PRECISION ELECTRONICALLY COMPENSATED CURRENT TRANSFORMER

Common Mode Rejecter for Testing Meters with Interconnected Current and Voltage Circuits *

Models
CMR-I 2130
CMR-I 2230
CMR-I 2330

User’s Guide
Version 3.2c * PATENTED
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1. Introduction

The Precision Electronically Compensated Current Transformer CMR-I is an universal lightweight electronically controlled precision through-hole high power current transformer unit for precise galvanically isolated current transmission. The unit is dedicated for testing of electricity meters with closed current and potential circuits but its versatility enables utilization in extensive measurement and test applications.

The Precision Electronically Compensated Current Transformer CMR-I is constructed as universally applicable standalone unit enabling establishment of any user defined current ratio between primary and secondary coil. The current ratio is defined by primary and secondary coil via number of respective turns.

The internal electronics of the CMR-I unit is keeping the magnetic flux in the core on zero value and therefore assures exact primary and secondary ampere-turns compensation. The compensation of ampere-turns is done with high accuracy specified for actual model.
2. Description

2.1 PROTECT state

The Precision Electronically Compensated Current Transformer CMR-I checks the induced voltage value and the OPEN CIRCUIT state (high load impedance). In case that the induced voltage exceeds the maximum allowed value or Open circuit is detected the unit goes to PROTECT state.

In the PROTECT state the CMR-I unit is internally bypassed (the internal relay virtually shorts the output circuit) and the CMR-I unit acts as short circuit for primary side. This feature enables use multiple CMR-I units in series.

PROTECT state of any CMR-I unit does not affects remaining units connected in series because CMR-I unit always (also in PROTECT state) allows the current to flow without influencing it. This feature enables testing meters on partially loaded meter test rack without need of bypassing the unused positions.

Due to nonzero resistance of internal shorting path some residual current can flow through secondary output circuit in PROTECT state. Magnitude of this current depends on the secondary circuit total impedance.

PROTECT state is indicated by blinking of red LED (in case of multiphase unit separately for each phase) and can be reset by pressing the RESET button.

2.2 Indication Panel

Indication Panel of three-phase CMR-I unit

Description of Indication Panel components (firmware 3.00 and higher):

- Button Reset can be used for resetting (un-protecting) the unit when it is in PROTECT state
- Green LED Power indicates presence of power supply feeding the internal electronics
- Red (Protect) and Yellow (Signal) LEDs indication:

<table>
<thead>
<tr>
<th>Output Voltage</th>
<th>Yellow LED (Signal)</th>
<th>Red LED (Protect)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None or very small</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>Less than 70% of maximum allowed value</td>
<td>Flashing</td>
<td>OFF</td>
</tr>
<tr>
<td>Over 70% of maximum allowed value</td>
<td>Constantly ON</td>
<td>OFF</td>
</tr>
<tr>
<td>Near to the maximum allowed value</td>
<td>Constantly ON</td>
<td>Randomly flashing or constantly ON</td>
</tr>
<tr>
<td>Over allowed limit</td>
<td>OFF</td>
<td>Flashing</td>
</tr>
</tbody>
</table>
2.3 Side Panels

Left Side Panel of CMR-I unit

Right Side Panel of CMR-I unit

Description of Side Panels connectors:

- **COM** .......... communication (interconnection with PC or with other CMR-I unit)
- **DC IN** ....... power supply – input (interconnection with PSCI or previous CMR-I unit)
- **DC OUT** .... power supply – output (interconnection with PSCI or next CMR-I unit)
- **GND** .......... grounding

2.4 Power Supply

CMR-I unit requires power supply with +/- 15 V DC voltages.

Recommended power supply is PSCI 1220A (offered as optional accessory for CMR-I units) which can be alternatively used as:

- power supply for max. 30 pieces of single-phase CMR-I units
- power supply for max. 15 pieces of two-phase CMR-I units
- power supply for max. 10 pieces of three-phase CMR-I units
Main Panel of Power Supply PSCI 1220A

Description of Main Panel components:
- DC-Out1 .... connector of first power supply channel
- DC-Out2 .... connector of second power supply channel
- Power ........ mains power switch

Power Supply PSCI 1220A consists from two interconnected power supply channels. Internally interconnected connectors DC-Out1 and DC-Out2 can be used as needed. In case of feeding higher number of CMR-I units connect one group of CMR-I units (for example all units from one side of the handling rack) to one power supply channel and other group of CMR-I units (for example all units from other side of the handling rack) to second power supply channel.

Standard accessory supplied with each CMR-I unit is one short power supply cable for interconnection of power supply between two neighboring CMR-I units.

Standard accessories supplied with each PSCI 1220A Power Source are two longer power supply cables for interconnection of Power Supply with two nearest CMR-I units.

2.5 Connection diagram

Basic connection diagram
3. Basic Definitions

3.1 Current Ratio

Current ratio is specified by number of turns of the primary and secondary coil:

\[ M = \frac{N_p}{N_s} \]

- \( M \) ........ current ratio
- \( N_p \) ........ number of primary turns
- \( N_s \) ........ number of secondary turns

Secondary current is:

\[ I_S = I_p \times M \]

- \( I_S \) ........ secondary current
- \( I_p \) ........ primary current
- \( M \) ........ current ratio

3.2 Maximum Current

Maximum current is specified by maximum AMPERE*TURNS (technical specification parameter).

Maximum number of primary turns for given current is

\[ N_{MAX} = \frac{I_V}{I_{MAX}} \]

- \( N_{MAX} \) .... maximum number of primary turns
- \( I_V \) ....... maximum AMPERE*TURNS (from tech. specification)
- \( I_{MAX} \) .... maximum current (of source or load)

The obtained result has to be rounded down!

or

Maximum current for given number of primary turns is

\[ I_{MAX} = \frac{I_V}{N_{MAX}} \]

- \( I_{MAX} \) .... maximum current (of source or load)
- \( I_V \) ....... maximum AMPERE*TURNS (from tech. specification)
- \( N_{MAX} \) .... maximum number of primary turns

WARNING: Exceeding the maximum current may lead to permanent damage of the unit !!!

3.3 Maximum Load Impedance

Total load impedance of secondary circuit is equal to sum of impedances of all components of the secondary circuit (impedance of secondary winding, impedance of wires, impedance of contacts, impedance of meter etc.).

Maximum load impedance in secondary circuit is defined by following criteria:

A. Maximum load impedance given by specified maximum output voltage per turn

Maximum total load impedance (including resistance of the coil itself) given by maximum output voltage per turn (*) technical specification parameter is

\[ R_{MAX} = \frac{U_{MAX}}{I_{MAX}} = \frac{N_s \times U_{MAX1}}{I_{MAX}} \]

- \( R_{MAX} \) .... maximum total load resistance (absolute value)
- \( U_{MAX} \) .... maximum output voltage
- \( U_{MAX1} \) .... maximum output voltage per turn (*)
- \( I_{MAX} \) .... maximum expected output current
- \( N_s \) .... number of turns of secondary winding
B. Maximum load impedance given by maximum load resistance

Maximum load impedance which ensures the specified current ratio accuracy given by maximum load resistance per square-turn (* technical specification parameter) is

\[ R_H = R_{H1} \times N_S^2 \]

\[ R_H \quad \text{maximum load resistance (absolute value)} \]
\[ R_{H1} \quad \text{max. load resistance per square-turn (*)} \]
\[ N_S \quad \text{number of turns of secondary winding} \]

**WARNING:** The load impedance MUST NOT exceed A nor B criteria !!!

Decreasing the load impedance below these limit values decreases the transformer error.

In case of higher load impedance the number of secondary turns has to be increased. The required transformer ratio is then achieved by proper number of primary turns.

Calculation of minimum secondary coil turns for given load impedance:

\[ N_{S_{\text{min}}} = \frac{R_L}{\sqrt{R_H}} \]

\[ N_{S_{\text{min}}} \quad \text{minimum secondary coil turns} \]
\[ R_H \quad \text{maximum allowed impedance limit} \]
\[ R_L \quad \text{total load impedance of the secondary coil} \]

result has to be rounded up!

Increasing the number of secondary turns above the calculated minimum turns significantly decreases the transformer error.

**REMARK:**

Criteria A for maximum output voltage per turn is internally measured and indicated by CMR-I unit continuously. The voltage level is indicated by YELLOW and RED LED on front panel and can be monitored via serial interface.

### 3.3.1 External Measurement of the Voltage per Turn

The voltage per turn can be exactly determined via single wire passed through the hole of working CMR-I (this wire represents 1 turn) and measurement of voltage on ends of the wire. The measurement loads the transformer with high impedance of voltmeter only. Advantage of this measurement is that includes the whole secondary current circuit including wiring.
3.4 Power Loss

Primary current source (test system) must cover the total power consumption of CMR-I unit loaded with secondary side load circuit. The transformer power loss can be minimized by minimizing the power losses in both coils. Absolute minimum loss of coil can be achieved by fulfilling these two criteria:

1. choosing primary and secondary wire diameter ratio producing approximately equal losses in primary and secondary coil

\[
\frac{s_p}{s_s} \approx \frac{N_S}{N_P}
\]

2. choosing maximum wire diameters which are capable to fit into the transformer hole

Total power consumption is approximately

\[
S \leq S_s + P_s + P_p
\]

Secondary load power is

\[
S_s = I_s^2 \cdot |Z_L|
\]

Secondary coil power loss is

\[
P_s = I_s^2 \cdot R_s
\]

Primary coil power loss is

\[
P_p = I_p^2 \cdot R_p
\]

Secondary coil resistance (in Ω) for copper wire is approximately

\[
R_s = 0.025 \times \frac{l_s}{d_s^2}
\]

or

\[
R_s = 0.02 \times \frac{l_s}{s_s}
\]

Primary coil resistance (in Ω) for copper wire is approximately

\[
R_p = 0.025 \times \frac{l_p}{d_p^2}
\]

or

\[
R_p = 0.02 \times \frac{l_p}{s_p}
\]
3.5 Examples

In these examples following parameters of CMRI unit from technical specification are used:

- maximum output voltage \( U_{\text{MAX}} \) .................................................. 0.42 V
- maximum AMPERE*TURN \( IV \) ......................................................... 240 A
- maximum load resistance \( RH \) ......................................................... 0.05 \( \Omega \)

3.5.1 Single Wire Application

One turn i.e. one single through going wire as primary coil and similar one wire as secondary coil create current ratio 1:1. The required maximum current is \( I_{\text{MAX}} \) = 120 A.

Resistance of secondary coil (Cu cable with effective cross-section 25 mm\(^2\) and length approx. 1 m):

\[
R_S = 0.025 \times \frac{1m}{25mm^2} = 0.001 \Omega
\]

Maximum total impedance calculated from criteria A:

\[
R_{\text{MAX}} = \frac{U_{\text{MAX}}}{I_{\text{MAX}}} = \frac{N_S \times U_{\text{MAX}}}{I_{\text{MAX}}} = \frac{1 \times 0.42V}{120A} = 0.0035 \Omega
\]

Maximum load impedance:

\[
R_Z = R_{\text{MAX}} - R_S = 0.0035 \Omega - 0.001 \Omega = 0.0025 \Omega
\]

Criteria A is fulfilled when load will not reach value 0.0025 \( \Omega \). Criteria B is fulfilled because \( R_{\text{MAX}} \) (0.0035 \( \Omega \)) < \( RH \) (0.05 \( \Omega \)).
3.5.2 High Impedance Application

CMR-I unit transformer is loaded with high impedance. Load parameters (indirect meter):
- nominal current $I_{NOM}$ ........................................... 1 A
- maximum current $I_{MAX}$ ........................................ 1.2 A
- current circuit resistance $R_L$ .................................. 2 Ω

Required current ratio $N_S:N_P$ ................................... 1:1

Minimum number of turns of secondary circuit obtained from criteria B:

$$N_{S_{min}} = \frac{R_L}{R_H} = \sqrt{\frac{2\Omega}{0.05\Omega}} = 6.3 \approx 7$$

The transformer with 7:7 turns is satisfactory.

Check for criteria A:

$$U_{IT} = I_{MAX} \times R_L / N_S = 1.2 \times 2 / 7 = 0.34V$$

Criteria A is fulfilled because $U_{IT}<0.42V$

3.5.3 Current Multiplier Application

- Current source with small maximum current is used
- Maximum current of current source $I_P$ ........................................... 40 A
- Expected maximum current in secondary circuit $I_S$ ............................. 120 A
- Maximum current of load $I_{MAX}$ ......................................................... 120 A

Current ratio of transformer:

$$M = \frac{I_S}{I_P} = \frac{120A}{40A} = 3$$

Number of primary turns (at $N_S=1$):

$$N_P = M \times N_S = 3 \times 1 = 3$$

The turn ratio is 3:1, i.e. 3 turns of primary coil and 1 through-wire as secondary coil.

Maximum load impedance calculated from criteria A:

$$R_{MAX} = \frac{U_{MAX}}{I_{MAX}} = \frac{N_S \times U_{MAX}}{I_{MAX}} = \frac{1 \times 0.42V}{120A} = 0.0035\Omega$$

Criteria B is fulfilled because $R_{MAX} (0.0035 \Omega) < R_H (0.05 \Omega)$. 
4. Communication

4.1 Introduction

The Precision Electronically Compensated Current Transformer CMR-I 2x30 is (in difference to previous version CMR-I 1x30) equipped with communication module. The communication module enables to monitor and control the CMR-I from computer (PC) via RS-422 line.

Communication between computer and CMR-I units is done via protocol which uses unique communication address of every connected CMR-I unit thus enables to connect multiple CMR-I units to the same communication line.

Communication protocol and commands for communication between computer and CMR-I units are available in form of DLL library. The user can this DLL directly implement into his control software. Basic control, diagnostic and monitoring of CMR-I units from computer can be done also via universal program SERVICER which can be supplied by manufacturer for testing and servicing purposes. Both the DLL library and the SERVICER are available for free.

4.2 Connection to PC

Connection of computer (PC) to CMR-I unit shown in previous chapters description is:

![Connection Diagram](image)

In case of multiple CMR-I units on communication line the adjacent CMR-I units are interconnected with communication cable directly between their COM connectors:
4.2.1 Communication Port RS-422 in PC
For communication of computer (PC) with CMR-I units at least one RS-422 port with connector reduction for connection of communication cable (typically of type RJ45) is required. RS-422 port can be added to computer also by using some optional communication components offered with CMR-I units:

**RS-422 communication sets:**
- **CCC 1001**  Externally RS-232 / RS-422 converter with RJ45 reduction (CC 1001 + CSA 1001)
- **CCC 1002**  Externally USB / RS-422 converter with RJ45 reduction (CC 1002 + CSA 1002)
- **CCC 2010**  Internally RS-422 PCI controller with RJ45 reduction (CC 2010 + CSA 2010)
- **CCC 4010**  Internally RS-422 PCI-Express controller with RJ45 reduction (CC 4010 + CSA 2010)

**RS-422 communication sub-components:**
- **CC 1001**  Externally RS-422 communication converter RS-232 / RS-422
- **CC 1002**  Externally RS-422 communication converter USB / RS-422
- **CC 2010**  Internally RS-422 double-channel communication controller (PCI card)
- **CC 4010**  Internally RS-422 double-channel communication controller (PCI-Express card)
- **CSA 1001**  Serial adapter for CC 1001 (connector reduction DB9 / RJ45)
- **CSA 1002**  Serial adapter for CC 1002 (connector reduction DB9 / RJ45)
- **CSA 2010**  Serial adapter for CC 2010 and CC 4010 (connector reduction DB9 / RJ45)

Drivers for communication converters are available from these links:

<table>
<thead>
<tr>
<th>Converter ID</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC(C) 1002</td>
<td><a href="http://www.appliedp.com/downloads/driver/driver_ccc1002.zip">http://www.appliedp.com/downloads/driver/driver_ccc1002.zip</a></td>
</tr>
<tr>
<td>CC(C) 4010</td>
<td><a href="http://www.appliedp.com/downloads/driver/driver_ccc4010.zip">http://www.appliedp.com/downloads/driver/driver_ccc4010.zip</a></td>
</tr>
</tbody>
</table>

4.2.2 Interconnection Communication Cables
The CMR-I unit is delivered with interconnection communication cable with RJ45 connectors on both sides. The consignment of CMR-I units contains at least one 5 m communication cable for connection of PC to first CMR-I unit and short 0.3 m communication cables for interconnecting all CMR-I units.

4.2.3 Communication Connector COM
Every CMR-I 2x30 unit has two communication connectors of type RJ45 labeled as COM. The connectors are in series which enables chaining of the CMR-I units. The COM connectors are interchangeable.

<table>
<thead>
<tr>
<th>Pin #</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>RX-</td>
<td>RS-422 z PC (-5V level)</td>
</tr>
<tr>
<td>6</td>
<td>RX+</td>
<td>RS-422 z PC (+5V level)</td>
</tr>
<tr>
<td>7</td>
<td>TX-</td>
<td>RS-422 do PC (-5V level)</td>
</tr>
<tr>
<td>8</td>
<td>TX+</td>
<td>RS-422 do PC (+5V level)</td>
</tr>
</tbody>
</table>
4.3 Firmware

Firmware changelog with links to firmware downloads is available from these links:

- old generation CMR-I devices (serial numbers #27xxxxxxxx):
  http://www.appliedp.com/download/fw/cmri/changelog.txt
- new generation CMR-I devices (serial numbers #47xxxxxxxx):
  http://www.appliedp.com/download/fw/cmri/changelog4.txt

Firmware can be uploaded to CMR-I devices using software Firmware Upload CMR-I (see below).

4.4 Software

There are some software utilities developed by Applied Precision for CMR-I product and all are available free of charge.

Software utilities for CMR-I product are designed for simultaneous usage with whole batch of CMR-I units and therefore they are using file cmriaddr.ini which stores communication addresses of CMR-I units on all positions. File cmriaddr.ini has to be located in same directory as the software utility. In case when address file is missing then some software utilities are running in demo mode and some are able to operate in broadcast mode (communicate to address 0 which means one way communication to all connected CMR-I units).

**Rules** for storing communication addresses of CMR-I units in file cmriaddr.ini:
- text after character ';' is ignored
- communication addresses are in hexadecimal format in form 0xABCDEF
- separator(s) between addresses can be: space, comma, tab or end line character
- any number of communication addresses can be stored in one line

**Example** of storing communication addresses of CMR-I units in file cmriaddr.ini:

```plaintext
;2767071564 ;2767071566 ;2767071567 ;2767071568
0x10028D 0x10028E 0x10028F 0x100290
;2767071569 ;2767071570 ;2767071571 ;2767071572
0x100291 0x100292 0x100293 0x100294
```

4.4.1 Firmware Upload - CMRI

This software can be used in Windows XP, Windows 7 or newer operating systems. It is designed for easy firmware upload to CMR-I devices.

Software is available from this link:
http://www.appliedp.com/download/software/servicer/fwuploadcmri/fwuploadcmri_sw.zip

4.4.2 Device Controller - CMRI

This software can be used in Windows XP, Windows 7 or newer operating systems. It is designed for easy control of CMR-I devices and enables for example online checking of burden (contact quality) on measuring positions.

Software is available from this link:
http://www.appliedp.com/download/software/servicer/devcontrolcmri/devcontrolcmri_sw.zip

4.4.3 DLL Package

CMRIDLL package is available for all CMR-I users for implementation of control of CMR-I units into user’s control software. This DLL package contains implementation of communication protocol with all functions required for control of CMR-I units. DLL package is available on request.
5. Method of Accuracy Checking

The proper function of CMR-I unit can be tested (periodically or at strange behaviour) with control measurement described below:

Direct CMR-I error measurement for ratio 1:1 and 1:2 (only one phase is shown - the same circuit is used for each phase of multiphase unit):

Control miliampermeter measures differential current e.g. difference between secondary current $I_s$ and total primary current $I_p$.

Evaluation of relative error: $\sigma = \frac{I_s - I_p}{I_p}$

Measured relative error can be directly interpreted as:

- **max. relative error of current amplitude** providing that error vector is in phase

  or

- **max. phase error** from formula $\varphi \approx \arctan(\sigma)$ providing that amplitude error is negligible

For real circuit both errors contribute so the components are smaller than the measured absolute value.

Correct measurement conditions:

- impedance of miliampermeter smaller than 0.01 $\Omega$

  - drop of potential calculated to primary side of miliampermeter smaller than 30 mV

Inaccuracy of miliampermeter is second-order error. For example an error 0.05 % of CMR-I unit is measured with miliampermeter with 5 % error specification. This miliampermeter affects the measured accuracy by 0.0025 % only.
DECLARATION OF CONFORMITY

Manufacturer’s Name: Applied Precision Ltd.
Manufacturer’s Address: Stavitelska 1
831 04 Bratislava
SLOVAKIA

Declares, that the product

Product Name: Precision Electronically Compensated Current Transformer
Model Number(s): CMR-I 2130A, CMR-I 2130E, CMR-I 2130S
CMR-I 2230A, CMR-I 2230E, CMR-I 2230S
CMR-I 2330A, CMR-I 2330E, CMR-I 2330S
Product Option(s): all options of the above product

Conforms with the following European Directives:


Conforms with the following product standards:

EMC: EN 61326 (dated 1997)

Product is safe under conditions of standard application and carries the CE marking

1st October 2007

Dr. Ladislav GRNO
Director

DATE
NAME and POSITION