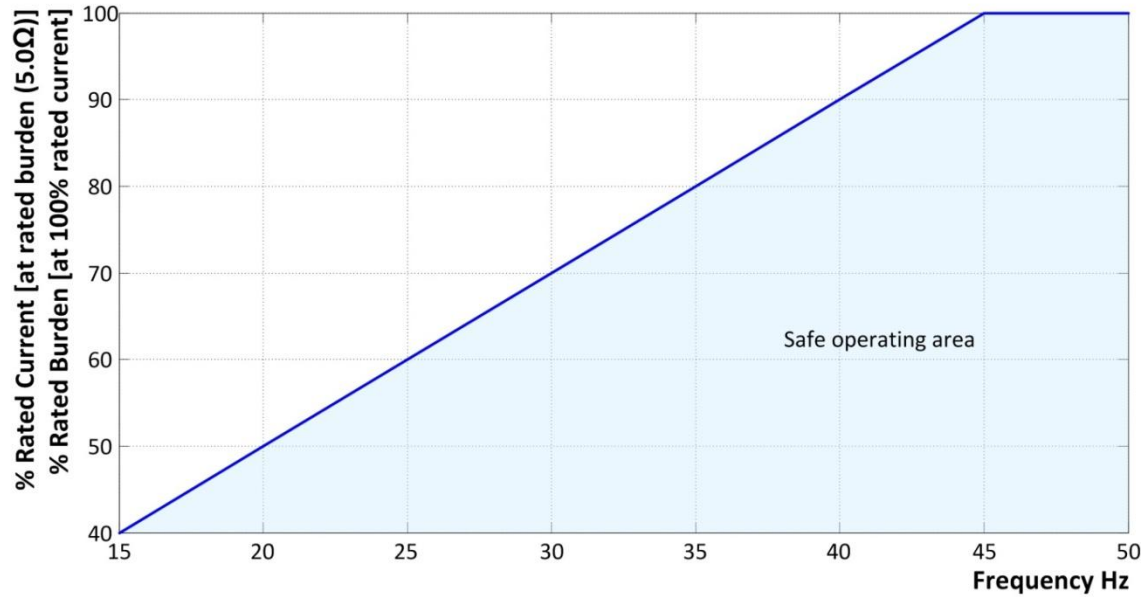

Figure 5. De-rating curve for both burden resistance or current rating
for operation at frequencies below 45Hz

6. Class: Accuracy and phase displacement

The previous sections have defined the RCT1A in terms of:

- Section 3. Rated burden, *5VA pf 1*
- Section 4. Rated current, *where for the RCT current ratings are from 500A to 50kA*
- Section 5. Rated frequency, *50/60Hz*

The factors that determine accuracy of a Rogowski current transducer are different to a CT. The accuracy considerations for the RCT1A are largely the same as the RCTi and RCTi-3ph. The accuracy considerations for the RCTi and RCTi-3ph are defined in detail in RCTi- technical notes -001.pdf. In the following table we will assume:

- Position of the conductor is central in the Rogowski coil loop, or conductor fills 30% of the Rogowski loop.
- Any adjacent conductors are distant from the coil by at least the coil radius, and do not carry a current greater than the current in the conductor being measured.
- Ambient temperature is 25°C

The low frequency bandwidth of the RCT1A and RCTi is set by high stability passive components, thus the phase error at low frequency is predictable and repeatable to a high tolerance. The table below shows the maximum phase error at rated frequency as the rated current varies:

RCT Product	±Percentage current (ratio) Max error at percentage of rated current shown below				±Phase displacement (^{o}) at Max percentage of rated current shown below			
	5%	20%	100%	120%	5%	20%	100%	120%
RCT1A ≥ 500A and RCTi (RCTi-3ph) ≥ 2000A	3.0	1.5	1.0	1.0	1.5	0.75	0.5	0.5
RCTi (RCTi-3ph) < 2000A					3.0	1.5	1.0	1.0

Table 6. RCT Class definition

Current ratio error class:

In these conditions both the RCTi and RCT1A can be considered equivalent to a Class 1 instrument CT.

Phase displacement class:

For current ratings of the RCT1A ≥ 500A and RCTi (or RCTi-3ph) ≥ 2000A the phase displacement is equivalent to a Class 0.5 CT.

For the RCTi < 2000A the phase displacement is equivalent to a Class 1 CT.

For more detail about the pahse tolerance of the RCTi and RCTi-3ph at low frequency see RCTi –technical notes -001.pdf.

7. Overloads, Outages and Start-up

7.1   Open circuit burden

Unlike current transformers there is **no safety risk** from an open circuit burden on the RCT1A.

The RCT1A amplifier has feedback to control the secondary current through the burden. If the burden is open circuit then there is no feedback path and the output voltage of the RCT1A will fluctuate between ±15V.

Figure 7. and Figure 8. show the typical output voltage of the RCT1A with an open circuit burden.
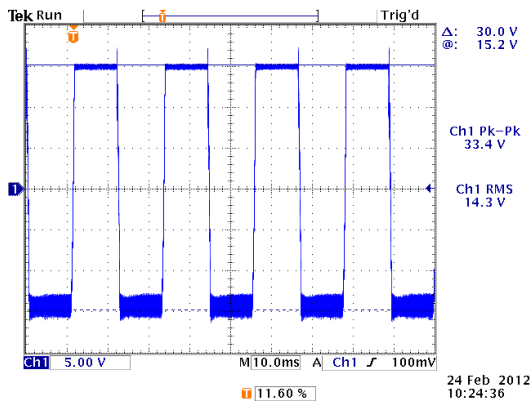

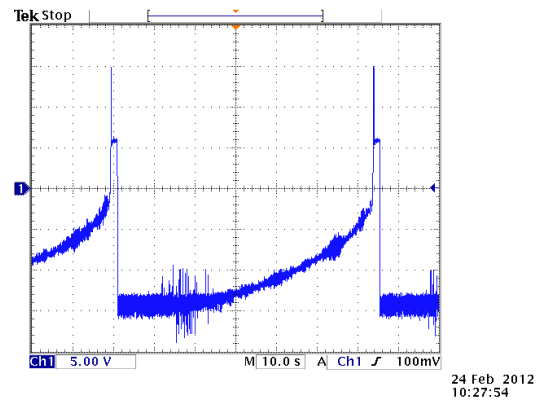*Figure 7. The voltage across the open circuit secondary terminals of the RCT1A with rated primary current*

Figure 8. The voltage across the open circuit secondary terminals of the RCT1A with no primary current

The RCT1A will operate without damage in these conditions.

7.2   Short circuit burden

As explained in Section 7.1, there is no danger of large voltages on the secondary side of the RCT1A. Therefore it is not necessary or recommended that the burden is short circuit during installation or when not in use. However, the RCT1A will not be damaged by a short circuit burden provided the primary current is not significantly above the primary current rating.

7.3   Start up and recovery after power outage

7.3.1   Start-up

On no-load, when the primary current is 0A, the RCT1A will take up to 20 seconds to settle to a quiescent state of 0A on the secondary output. This delay is necessary to prevent damage to the power amplifier whilst the integrator settles.
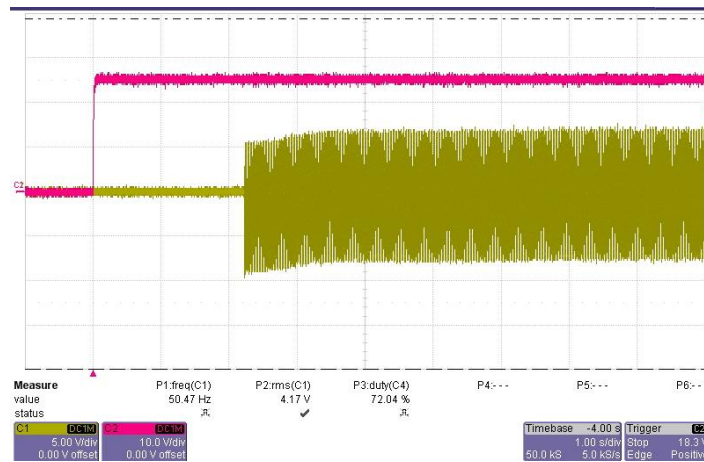
Figure 9. Start-up of RCT1A, time base 1sec /div

Although not recommended the RCT1A will not be damaged by being powered on when the Rogowski coil is encircling a live conductor carrying rated current. An example of the turn on behaviour is shown in Figure 9. The burden is 5Ω and the primary conductor is carrying rated current. Channel 2 (Magenta trace) shows the input voltage to the RCT1A which goes from 0V to +24Vdc, and Channel 2 (Yellow trace) is the secondary output across the 5Ω burden.

7.3.2 Power outages

PEM recommend that the RCT1A is powered from a CE marked regulated DC/DC power supply of sufficient power rating. It is understood that a voltage supply may be subject to power outages (or voltage 'drop-outs') due to external effects such as lightning strikes, system overloads etc. Therefore it is useful to know how the RCT1A would perform in such circumstances.
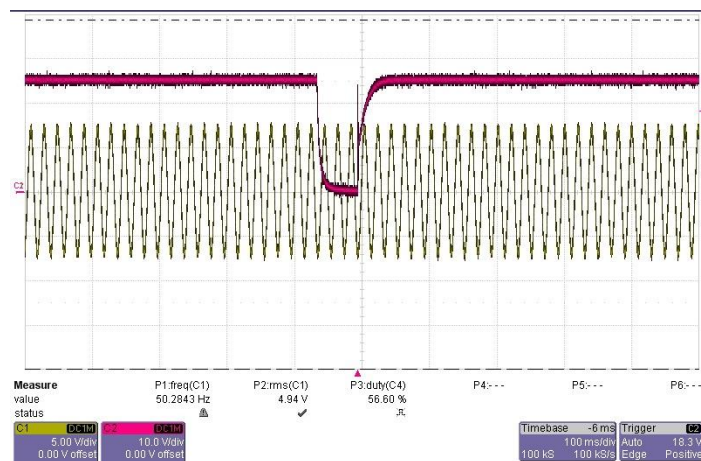

Figure 10. Single drop-out of power supply, timebase 100 msec /div
Ch1 (Yellow trace) 5V/div – RCT1A output voltage measured across 5Ω burden
Ch2 (Magenta trace) 10V/div – Input voltage to RCT1A power supply

Figure 10. shows a single drop out condition, i.e. Time ON (+24Vdc) >> Time OFF (0V) . The duration of the drop-out (Time OFF) is varied from a few milli-seconds to 100ms. The RCT1A is measuring rated current at 50Hz and the secondary burden is 5Ω. For a voltage drop-out of Time OFF ≤ 70ms the RCT1A maintains normal operation. For a drop out of greater than 70ms the RCT1A switches off but resumes normal operation once the drop-out is cleared.
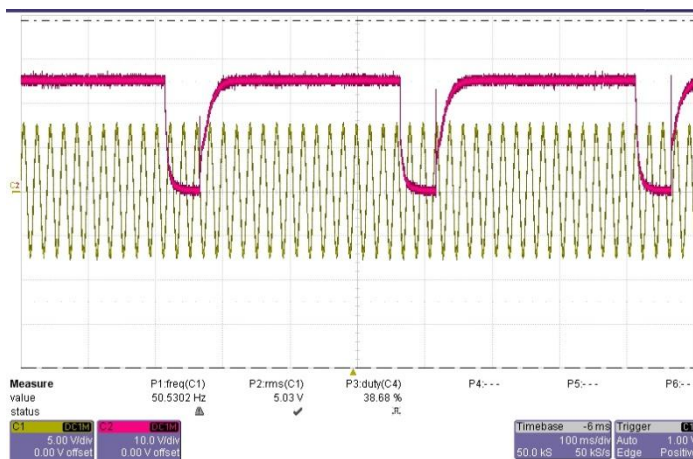
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Figure 11. Repetitive drop-out of power supply, timebase 100 msec /div

Figure 11. shows how often this single drop out can be repeated and still maintain normal operation. The figure shows a Time ON (+24Vdc) = 350ms and Time OFF (0V) = 70ms. The RCT1A maintains normal operation. With Time ON < 350ms the RCT1A turns off. Once the drop out condition is cleared the RCT1A resumes normal operation.

7.4 Over-current

The RCTi and RCTi-3ph cannot be damaged by overcurrent surges (insert hyperlink here).

Unlike voltage output Rogowski transducers such as the RCTi, the RCT1A electronic amplifier **can be damaged** by an overcurrent.

The graph below summarises the overcurrent limits for the RCT1A as a function of burden resistor.
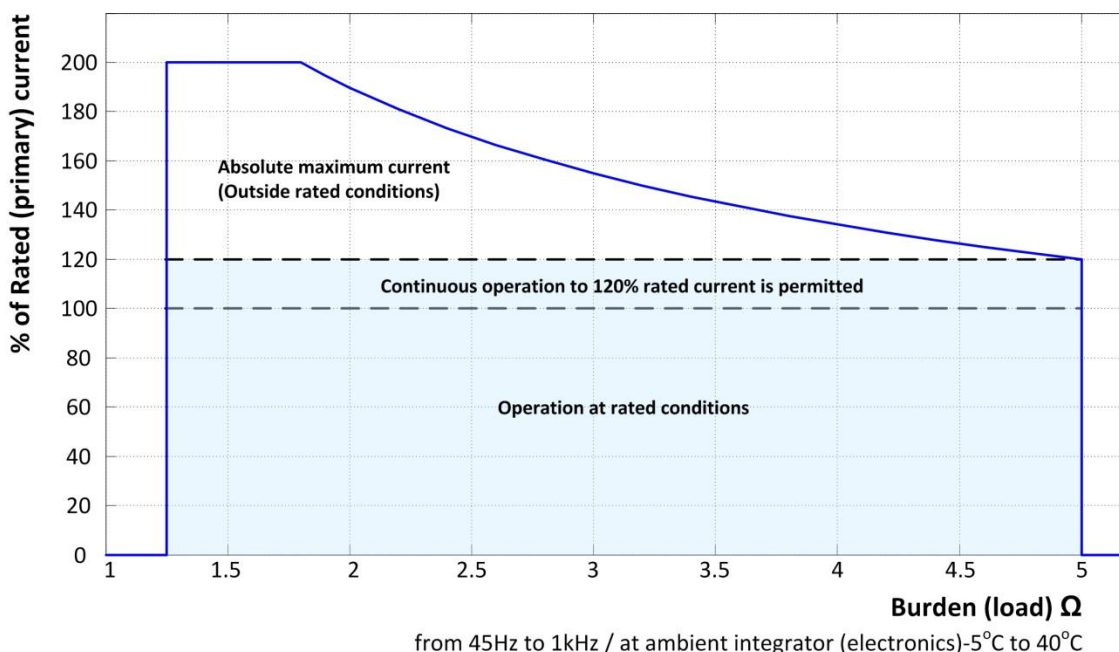

Figure 12. Safe operating area for primary current

8. Product safety and standards

8.1 How does PEM rate the voltage insulation of its Rogowski coils?

The RCT1 range is intended for permanent installation on equipment.

Every Rogowski coil supplied by PEM is given a peak voltage insulation rating. The rating is derived from the following test:

*The coil is exposed to an **AC test voltage = (2 x Peak voltage rating (kV) + 1)/√2 (kV rms)**, for 60 seconds at 50Hz. The RCT range is rated at 2kV peak and will be flash tested at 4kVrms (11kV peak to peak), 50Hz, for 1 minute.*

The user should visually inspect the Rogowski coil and cable for insulation damage each time the transducer is used. Every Rogowski coil has at least two layers of insulation covering the winding. These are always different colours making visual inspection of the integrity of the insulation easier.

It is advisable that the user grounds the output terminal S2 from a safety viewpoint so that in the event of an insulation breakdown at the coil (due to exceeding the voltage rating or due to mechanical damage), a fault current path exists via the cable connecting the S2 terminal to ground on the subsequent recording equipment.

As for the majority of plastics, the material used for insulating PEM's Rogowski coils can be damaged by exposure to corona over a reasonably long period of time.

The RCT has been designed for permanent installation and hence continuous exposure to nearby voltages. For voltages to ground of less than 2kV peak (i.e. 1.41kVrms for a sinusoidal voltage), corona effects will be negligible, and continuous operation is permitted.

For voltages to ground of more than 2kV peak the coil must be sufficiently distanced from the high voltage conductor or device, using air and / or insulating materials such that corona does not occur in the vicinity of the coil. Sharp corners should be avoided on the high voltage structures near the Rogowski coil as sharp corners lower the voltage at which corona begins. PEM has no control over how its customers install Rogowski coils, and hence the responsibility for long continuous life when operating in a HV environment lies with the customer.

8.2 Product safety and EMC compliance

The RCT range of current transducers has been designed, assessed and third party tested to ensure they comply with relevant EU standards and all products carry the CE mark of conformity. In addition, the range has been assessed and tested against the relevant FCC CFR regulations. The CE Declaration of Conformity can be found on our website.

All RCT products comply with:

EMC:	IEC 61326-1:2006
EMC:	CFR47 Part 15 Class A
Safety:	IEC 61010-1:2001; Pollution Degree 2

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Refer to the 'Instructions for use' document before use.