TECHNICAL NOTE

Use of Rogowski coils and Resistive Voltage Dividers in Medium Voltage Switchgear

Medium voltage (MV) switchgear requires the transformation of the primary system voltages, anywhere from 2.4 kV to 52 kV, and continuous primary currents, up to 4000 A to a much lower level whereby relays, meters, monitoring and other control elements can function to provide protection and control for connected loads and systems the switchgear serves.

Traditionally, this transformation has been accomplished using conventional current (CT) and voltage (VT) transformers. However, there are risks and performance issues when using these conventional transformers.

Issues and risks when using conventional CTs:

- System engineers must calculate with some degree of precision the current values of the specific loads and specify CT ratios that coordinate with the full load current (FLC) and fault current (FC) values.
- CT burden studies should also be conducted to determine proper requirements
- The higher the accuracy, or more burden the CTs need to drive, the larger the CTs become. Sometimes these become too large to fit in the available mounting spaces in the circuit breaker compartment.
- These CT determinations must be made and provided to manufacturers before accurate quotes can be obtained.
- Changes in loads or systems require changing CTs.
- CTs can saturate when subjected to fault currents, or other conditions that cause the current to increase dramatically over the ratings of the CTs.
- Personnel safety is also a concern when using conventional CTs as dangerously high voltages can occur on the secondary of the CT circuits if the circuit is accidentally opened when the primary bus is energized, such as when performing maintenance or testing.

Rogowski coils have been around for more than a century and within the last couple of decades have become more useful in MV applications due primarily to the integration of the outputs into the relays and meters.

A Rogowski coil is a device used to measure alternating current. It comprises a toroidal winding where the current carrying conductor passes through the center of the toroid. The core, therefore, is pure air versus the ferromagnetic core used in conventional CTs. See Figure 1.

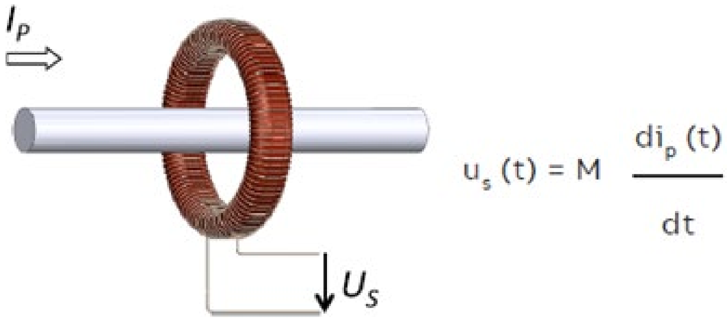

Figure 1

The current sensor output is a low level voltage which is proportional to the derivative of the current. This provides superb performance and operates linearity over the entire range of the primary current. See Figure 2 for a typical performance curve.

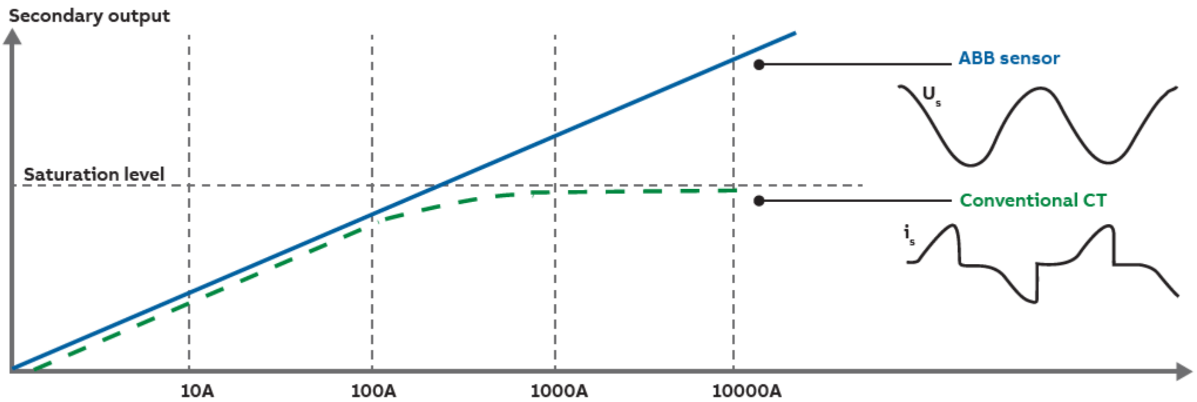

Figure 2

For ABB MV ANSI metal-clad switchgear, the ABB KECA 80 C184 current sensors are used in Advance, Advance 27, SafeGear and SafeGear HD product lines. These are located over the breaker bushings just like conventional CTs are. See Figure 3.

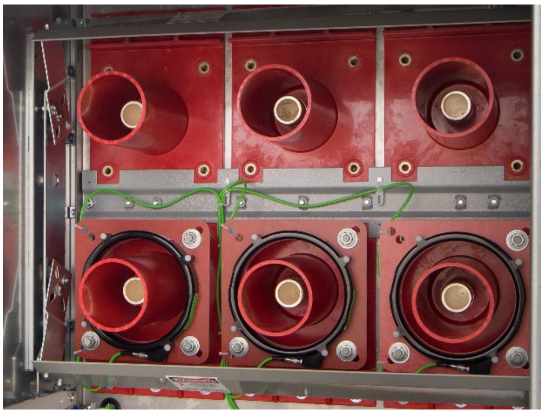

Figure 3

Up to 4 current sensors can be installed per breaker bushing for a total of 8 sensors per phase. A mix of standard accuracy conventional CTs and current sensors is also available. Each bushing can accommodate 1 standard accuracy CT and 2 sensors. If high accuracy CTs are required, then no sensors can be placed on the same bushing.

The KECA 80 C184 sensors rating application parameters are:

- 720V (When installed on breaker bushings, these are suitable for use in 5 – 27 kV nominal voltage systems)
- Up to 4000A continuous current
- Up to 63 kA short circuit current

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Table 1 Technical parameters

Characteristic		Value
Rated primary current of application		up to 4000 A
Rated primary current, I_{pr}		80 A
Rated transformation ratio, K_{ra}		80 A/0.180 V at 60 Hz
		80 A/0.150 V at 50 Hz
		3 mV/Hz
Rated secondary output, U_{sr}		i.e. 180 mV at 60 Hz or 150 mV at 50 Hz
Rated continuous thermal current (rating factor), I_{cth}		4000 A
Rated short-time thermal current, I_{th}		85 kA/3s
Rated dynamic current, I_{dyn}		230 kA
Rated frequency, f_r		60/50 Hz
Rated extended primary current factor, K_{pcr}		50
Accuracy limit factor, K_{alf}		400
Accuracy class		0.5/5P
Rated burden (input impedance), R_{br}		10 MΩ
Weight		1.43 lbs. (0.65 kg)
Temperature category	Operation	- 25°C/+80°C
	Transport and storage	- 40°C/+80°C
Cable connector		RJ45 (CAT-6)

Current sensor accuracy is defined in IEC 61869 as 0.5/5P630 (5P400). The standard combines metering and protection class into one accuracy rating. Current sensors can transmit currents from just a couple of Amps up to short circuit values. Accuracy of sensor is as rated when correction factors are entered into the relay or meter.

Figure 4 shows the graphical representation of the current sensor accuracy.

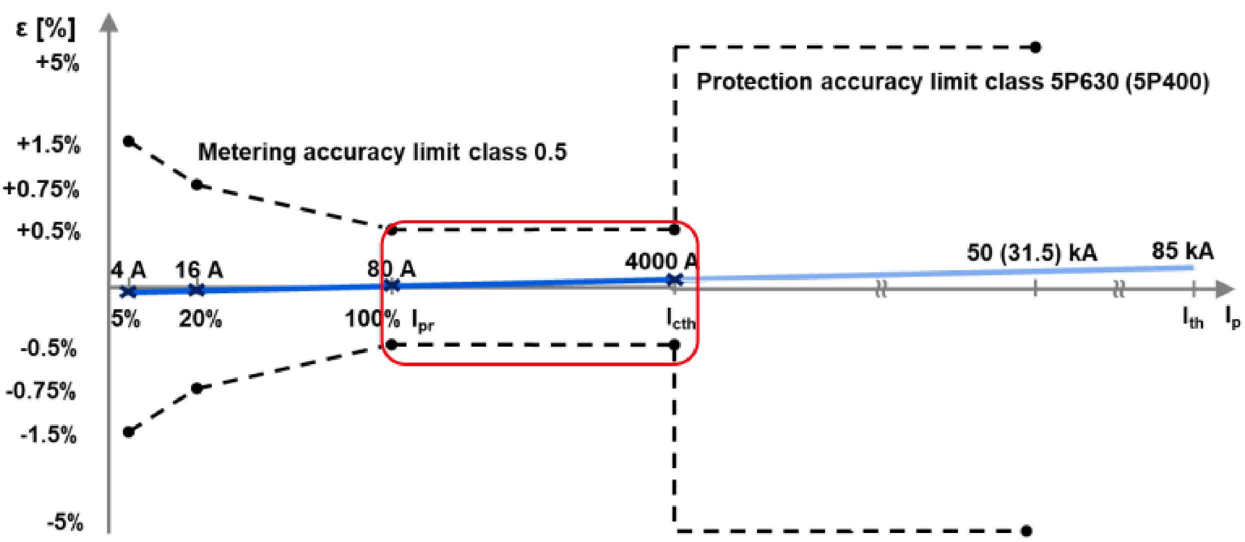
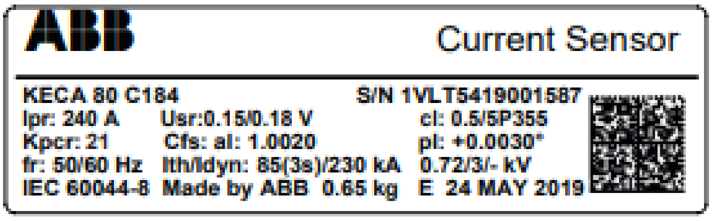


Figure 4

KECA 80 C184 current sensors are UL Listed and we can apply UL labels to all of our ANSI MV switchgear product lines with these sensors installed.

Secondary cables are shielded Cat 5E, pre-installed, 5m lengths with RJ-45 connectors installed at ends to be connected to devices, usually the AR4 or AR5 combiner. Pin configurations are as specified by IEC 61869-10. Every sensor is accuracy tested with its own cable and connector. The sensor ratings label applied to each sensor will include a ratio correction factor (Cfs). These Cfs values are entered into the relay or meter to ensure the accuracy of that specific sensor and cable combination.



Issues and risks addressed when using current sensors:

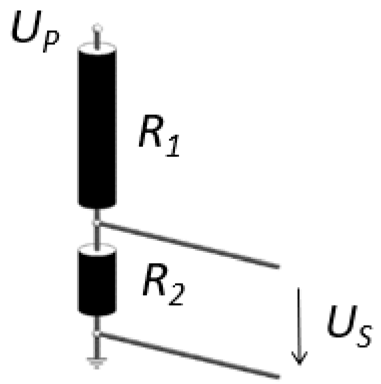
- One sensor is used for all ratings on all product lines regardless of actual loads. It is not necessary to know what your loads are anytime during quotation through manufacturing.
- Changes to loads does not require hardware or wiring changes.
- No need for CT burden calculations.
- There is ample space for multiple sensors to be installed on breaker bushings.
- No saturation – performs even in fault current conditions.
- No dangerous open CT secondaries.
- Extremely low watt loss during operation.
- Substantial weight savings: ~1.5lbs for sensor vs 38lbs for CT (ea).
- High accuracy and linear performance ensures accurate readings throughout the entire operating current range.

Issues and risks when using conventional voltage transformers (VTs):

- VTs must be specified for the correct ratio, voltage ratings, BiL ratings and configuration style, (i.e., open delta vs wye-wye configurations) before ordering the equipment.
- Changes in the system voltage needs could result in changing hardware and wiring
- The use of VTs in MV metal-clad switchgear requires the use of drawout carriages or trays. They take up much space and can increase the overall footprint of the switchgear lineup.
- They require personnel to operate the draw-out mechanisms.
- They require fuses on the primaries and secondaries. Fuses decrease system reliability as there is a risk of failure, which then can cause the need for shutdowns and maintenance.
- Some applications of VTs can create ferro-resonance situations which could lead to catastrophic failures of the VTs.

Resistive voltage dividers (RVDs) have also been around for decades. As with Rogowski coils, it was the adaptation of relays and meters to be able to use these low voltage signals in an accurate manner that facilitated their use in MV equipment.

RVDs are passive elements with a failure mode of opening, not shorting. They are non-saturable and linear over the whole measuring range. See Figure 5.



$$U_S = \frac{R_2}{R_1 + R_2} U_P$$

Figure 5

ABB MV ANSI switchgear uses two different type KEVA voltage sensors. The KEVA 17.5 B21 sensor is used for all 5-15 kV voltage classes for the Advance, SafeGear and SafeGear HD product lines, and the KEVA 24 B21 for the Advance 27 product line.

RVDs are installed in the bus and cable compartments very similar to how surge arresters are installed. Primary connections to these can be by insulated solid copper cable (i.e. Natvar or Grayline), shielded cable or bus. Most common connections are solid copper or shielded cable. See Figure 6 for an example of voltage sensors mounted in the cable compartment of MV switchgear connected with insulated solid copper rod.

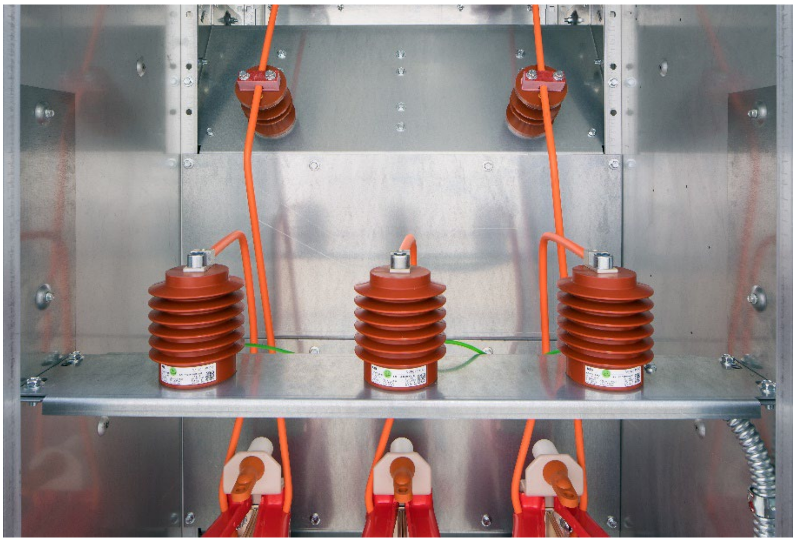


Figure 6

Future plans are for these KEVA sensors to serve dual purposes, one as a voltage sensor and the other as a bus standoff insulator support. This will further improve the configuration capabilities of the switchgear and require less space in the cable compartment, leaving room for other needed components such as ground CTs and lightning arresters. This can also enable the installation of voltage sensors on the main bus in a 2-high breaker frame.

The KEVA 17.5 B21 technical parameters are:

- Highest system voltage = 17.5 kV (phase-to-phase)
- Rated primary voltage = 15/√3 kV (phase-to-ground)

- Rated output voltage = 0-10 V
- Rated power frequency test voltage = 38 kV (42 kV possible)
- Rated lightning impulse test voltage = 95 kV
- Rated frequency = 50/60 Hz
- Accuracy Class = 0.5/3P
- Operating temperatures:
    - During operation = -25°C/+55°C
    - Transport and storage = -40°C/+80°C
- Transformation ratio = 10,000:1
- Rated burden (input impedance) = 10 MΩ
- Weight = 4.3lbs (2.0 kg)
- Cable length = 5.5 meter cable using RJ45 connector
- Lifecycle design = 30 yrs

The KEVA 24 B21 technical parameters are:

- Highest system voltage = 24 kV (phase-to-phase)
- Rated primary voltage = 22/√3 kV (phase-to-ground)
- Rated output voltage = 0-10 V
- Rated power frequency test voltage = 50 kV
- Rated lightning impulse test voltage = 125 kV
- Rated frequency = 50/60 Hz
- Accuracy Class = 0.5/3P
- Operating temperatures:
    - During operation = -25°C/+55°C
    - Transport and storage = -40°C/+80°C
- Transformation ratio = 10,000:1
- Rated burden (input impedance) = 10 MΩ
- Weight = 5.6 lbs (2.52 kg)
- Lifecycle design = 30 yrs

Voltage sensor accuracy is defined in IEC 61869 as 0.5/3P. The standard combines metering and protection class into one accuracy rating. Accuracy of sensor is highest when correction factors (Cfs) are entered into the relay or meter.

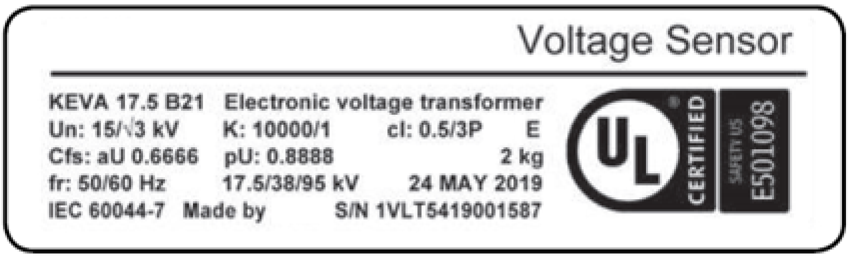


Figure 7 shows a graphical representation of the voltage sensor accuracy.

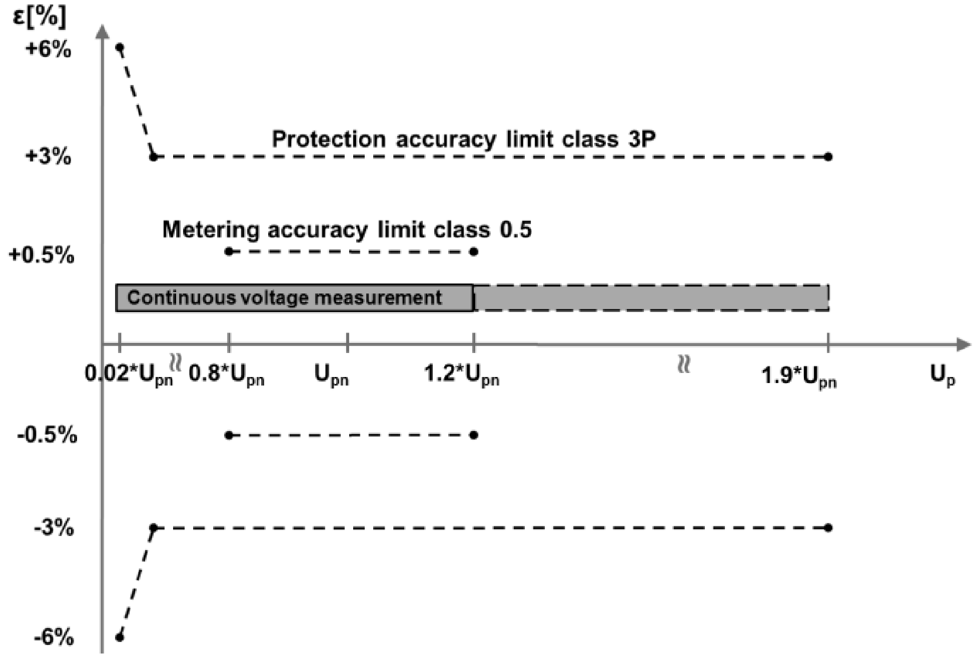


Figure 7

Applicable standards

The current sensors are constructed and certified to IEC 68169-10 and voltage sensors per IEC 61869-6. There are currently no specific IEEE standards for the construction and performance of these sensors. However, there are guides being formed for the use and application of these sensors. These standards will also reference the IEC standards for construction and performance.

The various IEEE switchgear standards, namely, C37.20.2; C37.20.3; C37.20.9 have all been revised to include the use of sensors certified to IEC 61869 as acceptable for use in switchgear certified to these IEEE standards. ABB switchgear using the ABB KECA and KEVA sensors are fully certified as per IEEE C37.20.2. ABB can also provide UL Listed switchgear using these sensors.

Application considerations (reference ABB doc. #1VAL107502-FA for more detailed information)

- ABB MV switchgear is fully certified to IEEE C37.20.2 for both arc-resistant and non-arc-resistant switchgear and IEEE C37.20.7 for arc-resistant switchgear when using ABB KECA and KEVA sensors.
- Relays and meters must be of the type that have input cards specifically designed for use with low energy analogue inputs from the ABB KECA and KEVA sensors. They should be design type tested for accuracy performance using the KECA and KEVA sensors.
- Amplitude and phase angle ratio correction factors are determined for each specific sensor during manufacturing and are included on the label for each individual sensor. These factors must be entered in the relay or meter to achieve rated accuracies.
- A dedicated set of sensors are needed for each set of protection relays or meters. The secondary of the sensors cannot be connected in series for current or parallel for voltage.
  - When IEC-61850 is used for relay and metering communications, the current and voltage values can be shared from device to device via process bus, possibly negating the need for some sensors.

- Available space within the main bus compartment of 2-high breaker configurations prohibit the installation of voltage sensors in that location. Main bus voltage sensor connections can be made in most 1-high breaker and auxiliary frame configurations.
- The location of the sensors relative to the relays and meters must be within the cable length of the sensor. Cables cannot be lengthened or cut. Longer cables can be ordered, up to 100m. The sensors must be manufactured and tested with these longer length cables. Additional lead times and costs would apply.
- Only the secondary cables and RJ45 connectors supplied with the sensors can be used. Cables between the AR4/AR5 adapters, test switches and relays must utilize grounded RJ45 connectors and follow pinouts as defined by IEC 61869-6/-10. This is necessary to ensure proper shielding of the cables.
- Excess cable lengths should be located in a manner that does not cause noise interference in the cables.
- If a zero sequence CT is desired, order the ABB relays with the optional separate ground CT input card and order the ground CTs with 0-1 A output.
- Although there are polarities on the current sensors, it is not so important to install them in any particular manner as the polarity can be addressed in the relay settings, regardless of how they are physically installed.
- FT style test switches, FT-14D, are available for use with these sensors wired to relays and meters. These function the same as when used with conventional CTs and VTs.
- All voltage sensors are connected line to ground. The specific configuration needed (i.e., wye-wye or open delta) is configured within the relay.
- Fusing on the primary and secondary of the voltage sensors are not required and should not be used. IEEE C37.20.2 and UL both agree with this and do not require fusing on voltage sensors.
- After installation and commissioning, there are no additional maintenance requirements for these sensors.
- For frequencies other than 50 or 60 Hz, the sensors will operate just fine. However, the challenge will be in the relay or meter. The relay and meter manufacturers will need to be consulted for these unusual frequency rating applications.
- These sensors are not suitable for use in revenue metering applications. There is ongoing development that will make this possible in 2025.
- It is not necessary to utilize IEC-61850 for the relays or meters to use these sensors.
- Bus protection can be made with sensors using GOOSE messaging within the relays. Or conventional high impedance bus differential schemes can be applied using conventional CTs with current and voltage sensors for all other protection functions.

Typical connection of sensors to components

Figure 8 illustrates how the sensors are connected to the various components.

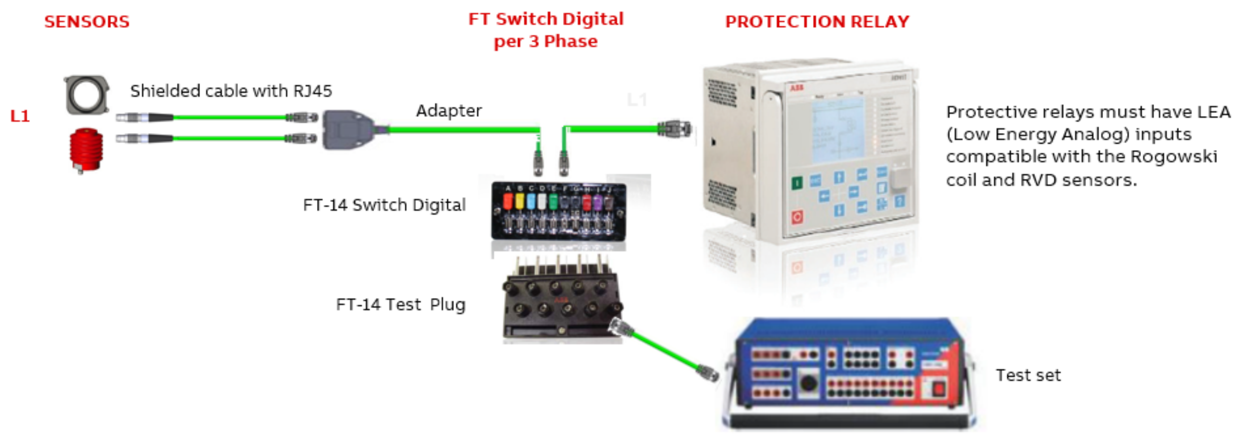


Figure 8

Adapters are used to combine the separate voltage and current sensors into a single cable. AR4 adapters are single phase units, one used for each phase. The AR5, 3-phase adapter is available for use. Either can be used.

No SIS style wiring is used between sensors, adapters, test switches and relays/meters for the transferring of current and voltage signals.

Test switches and test set up shown are optional. Reference ABB document #1VAL108402-TG for testing and commissioning of sensors in switchgear.

In summary, there are many advantages of using current and voltage sensors in MV metal-clad switchgear. ABB offers these advantages for all ratings with all of our product lines. It is not necessary to use IEC-61850 with the relays, but there are some further advantages if it is used, such as sharing information from one set of sensors to all relays and thus reducing the total number of sensors needed.

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