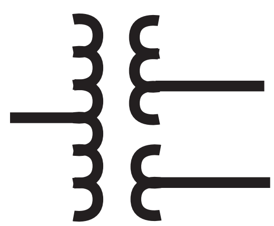
T-PRO

Transformer Protection Relay

Model 8700



User Manual

Version 4.2 Rev 0

Preface

Information in this document is subject to change without notice.

This manual is part of a complete set of product documentation that includes detailed drawings and operation. Users should evaluate the information in the context of the complete set of product documentation and their particular applications. ERLPhase assumes no liability for any incidental, indirect, or consequential damages arising from the use of this documentation.

While all information presented is believed to be reliable and in accordance with accepted engineering practices, ERLPhase makes no warranties as to the completeness of the information.

All trademarks used in association with B-PRO, F-PRO, L-PRO, ProLogic, T-PRO, TESLA, TESLA Control Panel, RecordGraph and RecordBase are trademarks of ERLPhase Power Technologies Ltd.

Windows® is a registered trademark of the Microsoft Corporation.

Procomm® is a registered trademark of Symantec.

HyperTerminal® is a registered trademark of Hilgraeve.

Modbus® is a registered trademark of Modicon.

Contact Information

ERLPhase Power Technologies Ltd.

Website: www.erlphase.com

Email: info@erlphase.com

Technical Support

Email: support@erlphase.com

Tel: 1-204-477-0591

Table of Contents

Using This Guide

This User Manual describes the installation and operation of the T-PRO transformer protection relay. It is intended to support the first time user and clarify the details of the equipment.

The manual uses a number of conventions to denote special information:

Example	**Describes**
Start>Settings>Control Panel	Choose the Control Panel submenu in the Settings submenu on the Start menu.
Right-click	Click the right mouse button.
Recordings	Menu items and tabs are shown in italics.
service	User input or keystrokes are shown in bold.
Text boxes similar to this one	Relate important notes and information.
..	Indicates more screens.
▶	Indicates further drop-down menu, click to display list.
	Indicates a warning.

Version Compatibility

This chart indicates the versions of *Offliner* Settings, RecordBase View and the User Manual which are compatible with different versions of T-PRO firmware.

RecordBase View and *Offliner* Settings are backward compatible with all earlier versions of records and setting files. You can use RecordBase View to view records produced by any version of T-PRO firmware and *Offliner* Settings can create and edit older setting file versions.

Minor releases (designated with a letter suffix - e.g. v3.1a) maintain the same compatibility as their base version. For example. T-PRO firmware v3.1c and *Offliner* Settings v3.1a are compatible.

T-PRO Firmware/Software Compatibility Guide

T-PRO Firmware	Setting Version	Compatible *Offliner* Settings
v4.2	11	4000 v1.1 or greater
v4.1a	10	v4.1 and greater
v4.1	10	v4.1 and greater
v3.5c	8	v3.5 and greater
v3.5b	8	v3.5 and greater
v4.0	9	v4.0 and greater
v4.0	9	v4.0 and greater

Please contact ERLPhase Customer Service for complete Revision History.

1 Overview

Introduction

The T-PRO (model 8700) is a microprocessor-based relay providing protection, monitoring, logging and recording for a power transformer. For asset management, the T-PRO includes adaptive overload, load shedding options and transformer overload early warning system (TOEWS©) functions.

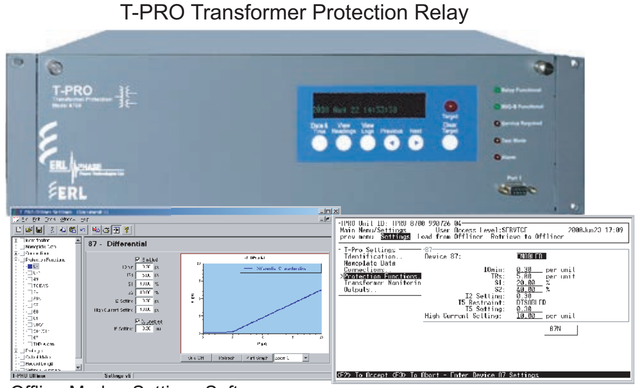
T-PRO has two working modes—online and offline. In the online mode you can use any communication software package (e.g. Procomm or HyperTerminal) to connect to the T-PRO using VT100 terminal emulation. In online mode you can:

- change and review relay settings
- view event and metering information
- initiate and retrieve recordings, and retrieve settings

In offline mode you can use *Offliner* Settings and RecordBase View software to:

- create and review relay settings
- analyze fault waveforms
- store records

T-PRO Transformer Protection Relay



Offline Mode - Settings Software

Online Mode - Terminal Mode

In addition to the protection functions T-PRO provides fault recording (96 samples/cycle) to facilitate analysis of the power system after a disturbance has taken place. The triggers for fault recording are established by programming the output matrix and allowing any internal relay function or any external input to initiate recording.

The primary protection is differential. The restraint is user-definable. 2nd and 5th harmonic restraint are provided as well as a high current unrestrained setting.

To provide a complete package of protection and control T-PRO provides other functions such as:

- temperature monitoring
- TOEWS for asset monitoring loss of life
- digital control of current inputs allow switching
- overexcitation, frequency (fixed level or rate of change), neutral overvoltage, undervoltage, thermal overload, THD, adaptive pickup overcurrent, neutral differential functions provide additional protection needs
- ProLogic control statements provide user-configurable logic functions

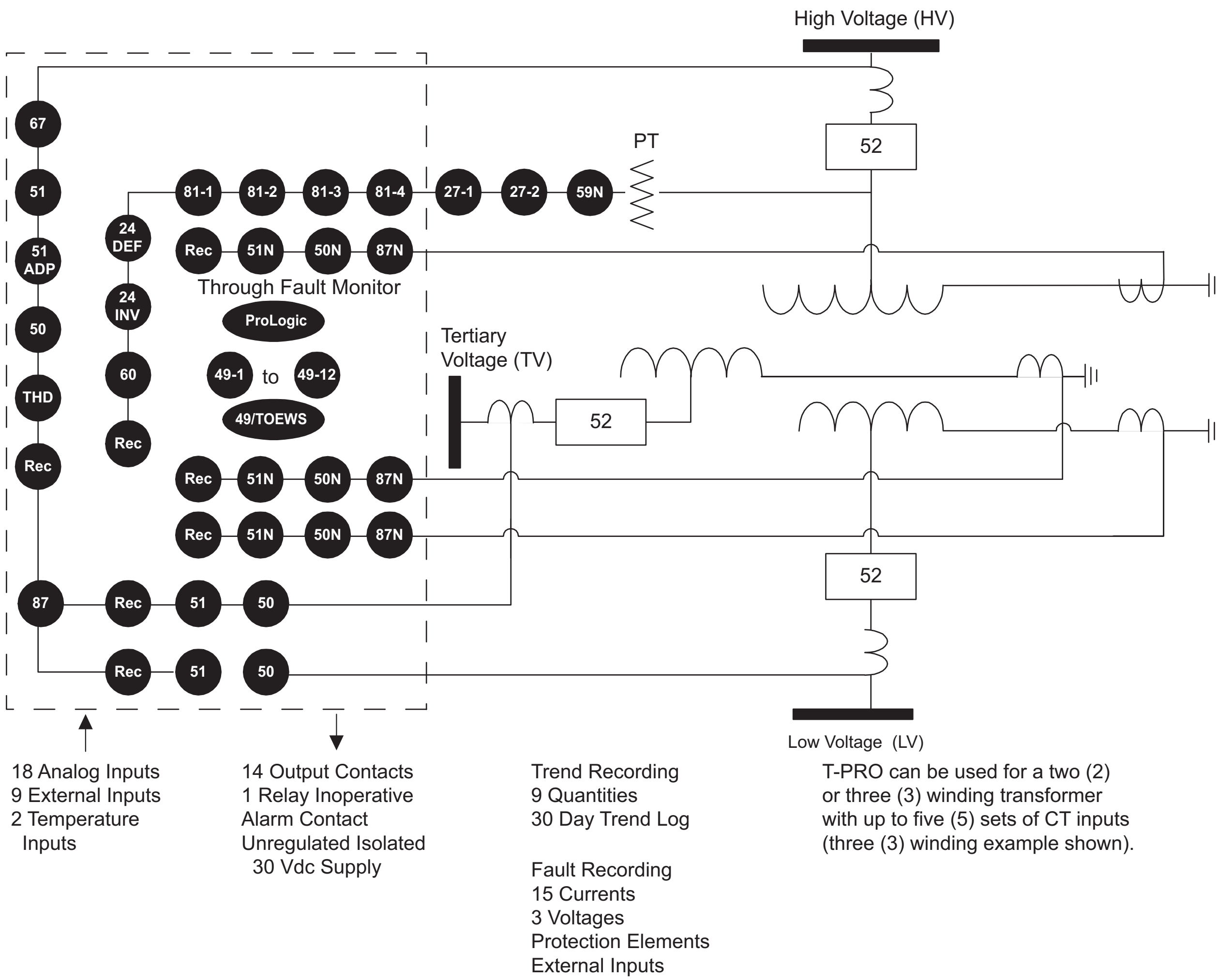
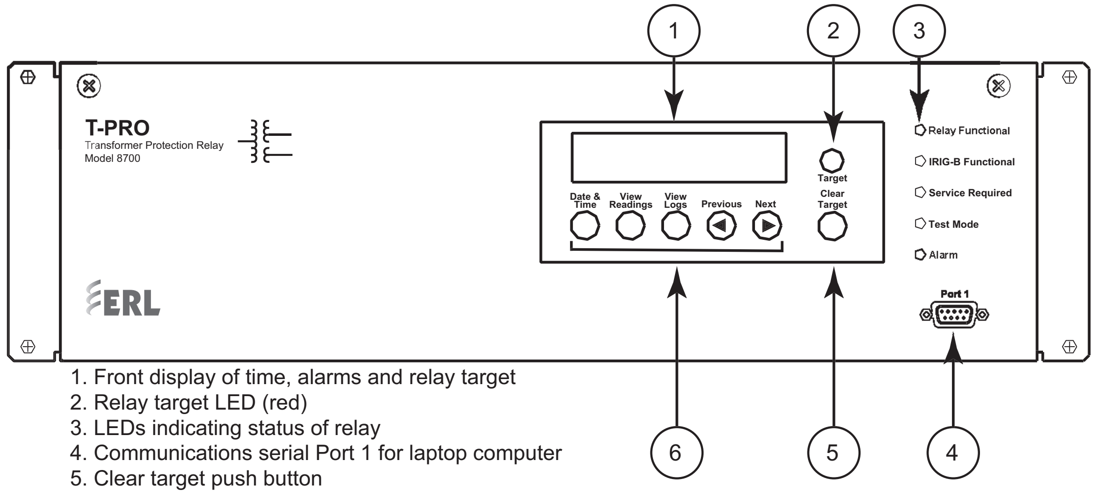


Figure 1.1: T-PRO Function Line Diagram

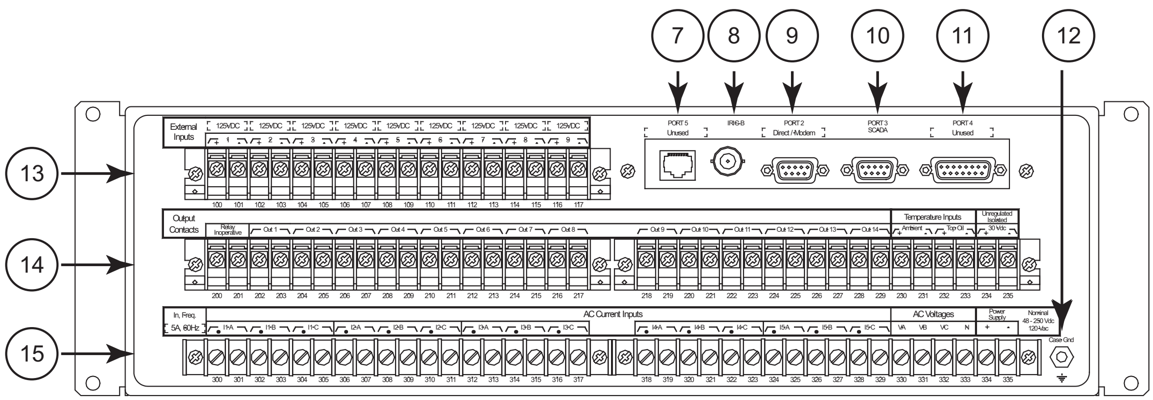
Front View



1. Front display of time, alarms and relay target
2. Relay target LED (red)
3. LEDs indicating status of relay
4. Communications serial Port 1 for laptop computer
5. Clear target push button
6. Push buttons to manipulate information on LED display

Figure 1.2: T-PRO Front View

Back View



7. Port 5 - 10BaseT Ethernet Port/Internal Modem (optional)
8. External clock, IRIG-B modulated or unmodulated
9. Port 2 - Direct/Modem RS-232 Port
10. Port 3 - SCADA
11. Port 4 - unused
12. Case ground
13. 9 programmable external inputs
14. This row contains two distinct areas from left to right
    - Relay inoperative contact and 14 programmable output relay contacts
    - Temperature inputs and isolated power supply
15. This row contains three distinct areas from left to right
    - 15 ac current inputs
    - 3 ac voltage inputs
    - Power supply

Figure 1.3: T-PRO Back View

AC Current and Voltage Inputs

T-PRO is provided with terminal blocks for up to 15 ac currents and 3 phase-to-neutral voltages.

Each of the current input circuits has polarity (•) marks.

A complete schematic of current and voltage circuits is shown, for details see “AC Schematic Drawing” in Appendix I and “DC Schematic Drawing” in Appendix J.

External Inputs

The T-PRO Relay contains 9 programmable external inputs. External dc voltage of either 48/125 volts or 125/250 volts nominal are possible depending on the range provided.

Output Relay Contacts

The T-PRO Relay has 14 output relay contacts. Each contact is programmable and has breaker tripping capability. All output contacts are isolated from each other. The output contacts are closed for a minimum of 100 ms after operation.

Relay Inoperative Alarm Output

If the relay becomes inoperative, then the Relay Inoperative Alarm output contact closes and all tripping functions are blocked.

Model Options/Ordering

T-PRO is available for either horizontal or vertical mount, for details see “Mechanical Drawings” in Appendix G.

T-PRO is available with an internal modem card or internal network card.

The CT inputs are 1 A nominal or 5 A nominal. The external inputs are 48/125 Vdc or 125/250 Vdc. The system base frequency is either 50 Hz or 60 Hz.

All of the above options must be specified at the time of ordering.

2 Setup and Communications

Power Supply

A wide range power supply is standard. The nominal operating range is 48 to 250 Vdc, 120 Vac, 50/60 Hz. To protect against a possible short circuit in the supply use an inline fuse or circuit breaker with a 5 A rating. Make the chassis ground connection to ensure proper operation and safety.

There are no power switches on the relay. When the power supply is connected, the relay starts its initialization process and takes about 40 seconds to complete showing the green Relay Functional LED.

Case Grounding

You must ground the relay to the station ground using the case-grounding terminal at the back of the relay, for details see for details see Figure 1.3: T-PRO Back View on page 1-3.

WARNING!

To ensure safety and proper operation you must connect the relay to the station ground using the rear grounding terminal on the relay.

Ground the relay even when testing.

Do not rely on the rack mounting screws to provide case grounding.

IRIG-B Time Input

The relay is equipped to handle modulated or unmodulated GPS satellite time IRIG-B signals. The IRIG-B time signal is connected to the BNC connection on the back of the relay. When the IRIG-B signal is provided to the relay and is enabled in the settings through the user interface, the IRIG-B functional LED comes on and the relay clock is referenced to this signal. No settings are required to differentiate between modulated or unmodulated signals; this is automatically detected by the relay.

You can enable or disable the IEEE 1344 extension in the terminal mode settings *Utilities>Setup>Time.* The enabled mode receives the year from the IRIG-B signal. Disable this setting, if the available IRIG-B signal has no year extension.

Communicating with the Relay (IED)

You can connect to the relay to access its user interface and SCADA services by:

- direct serial link (user interface and SCADA)
- external or internal modem link (user interface only)
- ethernet network link (user interface and SCADA)

Direct Serial Link

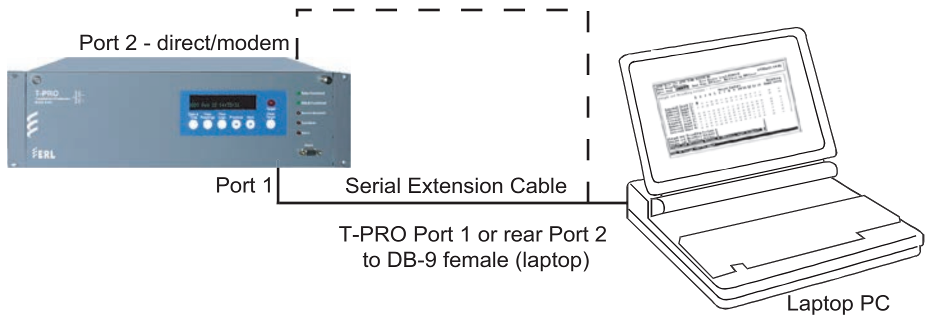


Figure 2.1: Direct Serial Link

The relay has three serial ports that provide direct access to its user interface and SCADA services.

All of the relay's serial ports (Ports 1, 2 and 3) are configured as EIA RS-232 Data Communications Equipment (DCE) devices with female DB9 connectors. This allows them to be connected directly to a PC serial port with a standard straight-through male-to-female serial cable, for pin-out see "Communication Port Details" on page 2-9.

The relay's user interface is accessed through a standard VT-100 terminal emulation program running on a PC. To create a direct serial link between the relay and your computer, connect the serial cable (provided) between your computer's serial port and Port 1 on the relay's front panel. Port 2 on the relay's back panel can also be used for direct serial access, provided the port is not configured for modem use. Once connected, run the terminal emulation software on your computer to establish the communication link, for details see "Using HyperTerminal to Access the Relay's User Interface" on page 2-5.

The relay's Modbus and DNP3 SCADA services can be accessed through a direct serial link to Port 3 on the relay's back panel, for details see "Accessing the SCADA Services" on page 2-8.

Modem Link - External

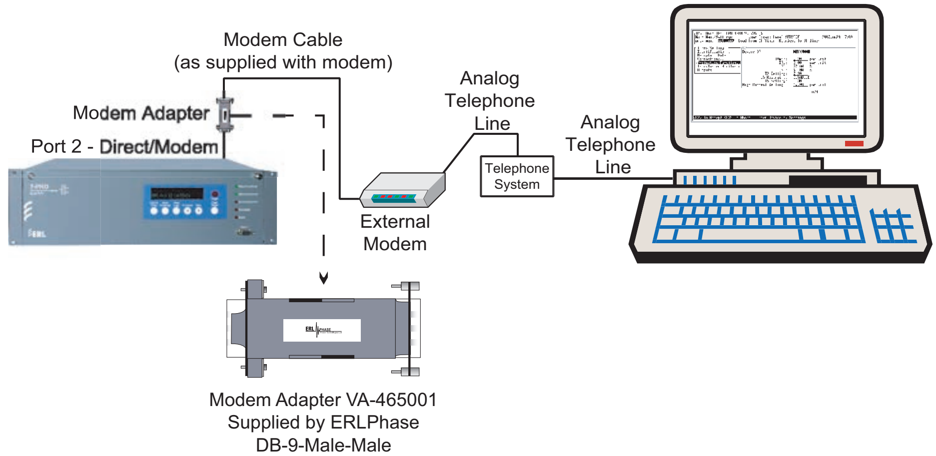


Figure 2.2: External Modem Link

Using an external modem, you can also access the relay's user interface through a telephone link between the relay and your computer.

Connect the serial port on the external modem to Port 2 on the relay's back panel. Both devices are configured as RS-232 DCE devices with female connectors, so the cable between the relay and the modem requires a crossover and a gender change. Alternatively, you can use the ERLPhase modem port adapter provided with the relay to make Port 2 appear the same as a PC's serial port. A standard modem-to-PC serial cable can then be used to connect the modem and the relay. For pin-out details see "Communication Port Details" on page 2-9.

Connect the modem to an analog telephone line or switch using a standard RJ-11 connector.

You must appropriately configure the relay's Port 2 to work with a modem. Log into the relay through a direct serial link, go to the *Utilities>Setup>Ports* screen, and set *Port 2 Modem* option to *Yes*. Set the *Baud Rate* as high as possible — most modems handle 57,600 bps. The *Initialize* setting allows you to set the control codes sent to the modem at the start of each connection session. The factory defaults are: "M0S0=0&B1" for an external modem and "M0S0=0" for an internal modem.

Modem Link - Internal

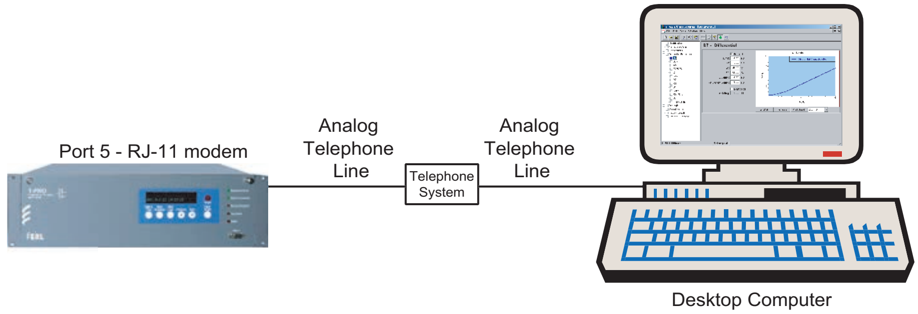


Figure 2.3: Internal Modem Link

You can access the relay's user interface through a telephone link between the relay and your computer using an optional internal modem. If the modem has been installed, Port 5 on the rear panel is labelled "INTERNAL MODEM."

Connect the relay's Port 5 to an analog telephone line or switch using a standard RJ-11 connector.

When an internal modem is installed, the relay's Port 2 is used to interface to the modem internally. Appropriate Port 2 settings are configured at the factory when the internal modem is installed. The factory defaults are: "M0S0=0&B1" for an external modem and "M0S0=0" for an internal modem.

Network Link

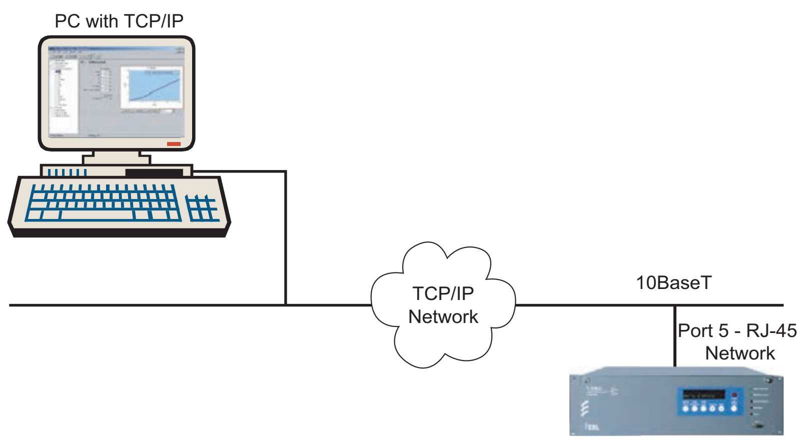


Figure 2.4: Network Link

You can access both the relay's user interface and DNP3 SCADA services simultaneously through the same network port with an optional Ethernet TCP/IP LAN link. If the Ethernet option has been installed, Port 5 on the rear panel will be labelled "NETWORK."

The user interface accessed through the LAN is the same as that available through a direct serial connection or a modem link, but requires the use of a Telnet client on your PC. The HyperTerminal program, which is included in Windows XP and is also available separately as HyperTerminal PE, provides Telnet services. To select Telnet, go to HyperTerminal's Properties dialog box and set the *Connect Using* field to *TCP/IP (Winsock)*. If this option is not available in the pick list, you require a newer version of HyperTerminal (v1.2 or greater). Alternatively, you can use any Telnet program that fully supports VT-100 terminal emulation and z-modem file transfer.

DNP3 SCADA services can also be accessed over the LAN, for details see “Accessing the SCADA Services” on page 2-8.

Connect Port 5 to the Ethernet LAN using an appropriate 10BaseT cable with an RJ-45 connector. The relay supports 10 Mbit Ethernet, although a dual speed 10/100 Ethernet hub or switch can be used.

By default, the relay is assigned an IP address of 192.168.1.100. If this address is not suitable, it may be modified using the relay’s Maintenance Menu. For details see “Using HyperTerminal to Access the Relay’s User Interface” on page 2-5.

Using HyperTerminal to Access the Relay’s User Interface

Change settings, view measured values and retrieve data from the relay using its user interface. This section describes how to configure a standard Windows VT-100 terminal program on your PC for use with the relay.

The computer must be connected to the relay by one of its serial, modem or Ethernet communication ports, for details see “Communicating with the Relay (IED)” on page 2-2.

The relay user interface is accessed using a standard VT-100 terminal style program on your computer eliminating the need for specialized user interface software. Any terminal program that fully supports VT-100 emulation and provides z-modem file transfer services can be used. The HyperTerminal program, which is included in Windows XP and is also available separately as HyperTerminal PE, is used here as an example.

Configure your terminal program as described in the table below and link it to the appropriate serial port, modem or TCP/IP socket on your computer.

Terminal Program Setup	
Baud rate	For a direct serial link the baud rate must match that of the relay serial port. For a modem link the baud rate refers only to the link between your computer and its own modem. Refer to “Setting the Baud Rate” on page 2-7 for further information.
Data bits	8
Parity	None
Stop bits	1
Flow control	Hardware or Software. Hardware flow control is recommended. The relay automatically supports both on all its serial ports.
Function, arrow and control keys	Terminal keys
Emulation	VT100

Terminal Program Setup	
Font	Use a font that supports line drawing (e.g. Terminal or MS Line Draw). If the menu appears outlined in odd characters, the font you have selected is not supporting line drawing characters.

To initiate a connection with the relay use HyperTerminal's *Call>Connect* function.

When the connection is established, press *Enter* in the terminal window to bring up the following login prompt.

```
---------- ERLPhase T-PRO 8700 Terminal User Interface login ----------


Log in using one of the following usernames:
  'view' - read-only access to settings and readings
  'change' - read/write access to settings and readings
  'service' - full access to all functions (Port 1 access only)
  'maintenance' - access to the maintenance menu
  'update' - to load a firmware update (Port 1 access only)


Notes:
- Serial and modem connections have a 60 minute inactivity timeout
- Usernames and passwords are case sensitive

login:
```

Instructions for logging in and running the user interface are given in "Terminal Mode" on page 3-5.

If you see incorrect characters on a direct serial connection, it may mean there is a mismatch between the relay's baud rate and that of the PC.

Ending a User Interface Session

Use the *Quit* function in the relay's user menu to end a session. This closes the interface and requires the next user to login to the relay.

The relay automatically ends a session when it detects the disconnecting of a direct serial cable or a modem hang-up. For other types of connections (e.g. serial switches or Ethernet) use the Quit function to ensure the interface is closed and login protection is activated.

Setting the Baud Rate

> The baud rate of the relay's serial ports can be shown on the relay's front panel display. From the main *Date & Time* display, press the *Next* button.

Direct Serial Link

For a direct serial connection both the relay and your computer must be set to the same baud rate.

To change the baud rate of a relay serial port:

1 Access the relay's user interface through any of the available ports.

2 Login to the user interface and go to the *Utilities>Setup>Ports* menu, for details see "Terminal Mode" on page 3-5.

3 Select the desired baud rate for the appropriate port by toggling through the options using the Space or Enter keys. Save the new setting with the F2 key. The message "New communications settings loaded" will appear.

The new baud rate will be used on that port the next time you login to it.

To change the baud rate on your computer's serial port:

1 From HyperTerminal bring up the *Properties* dialog box, press the *Configure* button and set the baud rate field to the desired value.

2 Save the changes.

Modem Link

Unlike a direct serial link, the baud rates for a modem link do not have to be the same on your computer and on the relay. The modems automatically negotiate an optimal baud rate for their communication.

The baud rate set on the relay only affects the rate at which the relay communicates with the modem. Similarly, the baud rate set in HyperTerminal only affects the rate at which your computer communicates with its modem. Details on how to set these respective baud rates are described in "Modem Link - External" on page 2-3, except that you modify the Port 2 baud rate on the relay and the properties of the modem in HyperTerminal.

Accessing the SCADA Services

The relay supports DNP3 (Level 2) and Modbus SCADA protocols as a standard feature on all relays. DNP3 is available through a direct serial link or the Ethernet LAN on top of either TCP or UDP protocols. The Modbus implementation supports both RTU (binary) or ASCII modes and is available through a direct serial link.

The relay's Port 3 is dedicated for use with Modbus or DNP3 serial protocols. Port 3 uses standard RS-232 signalling. An external RS-232<->RS-485 converter can also be used to connect to an RS-485 network.

For details on connecting to serial Port 3 see "Communicating with the Relay (IED)" on page 2-2 and "Communication Port Details" on page 2-9.

The DNP3 protocol can also be run across the optional Ethernet LAN. Both DNP over TCP and DNP over UDP are supported, for details on connecting to the Ethernet LAN see "Network Link" on page 2-4.

Complete details on the Modbus and DNP3 protocol services can be found in "Modbus RTU Communication Protocol" in Appendix E and "DNP3 Communication Protocol" in Appendix F.

Protocol Selection

To select the desired SCADA protocol, login to the relay's user interface and access the *Utilities>Setup>SCADA* menu. Select the protocol and set the corresponding parameters.

> The DNP3 LAN/WAN - TCP and UDP options are only available if the unit has an optional Ethernet LAN port installed.

Communication Parameters

Port 3's communication parameters are set using the *Utilities>Setup>Ports* menu in relay's user interface. Both the baud rate and the parity bit can be configured. The number of data bits and stop bits are determined automatically by the selected SCADA protocol. Modbus ASCII uses 7 data bits. Modbus RTU and DNP Serial use 8 data bits. All protocols use 1 stop bit except in the case where either Modbus protocol is used with no parity; this uses 2 stop bits, as defined in the Modbus standard.

Diagnostics

Protocol monitor utilities are available to assist in resolving SCADA communication difficulties such as incompatible baud rate or addressing. The utilities can be accessed through the Maintenance user interface, for details see "Maintenance Menu" on page 2-12.

Communication Port Details

Port	Location	Function
1	Front Panel	RS-232 Data Communication Equipment (DCE) female DB9. Used for user interface access through a direct serial connection. Default Setting: 38,400 baud, 8 data bits, no parity, 1 stop bit.
2	Rear Panel	RS-232 DCE female DB9. Used for: • User interface access through a direct serial connection. • User interface access through an external modem. The optional ERLPhase Modem Adapter converts this port to a Data Terminal Equipment (DTE) to simplify connection to an external modem. Default Setting: 9,600 baud, 8 data bits, no parity, 1 stop bit. Port 2 is disabled if the relay is equipped with an internal modem (see Port 5).
3	Rear Panel	RS-232 DCE female DB9. Used for SCADA communication. Default Setting: 9,600 baud, 8 data bits, no parity, 1 stop bit.
4	Rear Panel	Not used
5	Rear Panel	RJ-11/RJ-45 receptacle. When equipped with optional internal modem: • Used for user interface access through modem. When equipped with optional internal Ethernet card: • User interface access. • DNP SCADA access. Default Ethernet IP address: 192.168.1.100.

Signal Name	Direction PC<-> Relay	Pin # on the Relay Port
DCD	←	1
RxD	←	2
TxD	→	3
DTR	→	4
Common		5
DSR	←	6
RTS	→	7
CTS	←	8
No connection		9

Notes:

- Relay is DCE, PC is DTE
- Pins 1 and 6 are tied together internal to the relay

Male DB-9 Cable End for Relay Port	Female DB-9 Cable End for Computer Port
Pin # on Cable	Pin # on Cable
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9

Signal Name	Direction Modem <-> Relay	Pin # on the Modem Adapter
DCD	→	1
RxD	→	2
TxD	←	3
DTR	←	4
Common		5
DSR	→	6
RTS	←	7
CTS	→	8
No connection		9

Notes:

- Relay (with modem adapter) is DTE, modem is DCE
- Pins 1 and 6 are tied together internal to the relay

Maintenance Menu

The relay has a Maintenance Menu that can be accessed by connection through a VT-100 terminal emulator (such as the HyperTerminal). Using either direct serial or modem connection:

1 Use the terminal program to connect to the serial port, either through direct serial link or modem.

2 Select *Enter*, the relay responds with a login prompt.

3 Login as “maintenance” in lower case.

A menu appears as below.

```
NxtPhase System Utility v1.3

NxtPhase Corporation
Customer support : (204) 477-0591, support@nxtphase.com


1 : *Modify IP Address, subnet mask and default gateway (if applicable)
2 :  View system diagnostics
3 :  Retrieve system diagnostics
4 : *Restore ALL default settings, including calibration
5 : *Restore only default configuration settings (channel definitions, device se
ttings)
6 : *Restore only default system setup (ports, time settings)
7 : *Force hardware reset
8 :  View network statistics (if applicable)
9 :  Monitor SCADA
10: *Enable/Disable Internal Modem (if one exists)
11:  Exit

    * port 1 access only

Please enter a command:
[1-11] #
```

Figure 2.5:

> Commands 1, 4, 5, 6, 7 and 10 are Port 1 access only.

Modify IP address	Modifies the LAN IP address when equipped with an optional internal 10BaseT Ethernet card.
View system diagnostic	Displays the internal status log.
Retrieve system diagnostics	Automatically packages up the internal status log plus setting and setup information and downloads it in compressed form to your computer. This file can then be sent to our customer support to help diagnose a problem.
Restore settings	Use this menu to force the system back to default values, if you suspect a problem due to the unit’s settings, calibration and/or setup parameters.
Force hardware reset	Manually initiates a hardware reset. Note that the communication link is immediately lost and cannot be re-established until the unit completes its start-up.

View network statistics	View IP, TCP and UDP statistics when equipped with internal 10BaseT Ethernet card.
Monitor SCADA	Shows real time display of SCADA data.
Enable/disable Modem	Enables or disables the internal modem.

Firmware Update

The relay has an update login that can be accessed by a connection through a VT100 terminal emulator (such as HyperTerminal). This login is available only from Port 1.

1 Use the terminal program to connect to Port 1.

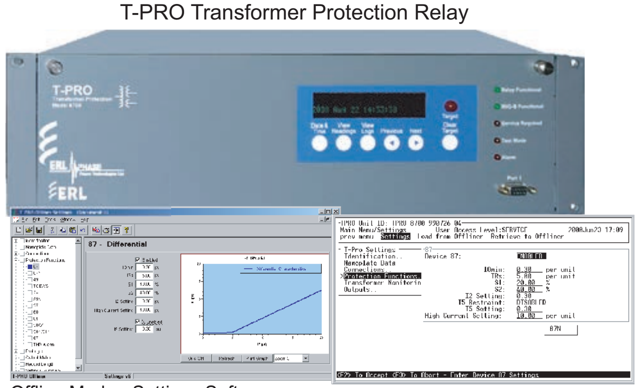
2 Select *Enter*, the terminal responds with a login prompt.

3 Login as **update** in lower case.

The firmware update is used to update the relay's software with maintenance or enhancement releases. Please see the T-PRO Firmware Update Procedure documentation that comes with the firmware update for instructions on how to update the firmware on the relay.

3 Using the IED (Getting Started)

T-PRO Transformer Protection Relay



Offline Mode - Settings Software

Online Mode - Terminal Mode

Start-up Sequence

The following initialization sequence takes place:

Test Mode—red LED on	2 seconds after power applied
Relay Functional—green LED on	5 seconds after power applied
Front Display—on	30 seconds after power applied
Test Mode—red LED off	40 seconds after power applied

When the relay is powered up, the normal sequence of LED operation is Test Mode followed by Relay Functional and IRIG-B Functional (if available), display on, then Test Mode off. The entire sequence takes about 40 seconds.

Ways to interface with the relay:

- Front panel display
- Terminal Mode
- *Offliner* Settings software

Front Panel Display

View or change settings using Terminal Mode or loading a setting file from *Offliner* Settings.

The front panel display is the fastest and easiest way of getting information from the relay.

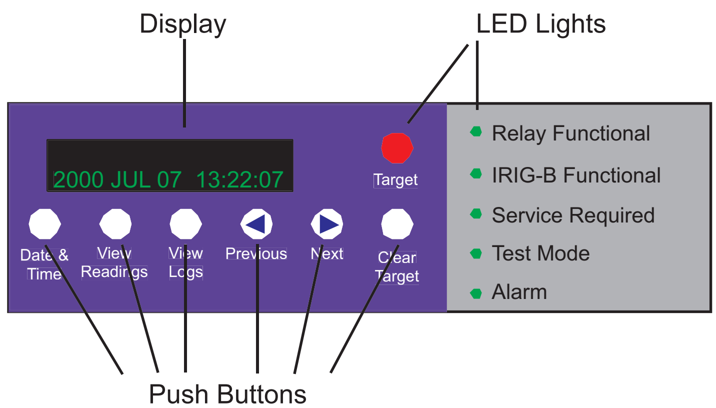


Figure 3.1: Front Panel Display

The display, the six LED lights and the six push buttons provide selective information about the relay.

LED Lights

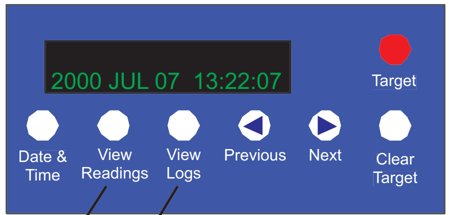
Relay Functional	Indicates when the relay is functional. When the Relay Functional green LED goes on, the rear Relay Inoperative contact changes to open and the protective functions become functional.
IRIG-B Functional	Indicates the presence of a valid IRIG-B time signal.
Service Required	Indicates the relay needs service. This LED can be the same state as the Relay Functional LED or can be of the opposite state depending on the nature of the problem. The following items bring up this LED: • DSP failure - protection difficulties within the relay. • Communication failure within the relay. • Internal relay problems.
Test Mode	Occurs when the relay output contacts are intentionally blocked. Possible reasons are: • Relay initialization on start-up • User interface processor has reset and is being tested. You cannot communicate with the relay through the ports until the front display becomes active and the Test Mode LED goes out. Normally, the red Target LED remains off after this start-up unless the relay had unviewed target messages. Output contacts are controlled from the *Utilities* menu.

Alarm	Occurs when an enabled relay function picks up. The red Alarm LED should be off if there are no inputs to the relay. If the Alarm LED is on, check the event log messages on the front display by pressing the *View Logs* button.
Target	Indicates that a fault has taken place. An event message with date and time is presented in the display.

Push Buttons

Date & Time	Pressing the Date & Time button displays the date and time stored on the relay. If the time is incorrect, connect to a PC in Terminal Mode and go to *Utilities>Setup>Time* to make the change or connect to the IRIG-B plug at the back of the relay. The front display time and date is automatically updated. The green IRIG-B Functional LED comes on. The relay accepts either modulated or unmodulated IRIG-B signals automatically. Options using IRIG-B, such as time skew for different time zones are available when you establish communication with the PC.
View Readings	Pressing the View Readings button obtains metering information about the transformer, for details see “Display” on page 3-4.
View Logs	Pressing the View Logs button displays the target information if a relay operation has occurred, for details see “Display” on page 3-4.
Previous/Next	Scroll through the menu by pressing Previous and Next.
Clear Target	When a fault takes place, the red target light appears. Use the Clear Target button to view all target information. If many faults have been stored, you may need to push this button several times. Clearing the target light does not clear the target information from the relay log. The relay holds all target messages during a power supply shutdown and restart. Pressing the Clear Target push button displays any targets not previously viewed on the front display and clears the Target LED after the last target has been viewed.

Display



View Readings

```
Pri   V  0.0 KV  ph-ph
      I  0.0 A   line
```

View Logs

```
2000Jun28  19:34:31.823
Top Oil Under-Range:Alrm
```

Figure 3.2: Display Examples

Front Panel Display Messages
PRI V, I, P, Q
Ambient, top oil, hot spot temperature, trip date and time of all functions involved.

Terminal Mode

1 Establish terminal mode connection, for details see “Using HyperTerminal to Access the Relay’s User Interface” on page 2-5.

2 Login as one of **view**, **change** or **service** (lower case). These three login names provide differing levels of permission.

> The relay supports the optional use of passwords. A pop-up dialogue box appears after login has taken place.
>
> If you have forgotten the password, go to *Access>Passwords* in Terminal Mode, for details see “Passwords” on page 3-6.

3 When connection is established and the terminal mode program appears on your screen, the following prompt should appear. If it doesn’t appear, press *Enter*.

```
---------- ERLPhase T-PRO 8700 Terminal User Interface login ----------


Log in using one of the following usernames:
  'view' - read-only access to settings and readings
  'change' - read/write access to settings and readings
  'service' - full access to all functions (Port 1 access only)
  'maintenance' - access to the maintenance menu
  'update' - to load a firmware update (Port 1 access only)


Notes:
- Serial and modem connections have a 60 minute inactivity timeout
- Usernames and passwords are case sensitive

login:
```

4 If login is successful, the Main Menu appears:

```
TPRO Unit ID: Your ID entered earlier
Main Menu      User Access Level: VIEW       2000 Jun 08 11:53
ID  Settings  Metering  Records  Event Log  Utilities  Access  Quit
```

view, change or **service**
(depends on how you log in)

> If the box around the menu does not appear as above, change the font in your terminal program to one that supports line draw characters, e.g. terminal fonts. Also ensure that emulation is set to VT100 (not VT100J).
>
> If there are incorrect characters in the display, improper line feeds or unerased portions, the baud rate is too high for the quality of the communication link. Use the *Utilities>Setup>Ports* menu to reduce the relay’s baud rate. The new rate is in effect at the next connection.

The relay supports three user access levels that control what relay functions are available to you. The current access level is always shown in the centre of the Main Menu heading.

To change the Access Level either login again using the desired access level as your login name or use the *Main Menu>Access* menu.

Access	Level	Allowed actions
view	lowest	View settings, online readings and logs. List and retrieve records. At this level you cannot affect the operation of the controller.
change	middle	Do all of the above, plus change the settings and delete records.
service	highest	Do all of the above two categories, plus calibrate the analog inputs, manually control output auxiliary relays and modify passwords.

Service access is only available through a local, front port connection.

Passwords

Individual passwords for the view and change access levels are available to prevent or limit remote access to the relay. Passwords are not required for the service level. This level is only available at the front of the local relay through serial Port 1.

You can only change the passwords from the service level through the Access menu minimizing the chance that a password is changed casually and provides a means of resolving situations where a password has been forgotten.

Terminal Mode Menus

Use the right and left arrow keys and the Enter key to move around in the terminal mode screen. The mouse does not work in VT100 terminal mode. Items from the menu are selected by moving the highlight to the desired item and activating it using the Enter key. As a short-cut, use the first letter of the menu item to access it directly.

Key	Function
<F2>	Accept or Freeze or Execute
<F3>	Quit or Exit
<Esc>	Back to previous menu level

The menu tree consists of a series of sub-menus, for details see Figure 3.3: Terminal Mode Menus on page 3-8.

The Enter key allows you to toggle through a list of selections, i.e. enabled/disabled. The Enter key toggles forward through the list, while the space bar moves backward through the list. In this manner you do not have to scroll through the entire list to get back to a previous selection, you can use the space bar.

For certain lists a pick box appears when there is a long list of selections to chose from, for example, ProLogic inputs. You can scroll though these boxes with the arrow keys or the Enter key. Use the F2 key to make a selection or F3 to leave.

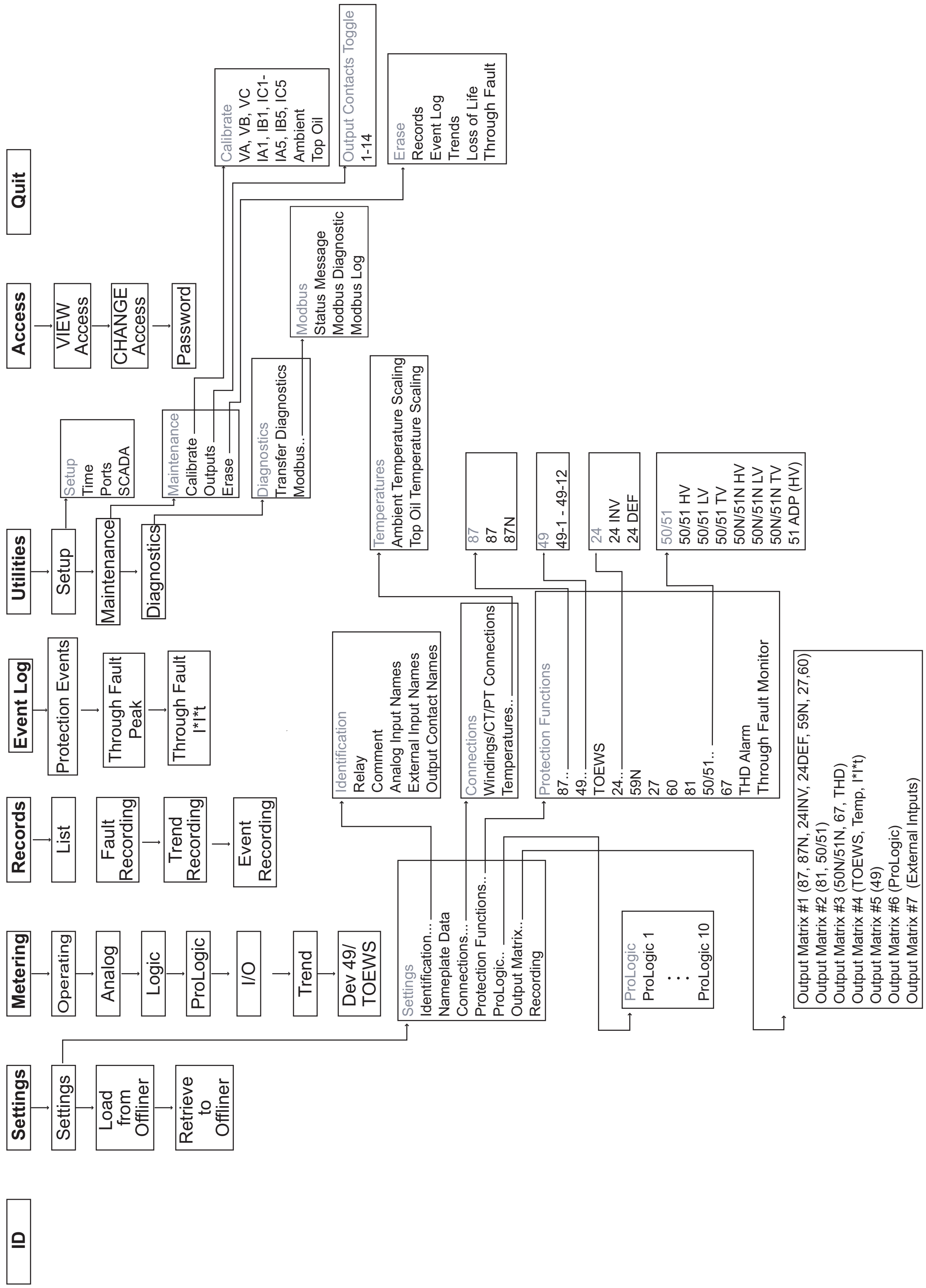


Figure 3.3: Terminal Mode Menus

The Main Menu display is:

```
ID  Settings  Metering  Records  Event Log  Utilities  Access  Quit
```

ID

Provides the device serial number, software version and required settings version, system frequency, CT rating and external input type. There are no user settings here.

Settings

Submenus: Settings, Load from *Offliner*, Retrieve to *Offliner*

Settings

Settings includes all the submenus pertaining to protection functions used to create a relay setting. When these settings are made or changed, you can load them into the relay allowing input of all settings information for the relay.

Settings submenus: Identification, Nameplate Data, Connections, Protection Functions, ProLogic, Output Matrix and Recording.

Identification..	
Relay	Serial Number, Software Version, Relay ID, Line Name, Station Name, Station Number and Location.
Comments	Enter any appropriate comment.
Analog Input Names	Name inputs, I1A, I1B, I1C, I2A, I2B, I2C, I3A, I3B, I3C, I4A, I4B, I4C, I5A, I5B, I5C, VA, VB, VC, N
External Inputs Names	Name external inputs 1 to 9.
Output Contact Names	Name auxiliary relay output contacts 1 to 14.

The following characters are not allowed in the above setting parameters: “ ”, “\”, “/”, “:”, “*”, “?”, “|”, ““‘, “<“, and “>”.

Load From *Offliner*

You can download the settings file into the relay using the terminal mode menu.

1 On the Window’s desktop, double-click T-PRO O*ffliner* Settings icon. The initial *Offliner* Settings screen appears.
2 Enter the required settings.
3 Save the settings to a file on your PC.
4 Start the Terminal Mode of T-PRO, login as **change** or **service,** then access the *Settings* menu and activate *Load from Offliner* function.
5 Reply *Yes* to the “Ready to load remote setting.” prompt.
6 In your terminal program, initiate transfer of the setting file created in step 2 above. (For example, with HyperTerminal, you would select *Transfer*, then *Send File*. Browse to find the file, then select *Open* and finally, *Send*.
7 When the file has been transferred, verified and loaded, a message “New settings loaded and secure” is displayed.

> A “serial number discrepancy” message may appear. This is to ensure that you are aware of the exact relay to which the settings are being loaded. If this happens, check the relay serial number using the terminal mode ID menu item. Type this serial number into the T-PRO Serial No. box in the Identification tab display area of *Offliner* Settings. Alternately you may check the Ignore Serial Number check box to bypass serial number supervision.

Retrieve To *Offliner*

To transfer the relay’s current settings to the PC do the following:

1. Navigate to *Settings>Retrieve To Offliner*.
2. Select *Enter*.
3. The relay asks you if you wish to continue. Select *Y* for yes.
4. The file is sent to the directory defined by the HyperTerminal menu *Transfer>Receive File*.

> When using HyperTerminal use Z-modem (no crash recovery), files are received and auto incremented.

Metering

Submenus: Operating, Analog, Logic, ProLogic, I/O, Trend, Dev 49/TOEWS.

Operating	Provides information about the differential operating quantities.
Analog	Provides secondary values of the ac analog voltages and currents.
Logic	Provides the present status of the internal logic states.
ProLogic	Displays the present status of all ProLogic states.
I/O	Displays the state of the external inputs and the output contacts.
Trend	Provides trend quantities.
Dev 49/TOEWS	Displays operating variables for current and temperature overload conditions.

Records

Submenus - List, Fault Recording, Trend Recording, Event Recording.

Records contains the means for initiating and retrieving recordings.

List	Lists all records. Retrieve records from this menu.
Fault Recording	Creates one fault record.
Trend Recording	Creates one trend record.
Event Recording	Creates one event record.

Retrieve Records from the Relay

To retrieve records from the relay do the following:

1 Navigate to *Records>List* and press *Enter*; a records list appears.

2 Select *Records* using the space bar and select *R*. (You can also press *Enter* to retrieve a record directly.) The record will be saved in the directory specified by the terminal emulation program.

When using HyperTerminal if “Use receiving protocol:” is set to “Z modem with Crash Recovery”, file transfers are skipped by HyperTerminal if the record already exists in the downloads folder. When using HyperTerminal use Z-modem (no crash recovery), files are received and auto incremented.

Delete Records from the Relay

To delete records from the relay do the following:

1 Navigate to *Records>List* and press *Enter*.

2 Select the records for deletion with the space bar and select *D*. The selected records will be deleted.

Event Log

Protection Events, Through Fault Peak, Through Fault I*I*t

The event log lists events stored in the relay. A complete list of the types of events logged is available, for details see “Event Messages” in Appendix D.

If an event triggered a record, then an (R) is displayed by the event.

Protection Events	Lists all the events except the Through Fault events
Through Fault Peak	Lists Through Fault peak value events
Through Fault I*I*t	Lists Through Fault I*I*t value events, including the total number of Through Faults and the accumulated Through Fault I*I*t values

Utilities

Sub-menus: Setup, Maintenance, Diagnostics.

To access different levels within the relay.

Setup	
	Time - set manual time, IRIG-B skew control. Requires change or service access level.
	Ports - change Baud rates on communication ports. Requires change or service access level.
	SCADA - select which SCADA protocol Modbus or DNP3) to run on the SCADA port. Configure parameters for the selected protocol such as address or timeout. Requires change or service access level.

Maintenance	
	Calibrate - calibrate all 18 analog ac. Requires service access level.
	Outputs - close and open output contacts independent of the associated relay functions. Requires service access level.
	Erase - use submenus Records, Event Logs and Trends to erase these records from the relay memory. Requires service access level. Loss of Life - Enter initial value of transformer. Requires change or service access level.
	Through Fault - Preset or reset the accumulated Through Fault quantities. Requires change or service access level.

Diagnostics	
	Transfer Diagnostics - transfers relay diagnostic file to the PC. The diagnostic file can be sent to ERLPhase for analysis.
	Modbus - allows Modbus Communications to enter its Diagnostic Mode. Follow directions on the screen. Programming done using the Modicon Modbus Protocol Reference Guide PI-MBUS-300 Rev. G published by Modicon, Inc., dated November 1994, for details see “Modbus RTU Communication Protocol” in Appendix E.

Access

Submenus: VIEW Access, CHANGE Access, Password. Provides the ability to change access levels and passwords.

View	Changes the access level to view. Allows read-only access to relay information.
Change	Changes the access level to change. Allows you to modify settings and delete records.
Service	Changes the access level to service. Allows you to do everything, including calibration, manual control of the output contacts and modification of passwords (available through local Port 1 connection only).
Passwords	Allows you to read and change passwords. Requires service access level.

Quit

Selecting this option ends serial port communication with the relay.

Metering Data

Front Panel Metering

The quantities provided on the front panel display are the L-L voltage line currents, the MW and the MVARs. These quantities are displayed for the side that the PT is connected to. In addition ambient, top oil and hot spot temperatures are displayed.

TUI Metering

The TUI provides the following metering quantities.

Operating

Operating metering provides the winding phase current in secondary amps, as well as the IO and IR currents in pu. Secondary amps refer to the reference CT input which is the first CT on the PT side. (Note that the reference CT input must be used because different CT ratios are allowed on the same voltage level side.) The positive sequence frequency is displayed.

Analog

Analog metering displays all secondary values of the voltage and current inputs, as well as the temperature input mA values.

Logic

Logic metering displays the status of all internal logic, including alarm and trip states of all the relay elements.

ProLogic

ProLogic metering displays the status of all the ProLogic.

I/O

I/O metering shows the status of all external inputs and output contacts.

Trend

Trend metering shows the current status of all trend quantities. These quantities are MW, MVAR, HV current, Device 51 pickup level, THD, ambient, top oil, hot spot temperature and transformer loss of life.

Dev49/TOEWS

Dev49/TOEWS metering displays the current values of the quantities used for the 49 device, as well as the status of TOEWS alarms and trip.

4 Protection Functions and Specifications

Protection and Recording Functions

This section describes the equations and algorithms of the relay protection functions. All functions with time delay provide an alarm output when their pick up level is exceeded. All functions use the fundamental component of the analog inputs, except for THD Alarm.

87 Differential Protection

The differential protection is used to detect transformer faults within the zone defined by comparing the currents on the HV, LV and TV side of the transformer.

The differential protection consists of four functions and are as follows:

1 A slope characteristic consisting of two slopes (S1 and S2) and an IOmin part.The slope characteristic is user adjustable.

   In the T-PRO relay the S1 parameter is typically set at 20%, the S2 parameter at 40% and the break point between the two slopes, IRs is linked to and at 2 times the transformer MVA user setting.

   The minimum pick- up, IOmin is user-settable and defines the minimum amount of fault current required to result in the slope characteristic operation

   The slope function is also controlled by the second and fifth harmonic current restraint functions. These functions are used to detect transformer energization and are used to block the differential function trip.

2 The fast trip function is related to the slope characteristic function but does not have any slope characteristic. This function is a constant operating current horizontal line that is user-settable.

3 A phase angle delta phase supervision function that provides supervision to the slope characteristic. This function is described in detail later, see “Delta Phase Slope Characteristic Supervision” on page 4-6.

   This function provides security to the SLOPE function for external faults by ensuring that the phase angle of the fault currents are within 90 degrees of each other for internal faults.

4 A rate of change of operating and restraint quantities function (ROCOD). This function compares the derivative of the operating and the restraint quantities. If a fault is internal to the protection zone, the positive derivative value of the operating quantity will always be greater than the derivative value of the restraint quantity. This function therefore adds sensitivity to the differential protection. A further description of the ROCOD function is provided, for details see Delta Phase Slope Characteristic Supervision on page 4-6.

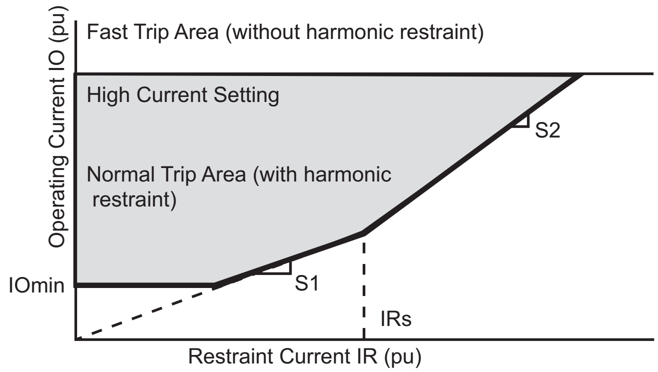


Figure 4.1: Differential Protection Characteristic

Differential Slope Characteristic Description

The slope characteristic consists of a restraint current, IR, on the horizontal axis and an operating current, IO on the vertical axis, see "87 Differential Protection" on page 4-1.

If IO and IR are in the normal trip area, the 2nd harmonic restraint is examined to determine whether the trip should be blocked. If IO and IR are in the fast trip area, the 2nd harmonic restraint is not examined. The 87 characteristic is bound by the fast trip zone. During energization harmonic restraint logic is needed to prevent false tripping. All settings are done on the basis of the per unit transformer quantities. Note that the fundamental current must be greater than 5% of nominal (i.e. >0.25A for a 5A relay) before the T-PRO will calculate a harmonic restraint value. Care should be taken to ensure that the IOmin setting always be above the 5% of nominal value.

Operating Current = IO = |IH + IL + IT| for each of phases A, B and C

Where:

IH is the current from the high voltage side current sources

IL and *IT* are currents from the low voltage side and tertiary side respectively

Restraint Current = IR = [|I1| + |I2| + |I3| + |I4| + |I5|] / 2 for each of phases A, B and C

Where:

I1, I2, I3, I4, I5 are current inputs into the relay terminals (magnitude sum)

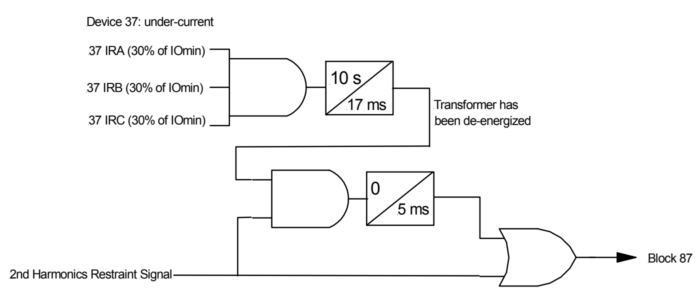
Differential Harmonic Restraint Description

The settings I2 and I5, which are for harmonic restraint to prevent false tripping during transformer energization inrush or transformer overexcitation conditions. If these are set for 0.3 pu, then if either the 2nd or 5th harmonic is more than 30% of the fundamental current, then the differential trip function is restrained. If the IOmin setting corresponds to a pickup value of < 0.25 A, then the harmonic restraint will not work.

When I2 Cross Blocking is enabled (default), the 2nd harmonics restraint blocks the 87 trip if the ratio of the 2nd harmonics to the fundamental exceeds the I2 setting in any phase; when it's disabled, the 2nd harmonics restraint blocks the 87 trip only if the ratio of the 2nd harmonics to the fundamental exceeds the I2 setting in at least two phases. The latter might be used for a 3 single-phase transformer energization, to ensure the transformer will trip correctly when energizing to a fault. Since the 2nd harmonic calculation is carried out on the internal delta currents (for zero sequence current elimination), as a result, the single-phase fault current will contribute into two phases. The

2nd harmonic on these phases will not exceed the set point due to the dominant fault current (fundamental).

As shown below, the 2nd harmonics restraint signal is stretched for 5 ms in the first cycle on transformer energization to prevent the 2nd harmonics restraint signal from any possible momentary reset due to the current signal transition in the first cycle. Note that this logic only becomes active when the transformer has been de-energized or very lightly loaded (the restraint current is less than 30% of IOmin setting).



I5 Restraint Enabled allows the T-PRO's differential element to be blocked using 5th harmonic current restraint. This prevents the 87 element from misoperating during a high over-voltage system condition. During the high voltage condition there is an increase in 5th harmonic current causing the current wave shape to distort creating an unbalance in the differential current circuit. This unbalance is not a true transformer differential, so this is a false trip condition that should be blocked.

87 Transformer Differential Setting Ranges	
87 Transformer Differential	Enable/disable
IOmin (pu)	0.1 to 1.0 pu
IRs (pu)	1.5 to 50 pu

S1 (%)	6 - 40 %
S2 (%)	20 - 200%
High Current Setting (pu)	0.9 - 100 pu
I2 Cross Blocking	Enable/Disable
I2 Setting (pu)	0.05 to 1.00
I5 Restraint	Enable/disable
I5 Setting (pu)	0.05 to 1.00

HV, LV and TV winding current calculations

The T-PRO has 5 three phase current inputs that can be used to sum currents going into a transformer winding. These inputs can be configured to have different CT ratios and CT connections. This flexibility requires that certain corrections be carried out before summing them to get the winding current. This process includes three steps:

- Selection of reference current input
- Phase Corrections
- Magnitude Corrections

The three steps are described in the following sections.

Selection of reference current input

The reference current input is the CT input that will be used as a reference for all the other CT inputs. All corrections will be performed with reference to this input. This selection is done automatically by the relay and is defined as being the first input on the PT side. Consider the following example:

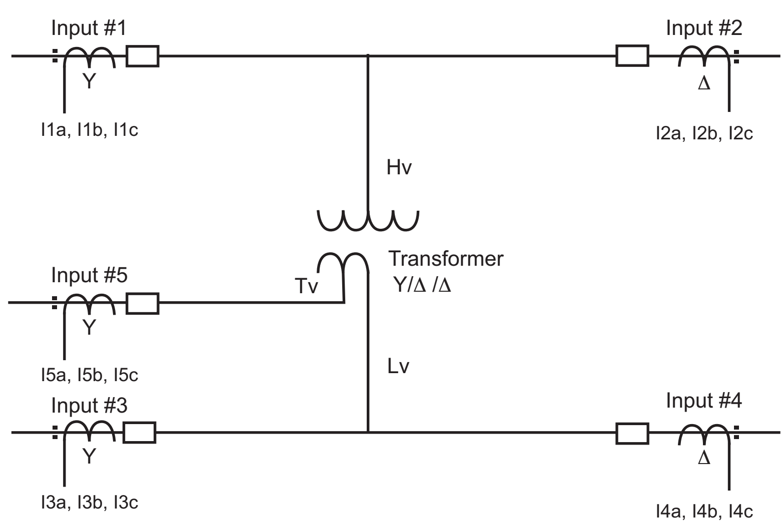


Figure 4.2: Reference Current Input

Phase Corrections

There are two corrections required, one for the transformer winding and one for CT connections. These corrections are always applied with reference to the reference input. Consider the above example.

The following table describes what corrections must be made to each input based on the example above.

Table 4.1: Phase Corrections

Winding	Voltage (KV)	Main Wind-ing	Phase	Curr. Input	Physical CT Conn.	Phase	CT Turn's Ratio	Total Phase Shift	Phase Correction Required	Phase After Correction
HV	230	Y	0^0(ref)	#1	Y	0^0	200 :1	0^0	0^0	0^0
				#2	Δ	-30^0	250 :1	-30^0	30^0	0^0
LV	115	Δ	-30^0	#3	Y	0^0	400 :1	-30^0	30^0	0^0
				#4	Δ	-30^0	450 :1	-60^0	$+60^0$	0^0
TV	13.8	Δ	$+30^0$	#5	Y	0^0	4000 :1	$+30^0$	-30^0	0^0

The formulas for the phase shift corrections are in “Analog Phase Shift Table” in Appendix L. Note that in addition to correcting the phase, these formulas will also eliminate the zero sequence current from the analog inputs.

Magnitude Corrections

The next step is to correct the magnitude of each current input. There are three things that need to be corrected for:

- CT Ratio Mismatch
- CT Connection Correction
- Transformer Ratio

The Magnitude Correction Factor is applied as follows:

$$Mismatch\_Correction\_Factor[i] = \frac{PhysicalCT\_Root3\_Factor[i] \times Voltage\_Level[i] \times CT\_Ratio[i]}{Voltage[REF] \times CT\_Ratio[REF]}$$

Where:

i = Current input being considered.
PhysicalCT_Root3_Factor[i] = 1 for a Y connected CT, 1/SQR(3) for Delta connected CT.
Voltage_Level[i] = Voltage level of the input being considered
CT_Ratio[i] = CT ratio of the input being considered.
Voltage[REF] = Voltage level of the reference (PT) side.
CT_Ratio[REF] = CT ratio of the first current input on the reference (PT) side.

After the phase and magnitude corrections have been performed, the currents can now be summed on a single-phase basis to arrive at the HV, LV and TV winding currents. For the example above the following summations will take place:

$$IHa = I1A + I2A \quad ILa = I3A + I4A \quad ITa = I5A$$
$$IHb = I1B + I2B \quad ILa = I3B + I4B \quad ITa = I5B$$
$$IHc = I1C + I2C \quad ILa = I3C + I4C \quad ITa = I5C$$

These delta currents (i.e. with zero sequence current elimination) are used in device 87 regardless.

However, for device 50/51, 67, 49 and TOEWS, whether the delta currents (with zero sequence current elimination) or the Wye currents (without zero sequence current elimination, i.e. without applying the formulas in Appendix L) are used will depend on how the CTs are connected. Wye current quantities will be used in these functions when all the associated input CTs are connected in Wye; otherwise Delta current quantities will be used (i.e. at least one of the associated input CTs are connected in Delta).

Delta Phase Slope Characteristic Supervision

The slope characteristic of the transformer differential operates on Kirchoff's current principle. This principle states that current entering an area must be equal to the current leaving this area if no faults are present in this area. The protection zone is defined as the area within the measurement CT locations.

In the ideal situation the slope characteristic can be set to cause the characteristic to trip only for internal faults. In practice, however, current measurement errors caused by CT saturation, DC offsets, or parallel transformer bank sympathetic energization can disrupt this current measurement balance and cause the relay to trip unnecessarily for external faults.

The delta phase function is provided to supervise the slope characteristic and prevent relay differential tripping for external faults by providing extra security to the differential function. In operation, delta phase compares the phase angle of the HV, LV and TV currents to determine which currents are a fixed angle of 90 degrees of each other. If all currents are within 90 degrees or less of each other, this is recognized as the condition necessary for an internal fault. If one or more the currents are greater than 90 degrees of one another, this is recognized as an external fault. Extensive simulation and testing has shown that even with CT current distortion issues, the phase angle of the currents is maintained and can be used to verify external or internal faults, for details see Figure 4.3: Delta Phase Supervision of T-PRO 87T Slope Characteristic on page 4-7.

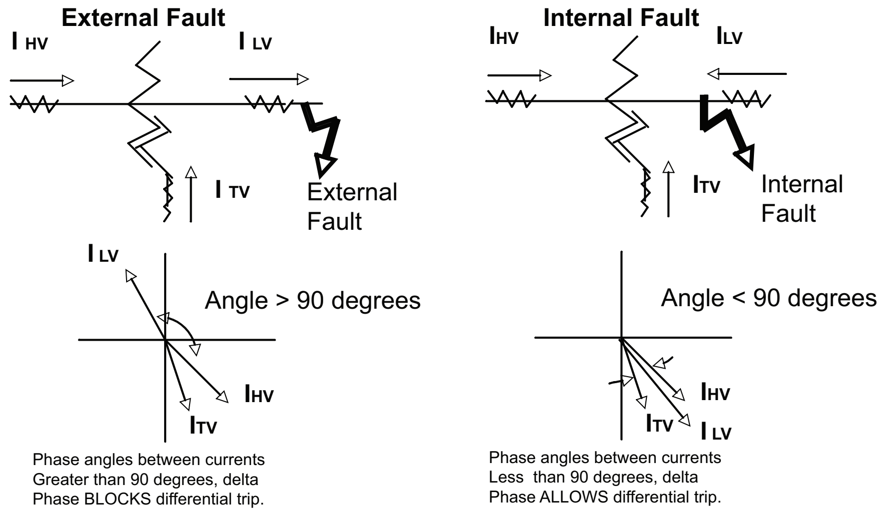


Figure 4.3: Delta Phase Supervision of T-PRO 87T Slope Characteristic

The overall logic function of the differential 87 function can be seen in “Differential 87 Differential Logic” on page 4-7.

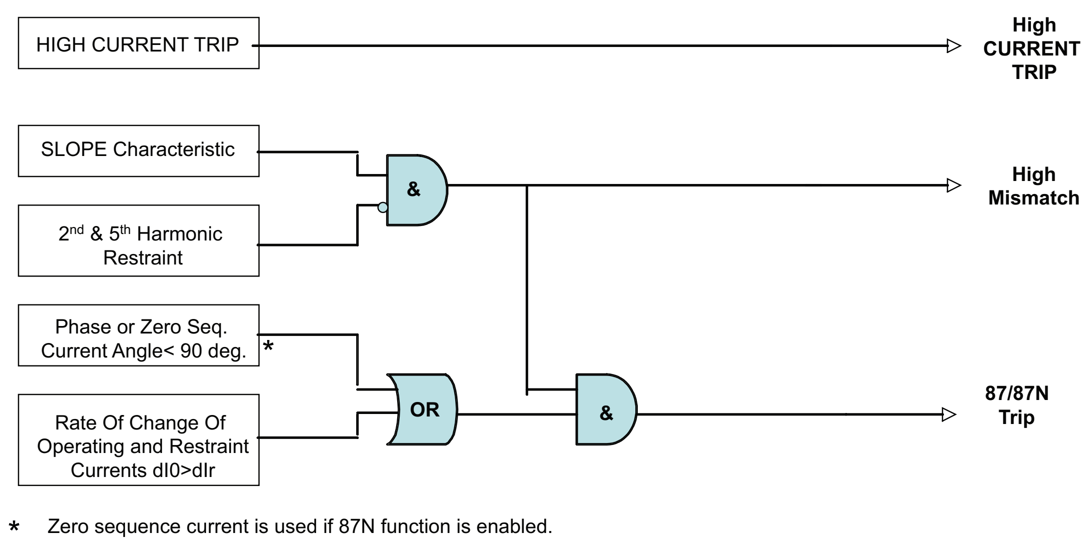


Figure 4.4: Differential 87 Differential Logic

Rate Of Change Of Derivative Function (ROCOD)

For some internal fault cases where a radial load may be present on the low side or on the tertiary side of the transformer, a high resistance ground fault may not cause the load current to change. As a result delta phase may not be able to operate until the fault resistance becomes low.

To cater to this condition, a rate of change of the operating and the restraint current is performed. It has been found that for internal faults the positive magnitude of the operating current derivative will always exceed the positive value of the restraint current derivative. If this condition occurs, this ROCOD function allows the slope function to trip. If the fault is external to the differential zone, the positive value of the operating current will not exceed the positive value of the restraint current.

The ROCOD function is therefore in place to add sensitivity to the differential relay for internal faults.

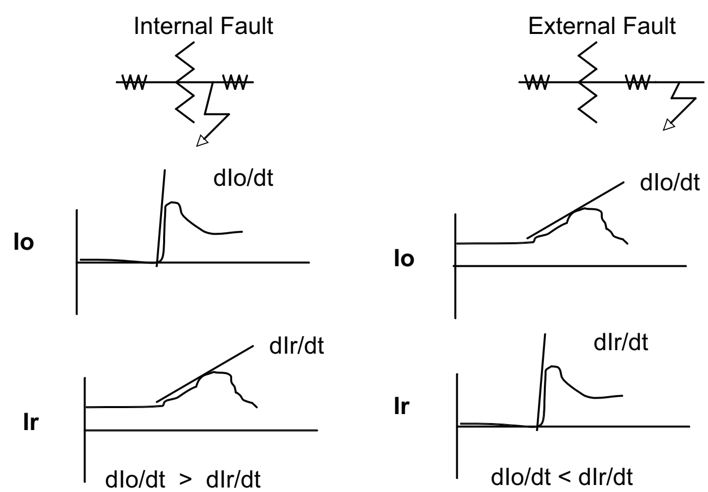


Figure 4.5: Rate Of Change Of Operating And Restraint Quantities

Figure 4.5: Rate Of Change Of Operating And Restraint Quantities on page 8 shows how the dio/dt and the dIr/dt quantities occur during an internal and during an external fault.

For an internal fault, the dIo/dt quantity will always be greater than the dIr/dt quantity. When this happens, ROCOD generates a positive logic that will allow the slope function to generate a relay trip. On the other hand, if an external fault occurs, dIo/dt will always be less than dIr/dt. This in turn will prevent operation of ROCOD and thus prevent operation of a differential trip.

87N Neutral Differential

Neutral Differential protection function (sometimes called Restricted Ground Fault) protects against internal winding-to-ground faults in cases where the normal differential protection (87) may not see a ground fault which occurs on the lower third section of one of the windings. In this case, the 87 setting is normally too high to see the fault, but the 87N is very sensitive, because the fault current for a near-neutral-to-ground fault can be very high. To intentionally limit this current, sometimes a grounding resistor is connected between the transformer neutral and ground.

The principle of operation is that the transformer neutral current (IN) is compared to the sum of the three phase currents (3I0), for a grounded wye winding. If these are not equal, there is an internal ground fault on that winding.

The characteristic used is the same as that for the 87, for details see “87 Differential Protection” on page 4-1.

Operating Current

$$IO = |IA + IB + IC + IN|$$

Restraint Current

$$IR = [|IN| + |IA + IB + IC|]/2$$

Where:

IA, IB and IC are the phase currents

IN is the neutral current for a particular three-phase winding of the transformer

All current reference directions are into the transformer.

The 87N can also be used to protect an auto transformer.

$$IO = |3I0\_HV + 3I0\_LV + IN| \qquad (1)$$

Where:

IO = 0 for external ground faults

IO>0 for internal ground faults

$$IR = (|3I0\_HV| + |3I0\_LV| + |IN|)/2 \qquad (2)$$

Where:

3I0_HV, 3I0_LV and IN are all in primary amps. Note that this is a direct addition of the currents between different voltage levels, which is different from the calculation of 87 or 87N for ordinary transformer, i.e. no conversion (reflection) between different voltage levels is required. Since the 87N characteristic is defined in per unit rather than in primary amps, convert it to per unit by using the reference, i.e. the side primary base current where the PT is located.

When the reference input is determined, the base current is calculated as:

Ibase = MVA * 1000/(Root3 * Ref_Side_kV)

IO (pu) = IO/Ibase (3)

IR (pu) = IR/Ibase (4)

The settings depend on the value of the neutral grounding resistor (if used) and assumptions regarding CT saturation.

87N Neutral Differential Setting Ranges	
HV, LV, TV	Enable/disable
IOmin (pu)	0.1 to 1.0 pu
IRs (pu) (not settable)	2x MVA rating
S1 (%)	6 - 40%
S2 (%)	20 - 200%
CT Turns Ratio	1.00 to 10000.00

Note: 87N auto is available for autotransformer application. For this application, the HV side and the LV side CTs have the 3Io quantity calculated and the neutral CT is connected to Input # 5. In this way the 3Io is compared from the three sources.

87N Delta Phase Supervision

Like the 87 differential protection, the 87N neutral differential also is supervised by a delta phase function.

Because the 87N protection only uses the 3IO current from the phase and neutral CTs, delta phase uses the same 3IO currents for the phase angle comparison.

The delta phase principle of operation is one that compares the zero sequence current as seen by the phase CTs on one winding side of the transformer with the neutral current through the neutral connection. This comparison can be made on the HV, LV and TV sides of the transformer. Obviously, if a transformer winging is in a delta configuration, or if the phase CTs on that winding are in a delta configuration, the 87N cannot be applied to that winding. In addition, for the case of an auto transformer, an 87N setting option can be chosen to accommodate this transformer configuration. For an auto transformer, zero sequence currents from the HV, LV and common neutral side are compared.

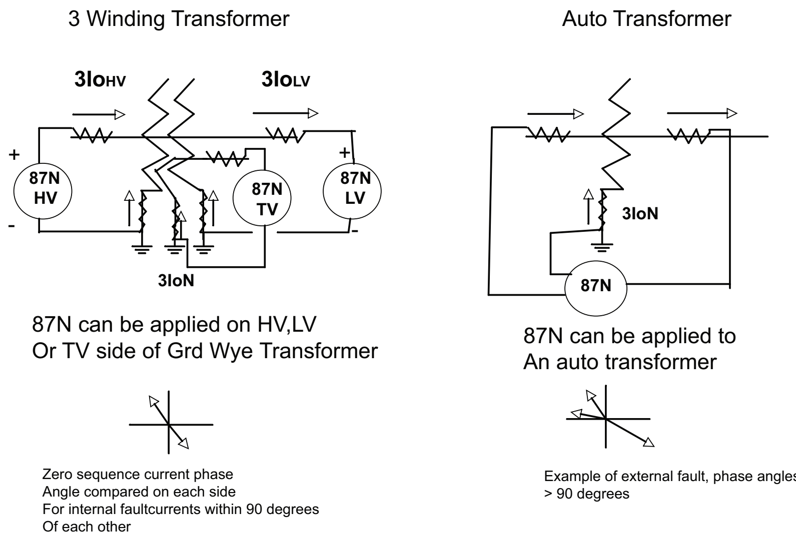


Figure 4.6: 87N Neutral Differential

The 87N differential has only one setting, that of IOmin. The slope characteristics like 87 are user adjustable. There is no fast trip function for the 87N protection function.

49-1 to 49-12 Thermal Overload

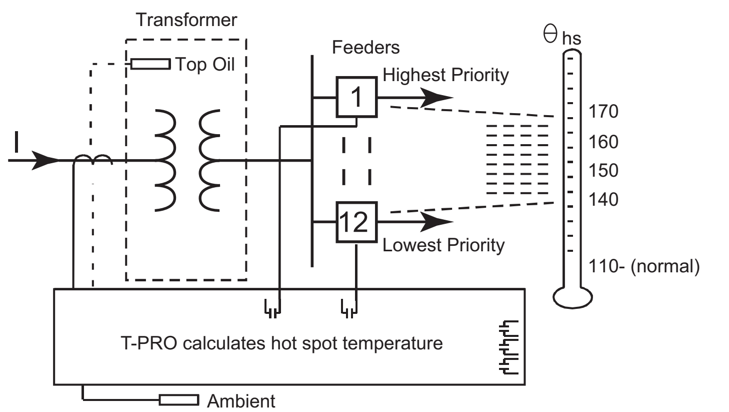


Figure 4.7: 49-1 to 49-12 Thermal Overload Modules

Thermal overload protection protects the transformer winding from excessive insulation damage due to heavy loading and/or high temperature conditions. There are 12 identical devices that use a combination of current and temperature monitoring to shed and to restore load based on the level of current in the winding and/or the temperatures inside the transformer.

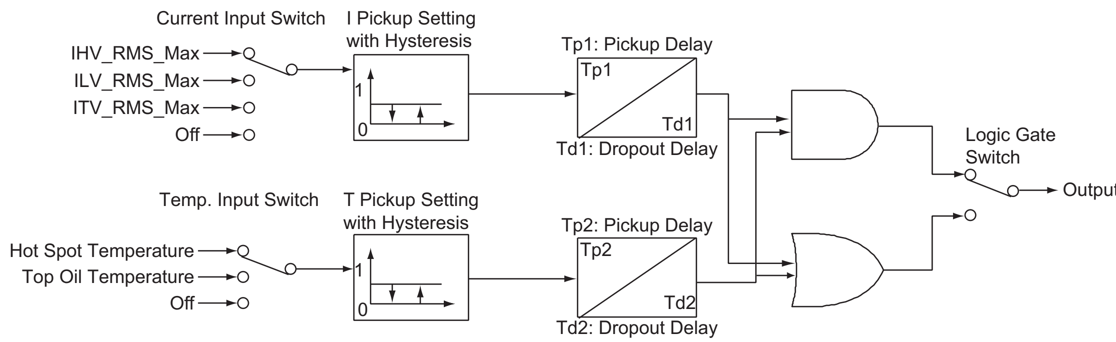


Figure 4.8: Thermal Overload Protection Logic Diagram

The Current Input Switch selects which winding current to either of the HV, LV or TV windings. It has a pickup level and delay setting, as well as hyteresis and pickup/dropout delay settings. All current settings are in pu and the time settings are in seconds. In this manner the current based portion of the 49 device is used to detect high loading situations and tolerates them for a specified time before the element operates. When the level of current drops below pickup, the hysteresis keeps the 49 device picked up until the current drops below the level specified by the hysteresis setting and the dropout delay timer has expired.

The Temperature Input Switch monitors the Top Oil Temperature (sensed or calculated) or the Hot Spot Temperature (calculated based on inputs). The settings are made in a similar fashion to the current settings with pickup and hysteresis levels and pickup and dropout delay settings. In this manner the temperature based portion of the 49 device monitors the internal temperatures of the transformer and tolerates them for a specified time.

An AND/OR gate provides two switches that can be ANDed or ORed together allowing for flexible logic and for monitoring different parts of the transformer under different loading and temperature conditions.

You can set each individual 49 device to provide a simple Alarm LED or a Target LED with a front panel message indicating which 49 device has operated.

49 Thermal Overload Setting Ranges	
Current Input Switch	Off, HV, LV, TV
Pickup (pu)	0.10 to 20.00
Hyteresis (pu)	0.00 to 1.00
Pickup Delay (Tp1, seconds)	0.00 to 1800.00
Dropout Delay (Td1,seconds)	0.00 to 1800.00
Temperature Input Switch	Off, Hot Spot, Top Oil
Pickup (degrees)	70.0 to 200.0
Hysteresis (degrees)	0.0 to 10.0
Pickup Delay (Tp2, hours)	0.00 to 24.00

Dropout Delay (Td2, hours)	0.00 to 24.00
LED Switch	Target LED or Alarm LED
Logic Gate	OR or AND

49TOEWS Transformer Overload Early Warning System

This feature extends the thermal overload concept of the previous section in two ways:

- Predicts excessive hot spot temperature to thirty minutes in advance.
- Predicts excessive loss of life to thirty minutes in advance.

Both of these are based on the availability of an adequate thermal model of the transformer, for details see “Top Oil and Hot Spot Temperature Calculation” in Appendix N. To use this feature the relay must have an ambient temperature probe available from ERLPhase.

Excessive Hot Spot Temperature Warning

Enabling this feature, hot spot temperature is calculated at every time step (five seconds) into the future. The assumption is that the load current and ambient temperature do not change.

If this calculation indicates that the hot spot temperature exceeds its trip setting, the following happens:

- 15-minute warning alarm is activated, if the calculated time is fifteen minutes or less.
- 30-minute warning alarm is activated, if the calculated time is between thirty minutes and fifteen minutes.
- Trip output is activated if the calculated time is zero.

The actual time to trip, in minutes, is also available (30, 29,...1, 0 minutes). If the time to trip is greater than 30 minutes, the display value is “+++++”.

Excessive Loss of Life Warning

This feature overcomes a difficulty with simple over-temperature as an indication of overload.

If the hot spot temperature trip setting is 140°C and the temperature hovers at values just below that level, then damage to the cellulose insulation occurs, but no trip. Also, if the temperature briefly exceeds the setting (less than an hour) and then falls back to normal levels, a trip should not occur, but will.

You can overcome these unreliability and security issues by using the “loss of life” concept. The calculation is outlined in “Top Oil and Hot Spot Temperature Calculation” in Appendix N.

The 30-minute warning, 15-minute warning and trip outputs occur if either the hot spot temperature or loss of life limits are exceeded.

The three settings are:

THS Trip Setting

Use 175°C with loss of life protection enabled. The latter will not allow temperatures near this level to last too long.

If loss of life protection were not enabled, then a lower setting would be necessary, say 140°C, a temperature at which oil bubbles might start to form, depending for one thing, on the oil water content.

THS To Start Loss of Life Calculation

For this 65°C rise transformer the normal hot spot temperature is 110°C. Therefore, some value above this is appropriate for the start of "excessive loss of life" calculation initiation. Select 125°C.

Loss of Life Trip Setting

Select 2 days as the setting. This, in combination with the above, allows overloads similar to those recommended in the Standard (C57.91-1995).

A study for this transformer shows that for these settings, a sudden overload will trip due to hot spot temperature for times less than about fifteen minutes, and due to excessive loss of life for times greater than about fifteen minutes. The software for this kind of study is available from ERLPhase.

TOEWS Transformer Overload Early Warning System Setting Ranges	
TOEWS	Enable/disable
THS (Temperature Hot Spot) Trip Setting (degrees)	70.0 to 200.0
THS to Start LOL (Loss of Life) Calculation (degrees)	70.0 to 200.0
LOL (Loss of Life) Trip Setting (days)	0.5 to 100.0

24 Overexcitation

24INV provides inverse-time overexcitation (over-fluxing) protection. The activating quantity is the ratio of voltage to frequency because flux is proportional to the voltage and inversely proportional to the frequency. 24INV protects the transformer from overfluxing because either voltage increases or system frequency changes.

24INV is defined as:

$$T = \frac{K}{\left(\frac{V}{f} - Pickup\right)^2}$$

Where:

T is the tripping time in seconds

V is the positive sequence voltage in per unit

f is the frequency in per unit

K is a parameter raising or lowering the inverse time curve

Pickup is the user-set value of V/f at which the element starts to progress toward trip

The element uses the positive sequence voltage and compares the pu positive sequence magnitude to the pu positive sequence frequency.

24DEF Definite Time Delay protection is similar to the 24INV except that the operating time delay is definite. Use this function to trip off a capacitor bank on the HV side of the system if a controller fails.

24 Overexcitation Setting Functions	
K	Factor for altering inverse time curve
Pickup (24INV)	Minimum level that operates device 24INV
Reset Time	Time for 24INV to reset after element has dropped out
Pickup (24DEF)	Minimum level that operates device 24DEF
Pickup Delay	Operating time for 24DEF

24 Overexcitation Setting Ranges	
24INV	Enable/disable
K	0.10 to 100.00
Pickup (pu)	1.00 to 2.00
Reset Time (seconds)	0.05 to 100.00

24DEF	Enable/disable
Pickup (pu)	1.00 to 2.00
Pickup Delay (seconds)	0.05 to 99.99

59N Zero Sequence Overvoltage

Zero Sequence Overvoltage protection is provided for ground fault monitoring. This function also uses standard IEC and IEEE curves as well as a user-defined curve type.

You can apply the PT voltage source either to the HV or the LV side of the transformer. When used, apply the device 59N ($3V_0$) to this winding to provide ground fault monitoring looking at the zero sequence voltage.

Pickup

$$T(3V_0) = TMS\left[B + \frac{A}{\left(\frac{3V_0}{3V_{0Pickup}}\right)^p - 1}\right]$$

Reset

$$T(3V_0) = TMS\left[\frac{TR}{\left(\frac{3V_0}{3V_{0Pickup}}\right)^2 - 1}\right]$$

Table 4.2: IEC and IEEE Curves

No	Curve Type	A	B	p
1	IEC Standard Inverse	0.14 (fixed)	0.00 (fixed)	0.02 (fixed)
2	IEC Very Inverse	13.50 (fixed)	0.00 (fixed)	1.00 (fixed)
3	IEC Extremely Inverse	80.00 (fixed)	0.00 (fixed)	2.00 (fixed)
4	IEEE Moderately Inverse	0.0103(fixed)	0.0228 (fixed)	0.02 (fixed)
5	IEEE Very Inverse	3.922 (fixed)	0.0982 (fixed)	2.00 (fixed)
6	IEEE Extremely Inverse	5.64 (fixed)	0.0243 (fixed)	2.00 (fixed)
7	User-defined	[0.001, 1000]	[0.0, 10.0]	[0.01, 10.0]

59N Zero Sequence Overvoltage Setting Functions	
3VO Pickup	Minimum level that operates device 59N
Curve Type	Sets the type of curve
TMS	Factor for inverse time curve
A, B, p	Parameters for defining the curve
TR	Factor for altering the reset time

59N Zero Sequence Overvoltage Setting Ranges	
59N	Enable/disable
$3V_0$ Pickup (volts)	75.00 to 150.00
Curve Type	See “IEC and IEEE Curves” on page 4-16
TMS	0.01 to 10.00
A	0.0010 to 1000.0
B	0.0000 to 10.0
p	0.01 to 10.00
TR	0.10 to 100.00

27 Undervoltage

Two sets of undervoltage protection elements are provided to monitor the bus voltage. When the voltage level applied to the analog voltage inputs is below the pickup level, the 27 operates after the time delay has expired. The 27-1 and 27-2 functions are identical in terms of operation. Use the gate switch to select between an AND or an OR gate in order to detect a three-phase undervoltage or a single-phase undervoltage condition. When the gate switch is set to OR, a drop of voltage on any one phase causes the element to operate. Set the definite time delay to 0.0 for a instantaneous output.

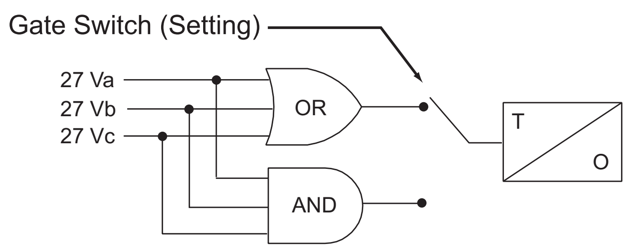


Figure 4.9: 27 Undervoltage

27 Undervoltage Setting Functions	
Pickup (volts)	Minimum level that operates device 27
Pickup Delay (seconds)	Operating time of the 27
Gate Switch	Allows either single-phase or three-phase operation

27 Undervoltage Setting Ranges	
27-1, 27-2	Enable/disable
Gate Switch	AND or OR
Pickup (volts)	1.0 to 120.0
Pickup Delay (seconds)	0.00 to 99.99

60 AC Loss of Potential

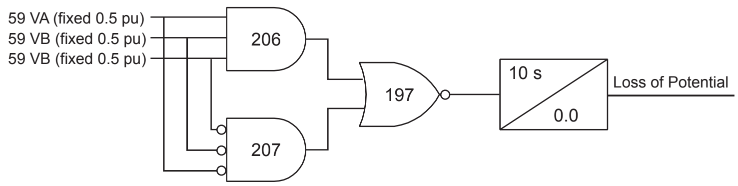


Figure 4.10: AC Loss of Potential Logic

This protection detects the loss of potential from either one or two phases of a PT and issues an alarm. The alarm is intended to detect a blown fuse or an open circuit in the PT circuit.

If this function is enabled and an ac loss of potential takes place, an output contact can be closed.

60 Loss of Potential Setting Ranges	
60 Loss of Potential	Enable/disable
Pickup Time Delay	10 seconds (fixed)

81 Over/Under Frequency

The relay has four frequency devices available. Each frequency element can be set to operate either at a fixed level of under-frequency, a fixed level of over-frequency, or at a rate of change level (df/dt). The df/dt function can be set to operate for a positive rate of change or a negative rate of change. Each frequency element has a definite time delay setting to create a time delayed output. A fixed level of positive sequence voltage of 0.25 pu or 5 volts, whichever is greater provides an undervoltage inhibit on each element.

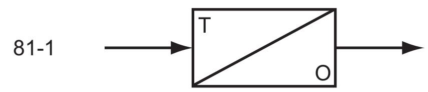


Figure 4.11: Over/Under Frequency

81 Frequency Setting Functions	
Pickup	Minimum level that operates device 81
Pickup Delay	Operating time for the 81

81 Frequency Setting Ranges	
81-1, 81-2, 81-3, 81-4	Enabled, disabled, fixed level, rate of change
Pickup (Hz/second) (60 Hz) Fixed Level	Between [50.000, 59.995] or [60.005, 70.000]
Pickup (Hz/second) (60 Hz) Rate of Change	Between [-10.0, -0.1] or [0.1, 10.0]
Pickup Delay (seconds) (60 Hz) Fixed Level	0.05 to 99.99
Pickup Delay (seconds) (60 Hz) Rate of Change	0.20 to 99.99
Pickup (Hz/second) (50 Hz) Fixed Level	Between [40.000, 49.995] or [50.005, 60.000]
Pickup (Hz/second) (50 Hz) Rate of Change	Between [-10.0, -0.1] or [0.1, 10.0]
Pickup Delay (seconds) (50 Hz) Fixed Level	0.05 to 99.99
Pickup Delay (seconds) (50 Hz) Rate of Change	0.20 to 99.99

50/51 Overcurrent

Pickup

$$T(I) = TMS\left[B + \frac{A}{\left(\frac{I}{I_{Pickup}}\right)^p - 1}\right]$$

Reset

$$T(I) = TMS\left[\frac{TR}{\left(\frac{I}{I_{Pickup}}\right)^2 - 1}\right]$$

These functions provide backup protection for device 87 and downstream protections. Device 50/51HV provides high voltage side instantaneous and inverse time, device 50/51LV provides overcurrent protection for the LV winding and 50/51TV provides overcurrent protection for the TV winding.

Depending on the associated CT connections, either the Wye current or the Delta currents could be used in the 50/51 functions for details see Magnitude Corrections on page 4-5.

Each of the above overcurrent functions provide three IEC inverse time curve types and three IEEE inverse time types of overcurrent protection as well as a user-defined inverse time type is also provided. Each device 50/51 is applied on each of the windings as defined by the settings. Each operates on the sum of that particular winding side per unit current (positive and negative sequence values only) irrespective of the CT ratio or connection on that side.

The input of each device 50/51 is the maximum fundamental rms current, Imax, among phases A, B and C. If Imax is greater than pickup, an alarm is set and the relay starts to integrate towards trip. When the integrated torque is greater than 1, a trip signal is issued.

The 51 characteristic reset is a back integration process where the reset time is based on the time the relay takes to reset from its trip condition.

An adaptive feature is applied to device 51HV as well and is described in “51ADP Adaptive Overcurrent” on page 4-21. The 50 device is an instantaneous element and operates when the Imax B is above the pickup level for the desired time.

50/51 Phase Overcurrent Setting Functions	
50 Pickup	Minimum level that operates device 50
50 Pickup Delay	Operating time for the 50
51 Pickup	Minimum level that operates device 51
Curve Type	Sets the type of curve
TMS	Factor for altering inverse time curve
A, B, p	Parameters for defining the curve
TR	Factor for altering the reset time

50/51 Phase Overcurrent Setting Ranges	
50	
HV, LV, TV	Enable/disable
Pickup (pu)	0.10 to 20.00
Pickup Delay (seconds)	0.00 to 99.99
51	
HV, LV, TV	Enable/disable
Pickup (pu)	0.50 to 2.10 (for HV) 0.10 to 5.00 (for LV, TV)
Curve Type	See Table 4.2: “IEC and IEEE Curves” on page 4-16
Tms (Time Multiplier Setting)	0.05 to 1.00 (if curve type is 1 to 3) 0.50 to 10.00 (if curve type is 4 to 6) 0.05 to 10.00 (if curve type is 7)
A	0.0010 to 1000.0
B	0.0000 to 10.00
p	0.01 to 10.0
TR	0.10 to 100.00
51ADP	Enable/disable
Multiple of Normal LOL	0.5 to 512.0

51ADP Adaptive Overcurrent

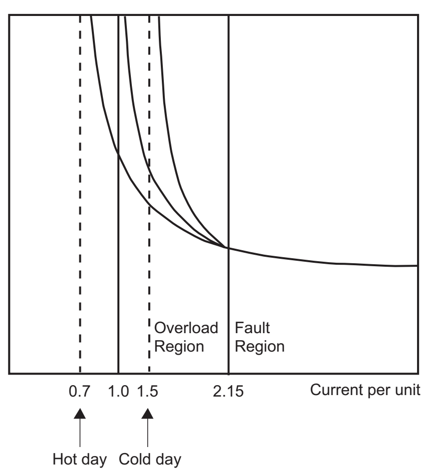


Figure 4.12: Ambient Temperature Adaption

Ambient Temperature Adaption (ADP) adjusts the pickup level of device 51HV based on the ambient temperature, a user-entered multiplier of normal loss of life and the equations defined in IEEE standard C57.92.1981. The adaptation function is executed at a rate of one time per second.

If this function is enabled, the calculated adaptive pickup value becomes the device 51HV pickup setting. The 51ADP function re-shapes the inverse-time curve only in the overload region (up to 2.15 per unit), for details see Figure 4.12: Ambient Temperature Adaption on page 21.

If the ambient temperature signal is out of range, the pickup of device 51HV reverts to the user-set value.

51ADP Adaptive Overcurrent - Cold Climates

If this function is turned on, the 51HV pickup is affected by the ambient temperature input and the rate of loss of life setting value. If this function is not used, the 51HV pickup is not affected.

If rate of loss of life is set to one and ambient temperature is 30 degrees Celsius, the pickup level of 51 will be 1.0 per unit. Use the curves in Example 1, “Loss of Life of Solid Insulation” in Appendix M to change the 30°C pickup level.

The alarm function of 51HV indicates when the pickup threshold has been exceeded.

When the ambient temperature input probe is connected, you can use the adaptive overcurrent function. Set the rate of loss of life value to 1.0. The pickup values can be affected over the range 0 < pickup < 2.15 per unit. No change in the overcurrent characteristic takes place above 2.15x pickup. Since most fault coordination with other overcurrent relays occurs at fault levels above this value, coordination is not usually affected by the adaptive nature of the 51ADP function. However, check all specific applications.

If the ambient temperature input goes out of range with the adaptive function armed, an alarm is generated. The event is logged and the overcurrent pickup reverts to the user setting provided for the 51HV.

50N/51N Neutral Overcurrent

T-PRO provides overcurrent protection for up to three neutral connected transformer windings using an analog current input set number 5. To apply these devices connect I5 A current to HV side transformer neutral current, I5B to LV side transformer neutral CT and I5C to TV side transformer neutral. If only one function is used (e.g. 50N/51N-HV), connections to analog inputs I5B and I5C are not used and can not be used as inputs for the differential protection, but these inputs can be used for fault recording from a CT source. Neutral Overcurrent is similar to 50/51 except that the input currents are taken from the transformer neutral CTs and are in secondary amps rather than per unit.

To enable 50N/51N, Current Input #5 must be set to 51N (i.e. option 87N/51N) in Connection (Winding/CT Connections). If Input 5 is set to 87N auto, only 50/51N-HV is available.

50N/51N Neutral Overcurrent Setting Functions	
50N Pickup	Minimum level that operates device 50N
50N Pickup Delay	Operating time for the 50N
51N Pickup	Minimum level that operates device 51N
Curve Type	Sets the type of curve
TMS	Factor for altering inverse time curve

A, B, p	Parameters for defining the curve
TR	Factor for altering the reset time

50N/51N Neutral Overcurrent Setting Ranges	
50N	
HV, LV, TV	Enable/disable
Pickup (A)	0.50 to 50.00
Pickup Delay (seconds)	0.00 to 99.99
51N	
HV, LV, TV	Enable/disable
Pickup (pu)	0.50 to 50.00
Curve Type	See Table 4.2: “IEC and IEEE Curves” on page 4-16
Tms (Time Multiplier Setting)	0.05 to 1.00 (if curve type is 1 to 3) 0.50 to 10.00 (if curve type is 4 to 6) 0.05 to 10.00 (if curve type is 7)
A	0.0010 to 1000.0
B	0.0000 to 10.00
p	0.01 to 10.0
TR	0.10 to 100.00

67 Directional Overcurrent

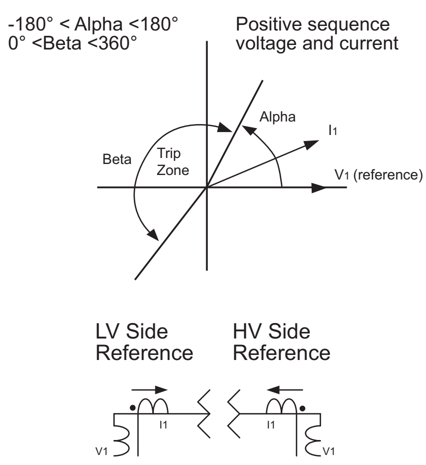


Figure 4.13: Directional Overcurrent Protection Characteristic

This device provides directional overcurrent protection applied to the HV or LV winding that has the PT connected to it.

If the angle between the positive sequence current and the positive sequence voltage is in the region labelled “Beta,” then a timed trip occurs. Use either HV side voltage and HV side current or LV side voltage and LV side current, depending on which side the PT is connected. In either case, the reference direction is into the transformer.

You can select an inverse time characteristic of the function.

Directional Overcurrent allows for the application of a directional controlled overcurrent relay. Direction is determined from the reference voltage quantities of the HV side PT.

67 Directional Overcurrent Setting Functions	
67 Pickup	Minimum level that operates device 67
Curve Type	Sets the type of curve
TMS	Factor for altering inverse time curve
A, B, p	Parameters for defining the curve
TR	Factor for altering the reset time
Alpha	Defines the starting angle for the trip region
Beta	Defines the size of the trip region in degrees offset from alpha

67 Directional Overcurrent Setting Ranges	
67	Enable/disable
Curve Type	See Table 4.2: “IEC and IEEE Curves” on page 4-16
Pickup (pu)	0.05 to 1.95
TMS	0.01 to 10.00
A	0.001 to 1000.0
B	0.00 to 10.00
p	0.01 to 10.00
TR (seconds)	0.10 to 100.00
Alpha (degrees)	-179.9.0 to 180.0
Beta (degrees)	0.1 to 360.0

THD Alarm

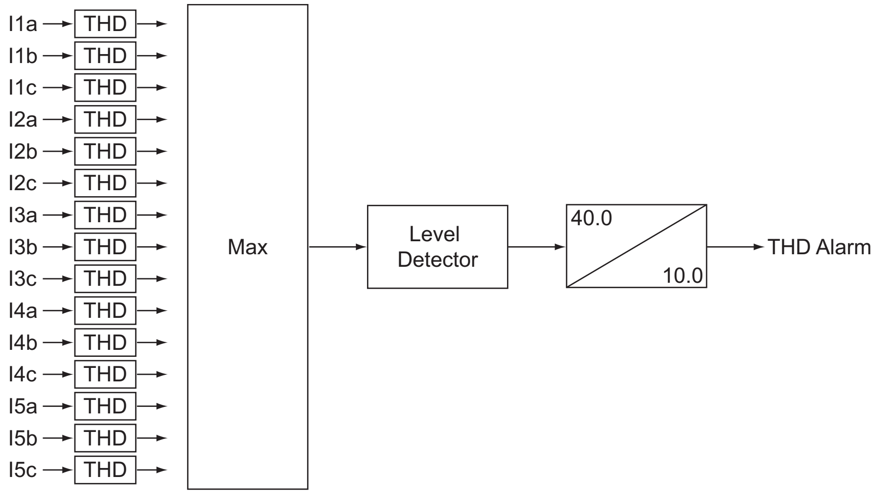


Figure 4.14: Total Harmonic Distortion Function

The THD Alarm function alerts you to the degree of current waveform distortion and therefore harmonic content.

Setting this value at 10% means that the THD function operates if the total harmonic distortion exceeds 10% in any of the fundamental protection currents.

THD = square root of the sum of the squares of the harmonics (2nd–25th) divided by the fundamental times 100 for THD% value.

.

THD is defined as

$$THD = \frac{\sqrt{\sum_{n=2}^{25} I_n^2}}{I_1} \times 100$$

Where:

I_1 is the fundamental component

I_2 to I_{25} are the harmonics components

The inputs to this function are the THD values of all the current input channels that are connected to the transformer. The channels that are not connected to the transformer (e.g. for recording only) or channels with low fundamental signals (less than 14% of nominal current) are not calculated for THD. The alarm is activated if the highest THD found exceeds the setting. There is a built-in fixed time delay of from 30–40 seconds pickup and 1–10 seconds dropout to ensure that this is not just a fault condition. This function is executed in a slow rate, once per second. The THD values are calculated from the 96 samples buffer rather than the decimated 8 samples buffer because higher harmonics content (up to the 25th) can be included with 96 samples.

Total Harmonic Distortion (THD) Alarm	
THD Alarm	Enable/disable
Pickup (%)	5.0 to 100.0

Through Fault Monitor

The Through Fault monitor function in T-PRO is used to monitor the through faults that the transformer has experienced so as to analyze thermal and mechanical effects of through faults to the transformer. The monitored quantities include the duration of each through fault, the current peak RMS value and the accumulated I2t value of each phase during each through fault. Besides, the total number of the through faults and the total accumulated I2t values of each phase over the transformer life are also monitored.

The overall through fault monitor scheme is shown in the following figure:

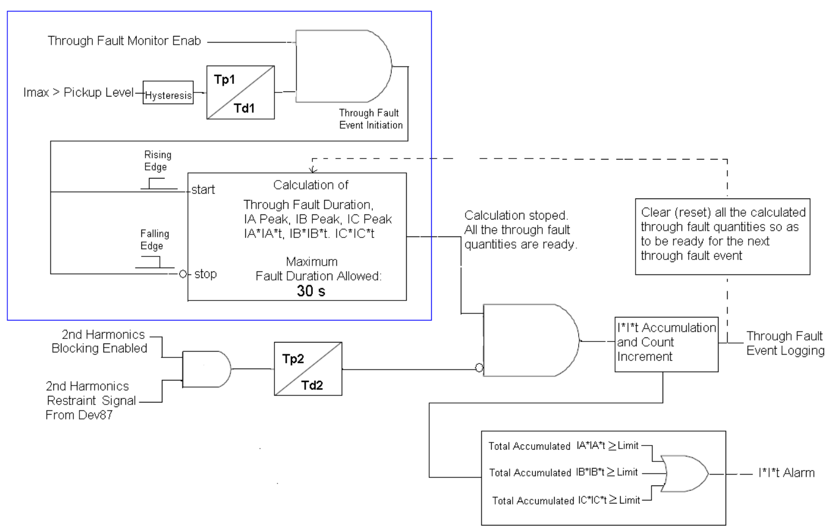


Figure 4.15: Overall Through Fault Monitor Scheme

The through fault duration is defined as from when the input current Imax (the maximum current among phase A, B and C) exceeds the pickup threshold to when Imax drops below the pickup threshold - hysteresis. Note that the maximum allowed through fault duration is 30 seconds, this is to avoid the through fault event may never stop in case the pickup setting is set improperly so that the through fault event might be triggered under some load conditions. Pickup delay Tp1 and dropout delay Td1 are set to zero by default, however they can be set to other values based on user’s needs.

The 2nd harmonics restraint logic output from device 87 is brought here to be used to block the through fault event creation on inrush. The pickup and dropout timer (Tp2 and Td2) are used to distinguish between the 2nd harmonics caused by the fault transient and the 2nd harmonics caused by transformer energization inrush. 2nd harmonics in the fault current only last for a very short period of time (e.g. 1 cycle or shorter) and 2nd harmonics in the inrush current last for quite a long time (e.g. a second or even longer). The figure below showed that the 2nd harmonics existed in the fault current during load to fault transition.

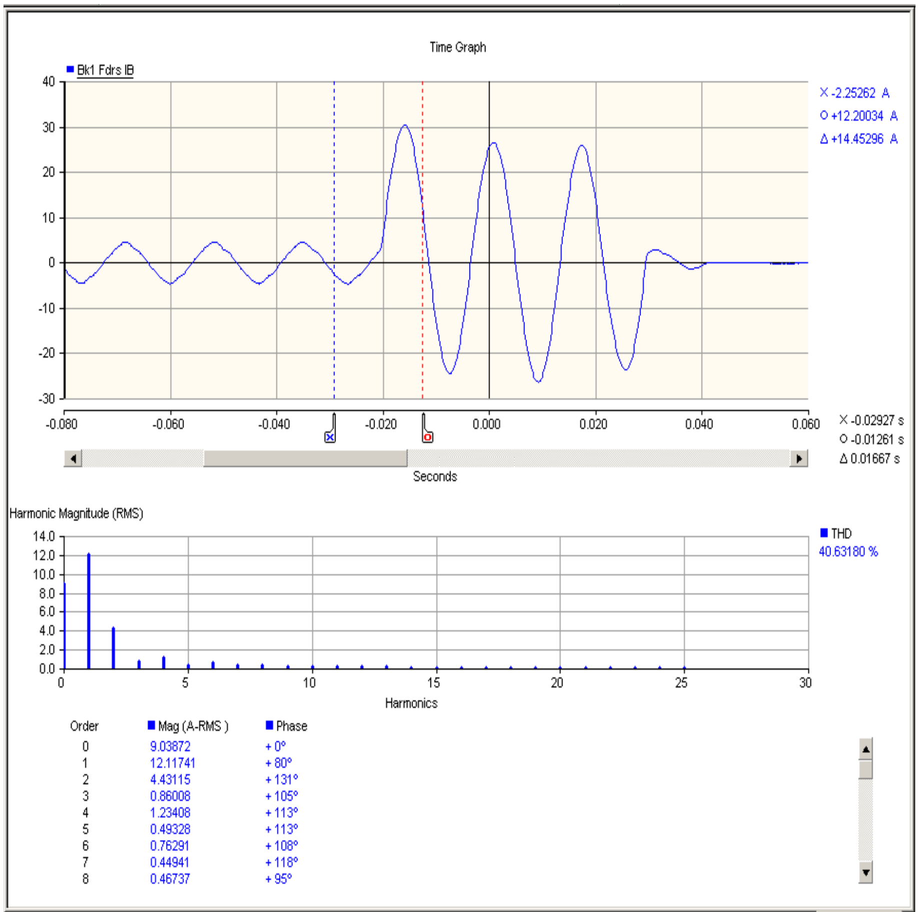


Figure 4.16: 2nd Harmonics Contents in Fault Current

Tp2 setting (default to 20ms) is used to ensure that the 2nd harmonics blocking will be only applied on the inrush current (rather than fault current). Td2 setting is used to stretch the 2nd harmonics blocking signal once it picks up. This is to prevent it from early reset in order to endure a reliable blocking.

An alarm will be issued when the total accumulated I^2t value of any phase exceeds the preset threshold. When this occurs, some necessary maintenance to the transformer should probably be performed. After that is completed, the total accumulated I^2t value should be reset. The I^2t alarm limit threshold may also need to be adjusted accordingly after successive accumulated I2t values have been reached.

The through fault events and the associated monitored quantities can be viewed through Event Log/Through Fault Peak and Event Log/Through Fault I*I*t in Terminal VI respectively. They can also be retrieved to RecordBase View and exported to MS Excel CSV format (refer to RecordBase View for details). To avoid data loss of the through fault events, “Event Auto Save” feature should be enabled.

Through Fault Monitor Setting Ranges	
Through Fault Monitor	Enable/Disable
Input Current	HV, LV OR TV
Pickup Level (pu)	0.10 to 20.00
Hysteresis (pu)	0.00 to MIN (1.00, Pickup Level)
Pickup Delay (Tp1, seconds)	0.00 to 99.99
Dropout Delay (Td1, seconds)	0.00 to 99.99
I*I*t Alarm Limit (kA^2*s)	0.1 to 9999.9
2nd Harmonics Block	Enable/Disable
2nd Harmonics Block Pickup Timer (Tp2, seconds)	0.00 to 99.99
2nd Harmonics Dropout Timer (Td2, seconds)	0.00 to 99.99

ProLogic

ProLogic Control Statements

With ProLogic you can pick any of the protection functions or external inputs and place them into Boolean-like statements. ProLogic handles up to five functions to generate one ProLogic statement; ten statements are possible. The results from these statements are mapped to output contacts using the output matrix.

The ProLogic control statements are used to create Boolean-like logic. The relay can use any of the protection functions or external inputs combined with logic gates to create a ProLogic control statement. The possible gates are AND, NAND, OR, NOR, XOR, XNOR, NXOR and LATCH. The control can be time delay pickup and or time delay dropout, and can drive the front panel target LED. Ten ProLogic control statements outputs are available and can be used in the output matrix to customize the relay to your specific needs. Inputs to ProLogic are all the elements plus previous ProLogic statements for logic nesting usage.

The example shows A to E inputs are status points of devices that are user-selectable. Each ProLogic output can be given a specific name, pickup and reset time delay.

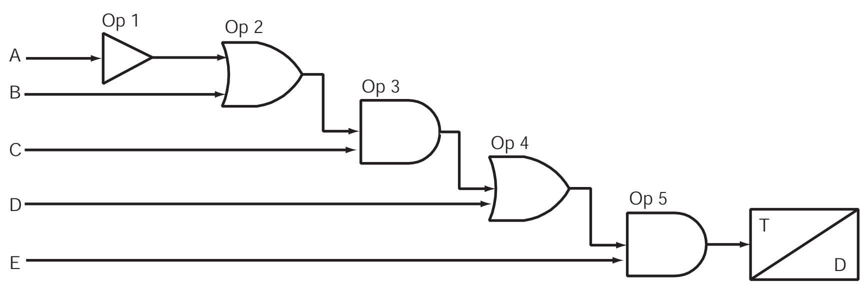


Figure 4.17: ProLogic

ProLogic Setting Functions	
Name	Give the ProLogic a meaningful name
Pickup Delay	Delay time from pickup to operate
Dropout Delay	Delay time from dropout to a ProLogic status of low
A, B, C, D, E	Relay elements as input statements
Operators	Boolean-type logic gates

Recording Functions

The T-PRO Relay provides numerous recording and logging functions, including a fault recorder, a trend log and an event log to analyze faults, to know the performance of the relay and to observe the status of the protected device.

Fault Recorder

Fault recording captures the input signal waveforms and other derived quantities when a fault or an abnormal situation occurs. The relay determines this by allowing the functions in the Output Matrix to enable the Recording or fault record option. Obtain this information by uploading the records from the relay using the terminal mode file transfer process and view them with RecordBase View. Up to a total of 15 seconds of information can be stored with automatic overwrite of the oldest data.

The quantities recorded are:

- 18 analog channels (3 voltages and 15 currents in secondary volts and amperes respectively), 96 samples/cycle up to the 25th harmonic
- 9 external digital inputs, 96 samples/cycle
- 6 derived analog channels (3 operating currents, 3 restraint currents, all are magnitude quantities in per unit), 8 samples/cycle. These derived and analog channels are displayed as a Differential Trajectory graph).
- 57 relay internal logic signals, 8 samples/cycle
- 10 ProLogic signals, 8 samples/cycle.

Parameters that are user-selectable with respect to recording faults:

- Record length (30–120 cycles of which 10 cycles is pretrigger) with automatic extension to capture successive triggers
- Recorder triggering by any internal logic or external digital input signal

Trend Recorder

The trend recorder provides continuous, slow-speed recording of the transformer and its characteristics with an adjustable sample period from 3 to 60 minutes per sample. This same global trend sampling rate is applied to all the trend quantities. The relay stores a fixed number of samples. At the nominal sample period of 3 minutes per sample T-PRO stores one month of trend records with automatic overwrite of the oldest. If the sample interval increases to 30 minutes per sample, the relay stores 300 days of trend records.

Sample Interval	Trend Record Length
3 minute	30 days
5 minute	50 days
10 minute	100 days
30 minute	300 days
60 minute	600 days

Figure 4.18: Examples of the Trend Record Length

Use the terminal mode file transfer to view the trend records, and then open RecordBase View software to analyze the records.

To view the present values of trend quantities use the Metering option of the terminal mode interface:

- Ambient Temperature (in degrees Celsius) if the ambient input is active.
- Top Oil Temperature (in degrees Celsius) either calculated from ambient or measured if input is active.
- Hot Spot Temperature (in degrees Celsius) calculated from Top Oil Temperature.
- Transformer Load HV side maximum current among phase A, B and C in per unit.
- Device 50/51HV pickup in per unit equal to the Dev51ADP's adaptive pickup value if Dev51ADP is turned on or equal to the default pickup setting of Dev51 if it's turned off. If ambient is not available, the default pickup setting is used.
- Accumulated loss of life in percent of total loss of life as defined by the C57 standard.
- HV or LV side real power in MW (for HV side PT, power leaving the HV bus is positive and for LV side PT, power going to HV side is considered positive).
- HV or LV side reactive power in MVAR (same definition as for real power above).
- Maximum selected THD value in percent of the fundamental of all the analog current inputs selected for protection. Analog current inputs used for recording only not included.

Logging Functions

Event Log

The relay maintains a log of events in a 250 entry circular log. Each entry contains the time of the event plus an event description. This log includes the time that the event took place and a predefined description of the event. Trip and alarm events are logged only if these events have been user-programmed to initiate output relay closures or have been programmed to initiate fault recording in the Output Matrix of the settings.

The event log can be viewed in two ways:

Front Panel	The front panel display shows events in abbreviated form (Trip and Alarm events only).
Terminal User Interface	The full event log is available through the Event Log menu of the terminal user interface.

> This display is a snapshot of the event list which must be manually refreshed to display new events that occur while the display is up.

There is a list of Event Messages, for details see "Event Messages" in Appendix D.

5 *Offliner* Settings Software

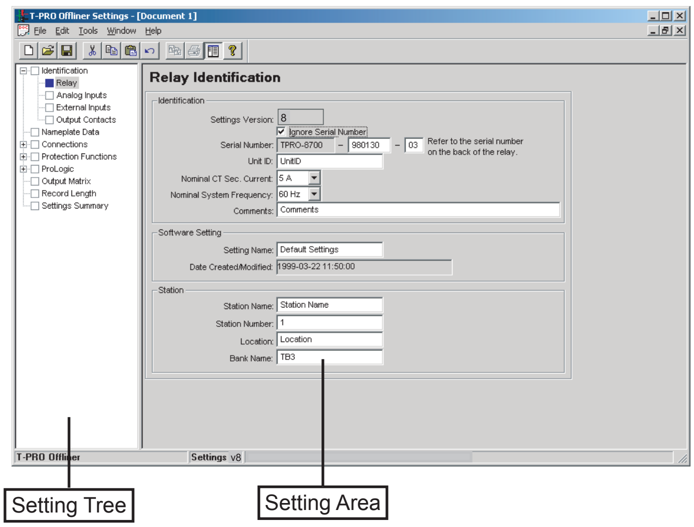


Figure 5.1: Opening Screen

Introduction

Use the *Offliner* Settings software to create relay settings on a PC. *Offliner* Settings provides an easy way to view and manipulate settings.

PC System Requirements

Hardware

The minimum hardware requirements are:

- 1 GHz processor
- 2 GB RAM
- 20 GB available hard disk space
- USB port
- Serial communication port

Operating System

The following software must be installed and functional prior to installing the applications:

- Microsoft Windows XP Professional Service Pack 3 or
- Microsoft Windows 7 Professional Service Pack 1 32-bit or 64-bit

Installing PC Software

Insert the CD-ROM in your drive. The CD-ROM should open automatically. If the CD-ROM does not open automatically, go to Windows Explorer and find the CD-ROM (usually on D drive). Open the T-PRO.exe file to launch the CD-ROM.

To install the software on your computer, click the desired item on the screen. The installation program launches automatically. Installation may take a few minutes to start.

To view the T-PRO User Manual you must have Adobe Acrobat on your computer. If you need a copy, download a copy by clicking on Download Adobe Acrobat.

Anti-virus/Anti-spyware Software

If an anti-virus/anti-spyware software on your local system identifies any of the ERLPhase applications as a "potential threat", it will be necessary to configure your anti-virus/anti-software to classify it as "safe" for its proper operation. Please consult the appropriate anti-virus/anti-spyware software documentation to determine the relevant procedure.

Offliner Features

The *Offliner* software includes the following menu and system tool bar.

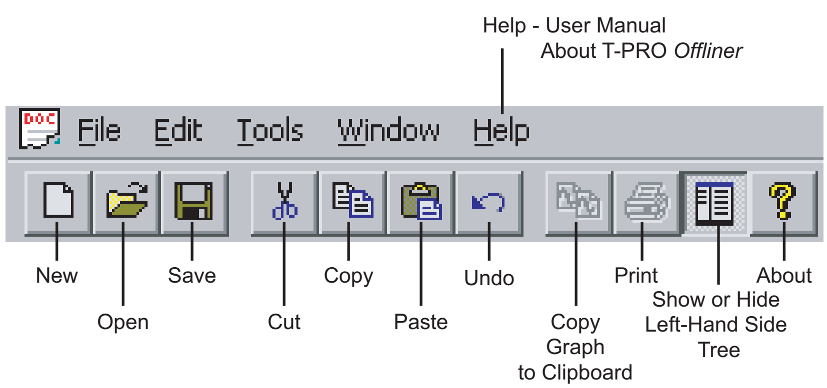


Figure 5.2: Top Tool Bar

Tool Bar	
Windows Menu	
Icon	Restore, minimize, close.
File	New, open, close, save, save as, convert to print, print setup and exit.
Edit	Undo, cut, copy, paste.
Tools	Options

Window	Cascade, tile.
Help	User Manual, About T-PRO Offliner.
Settings Program Icons	
New	Create a new document.
Open	Open an existing document.
Save	Save the active document.
Cut	Cut the selection.
Copy	Copy the selection.
Paste	Insert clipboard contents.
Copy graph to clipboard.	Copy graph to clipboard.
Print	Print active document.
About	Display program information.
Show or Hide Left-Hand Side Tree	Show or Hide the Tree View.
Undo	Undo last action.

Graphing Protection Functions

Grid On/Grid Off

The graph can be viewed with the grid on or off by clicking the Grid On or Grid Off button. A right-click on the trace of the curve gives you the x and y coordinates.

Print Graph

To print a particular graph, click the *Print Graph* button.

Zoom on Graphs

Graphs can be zoomed to bring portions of the traces into clearer display. Left-click on any graph and drag to form a small box around the graph area. When you release the mouse, the trace assumes a new zoom position determined by the area of the zoom coordinates.

To undo the zoom on the graph, click the Refresh button.

Handling Backward Compatibility

Offliner Settings displays the version number in the second pane on the bottom status bar. The settings version is a whole number (v2, v3, v4, etc.).

The *Offliner* Settings is backward compatible. Open and edit older settings files and convert older settings files to a newer version. *Offliner* Settings handles forward conversion only; it converts an older setting file to a newer setting file.

Converting a Settings File

1 Open the setting file you wish to convert.

2 In the *File* menu, select *Convert to...* and then select the *version x* (where x is the newer version). A dialog box pops up prompting *Offliner* for a new file name. Use either the same file name or enter a new file name. The conversion process inserts default values for any newly added devices in the new setting file. When the conversion is complete, *Offliner* Settings displays the new file.

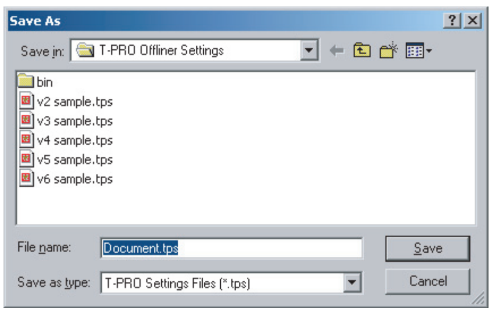


Figure 5.3: Converting Setting Files

Sending a New Setting File to the Relay

1 Make sure the settings version and the serial number of the relay in the setting file match. The relay will reject the setting file if either the serial number or the settings version do not match.

> A “serial number discrepancy” message may appear. This is to ensure that you are aware of the exact relay in which settings are to be loaded. If this happens, check the relay serial number using the terminal mode ID menu item. Type this serial number into the T-PRO Serial No. box in the Identification tab display area of *Offliner* Settings. Alternately you may check the Ignore Serial Number check box to bypass serial number supervision.

2 Check the serial number and the settings version of the relay, for details see “ID” on page 3-9. The Device Serial Number and Required Settings Version on the Identification screen indicate the serial number and the settings version of the relay.

Creating a Setting File from an Older Version

1 *Offliner* Settings displays a default setting file on start up showing the settings version in the bottom status bar. As an example T-PRO *Offliner* is shipped with a set of default sample files of older settings versions. These

sample files are “v2 sample.tps”, “v3 sample.tps”, etc. Each sample file contains default values of an older settings version. For a new installation these sample files are placed in the default directory C:\Program Files\ERLPhase\T-PRO Offliner Settings, or you can choose the path during the *Offliner* software installation. If an older version of T-PRO *Offliner* was previous ly installed on your PC, then the default directory may be C:\Program Files\APT\T-PRO Offliner Settings.

2 Open a sample file of the desired version. Use *File/Save As* to save the sample file to a new file name. Then edit the setting file and the serial number, save it and load it into the relay.

RecordBase View Software

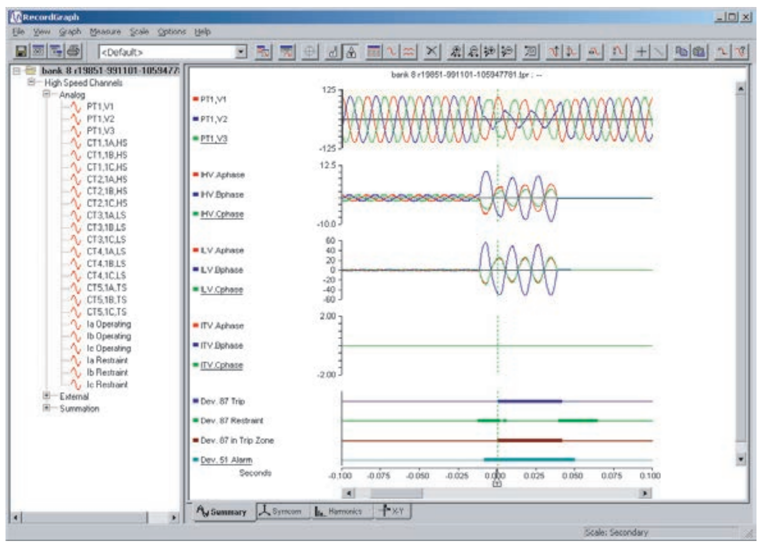


Figure 5.4: RecordBase View

Use RecordBase View to analyze the records from a relay.

1 Set the receive directory on your terminal program to point to a convenient directory on your PC’s hard disk or network. For example with HyperTerminal, select *Transfer>Receive File* to set the receive directory.

2 Select one or more records on the relay using the *List* function in the Terminal Mode’s *Records* menu.

3 Initiate transfer of the selected records by selecting *R* on the keyboard.

4 Start the RecordBase View program and use the *File>Open* menu command to open the downloaded record files located in the receive directory specified in step 1.

For further instructions refer to the RecordBase View Manual at the back of the printed version of this manual.

Main Branches from the Tree View

Identification

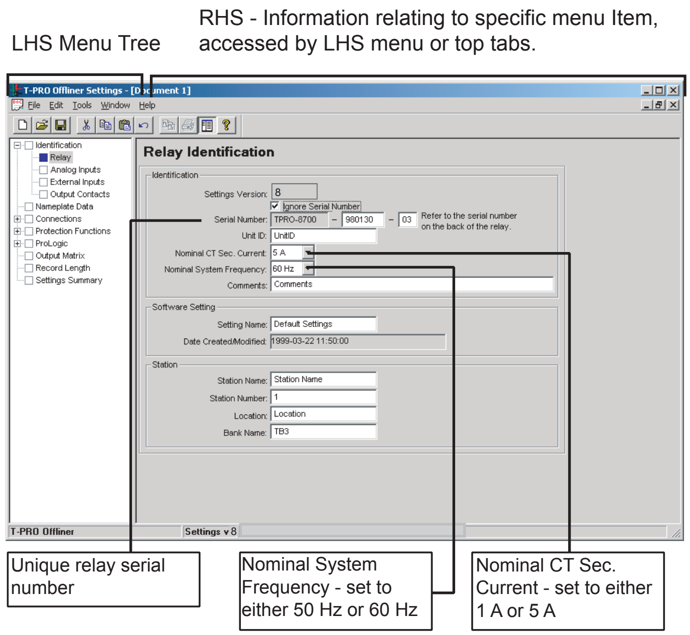


Figure 5.5: Relay Identification

The first screen presents all the menu items in the left menu tree. You can access the menu items by clicking the tabs at the top of the screen or the item on the left menu tree.

Identification	
Settings Version	Indicates the version number.
Ignore Serial Number	Enable/disable
Serial Number	Available at back of each relay.
Unit ID	User-defined up to 20 characters.
Nominal CT Sec. Current	5 A or 1 A
Nominal System Frequency	60 Hz or 50 Hz
Comments	User-defined up to 78 characters.
Setting Software	
Setting Name	User-defined up to 20 characters.
Date Created/Modified	Indicates the last time settings were entered.
Station	
Station Name	User-defined up to 20 characters.
Station Number	User-defined up to 20 characters.
Location	User-defined up to 20 characters.
Bank Name	User-defined up to 20 characters.

Important Note

Nominal CT Sec. Current can be set to either 1 A or 5 A.

Nominal System Frequency can be set to either 50 Hz or 60 Hz.

Ensure setting selection matches that of target T-PRO.

The serial number of the relay must match the one in the setting file, or the setting will be rejected by the relay. This feature ensures that the correct setting file is applied to the right relay.

You can choose to ignore the serial number enforcement in the identification screen. The relay only checks for proper relay type and setting version if the ignore serial number has been chosen.

Analog Inputs

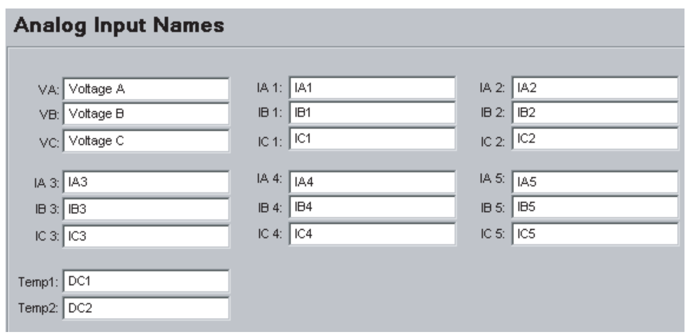


Figure 5.6: Analog Inputs

Identify all ac voltage and current inputs to the relay. These names appear in any fault disturbance records the relay produces.

Analog Input Names	
Voltage Inputs	VA, VB, VC
Current Inputs	IA1, IB1, IC1
	IA2, IB2, IC2
	IA3, IB3, IC3
	IA4, IB4, IC4
	IA5, IB5, IC5
Temp Inputs	Temp 1, Temp 2

External Inputs

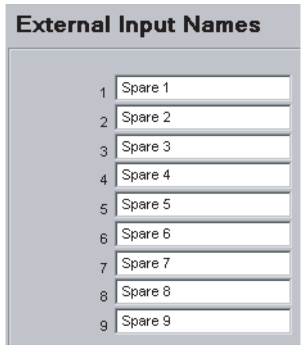


Figure 5.7: External Inputs

Define meaningful names for the nine external digital inputs.

External Input Names	
1 to 9	User-defined

Output Contacts

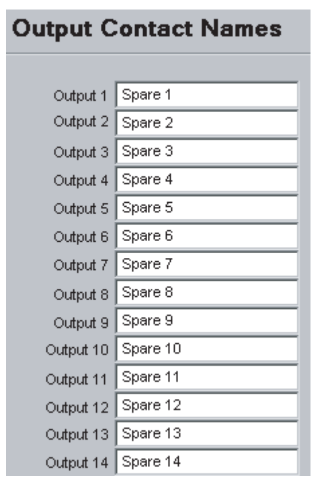


Figure 5.8: Output Contacts

Define meaningful names for the 14 output contacts.

Output Contact Names	
Outputs 1 to 14	User-defined

Nameplate Data

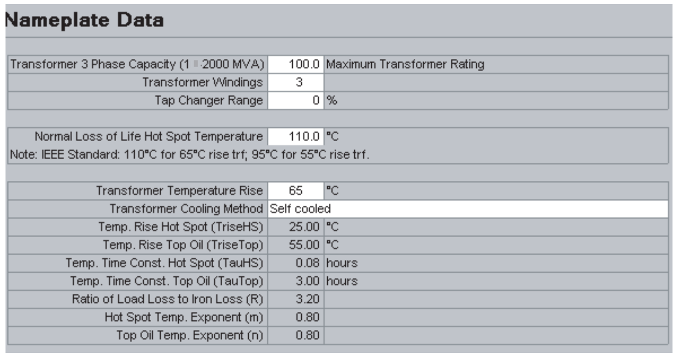


Figure 5.9: Nameplate Data

This data informs the relay that the transformer maximum rating is 100 MVA. This quantity becomes the per unit base quantity for the relay. Any reference in the settings or the outputs related to per unit are based on this value. The temperature rise value and the cooling method provided form the basis for loss of life calculations for the transformer. When user-defined is selected in transformer cooling method, 7 transformer temperature parameters become editable.

If you select other cooling methods, these parameters are no longer editable, and the default values (based on IEEE standards) are used for the transformer temperature calculation.

Nameplate Data	
Transformer 3-phase Capacity (MVA)	1 to 2000
Transformer Windings	2 or 3
Tap Changer Range (percent)	-100 to 100
Normal Loss of Life Hot Spot Temperature (degrees)	70.0 to 200.0
Transformer Temperature Rise (degrees)	55 or 65
Transformer Cooling Method	Self-cooled Forced air cooled, (OA/FA) rated 133% or less of self cooled rating Forced air cooled, directed flow (FOA, FOW, OA/FOA/FOA) Forced air cooled, (OA/FA/FA) rated over 133% of self-cooled rating Forced air cooled, non-directed flow (FOA/FOW, OA/FOA/FOA) User-defined
Temp. Rise Hot Spot (TriseHS) (degrees)	10 to 110
Temp. Rise Top Oil (TriseTop) (degrees)	10 to 110
Temp. Time Const. Hot Spot (TauHS) (hours)	0.01 to 2.00

Temp. Time Const. Top Oil (TauTop) (hours)	0.02 to 20.00
Ratio of Load Loss to Iron Loss (R)	0.50 to 10.00
Hot Spot Temp. Exponent (m)	0.50 to 2.00
Top Oil Temp. Exponent (n)	0.50 to 2.00

Connections

Windings/CT Connections

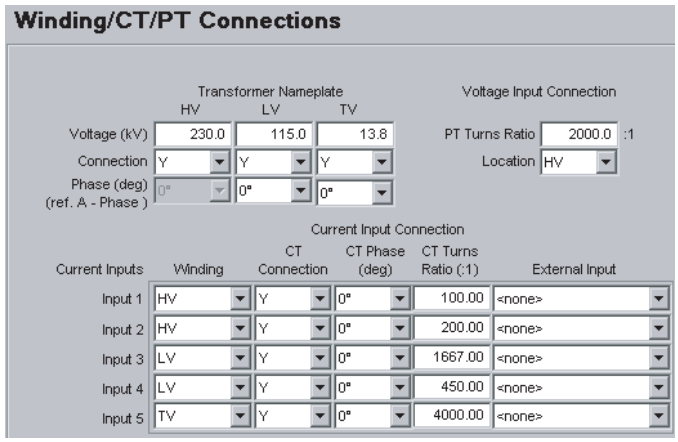


Figure 5.10: Windings /CT

Winding CT Connection			
Transformer Nameplate			
Winding	HV	LV	TV
Voltage (kV)	LV to 1000.0	TV to HV	1.0 to LV
Connection	Choose delta or wye	Choose delta or wye	Choose delta or wye
Phase (degree)	0, 30, 60, 180, -30, -60 (Options depend on connection)		
Voltage Input Connection			
PT Turns Ratio (:1)	1.0 to 10000.0		
Location	HV or LV		
Current Input Connection			
Current Input	1 to 5		
Winding	HV, LV, TV, NC, 51N/87N (for Input 5), 87N auto (for Input 5)		
CT Connection	Choose delta or wye		
CT Phase (degree)	0 or 180, -30 or 30 (Options depend on connection)		

CT Turns Ratio (:1)	1.00 to 10000.00
External Control	None, 1 to 9

This setting provides the relay with the information related to CT ratios, winding connections (wye or delta), main winding nominal voltage and main winding connection. The relay allows any combination of wye and delta combinations in the main and CT windings. Since the actual current inputs used by the differential relay do not contain any zero sequence quantities no external zero sequence current trap is required. The relay is secure for external faults.

The field location associated with the PT ratio is user-selectable and you can connect to the HV or the LV side. The field toggles when clicked between HV and LV.

You can assign five sets of ac currents to the HV, LV, TV sides or to NC (not connected). Assigning a current to NC makes it available to be recorded. In our example:

- Inputs 1 & 2 are assigned to the HV (high voltage) side
- Inputs 3 & 4 are assigned to the LV (low voltage) side
- Input 5 is assigned to the TV (tertiary voltage) side

The current inputs must have at least one input on each of the HV, LV and TV side. An error message appears if this is violated. If the 51N or 87N functions are used, analog input # 5 is automatically used for neutral current inputs.

You can use the 87N in T-PRO for autotransformers provided there is a zero sequence current trap. If that is the case, analog input IA5 becomes the input for this current. IB5 and IC5 are not used.

T-PRO allows assignment of external control to the ac input as indicated in the above figure. In this example ac current inputs 1, 2, 3 are controlled by external inputs 1, 2, 3 respectively, i.e. the ac current input will be automatically shut off internally when the corresponding external input is high. In general, each of 5 ac current inputs can be controlled by any of the relay's external inputs. In this way, the differential protection and overcurrent protection will automatically adapt to the different transformer configurations in real time.

Temperature Scaling

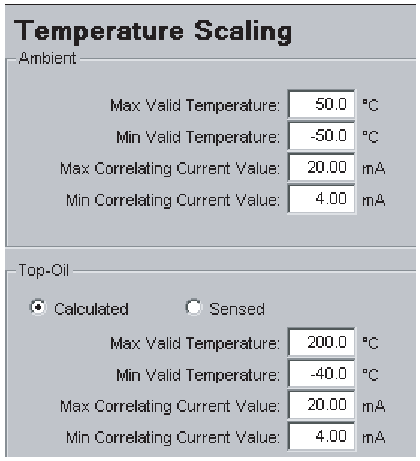


Figure 5.11: Temperature Scaling

Ambient and Top Oil Temperature

Relate the Ambient and Top Oil temperature range with the corresponding mA input current quantity. This relationship is defined at both the high and the low levels. An input received outside this range results in an alarm indicating an over or under condition. You can also set whether the top oil is sensed or calculated.

Temperature Scaling	
Ambient	
Maximum Valid Temperature (degrees)	x to 50.0, x = Minimum Valid Temperature +10°
Minimum Valid Temperature (degrees)	-50.0 to x, x = Maximum Valid Temperature -10°
Maximum Current Value (mA)	x to 20.00, x = Minimum Current Value +1 mA
Minimum Current Value (mA)	4.00 to x, x = Maximum Current Value -1 mA
Top Oil	
Calculated	Enable/disable
Sensed	Enable/disable
Maximum Valid Temperature (degrees)	x to 200.0, x = Minimum Valid Temperature +10°
Minimum Valid Temperature (degrees)	-50.0 to x, x = Maximum Valid Temperature -10°
Maximum Current Value (mA)	x to 20.00, x = Minimum Current Value +1 mA
Minimum Current Value (mA)	4.00 to x, x = Maximum Current Value -1 mA

Protection Functions

The protection function features are described in detail, see “Protection Functions and Specifications” on page 4-1.

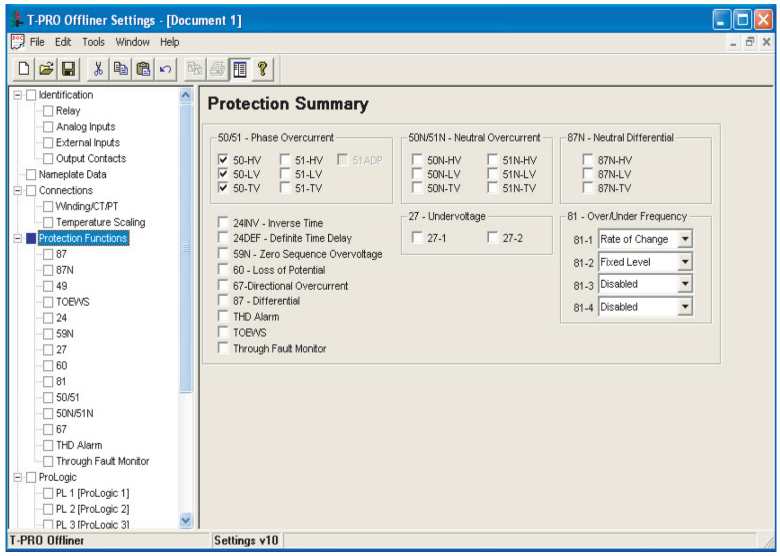


Figure 5.12: Protection Functions

ProLogic

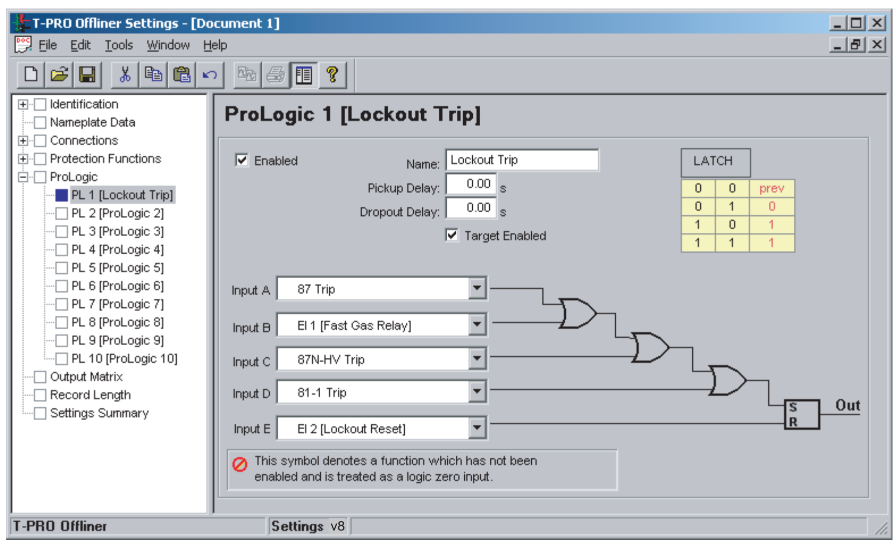


Figure 5.13: ProLogic Example - Lockout Trip

The relay’s integrated ProLogic feature provides Boolean control logic (graphic-driven) with multiple inputs to create an output based on qualified inputs. ProLogic enables up to 10 ProLogic control statements and allows those logics to be programmed to output contacts. Name the function being created and set a pickup and dropout delay. Start with input A by selecting any of the relay functions or digital inputs using the pulldown list. Repeat for up to 5 possible inputs. Put these inputs into AND/OR, NAND/NOR and exclusive logics by clicking on the gate. Invert the input by clicking on the input line.

The output of ProLogic 1 can be nested into ProLogic 2 and so forth. If Target Enabled is selected, you can illuminate the front target LED on operation of this function. The operation of the ProLogic statements are logged on the events listing. ProLogic statements are shown on the view fault records.

In the example, ProLogic illustrates a lockout condition. Operation of device 87, receipt of fast gas operation, operation of device 87N or 81-1 results in a lockout trip where an output contact is held closed until a lockout reset input is received. This lockout reset quantity could be an external input or another function within the relay.

Record Length

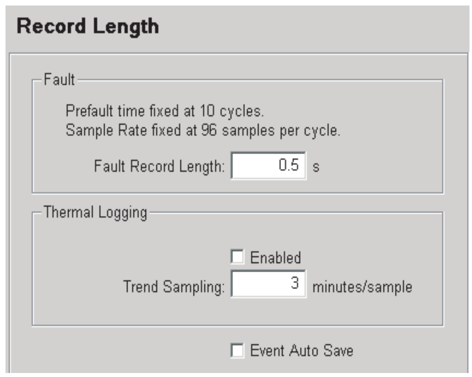


Figure 5.14: Record Length

Define the fault recording record length and the Output Matrix characteristics.

- Fault record sampling rate fixed at 96 samples per cycle
- Prefault data is fixed at 10 cycles.
- Thermal logging rate setting.

Record Length	
Fault	
Prefault time fixed at 10 cycles.	
Sample Rate fixed at 96 samples per cycle.	
Fault Record Length (seconds)	0.2 to 2.0
Thermal Logging	Enable/disable
Trend Sampling (minutes/sample)	3 to 60
Event Auto Save	Enable/Disable

Output Matrix

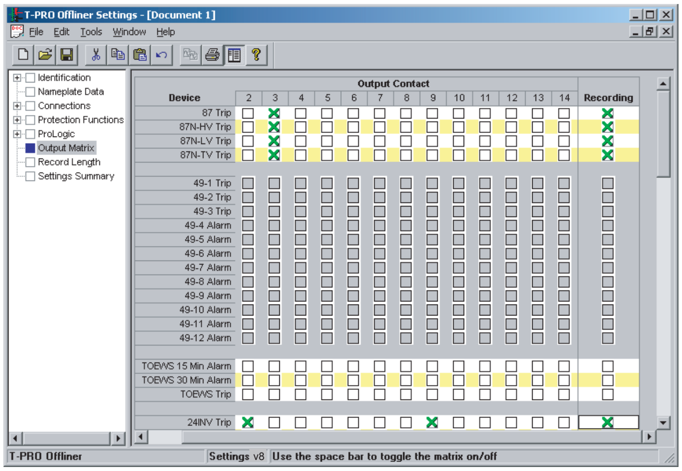


Figure 5.15: Output Matrix

The Output Matrix assigns protective functions to specific output relays and allows these internal protection functions to initiate fault recording. Clicking the check box toggles between checked and unchecked. A scroll bar on the right shows all the protection functions. The recording column on the extreme right allows the protection function to initiate a fault record. The alarm functions for time delay elements and refers to options that are selectable to determine when the threshold level of that function has been exceeded. All output relays have a 0.1 second stretch time.

At this stage the basic differential offline settings of the relay are complete. Save the settings to a file and then load this file into the relay after the terminal connection with the relay is established.

The output contact matrix determines which function initiates which output relay. Functions also initiate recording as required.

> For a particular function to operate correctly, it must be enabled and must also have its logic output assigned to at least one output contact if it is involved in a tripping function.

Print the entire output matrix by selecting the printer icon. This printout is produced on 2 pages.

Setting Summary

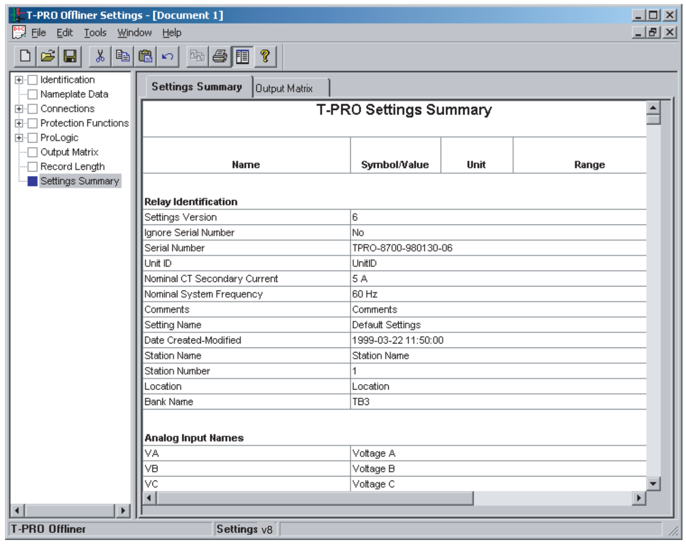


Figure 5.16: Settings Summary

Select Settings Summary to view and print the relay settings in text form, for details see “IED Settings and Ranges” in Appendix B.

6 Acceptance/Protection Function Test Guide

Acceptance Testing

ERLPhase relays are fully tested before leaving the factory. A visual inspection of the relay and its packaging is recommended on receipt to ensure the relay was not damaged during shipping.

> The electronics in the relay contain static sensitive devices and are not user-serviceable. If the front of the relay is opened for any reason exposing the electronics, take extreme care to ensure that you and the relay are solidly grounded.

Generally an analog metering check, as well as testing the I/O (External Inputs and Output Contacts) is sufficient to ensure the functionality of the relay. Further tests can be performed on delivery and acceptance of the purchaser's option according to the published relay specifications in "IED Settings and Ranges" in Appendix B.

The following acceptance test section is intended to be a guide for testing any and all protection elements in the relay. The most convenient time to perform these tests is on delivery, prior to in-service settings being applied. Once in-service settings are applied, ERLPhase recommends that enabled functions be tested to ensure that the designed application is fulfilled.

Test Equipment Requirements

- 3 voltage sources
- 2 sets of three-phase currents recommended (to test differential element), but can be completed single-phase by using 1 set of 3-phase currents (variable frequency capability)
- 1 ohmmeter
- 1 dc mA calibrating source

or

- 1-1 kΩ to 10 kΩ 1.0 W variable resistor and a milliammeter (up to 25mA)

> Set nominal CT secondary current to either 5 A or 1 A, and nominal system frequency to either 60 Hz or 50 Hz. This example uses 5 A/ 60 Hz.

Calibration

The relay is calibrated before it leaves the factory; but if component changes are made within the relay, you may need to do a re-calibration.

> Before you begin a new calibration, establish the accuracy of the equipment being used.

To perform a calibration, you must be logged into the relay in Terminal Mode at the Service access level. Proceed to the *Utilities>Maintenance>Calibrate*. The Calibrate menu leads you through every analog input and prompts you to apply the appropriate quantity.

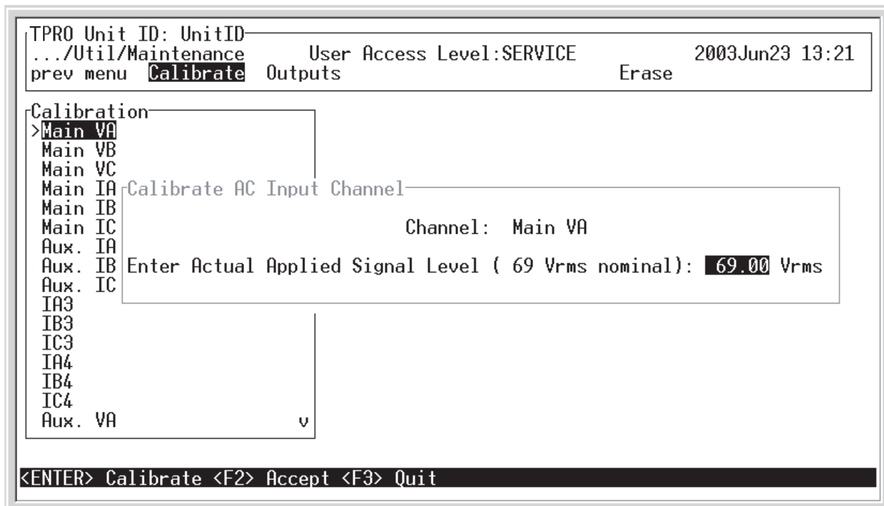


Figure 6.1: Enter actual applied signal level

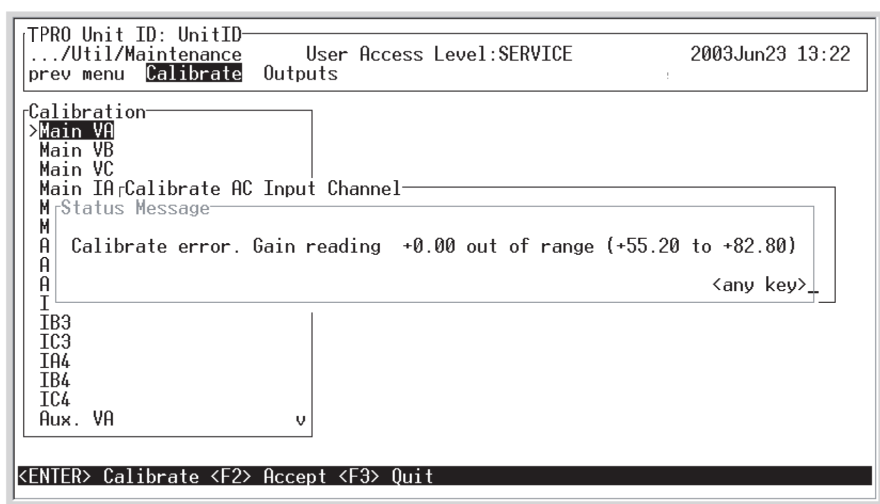


Figure 6.2: Calibration error - out of range

For example, when you select voltage VA for calibration, a prompt appears which asks you which quantity the relay should try to calibrate. If a 66 volt phase-to-neutral quantity is applied to the back VA terminals, 66.0 volts would be indicated as the desired calibration.

In a similar way, you are prompted to go through all 18 ac analog quantities and provide the information about the injected calibration quantities. You must have a test source to perform the function. Only the magnitude of the analog input requires calibration, not the angle.

When an analog input channel is calibrated, you can verify the quantity measured by selecting the Metering menu and the Analog Quantity submenu. VA of the ac voltage input is used as a reference quantity by T-PRO. Therefore, if it is absent, there is not a locked, valid relationship among all of the analog quantities.

Testing the External Inputs

To test the external inputs connect the relay to a laptop in *Terminal Mode, Service level>Metering>I/O*. This screen displays the status of the Input and Output Contacts. Placing a voltage of 125 Vdc nominal, (150 V maximum), to each of the external inputs in turn causes the input to change from Low to High status. These inputs are polarity sensitive and this screen has a 0.5 seconds update rate.

Testing the Output Relay Contacts

Test the output relays to verify their integrity using the *Utilities>Maintenance>Outputs*. The output contacts are closed by pressing the *Enter* key. Toggle the output contacts from open to closed by pressing the *Enter* key. Verify the output contact status using an ohmmeter. When you exit this sub-menu, all contact status reverts to the open position

T-PRO Acceptance Test Procedure Outline

Devices to Test

- 60 AC Loss of Potential
- 24INV Time Inverse Overexcitation (volts per hertz)
- 24DEF Definite Time Overexcitation
- 59N Zero Sequence Overvoltage
- 27 Undervoltage
- 81-1 (set to fixed Over Frequency)
- 81-3 (set to fixed Under Frequency)
- 50N/51N (Neutral Overcurrent)
- 67 Directional Overcurrent
- 50/51 (Phase Overcurrent)
- 51 ADP Adaptive Overcurrent
- Top Oil Temperature Alarm
- Ambient Temperature Alarm
- 49
- 49 TOEWS
- 87 Differential (Single- and Three-Phase)
- THD Alarm
- 87N Neutral Differential

Nameplate Settings and Transformer Connections

To perform maintenance tests modify the applicable relay test quantities by going through the calculation processes described in the following procedures (i.e. substitute acceptance test setting values with your actual setting values).

1 To perform acceptance tests use the appropriate Acceptance Test Setting File, (TPROaccTestsetting##hz.tps). You can find this setting file in C:\Program Files\ERLPhase\T-PRO Offliner Settings after T-PRO *Offliner* Setting software has been installed. If an older version of T-PRO *Offliner* was previously installed on your PC, then the default directory may be *C:\Program Files\APT\T-PRO Offliner Settings*. See “About the Acceptance Test Setting File” on page 6-5). Load the Acceptance Test Setting File into the relay. Note that this file has “Ignore Serial Number” checked. If this was not checked, the exact T-PRO serial number would need to be entered into the file and saved in order for the T-PRO to accept it.

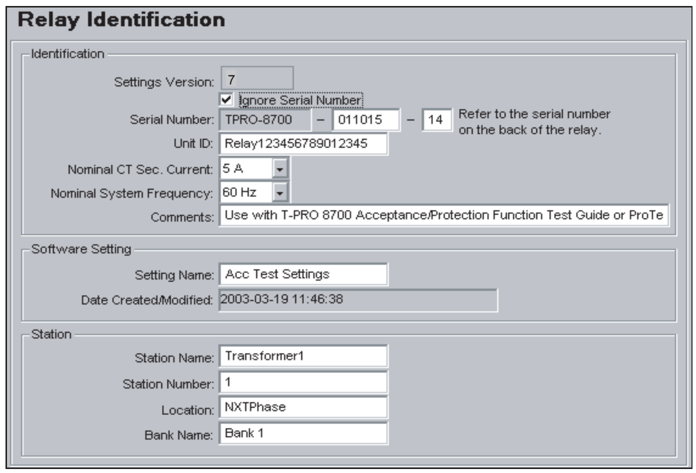


Figure 6.3: Relay Identification

About the Acceptance Test Setting File

The acceptance test setting file provided is not necessarily configured to a provide a realistic setting example. Its configuration is intended to demonstrate test methods for each relay element. Tests are organized to prevent interference of one protection element on the next within the relay for ease of testing without using multiple setting files and minimizing the number of test connection changes. Meanwhile, all contacts in the relay will be tested if all elements in this procedure are tested as written.

When the acceptance test file is loaded into the T-PRO, the Alarm LED may illuminate. This is no cause for concern; it is an indication of a protection element threshold exceeded. Generally this condition is caused by not having applied a minimum of 4 mA to the temperature inputs. Check *Metering>Logic* to find which elements are High.

Load the Setting File into T-PRO

Connect to T-PRO in service or change mode through the front port (Port 1) using your terminal program (e.g. HyperTerminal or Procomm).

```
---------- ERLPhase T-PRO 8700 Terminal User Interface login ----------


Log in using one of the following usernames:
  'view' - read-only access to settings and readings
  'change' - read/write access to settings and readings
  'service' - full access to all functions (Port 1 access only)
  'maintenance' - access to the maintenance menu
  'update' - to load a firmware update (Port 1 access only)


Notes:
- Serial and modem connections have a 60 minute inactivity timeout
- Usernames and passwords are case sensitive

login:
```

Figure 6.4: Login to the Relay

1 From the Main Menu select *Settings*.

2 From the Settings submenu select *Load From Offliner*.

3 Select *Y*, yes you are ready to continue.

```
TPRO Unit ID: UnitID
Main Menu/Settings        User Access Level: CHANGE          2003Mar25 08:52
prev menu  Settings  Load from Offliner  Retrieve to Offliner




Yes/No
Ready to load remote setting. Awaiting your Zmodem send. Continue [Y/N]?
```

Figure 6.5: Load from Offliner

4 Find "Send File" in your terminal software (e.g. for HyperTerminal it's under "Transfer").

5 Browse to the folder location where the setting file was saved and send it to the relay.

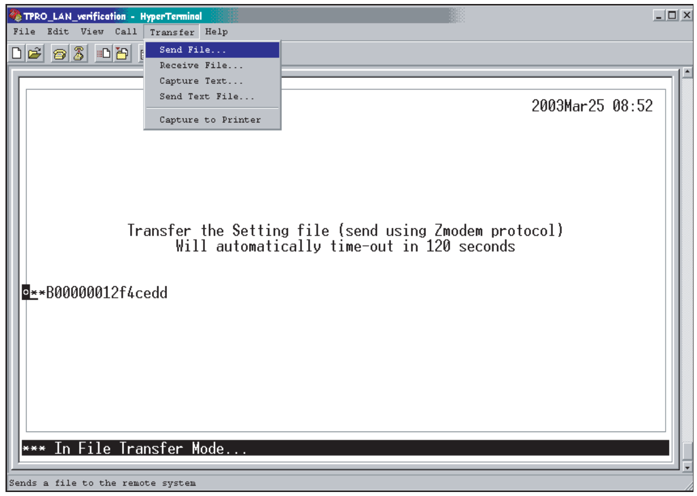


Figure 6.6: Send File

The relevant nameplate and connection settings for tests that follow are:

- MVA: 100
- Windings: 2
- HV kV: 230 Y (0°)
- LV kV: 115 Delta (-30°)
- HV CT: 250:1 Y (0°)
- LV CT: 500:1 Y (0°)
- PT Location: High Side
- Base Frequency: 60 Hz (1.0 per unit frequency)

Calculated Values

The PT location is on the high side; everything will be referenced to the high side.

Nominal secondary phase-to-phase voltage =
$$\frac{HVkV}{PTratio} = \frac{230kV}{2000} = 115.0V$$

Nominal secondary phase-to-neutral voltage =
$$\frac{115}{\sqrt{3}} = 66.4V$$

Primary Ibase =
$$\frac{kVA}{\sqrt{3}\cdot kV} = \frac{100e3}{\sqrt{3}\cdot 230} = 251A$$

Secondary Ibase =
$$\frac{PrimaryIbase}{CTratio} = \frac{251A}{250} = 1.004A$$

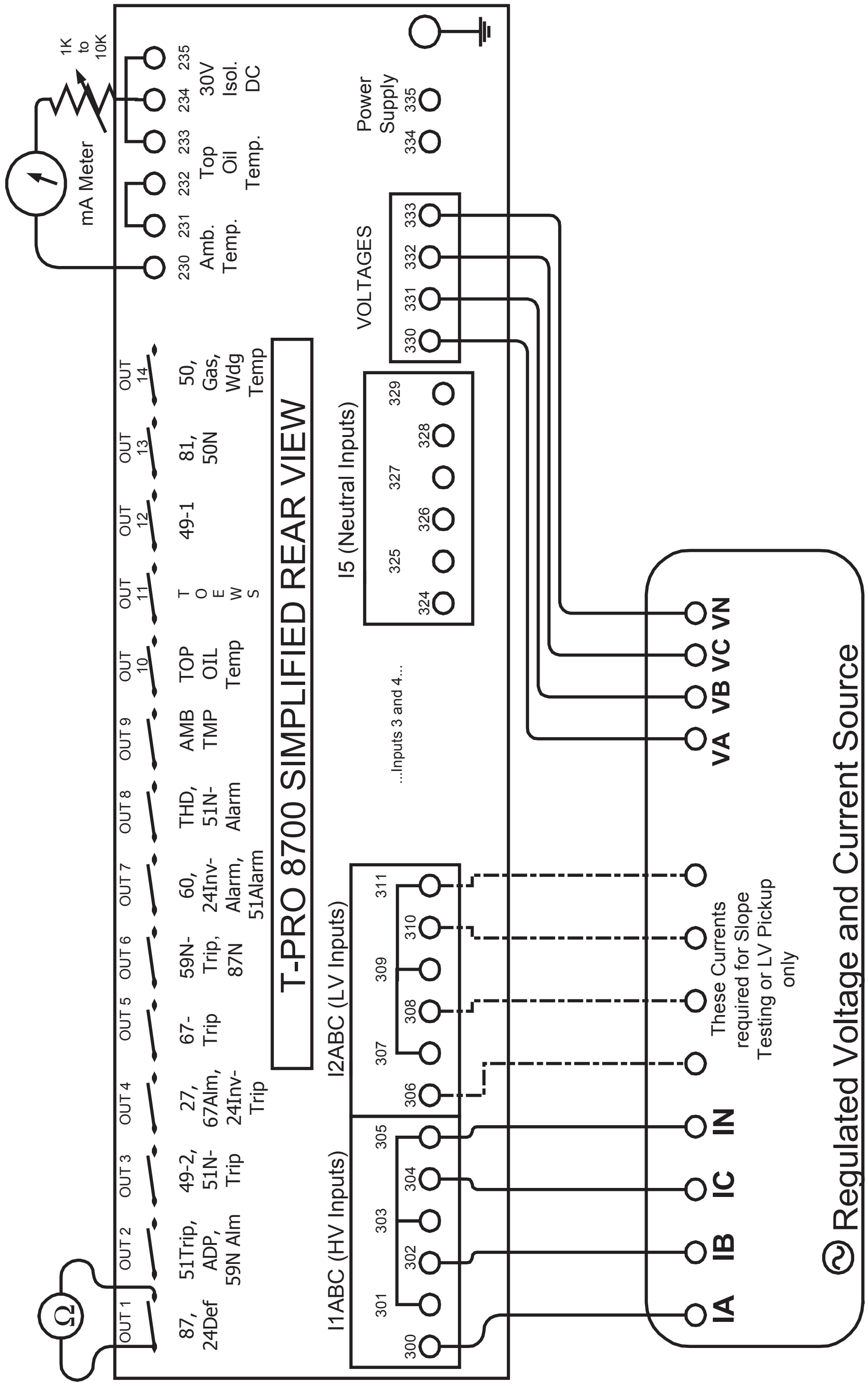


Figure 6.7: Suggested Test Connections for Acceptance Tests

Note 1

Where each test specifies "Metering>Logic", you view the following terminal screen:

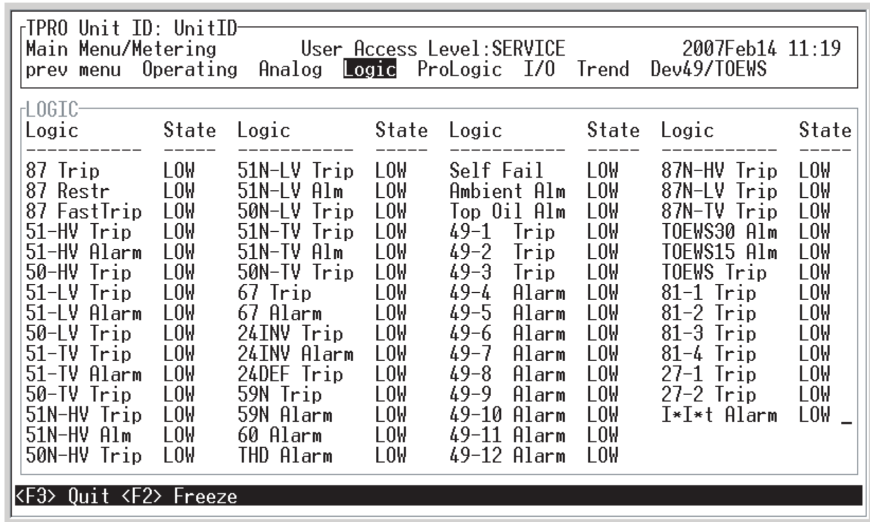


Figure 6.8: Metering Logic

60 Loss of Potential Test

Settings (Only Enable Setting can be modified)

- Voltage = 0.5 per unit on 1 or 2 phases (does not operate on loss of 3 phases).

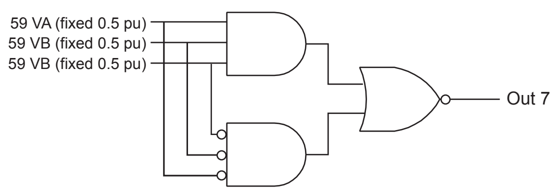


Figure 6.9: Logic Loss of Potential (60)

60 Test Procedure

1 In Terminal Mode access T-PRO *Metering>Logic.*

2 Monitor the following element for pickup: 60 Alarm.

3 Apply balanced 3-phase nominal voltage (66.4 V) to the T-PRO terminals:

Ph A: 330, 66.4 V ∠0 °

Ph B: 331, 66.4 V ∠-120 °

Ph C: 332, 66.4 V ∠+120 °

Ph N: 333

4 Observe: 60 Alarm = Low.

5 Ramp down single-phase voltage:

At 33.6 to 32.8 V (setting = 0.5 per unit = 66.4/2 = 33.2 V secondary)

60 Alarm = High

6 Turn all voltage off.

60 Alarm = Low

Timing Test

1 Monitor timer stop on Output Contact 7.

2 Set timer to start from single-phase 0.0 V to 66.4 V transition (i.e. V off to on).

Time Delay (definite) = 10 seconds

End of 60 test.

24 Overexcitation Test

Settings

- 24INV Pickup = 1.2 per unit = 1.2 * 66.4 V @ 60 Hz = 79.7 V @ 60 Hz
- K = 0.1
- 24DEF Pickup = 1.25 per unit = 1.25 * 66.4 V @ 60 Hz = 83 V @ 60 Hz

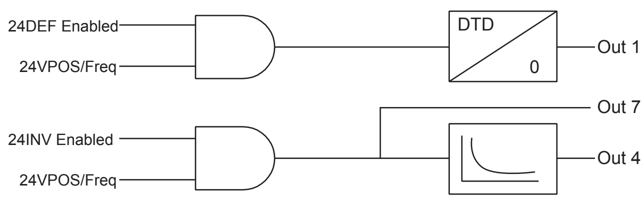


Figure 6.10: Logic Overexcitation (24)

24INVerse and 24DEFinite Test Procedure

1 In Terminal Mode access T-PRO *Metering>Logic*.

Monitor the following elements for pickup: 24INV Alarm, 24DEF Trip.

2 Apply balanced 3-phase nominal voltage to the T-PRO terminals:

Ph A: 330, 66.4 V ∠0 °

Ph B: 331, 66.4 V ∠-120 °

Ph C: 332, 66.4 V ∠+120 °

Ph N: 333

3 Slowly ramp the 3-phase voltage up.

At 79.5 – 80.5 V (expect 79.7 V):

24INV Alarm = High

Output Contact 7 = Closed

At 82.5 – 83.5 V (expect 83.0 V):

24DEF Trip = High

Output Contact 1 = Closed

4 Turn voltages off.

24INV Alarm = Low

Output Contact 7 = Open

24DEF Trip = Low

Output Contact 1 = Open

Timing Test

1 Monitor timer stop on Output Contact 4.

2 Set timer to start from 3-phase 0.0 V to 86.3 V transition (this equates to 1.3 per unit @ 60 Hz)

$$\text{Time Delay} = \frac{K}{\left[\frac{v}{f} - Pickup\right]^2} = \frac{0.1}{\left[\frac{\left(\frac{86.3}{66.4}\right)}{60} - \frac{\left(\frac{79.68}{66.4}\right)}{60}\right]^2} = \frac{0.1}{0.01} = 10s$$

Where:

v is the per unit voltage

f is the per unit frequency. Vary either v or f.

In this example we're varying v only (with f @ 60 Hz = 1.0 per unit).

End of 24 test.

59N Zero Sequence Overvoltage (3V0) Test

Settings

- 59N (3V0) Pickup = 75 V
- Time Curve = IEC Standard Inverse

    A = 0.14

    B = 0

    p = 0.02

    TMS = 0.2

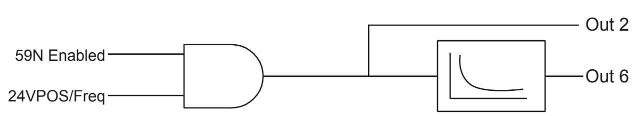


Figure 6.11: Logic Zero Sequence OverVoltage (59N)

59N (3V0) Test Procedure

1 In Terminal Mode access T-PRO *Metering>Logic*.

Monitor the following element for pickup: 59N Alarm.

2 Apply 3-phase prefault voltage "In-phase" to the T-PRO terminals as follows:

Ph A: 330, 20 V ∠0 °

Ph B: 331, 20 V ∠0 °

Ph C: 332, 20 V ∠0 °

Ph N: 333

Note: The above prefault 3V0 = VA + VB + VC = (20V ∠0 ° + 20V ∠0 ° + 20V ∠0 ° = 60V ∠0 ° V)

3 Slowly ramp the 3-phase voltage up.

At 24.5 – 25.5 V per phase (expect 25.0 V):

59N Alarm = High

Output Contact 2 = Closed

4 Turn voltage off.

59N Alarm = Low

Output Contact 2 = Open

Timing Test

1 Monitor timer stop on Output Contact 6.

2 Set timer start from 3-phase 0.0 V to 50.0 V transition (all at 0°).

3V0 = 50 + 50 + 50 = 150 V (This equates to 2x pickup.)

Time Delay =

$$TMS \cdot \left[B + \frac{A}{\left(\frac{3VO}{Pickup}\right)^{p} - 1} \right] = 0.2 \cdot \left[0 + \frac{0.14}{\left(\frac{150}{75}\right)^{0.02} - 1} \right] = \left(0.2 \cdot \frac{0.14}{0.014}\right) = 2.0s$$

End of 59N test.

27 (27-1 Single-Phase [OR], 27-2 Three-Phase [AND] Test

This example testing 27-2 only in this procedure, but testing 27-1 is just a matter of enabling the function and reducing only one-phase voltage.

Settings

- 27-1 Gate = OR (single-phase)
- 27-1 Pickup = 50 V secondary
- 27-1 Delay = 0.5 seconds
- 27-2 Gate = AND (3-phase)
- 27-2 Pickup = 50 V secondary
- 27-2 Delay = 0.6 seconds

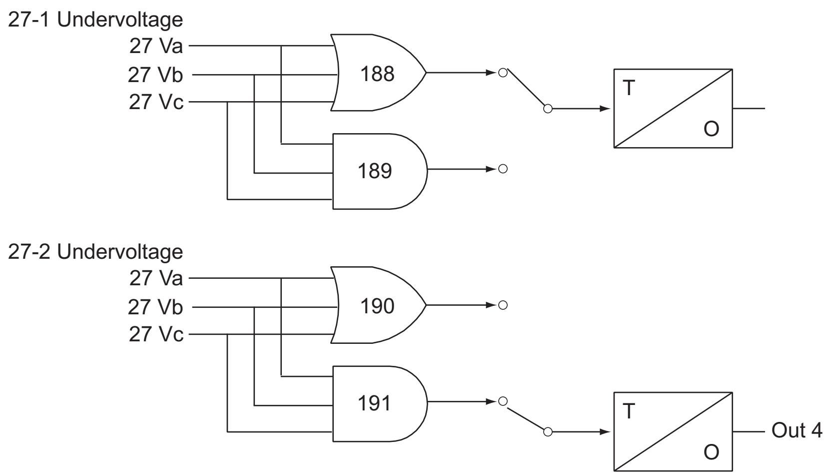


Figure 6.12: Logic UnderVoltage (27)

27 Three-Phase Undervoltage Test Procedure

1 In Terminal Mode access T-PRO *Metering>Logic*.
  Monitor the following element for pickup: 27-2 Alarm.

2 Apply balanced 3-phase voltage to the T-PRO terminals as follows:
  Ph A: 330, 66.4 V ∠0 °
  Ph B: 331, 66.4 V ∠-120 °
  Ph C: 332, 66.4 V ∠120 °
  Ph N: 333

3 Slowly ramp the 3-phase voltage magnitudes down.
  At 50.5 to 49.5 V per phase (expect 50.0 V):
  27-2 Alarm = High
  Output Contact 4 = Closed

4 Turn voltages off.

End of 27 test.

81 Over/Under Frequency Test

Settings

- 81-1 Over Frequency Pickup = 61 Hz
- 81-2 Over Frequency Rate of Change = 0.1 Hz/sec
- 81-3 Under Frequency Pickup = 59 Hz
- 81-4 Under Frequency Rate of Change = -0.1Hz/sec
- All Time Delays = 0.2 seconds

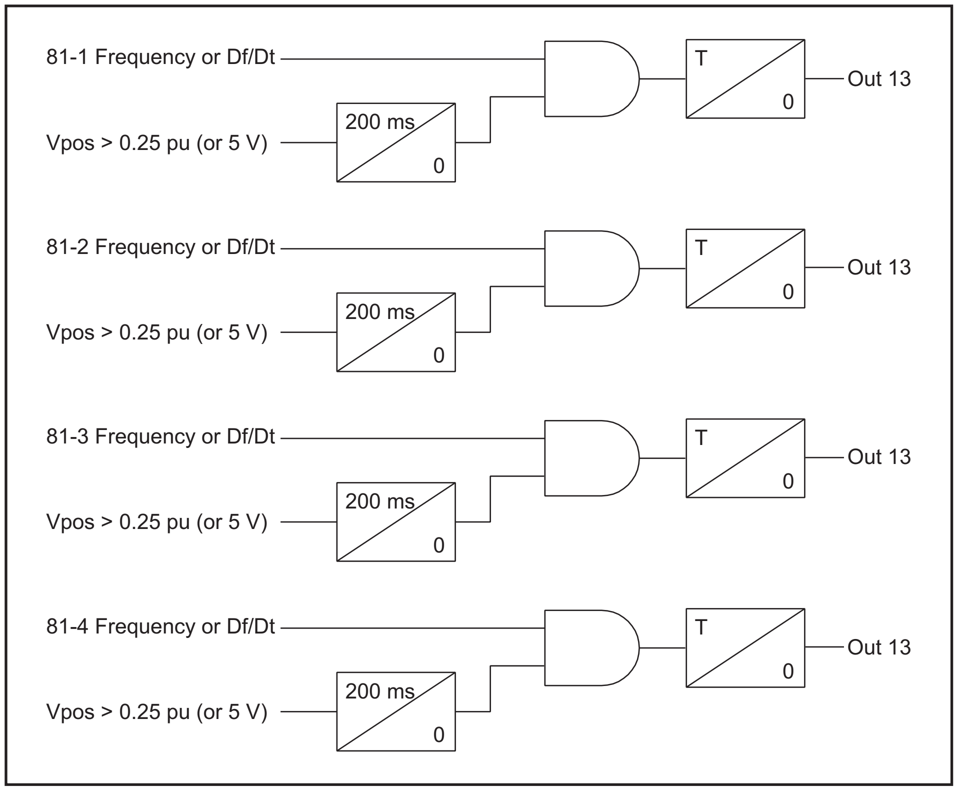


Figure 6.13: Logic Over/Under/Rate of Change of Frequency (81)

81 Test Procedure

1 In Terminal Mode access T-PRO *Metering>Logic.*

2 Monitor the following elements for pickup: 81-1 Trip, 81-3 Trip.

3 Apply balanced 3-phase nominal voltages to the T-PRO terminals.

Ph A: 330, 66.4 V ∠0°

Ph B: 331, 66.4 V ∠-120°

Ph C: 332, 66.4 V ∠+120°

Ph N: 333

4 Slowly ramp (less than 0.1 Hz/sec) the 3-phase voltage frequency up towards 61 Hz.

At 60.99 – 61.01 Hz: 81-1 = High (81-3 = Low)

Output Contact 13 = Closed

5 Slowly ramp (greater than -0.1 Hz/sec. e.g.: -0.05 Hz/sec) the 3-phase voltage frequency down towards 59 Hz.

At 58.99 – 59.01 Hz: 81-3 = High (81-1 = Low)

Output Contact 13 = Closed

6 Turn voltages off.

81-1 = Low

81-3 = Low

Output Contact 13 = Open

End of 81 test.

50N/51N Neutral Instantaneous and Time Overcurrent Test

Settings

- 50N Pickup = 5.0 A
- 51N Pickup = 2.0 A
- Time Curve = IEEE Extremely Inverse

A = 5.64

B= 0.0243

p = 2

TMS = 5.0

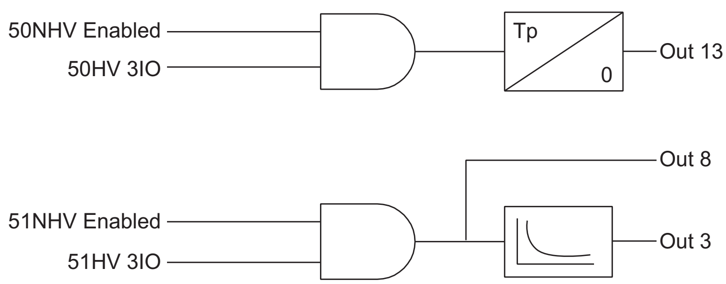


Figure 6.14: Logic Neutral Instantaneous and Time Overcurrent (50N/51N)

50N and 51N Test Procedure

1 In Terminal Mode access T-PRO *Metering>Logic*.

Monitor the following element for pickup: 51N Alarm.

2 Apply one-phase current to the T-PRO terminals as follows:

Ph N: 324–325, 1.8 A (I5A is the input for HV neutral)

3 Slowly ramp the current up.

At 1.95 to 2.05 A (expect 2.00 A):

51N Alarm = High

Output Contact 8 = Closed

4 Continue to raise current.

At 4.90 to 5.10 A (expect 5.00 A):

50N Trip = High

Output Contact 13 = Closed

5 Turn currents off.

51N Alarm = Low

50N Trip = Low

Contacts 8 and 13 = Open

Timing Test

1 Monitor timer stop on Output Contact 3.

2 Set timer start from one-phase 0.0 amp to 8.00 A transition (This equates to 4x pickup.).

$$\text{Time Delay} = TMS \cdot \left[B + \frac{A}{(I_{multiple})^p - 1}\right] = 5 \cdot \left[0.0243 + \frac{5.64}{(4)^2 - 1}\right] = 5 \cdot \left[0.0243 + \frac{5.64}{15}\right] = 2.00s$$

End of 50N/51N test.

67 Directional Time Overcurrent Test

Settings

- 67 Pickup = 1.2 per unit
- Alpha = 180° (This is the positive sequence current angle start point with respect to positive sequence voltage angle.)
- Beta = 180° (This is the operating “Window”. In this case the 67 element should operate between [Alpha to (Alpha + Beta)] = [180° to (180° + 180°)] = 180° to 360°)
- Time Curve = IEEE Moderately Inverse

  A = 0.0103

  B = 0.0228

  p = 0.02

  TMS = 8.0

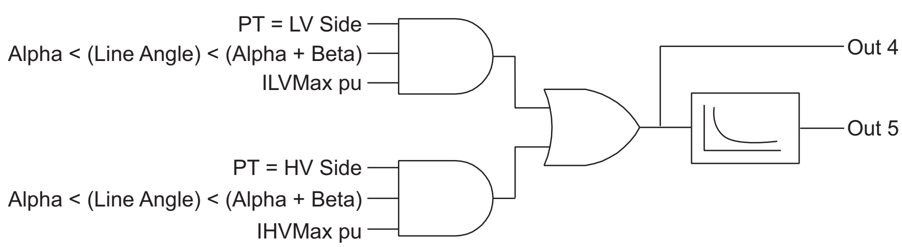


Figure 6.15: Logic Directional Overcurrent (67)

67 Test Procedure

1 In Terminal Mode access T-PRO *Metering>Logic.*

Monitor the following element for pickup: 67 Alarm.

2 Following are the default test quantities.

Apply balanced 3-phase currents to the T-PRO terminals as follows:

Ph A: 300–301, 1.0 A ∠-90°

Ph B: 302–303, 1.0 A ∠+150°

Ph C: 304–305, 1.0 A ∠+30°

Apply single-phase polarizing voltage to:

Ph A: 330–333, 66.4 V ∠0°

3 Slowly ramp the 3-phase currents up.

At 1.15 to 1.25 A (expect 1.20 A):

67 Alarm = High

4 Increase currents to 2.0 A.

Observe: 67 Alarm = High

5 Ramp current angle in positive direction from -90°.

At -1.0° to +1.0° (expect 0°):

67 Alarm = Low

6 Ramp current angle in negative direction from -90°.

At -179° to -181° (expect -180°):

67 Alarm = Low

7 Turn currents off (Keep voltage on for the timing test).

67 Alarm = Low

67 Timing Test

1 Monitor timer stop on Output Contact 5.

2 Set timer start from 3-phase current (default angles) 0 to 3.60 A transition (3x pickup).

Time Delay= $$TMS \cdot \left[B + \frac{A}{(I_{multiple})^{p} - 1}\right] = 8 \cdot \left[0.0228 + \frac{0.0103}{(3)^{0.02} - 1}\right] = 8 \cdot \left[0.0228 + \frac{0.0103}{0.0222}\right] = 3.89s$$

T-PRO Target: “Dir. Overcurrent (67): Trip”

End of 67 test.

50/51 Instantaneous and Time Overcurrent Three-Phase Test

Settings

- 50 Pickup = 1.5 per unit
- 51 Pickup = 1.2 per unit
- Time Curve = IEEE Very Inverse

  A = 3.922

  B = 0.0982

  p = 2

  TMS = 4.0

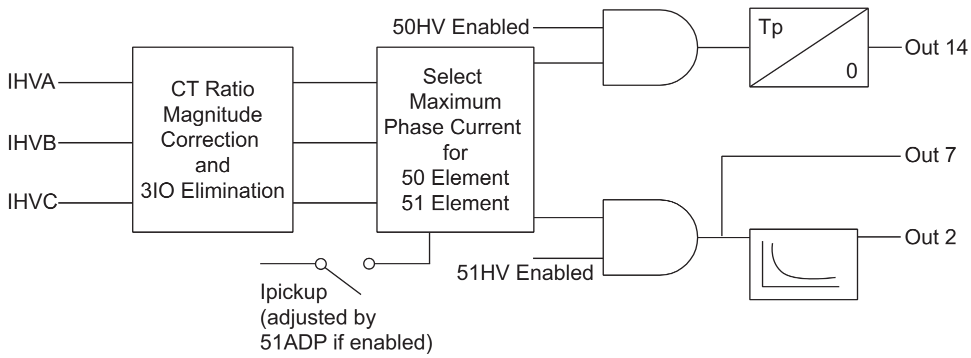


Figure 6.16: Logic phase Overcurrent (50/51)

50/51 Three-Phase Test Procedure

1 In Terminal Mode access T-PRO *Metering>Logic*.

Monitor the following element for pickup: 51 Alarm.

2 Apply balanced 3-phase currents to the T-PRO terminals as follows:

Ph A: 300–301, 1.0 A ∠0°

Ph B: 302–303, 1.0 A ∠120°

Ph C: 304–305, 1.0 A ∠+120°

3 Slowly ramp the 3-phase currents up.

At 1.15 to 1.25 A (expect 1.20 A):

51 Alarm = High

Output Contact 7 = Closed

4 Continue to raise currents.

At 1.45 to 1.55 A (expect 1.50 A):

50 Trip = High

Output Contact 14 = Closed

5 Turn currents off.

51 Alarm = Low (Output Contact 7 Open)

50 Trip = Low (Output Contact 14 Open)

Timing Test

1 Monitor timer stop on Output Contact 2.

2 Set timer start from 3-phase 0.0 A to 3.60 A transition (This equates to 3x pickup.).

Time Delay = $$TMS \cdot \left[B + \frac{A}{(I_{multiple})^p - 1}\right] = 4 \cdot \left[0.0982 + \frac{3.922}{(3)^2 - 1}\right] = 4 \cdot \left[0.0982 + \frac{3.922}{8}\right] = 2.35s$$

51ADP Adaptive Pickup Test

Settings

- Nameplate: Cooling: Type 1, Self Cooled OA or OW
- Ambient Temperature Scaling: 4mA = -40°C, 20mA = +40°C
- 51ADP Multiple of Normal Loss of Life = 1.0

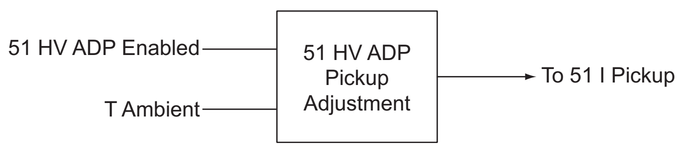


Figure 6.17: Logic Overcurrent Adaptive Pickup (51ADP)

51ADP Test Procedure

To simulate an ambient temperature of +30°C, inject 18.0 mA dc into the Ambient Temperature Input (+230, -231). In *Metering>Trend* confirm a +30°C reading.

Using the graph Figure M.3: Allowed Loading: 65°C Rise Transformer, Type 1 Cooling on page M-4, see that at +30°C the overload characteristic is de-rated to 1.0 per unit for a relative loss of life setting of 1.0.

1 In Terminal Mode access T-PRO *Metering>Logic.*

Monitor the following element for pickup: 51 Alarm.

Monitor 51HV Alarm: Output Contact 7.

2 Apply balanced 3-phase currents to the T-PRO terminals as follows:

Ph A: 300–301, 0.8A $\angle$0°

Ph B: 302–303, 0.8A $\angle$-120°

Ph C: 304–305, 0.8A $\angle$+120°

3 Slowly ramp the 3-phase currents up.

At 0.95 to 1.05 A (expect 1.0 A):

51 Alarm = High

Contact 7 = Closed

4 Turn currents off.

51 Alarm = Low

Out 7 = Open

End of 51ADP test.

Checking Ambient Temperature Alarm

1 In Terminal Mode access T-PRO *Metering>Logic*.

2 Monitor the following element for pickup: Amb. Alarm.

3 With 18 mA being injected into Ambient Temperature input:

Amb. Alarm = Low

Contact 9 = Open

Note: The Ambient Temperature Alarm will activate if the Ambient Temperature is outside of the Setting Range.

4 Ramp mA input up from 18 mA,

At Approximately 21 mA:

Amb. Temp Alarm = High

Contact 9 = Closed

5 Remove mA input from Ambient Temperature input.

Amb. Alarm = High (since 0mA is out of the setting range)

Contact 9 = Closed.

End of Ambient Temperature Alarm test.

Checking the Top Oil Temperature Alarm

Switch mA input from Ambient Temperature input to Top Oil Temperature input (+232, -233).

Top Oil Settings (measured)

Top Oil Temperature Scaling: 4 mA = -40°C, 20mA = +200°C

View the corresponding temperature in *Metering>Trend*.

1 In Terminal Mode access T-PRO *Metering>Logi*c.

Monitor the following element for pickup: TopOil Alarm.

2 With 18 mA being injected into Top Oil Temperature input:

TopOil Alarm = Low

Contact 10 = Open

Note: The Top Oil Temperature Alarm will activate if the Top Oil Temperature is outside of the Setting Range.

3 Ramp mA input up from 18 mA.

At approximately 21 mA:

TopOil Alarm = High

Contact 10 = Closed

4 Remove mA input from Top Oil Temperature input.
TopOil Alarm = High (since 0mA is out of the setting range)
Contact 10 = Closed.

End of Top Oil Temperature Alarm test.

49 Thermal Overload Test

mA is injected into Top Oil Temperature input (+232 – 233)

Settings

- 49 HV = 1.2 per unit
- Hysteresis = 0.1 per unit

AND

- Top Oil Temperature = 160°C
- Temperature Hysteresis = 1.0°C

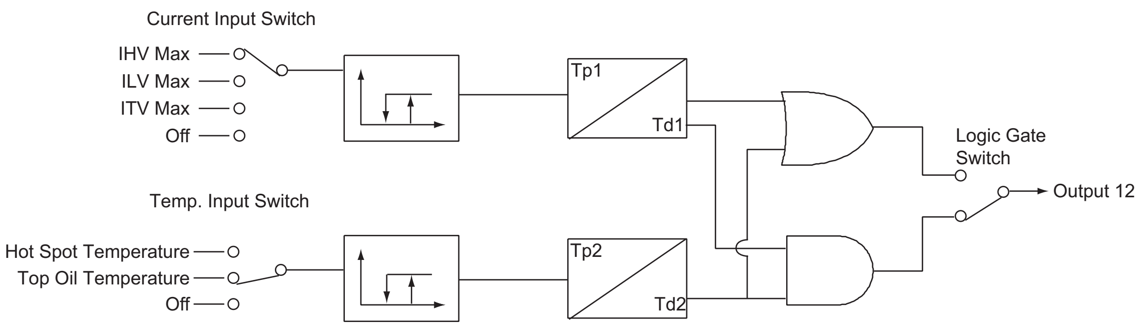


Figure 6.18: Logic Thermal Overload (49)

Monitor the following element for pickup: 49_1 Trip.

1 Inject:
18 mA into Top Oil Temperature input (160°C setting is exceeded)
3-phase currents into:
Ph A: 300–301, 1.0 A ∠0°
Ph B: 302–303, 1.0 A ∠-120°
Ph C: 304–305, 1.0 A ∠+120°
Observe:
49_1 Trip = Low
Contact 12 = Open

2 Ramp current up.
At 1.15 to 1.25 A (expect 1.20 A):
49_1 Trip asserts
Contact 12 = Closed

3 Decrease Top Oil Temperature to 16 mA.
49_1 Trip De-asserts
Contact 12 = Open

4 Ramp Top Oil Temperature input up to 17.0 to 17.6 mA

49_1 Trip Asserts

Contact 12 = Closed

5 Remove:

mA from Top Oil Temperature input

Currents from HV input

Contact 12 = Open

End of 49 test.

49 TOEWS Test

This system warns and trips for conditions of either excessive hot spot temperature or excessive loss of life during any one overloading occurrence.

Settings

- Transformer MVA 100
- Cooling Type 1: OA/OW
- Temperature Rise: 65°C
- Normal Loss of Life Hot Spot Temperature: 110°C
- Ths Trip Setting: 150°C
- Ths to start LOL Calculation: 120°C
- LOL Trip Setting: 1 day

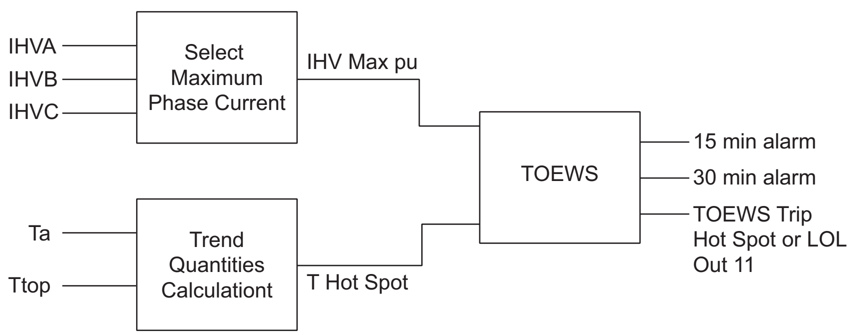


Figure 6.19: Logic Transformer Overload Early Warning System (49TOEWS)

TOEWS Test Procedure

1 Apply balanced 3-phase currents to the T-PRO terminals as follows:

Ph A: 300–301, 1.00 A ∠0°

Ph B: 302–303, 1.00 A ∠-120°

Ph C: 304–305, 1.00 A ∠+120°

2 Apply 16 mA dc (140°C) to Ambient Temperature input terminals +230, -231 (Top Oil Setting = Calculated)

Re-boot the T-PRO (cycle power) to reset the steady state condition, otherwise the T-PRO only assumes a new steady state after hours of “settling in”. When the T-PRO is installed, this is not a problem and is the correct way to respond.

3 In Terminal Mode access T-PRO *Metering>Dev49>TOEWS*.

Monitor the following elements for pickup.

30min Alarm = Low

15min Alarm = Low

Trip = Low

Observe:

HV current = 1.00 per unit.

Ambient Temperature = 20°C

Top Oil Temerature = 75°C

Hot Spot Temperature = 100°C

4 Increase current to simulate an overload condition (e.g. 180% Load).

Over a period of time (hours) observe, in order:

30 min Alarm = High

15 minutes later: 15 min Alarm = High

15 minutes later: TOEWS Trip = High

Contact 11 = Closed

Hint: If you set the T-PRO to trigger a recording on each of these events, you can ensure that you will retain records of when these elements operate.

T-PRO Target: “TOEWS: Trip”

Checking the warning and trip times can only be properly done by comparing “heat runs” made on software (an MS Excel spreadsheet) available from ERLPhase. Very stable temperature mA inputs and current inputs over a period of hours are necessary to get predictable and satisfactory timing test results.

End of TOEWS test.

87 Differential Test

This section covers the testing of the minimum operating point.

For more detailed testing see the example in "T-PRO Differential Slope Test Example" on page 6-33.

Settings

- IO_{min}: 0.3 per unit
- IRs: 2.0 per unit
- Slope 1: 20%
- Slope 2: 40%

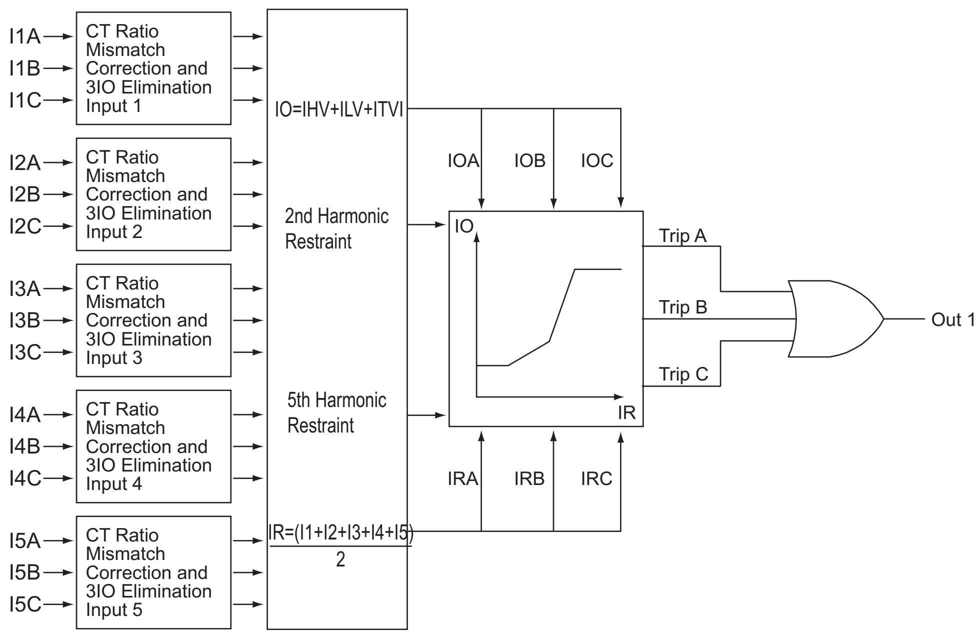


Figure 6.20: Logic Phase Differential (87

Magnitude Correction Factor

$$MCF = \frac{HVkV}{LVkV} \times \frac{HVCTRatio}{LVCTRatio} = \frac{230}{115} \times \frac{250}{500} = 1.0$$

Note: A delta connected CT on either side would add an additional factor of $\sqrt{3}$ to that side.

High side current at base = 1.00 A (in the "Calculations" section)

Low side current at base =

$$HighSideCurrentAtBase \cdot MCF = 1.00A \cdot 1.00 = 1.00A$$

Therefore:

$$HVMinimumOperate = 0.3pu \cdot 1.00A = 0.30A$$

$$LVMinimumOperate = HVMinimumOperate \cdot MCF = 0.30A \times 1.00 = 0.30A$$

87 HV Minimum Operate Test Procedure

1 In Terminal Mode access T-PRO *Metering>Logi*c.
  Monitor the following element for pickup: 87 Trip.

2 Prepare to apply balanced 3-phase currents to the T-PRO terminals as follows:
  Ph A: 300–301, ∠0°
  Ph B: 302–303, ∠-120°
  Ph C: 304–305, ∠+120°

3 Simultaneously and slowly ramp all 3 currents up:
  At 0.29 to 0.31A (expect 0.301A):
  87 Trip = High
  Contact 1 = Closed

4 T-PRO Target: "Diff. (87) on ???: Trip" (phase target will depend on which reaches pickup first).

The exact same test can be applied to the LV Side since the MCF is 1.0.

Testing 87 HV Minimum Operate Single-Phase

To test single-phase, obtain an additional MCF to compensate for the T-PRO zero sequence elimination (T-PRO uses formulae from "Analog Phase Shift Table" in Appendix L.).

T-PRO is a 3-phase relay, but will operate on a phase-by-phase basis (i.e. when the differential setting is exceeded on any one phase (or more), the 87 element will operate).

Calculate how much current each phase of the T-PRO will "see" by using 1.0 A as a base in the formulae of "Analog Phase Shift Table" in Appendix L. The result gives a ratio that is valid for any magnitude of current applied.

For a 0° shift, which is present on the HV side (Y ∠0° + Y ∠0° = 0°):

If you inject 1.0 A on Phase A only, on the high side, the values below can be confirmed in *Metering>Operating*.

$$IA = \frac{2Ia - Ib - Ic}{3} = \frac{2(1) - (0) - (0)}{3} = \frac{2}{3}A$$

$$IB = \frac{2Ib - Ic - Ia}{3} = \frac{2(0) - (0) - (1)}{3} = \frac{-1}{3}A$$

$$IC = \frac{2Ic - Ia - Ib}{3} = \frac{2(0) - (1) - (0)}{3} = \frac{-1}{3}A$$

Note that the strongest phase is IA, so IA operates first.

From the 3-phase test section note that IO_{min} = 0.30 A.

For the T-PRO to see 0.30 A on Phase A, inject 3/2 * 0.30A (= 0.45 A), since the T-PRO only sees 2/3 the current injected.

Single-Phase Method #1 Test Procedure

1 Connect current Source 300 – 301.

Slowly ramp current up.

At 0.44 to 0.46 A (expect 0.45 A):

87 Trip = High

2 Turn current off.

87 Trip = Low

Method 2

Another way to do the single-phase test is to use a single source injected A-B (into Terminal 300, out of 302 with 301 and 303 jumpered together).

So if you use 1.0 A, then Phase A = 1.0° ∠0 ° (= +1.0 A) and phase B = 1.0° ∠180° (= -1.0 A).

Apply the Phase Shift formulae from "Analog Phase Shift Table" in Appendix L.

$$IA = \frac{2Ia - Ib - Ic}{3} = \frac{2(1) - (-1) - (0)}{3} = \frac{3}{3} = 1.0A$$

$$IB = \frac{2Ib - Ic - Ia}{3} = \frac{2(-1) - (0) - (1)}{3} = \frac{-3}{3} = -1.0A$$

$$IC = \frac{2Ic - Ia - Ib}{3} = \frac{2(0) - (1) - (-1)}{3} = \frac{0}{3} = 0A$$

In this case see that the strongest phases are both A and B so they will operate first. Inject 1.0 A and the T-PRO will see 1.0 A, so no correction factor is required. If you use this method, injecting A-B will result in a minimum operating current of 1.0 * 0.30 = 0.30 A.

Single-Phase Method #2 Test Procedure

1 Connect current source 300–302 (Jumper 301–303).

Slowly ramp current up.

At 0.29 – 0.31 A (expect 0.301 A):

87 Trip = High

Testing 87 LV Minimum Operate Single-Phase

To test single-phase, perform the same process as on the HV side, again use "Analog Phase Shift Table" in Appendix L.

For a -30° shift, which is what is present on the LV Side (Delta (-30°) + Wye (0°) = -30°), use the +30° formulae to null the angle.

To inject 1.0 A on Phase A only on the LV Side:

$$IA = \frac{Ia - Ib}{\sqrt{3}} = \frac{(1) - (0)}{\sqrt{3}} = \frac{1}{\sqrt{3}} = 0.577A$$

$$IB = \frac{Ib - Ic}{\sqrt{3}} = \frac{(0) - (0)}{\sqrt{3}} = \frac{0}{\sqrt{3}} = 0A$$

$$IC = \frac{Ic - Ia}{\sqrt{3}} = \frac{(0) - (1)}{\sqrt{3}} = \frac{-1}{\sqrt{3}} = -0.577A$$

Note that the strongest phases are IA and IC, so they will operate first.

For the T-PRO to see 0.30 A on Phase A, you need to inject √3 * 0.30 A (= 0.52 A), since the T-PRO will only sees 1/√3 of the current injected.

For further clarification see the full example provided in “T-PRO Differential Slope Test Example” on page 6-33.

End of 87 test.

87 2nd Harmonic Restraint Test

Settings

- I2 Cross Blocking = Enabled
- I2 (2nd Harmonic) = 0.30 per unit (2nd Harmonic Restraint if ≥ 30% of fundamental current).

2nd Harmonic Restraint Test Procedure

1 In Terminal Mode access T-PRO *Metering>Logic.*

Monitor the following elements for pickup.

87 Trip

87 Restraint

2 Apply parallel currents to Terminals 300–302 (Jumper 301– 303):

Source 1 (Fundamental): 1.0 A ∠0° (Terminals 300 – 302)

Source 2 (2nd Harmonic): 0.40 A ∠0° (also Terminals 300 – 302)

Observe:

87 TRIP = Low

87 Restraint = High

3 Slowly ramp down Source 2.

At 0.31 to 0.29 A (expect 0.301 A):

87 Trip = High

87 Restraint = Low

End of 2nd harmonic restraint test.

87 High Current Setting Test

Settings

- High Current Setting = 5.0 per unit

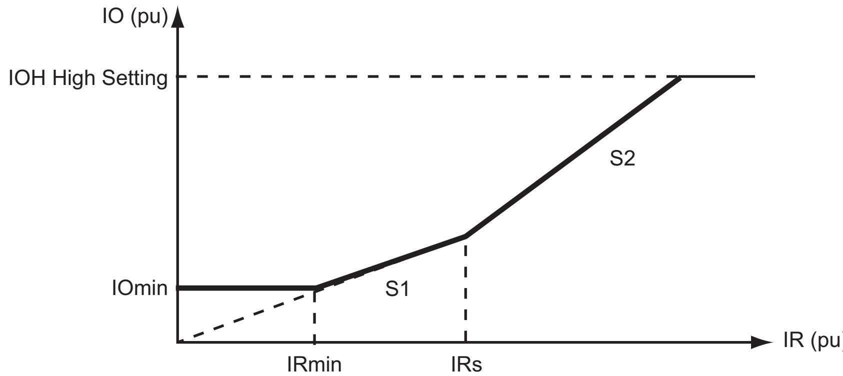


Figure 6.21: High Current Setting

87 High Current Test Procedure

1 In Terminal Mode access T-PRO *Metering>Logic.*

Monitor the following elements for pickup.

87 Trip

87 Restraint

87 FastTrip

2 Apply parallel currents to Terminals 300–302 as follows (Jumper 301–303):

Source 1 (Fundamental Frequency):

4.0 A ∠0° (Terminals 300 – 302)

Source 2 (2nd Harmonic):

4.0 A ∠0° (also Terminals 300 – 302)

3 Ramp Source 1 up.

At 4.90 to 5.10 A (expect 5.0 A):

87 Trip = High

87 Restraint = Low

87 FastTrip = High

Note: This test proves that when the High Current Setting is exceeded, the 87 will operate and 2nd Harmonic has no restraint affect.

4 Remove test currents.

End of High Current setting test.

THD Alarm Test

Settings

THD Alarm Pickup: 10%

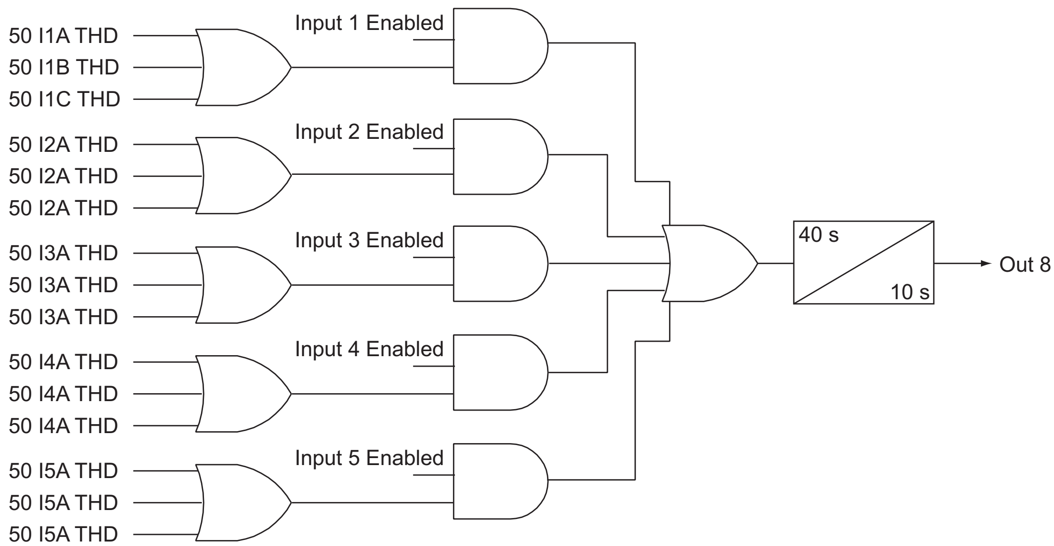


Figure 6.22: Logic Total Harmonic Distortion Alarm (THD)

For testing THD, use the fundamental with only one harmonic. In this case the T-PRO uses the following formula for calculating Total Harmonic Distortion:

$$THDpercent = 100 \cdot \frac{\sqrt{\sum_{2}^{25} I^2 n}}{Ifundamental} = \left(100 \cdot \frac{\sqrt{Iharmonic^2}}{Ifundamental}\right) = \left(100 \cdot \frac{Iharmonic}{Ifundamental}\right)$$

THD Test Procedure

1 In Terminal Mode access T-PRO *Metering>Logic.*

Monitor the following element for pickup: THD Alarm.

2 Apply parallel currents to terminals 300–301 as follows:

Source 1 (Fundamental): 2.0 A ∠0° (Terminals 300 – 301)

Source 2 (2nd Harmonic): 0.0 A ∠0° (also Terminals 300 – 301)

3 Slowly ramp Source 2 up.

At 0.19 to 0.21 A (expect 0.20 A)

THD Alarm = High

After 30 seconds:

Contact 8 = Closed

End of THD test.

87N Differential Test

Testing the 87N uses the same process as testing the 87 with the following exception: I5A is used for the neutral associated with HV wye connected winding (I5B for LV, I5C for tertiary).

Settings

- HV kV: 230 kV
- IO_{min}: 0.3 per unit
- IRs: 5.0 per unit
- Slope 1: 20%
- Slope 2: 40%
- HV CT Ratio: 250:1
- Neutral CT Ratio: 100:1

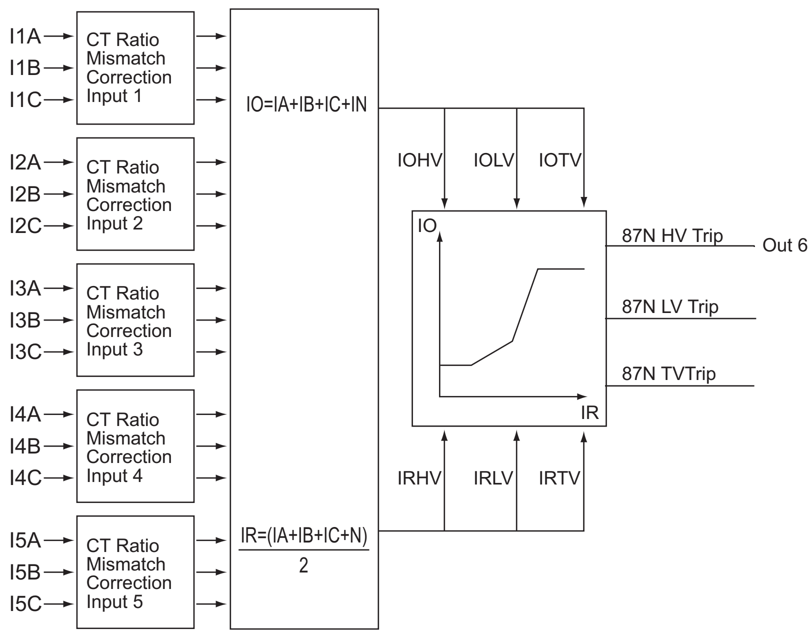


Figure 6.23: Logic Neutral Differential (87N)

MCF Calculation

$$MagnitudeCorrectionFactor(MCF) = \frac{PhaseCTRatio}{NeutralCTRation} = \frac{250}{100} = 2.50$$

Phase Winding 87N IO_{min} Pickup Calculation

Expect for I5A HV winding side

$$IOmin = \frac{kVA}{\sqrt{3} \cdot kV} \cdot \frac{1}{CTR} \cdot IOminPerUnit = \left(\left(\frac{100e3}{\sqrt{3} \cdot 230} \cdot \frac{1}{250}\right) \cdot 0.3\right) = 0.30A$$

Neutral Winding 87N IO_{min} Pickup Calculation

Expect for I5A HV winding side

$$IOmin = \frac{kVA}{\sqrt{3} \cdot kV} \cdot \frac{1}{CTR} \cdot IOminPerUnit = \left(\left(\frac{100e3}{\sqrt{3} \cdot 230} \cdot \frac{1}{100}\right) \cdot 0.3\right) = 0.753A$$

> Note: Repeat previous calculation for LV and TV winding side and remember I5B (326-327) should be selected for LV winding and I5C (328-329) for TV winding inputs.

87N IO_{min} Neutral Test Procedure

1 Connect current source to T-PRO Terminals 324–325.

(I5A HV)

2 Slowly ramp current up.

At 0.74 to 0.77 A (expect 0.753 A):

87N-HV Trip = High

T-PRO Target: “Neu. Diff. (87NHV): Trip”

Output Contact 6 = Closed

3 Turn current off.

End of 87N test.

T-PRO Differential Slope Test Example

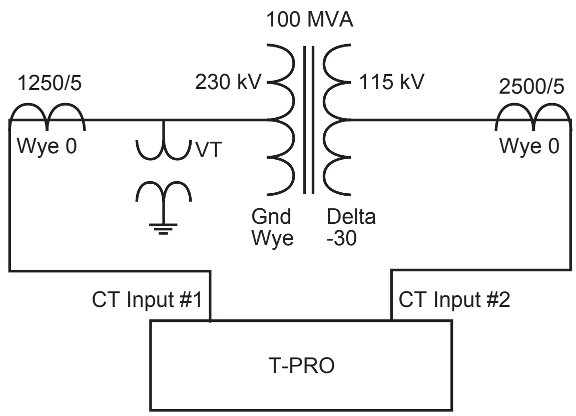


Figure 6.24: T-PRO Differential Slope Test Example

Testing T-PRO Transformer Relay Differential Element

Calculations to be performed prior to T-PRO testing

Settings for the 87 differential element:

- IO_{min} = 0.3 per unit
- IRS = 5.0 per unit
- S1 = 20%
- S2 = 40%

Establish base load current for transformer reference side (where the VTs are located). For this example the VTs are located on the 230 kV HV side winding.

$$I_{BasePri} = \frac{KVA}{\sqrt{3} \cdot kV} \tag{1}$$

$$= \frac{100000}{\sqrt{3} \cdot 230} = 251A$$

$$I_{?V\ BaseSec} = I_{?V\ BasePri} * CT_{DeltaFactor} * \frac{1}{CTRatio} \tag{1A}$$

Equation Note 1: “?” = “H”, “L” or “T” depending on the winding on which the base is being calculated.

Equation Note 2: “Delta factor” = 1.0 for wye connected CTs, √3 for delta connected CTs.

Calculate the Base current (amps) for each winding using Equation 1 and Equation 1A.

High Voltage Side:

$$I_{BasePri} = \frac{kVA}{\sqrt{3} \cdot kV} = \frac{100000}{\sqrt{3} \cdot 230} = 251A$$

$$I_{HVBaseSec} = I_{HVBasePri} \cdot CT_{DeltaFactor} \cdot \frac{1}{CTRatio}$$

$$= \left((251 \cdot 1.0) \cdot \frac{1}{250}\right) = 1.004A$$

Low Voltage Side:

$$I_{BasePri} = \frac{kVA}{\sqrt{3} \cdot kV} = \frac{100000}{\sqrt{3} \cdot 115} = 502A$$

$$I_{LVBaseSec} = I_{LVBasePri} \cdot CT_{DeltaFactor} \cdot \frac{1}{CTRatio}$$

$$\left((502 \cdot 1.0) \cdot \frac{1}{500}\right) = 1.004A$$

T-PRO Three-Phase Testing

1 Three-phase testing is done by applying a balanced 3-phase current into current input group #1 and another balanced set of currents into current input group #2

2 For this example inject HV side currents at angles: Ph A $\angle$0º, Ph B $\angle$-120º, Ph C $\angle$120º.

LV side currents at angles: Ph A $\angle$150º, Ph B $\angle$30º, Ph C $\angle$-90º.

Explanation of LV Side angle:

Because of a -30º net shift on the LV Side, adjust the LV test current angles by -30°. If you had a 0º shift on both sides, currents on the LV side for load or through fault conditions would be 180º from HV side (i.e. current into the transformer HV side and out of transformer LV side is normal). Shift the LV side by -30º because of the –30º delta connection.

The testing the points in the following graphic are highlighted.

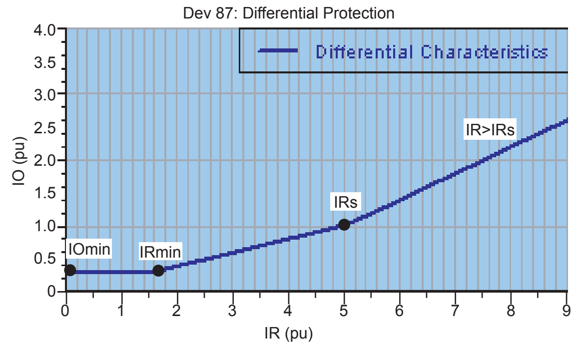
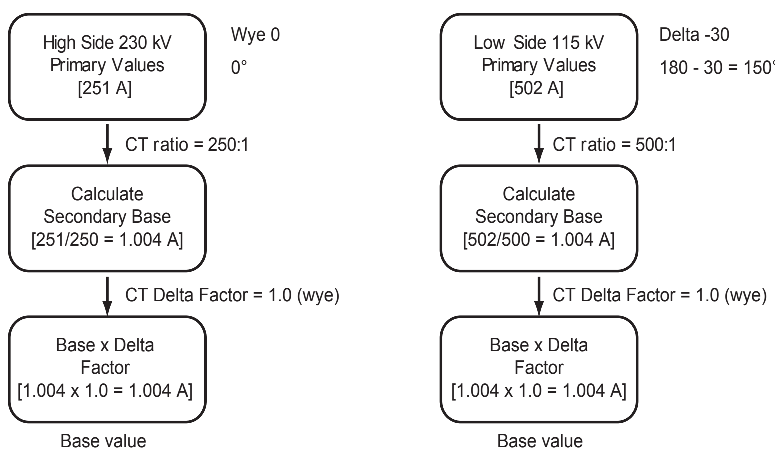


Figure 6.25: Three-Phase Testing Points

Load Conditions

The following diagram shows a summary of the process used for calculating the currents required to simulate load or through fault condition. This process checks the differential element for normal load or large external fault conditions. The T-PRO 87 element should not operate under such conditions unless the differential (operate current) exceeds the slope IO level at the corresponding amount of restraint current. Use Equations 1 and 1A to obtain the values in the diagram.

Summary of Calculations for Load/External Fault Conditions



Determine the IO and IR current values on the 87 through fault restraint (slope) characteristic where the T-PRO operates. Determine the current pickup values of current for any values of IO and IR on the curve.

3 The following formulae determine the operating currents for the differential slope characteristic:

$$IO = \overrightarrow{I_{HV}} - \overrightarrow{I_{LV}} \qquad (2)$$

or for a through fault

$$IO = |I_{HV}| - |I_{LV}|$$

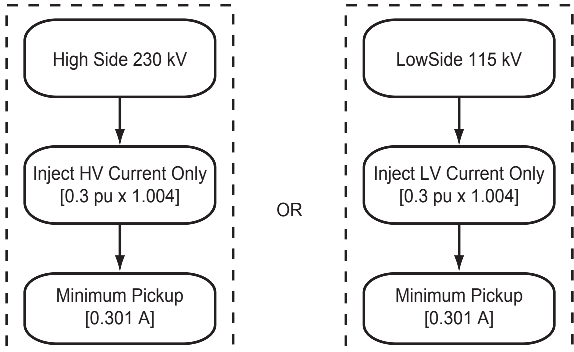
$$IR = \frac{|I_{HV}| + |I_{LV}|}{2} \qquad (3)$$

4 Testing of IO_{min} (minimum operating current).
Apply balanced 3-phase currents.
Watch for Target: “87 Trip”
IO_{min} = 0.3 per unit and IR = 0.0 per unit.

HV IO_{min}
Apply 3-phase current (ramp up).
$I_{HVbase\ sec}$ x IO_{min} = 1.004 x 0.3 = 0.301 A

LV IO_{min}
Apply 3-phase current (ramp up).
$I_{LVbase\ sec}$ x IO_{min} = 1.004 x 0.3 = 0.301 A

Minimum Operating Current of the Differential Element



5 Test IR = IR_{min} (minimum restraint current = 1.5 per unit).

$$IO = \frac{S1 \times IR_{min}}{100} \tag{4}$$

$$0.3 = \frac{20 \times IR_{min}}{100}$$

Note: at $IR = IR_{min}$, $IO = IO_{min}$

Therefore solve for I_{HV} and I_{LV} at IO = 0.3 per unit and IR_{min} = 1.5 per unit. Use Formulae 2 and 3 from above to solve for IO and IR.

$$IO = I_{HV} - I_{LV}$$

$$0.3 = I_{HV} - I_{LV}$$

$$IR = \frac{(I_{HV} + I_{LV})}{2}$$

$$1.5 = \frac{(I_{HV} + I_{LV})}{2}$$

$$1.5 \times 2 = I_{HV} + I_{LV}$$

$$3.0 = I_{HV} + I_{LV}$$

Determine the currents required to operate the 87 element using the above formulae.

Solve for I_{HV} by adding the two equations together.

$$0.3 = I_{HV} - I_{LV}$$

$$+3.0 = I_{HV} + I_{LV}$$

$$\text{Total } 3.3 = 2I_{HV}$$

$$\frac{3.3}{2} = I_{HV} = 1.65pu$$

$$I_{HVamps} = I_{HVbaseSec} \times I_{HVperunit} = 1.004 \times 1.35 = 1.356A$$

Now solve for I_{LV} by subtracting the two equations.

$$0.3 = I_{HV} - I_{LV}$$

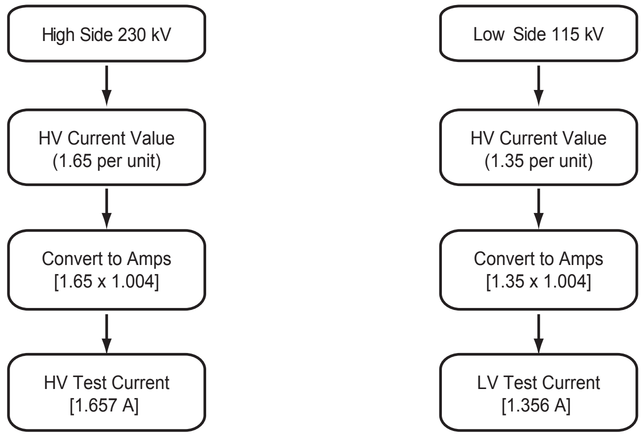
$$-3.0 = I_{HV} + I_{LV}$$

$$\text{Total } -2.7 = 2I_{LV}$$

$$\frac{-2.7}{-2} = I_{LV} = 1.35pu$$

$$I_{LVamps} = I_{LVbaseSec} \times I_{LVperunit} = 1.004 \times 1.35 = 1.356A$$

Summary of Calculations for Testing Minimum Restraint Current (IR_{min})



Test for IR = IRs = 5.0 per unit.

$$IO = \frac{S2 \times IR}{100} + \frac{S1 - S2}{100} \times IRs \qquad (5)$$

$$IO = \frac{40 \times 5}{100} + \frac{20 - 40}{100} \times 5$$

$$IO = 1.0pu$$

Therefore IRs = 5.0 per unit and IO = 1.0 per unit
Solving for I_{HV} and I_{LV}

$$IO = I_{HV} - I_{LV}$$

$$1.0 = I_{HV} - I_{LV}$$

$$IR = \frac{(I_{HV} + I_{LV})}{2}$$

$$5.0 = \frac{(I_{HV} + I_{LV})}{2}$$

$$5.0 \times 2 = I_{HV} + I_{LV}$$

$$10.0 = I_{HV} + I_{LV}$$

Solve for I_{HV} by adding the two equations together.

$$1.0 = I_{HV} - I_{LV}$$

$$+10.0 = I_{HV} + I_{LV}$$

$$\text{Total} \quad 11.0 = 2I_{HV}$$

$$\frac{11.0}{2} = I_{HV} = 5.5pu$$

$$I_{HVamps} = I_{HVBaseSec} \times I_{HVperunit} = 1.004 \times 5.5 = 5.522A$$

Now solve for I_{LV} by subtracting the two equations.

$$1.0 = I_{HV} - I_{LV}$$

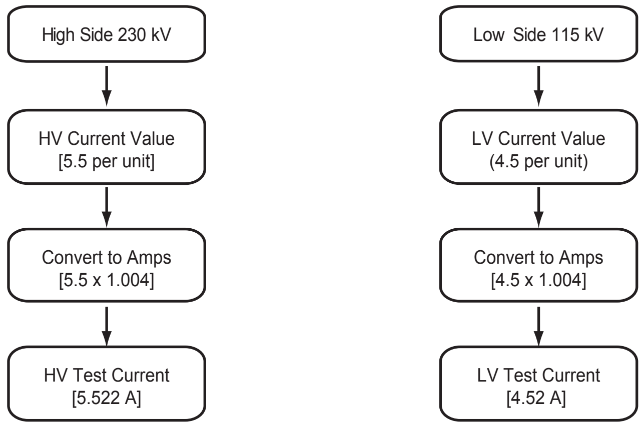
$$-10.0 = I_{HV} + I_{LV}$$

$$\text{Total} \quad -9.0 = -2I_{LV}$$

$$\frac{-9.0}{-2} = I_{LV} = 4.5pu$$

$$I_{LVamps} = I_{LVBaseSec} \times I_{LVperunit} = 1.004 \times 4.5 = 4.52A$$

Summary of Calculations for IRs Testing = 5.0 per unit



6 Test IR > IRs

Let IR = 7.0 per unit

$$IO = \frac{S2 \times IR}{100} + \frac{S1 - S2}{100} \times IRs$$

$$IO = \frac{40 \times 7.0}{100} + \frac{20 - 40}{100} \times 5.0$$

$$IO = (2.8 - 1.0)$$

$$IO = 1.8pu$$

Solving for I_{HV} and I_{LV}.

$$IO = I_{HV} - I_{LV}$$

$$1.8 = I_{HV} - I_{LV}$$

$$IR = \frac{I_{HV} + I_{LV}}{2}$$

$$7.0 = \frac{I_{HV} + I_{LV}}{2}$$

$$7.0 \times 2 = I_{HV} + I_{LV}$$

$$14.0 = I_{HV} + I_{LV}$$

Solve for I_{HV} by adding the two equations together.

$$1.8 = I_{HV} - I_{LV}$$

$$+14.0 = I_{HV} + I_{LV}$$

$$\text{Total } 15.8 = 2I_{HV}$$

$$\frac{15.8}{2} = I_{HV} = 7.9pu$$

$$I_{HVamps} = I_{HVbaseSec} \times I_{HVperunit} = 1.004 \times 7.9 = 7.93A$$

Now solve for I_{LV} by subtracting the two equations.

$$1.8 = I_{HV} - I_{LV}$$

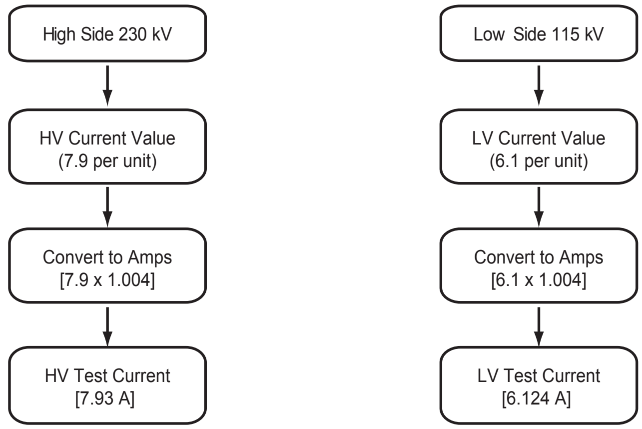
$$-14.0 = I_{HV} + I_{LV}$$

$$\text{Total } -12.2 = -2I_{LV}$$

$$\frac{-12.2}{-2} = I_{LV} = 6.1pu$$

$$I_{LVamps} = I_{LVbaseSec} \times I_{LVperunit} = 1.004 \times 6.1 = 6.124A$$

Summary of Calculations for Testing IR > IRS (IR = 7.0)



Summary of Three-Phase Test

1 Calculate base current for each side.

2 Determine an IO (operating) and IR (restraint) values to be tested.

3 Calculate I_{HV} and I_{LV} per unit currents for a given IO and IR.

4 Adjust angles by analog phase shift and convert I_{HV} and I_{LV} per units to amperes.

5 Apply I_{HV} and I_{LV} with 3-phase sources. Set reference side at zero degrees (0.0°) and the opposite side at the opposing angle. In this example, 180°-30° = 150° to account for the -30° delta shift.

T PRO Single-Phase Slope Test

Steps to perform Single-Phase Testing

1 Perform the current calculations for 3-phase testing from the previous section.

2 Determine the natural current phase shift into each of the current inputs of the T-PRO relay, and thus the compensating angle required to null that angle (e.g. a delta -30º connection requires a +30º shift, so use the +30º shift formula, see “Analog Phase Shift Table” in Appendix L).

3 Determine which phase to inject on each side.

4 Apply the additional magnitude correction factor to the calculated 3-phase test currents.

Monitor *Metering>Operating* values in the T-PRO relay to check. This screen shows the current phasors that the T-PRO uses for differential calculations (after performing phase shift manipulations), as well as the per unit operating and restraint currents.

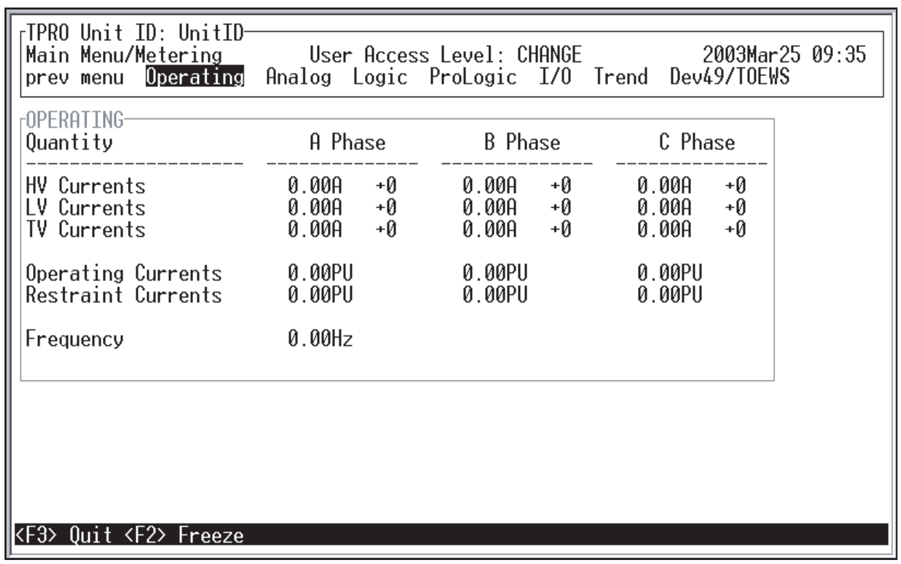


Figure 6.26: Metering/Operating Screen

Details of Calculations

Step 1:

Three-phase calculations.

See 3-phase test section.

Step 2:

Determine transformer net phase shift.

Sum the suffixes of your winding CT configurations.

e.g. (Delta +30º = 30º), (Wye –30º = –30º), (Delta 60º = 60º), (Wye 0º = 0º), etc.

To Demonstrate:

Transformer: HV = Wye 0º and LV = Delta -30º.

CTs: HV CT = Wye 0º and LV CT = Wye 0º:

Your Net High Side angle = 0º + 0º = 0º. (T-PRO uses 0º phase shift formulae to null the angle).

Your Net Low Side angle = -30º + 0º = -30º. (T-PRO uses

+30º phase shift formulae to null the angle).

Step 3:

The following Shift Requirement Table shows the net transformer phase shift on the left. Injecting into Phase A only of T-PRO yields current in the phases displayed in the right column. Confirm this by checking the T-PRO's *Metering>Operating* screen.

Table 6.1: Shift Requirement Table (Inject Phase A only)

Transformer Net Phase Shift (degrees)	Use Formulae from Analog Phase Shift Table (Appendix M)	Injecting only T-PRO A Phase shows these "Operating" Phase(s)
0º	0º	A
–30º	+30º	A – C
+30º	–30º	A – B
+60º	–60º	–B
–60º	+60º	–C
180º	180º	–A
+90º	–90º	C – B
–90º	+90º	B – C
150º	–150º	C – A
–150º	+150º	B – A
–120º	+120º	B
+120º	–120º	C

Table 6.2: Shift Requirement Table (Inject Phase B only)

Transformer Net Phase Shift (degrees)	Use Formulae from Analog Phase Shift Table (Appendix M)	Injecting only T-PRO B Phase shows these “Operating” Phase(s)
0º	0º	B
–30º	+30º	B – A
+30º	–30º	B – C
+60º	–60º	–C
–60º	+60º	–A
180º	180º	–B
+90º	–90º	A – C
–90º	+90º	C – A
+150º	–150º	A – B
–150º	+150º	C – B
–120º	+120º	C
+120º	–120º	A

Table 6.3: Shift Requirement Table (Inject Phase C only)

Transformer Net Phase Shift (degrees)	Use Formulae from Analog Phase Shift Table (Appendix M)	Injecting only T-PRO C Phase shows these “Operating” Phase(s)
0º	0º	C
–30º	+30º	C – B
+30º	–30º	C – A
+60º	–60º	–A
–60º	+60º	–B
180º	180º	–C
+90º	–90º	B – A
–90º	+90º	A – B
+150º	–150º	B – C
–150º	+150º	A – C
–120º	+120º	A
+120º	–120º	B

You should set up a test condition where both sides of the transformer see current on the same 2 phases (must be 2 phases only for the method explained here).

Note that the right-hand column above refers to the “strongest” phase, i.e. the one with the most current, as this is the phase that would operate first.

So for example, if you continue with the same transformer example of HV 0º and LV -30º:

Low side angle is -30º which means you inject current into Phase A input to yield “Operating” LV currents on Phase A and Phase C in the T-PRO.

Therefore inject Phase A only since it meets the condition of the T-PRO seeing 2 currents in the LV side of the operating element. Set this current to 0º to be the reference.

Now you know that it is necessary to see Phase A and Phase C currents in the HV side of the operating element (the same phases as on the low side). There is a net 0º shift on the HV side so from the “Analog Phase Shift Table” in Appendix L, injecting Phase A will yield Phase A only (and Phase B will yield Phase B only and Phase C will yield Phase C only).

So to obtain Phase A – Phase C on high side, inject current into polarity of Phase A and out of polarity Phase C. (This will simulate a through fault, so inject Phase A – Phase C @ 180º). See for details see Figure 6.27: Single-Phase Test Connections on page 6-47 for connection diagram.

Single-Phase Test Connections to T-PRO Relay

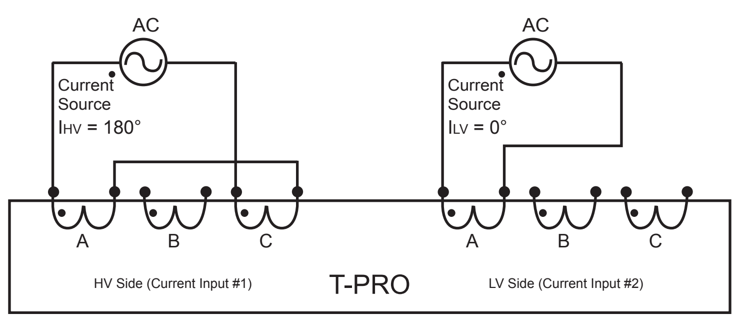


Figure 6.27: Single-Phase Test Connections

Step 4

Determining the additional Magnitude Correction Factor:

Using the above method, you only need to remember 2 Magnitude Correction Factors, 1.0 and √3. The values in the tables can be proven by manually calculating the phase shift resultants using the “Analog Phase Shift Table” in Appendix L.

The Table below relates the Net Transformer Shift angle to the applicable Correction Factor:

Table 6.4: Single-Phase Correction Factor Table

Transformer Net Phase Shift (degrees)	Additional Magnitude Correction Factor (Multiplier)
0º	1.0
+60º	1.0
+120º	1.0
+180º	1.0
–120º	1.0
–60º	1.0
+30º	√3
+90º	√3
+150º	√3
–150º	√3
–90º	√3
–30º	√3

Multiply the 3-phase current values (determined earlier) by the correction factor in the right column of the “Single-Phase Correction Factor Table” on page 6-48.

Performing the Single-Phase Test

1 Continuing with the example, on the 0º high side, our minimum operating point is:

Inject Phase A – Phase C (which = Phase A - Phase C): In the Single-Phase Correction Table, 0º gives a Correction Factor of 1.0.

HV 3-Phase IO_{min} * Additional MCF = 0.301 x 1.0 = 0.301 A

2 On the -30º Low Side our minimum operating point is:

Inject Phase A (which = Phase A - Phase C): In the table, -30º gives a Correction Factor of √3.

LV 3-Phase IO_{min} * Additional MCF = 0.301 x √3 = 0.522 A

Apply the same process to any other point being tested.

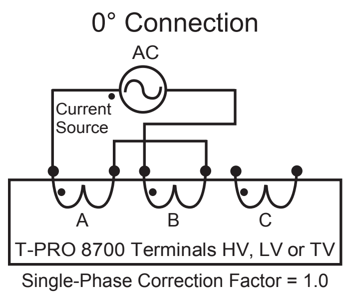
Conclusion

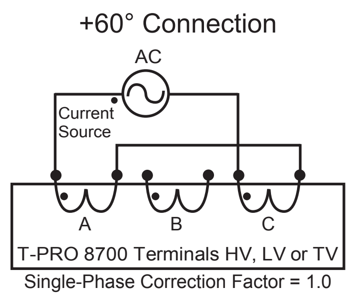
The only additional multipliers required to obtain single-phase test currents from 3-phase test currents are the multipliers in the “Single-Phase Correction Factor Table” on page 6-48.

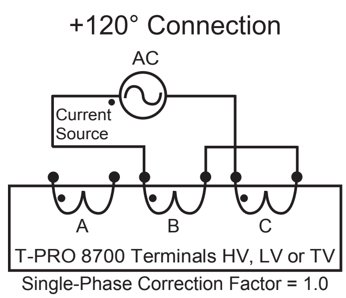
Note: Single-phase correction factor in these diagrams means multiplying 3-phase calculated amperes by this value to find the single-phase test current.

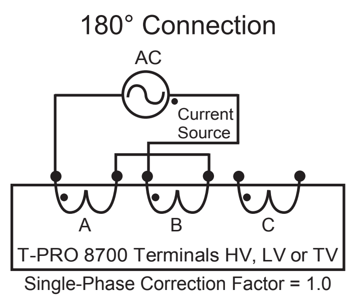
Also, these connections are applicable to any side. Find the appropriate connection for each side.

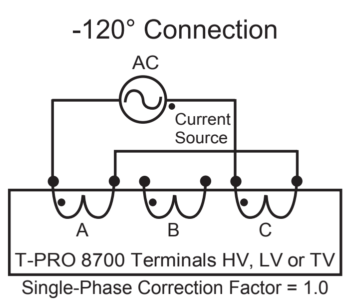
Other single-phase test connections to obtain A–B (in polarity A out polarity B):

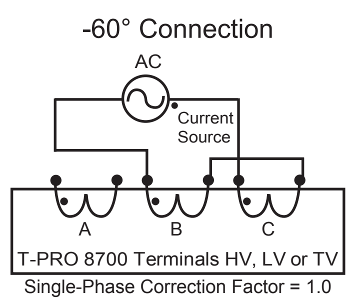


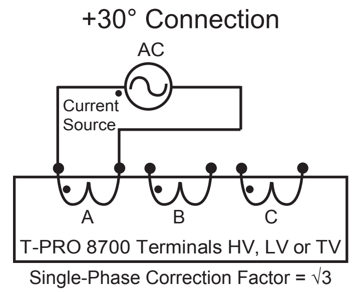


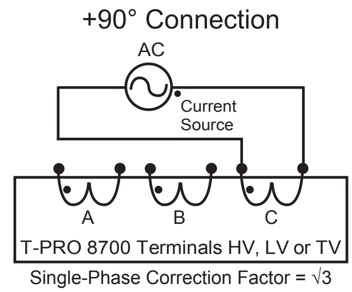


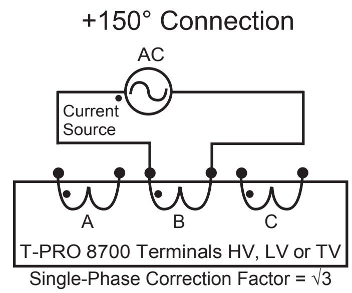


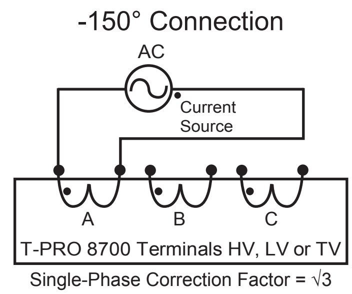


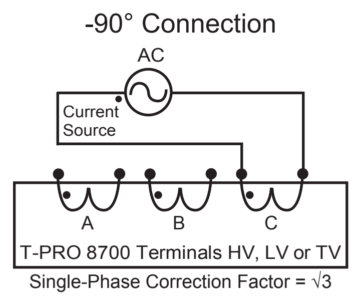


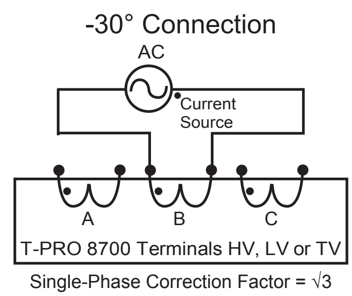

+30° Connection
AC
Current
Source
A
B
C
T-PRO 8700 Terminals HV, LV or TV
Single-Phase Correction Factor = √3


+90° Connection
AC
Current
Source
A
B
C
T-PRO 8700 Terminals HV, LV or TV
Single-Phase Correction Factor = √3


+150° Connection
AC
Current
Source
A
B
C
T-PRO 8700 Terminals HV, LV or TV
Single-Phase Correction Factor = √3


-150° Connection
AC
Current
Source
A
B
C
T-PRO 8700 Terminals HV, LV or TV
Single-Phase Correction Factor = √3


-90° Connection
AC
Current
Source
A
B
C
T-PRO 8700 Terminals HV, LV or TV
Single-Phase Correction Factor = √3


-30° Connection
AC
Current
Source
A
B
C
T-PRO 8700 Terminals HV, LV or TV
Single-Phase Correction Factor = √3

7 Installation

Physical Mounting

The relay is 3 rack units or 5.25 inches high and approximately 12.25 inches deep. The standard relay is designed for a 19-inch rack. A complete mechanical drawing is shown, for details see “Mechanical Drawings” in Appendix G.

To install the relay you need the following:

- 19 inch rack
- 4 - #10 screws

A vertical mounting package is also available.

AC and DC Wiring

For details see “AC Schematic Drawing” in Appendix I and “DC Schematic Drawing” in Appendix J.

Communication Wiring

EIA-232

The relay’s three serial ports (Ports 1, 2 and 3) are configured as EIA RS-232 Data Communications Equipment (DCE) devices with female DB9 connectors. This allows them to be connected directly to a PC serial port with a standard straight-through male-to-female serial cable. For pin-out details see “Communication Port Details” on page 2-9.

An adapter is available for connecting an external modem to Port 2. For details, see “Modem Link - External” on page 2-3.

RJ-45

The relay may have an optional internal modem or an optional internal 10BaseT Ethernet port. Connection to either of these is via the relay’s Port 5 RJ-45 receptacle. Labeling above the port will indicate which option, if any, has been installed.

IRIG-B Wiring

The relay accepts both modulated and unmodulated IRIG-B standard time signals with or without the IEEE 1344 extensions. The IRIG-B connector on the back of the relay is BNC type.

Temperature Probes

The ambient temperature probe must be mounted facing downward or horizontally with a slight downward angle to prevent the accumulation of moisture.

Connection of external ambient and top-oil temperature probes to the relay is detailed in “Temperature Probe Connections” in Appendix O.

Appendix A IED Specifications

T-PRO Model 8700 Specifications		
General:	**Quantity/Specifications**	**Note**
Nominal Frequency	50 or 60 Hz	
Operate Time	1 to 2 cycle typical	For 87 element including output contact operation
Sampling Rate	96 samples/cycle	Records up to 25th harmonic
Power Supply	Nominal Range: 48 to 250 Vdc, 120 Vac, 50/60 Hz Full Operating Range: 40 to 300 Vdc	Power Consumption: 30VA
Memory	Settings and records are stored in non-volatile memory	Records are stored in a circular buffer
Protection Functions:		
IEEE Dev. 87, 87N, 49, TOEWS, 24, 59N, 27, 60, 81, 50/51, 50N/51N, 67 and THD	2 or 3 winding transformer with up to 5 sets of CT inputs	Fault protection, overload management as well as monitoring and fault recording
Recording:		
Fault	96 s/c oscillography of all analog and external input channels Capacity: up to 15 x 2 second records	Viewing software provides waveform, symmetrical components and harmonic analysis
Trend	Variable rate logging of MW, MVAR, Ambient Temperature and Loss of Life, Top Oil, Hot Spot Temperature, HV Current, 51HV pickup level and THD	Variable length, dependant on sample rate
Events	250 events	Circular event log
A/D Resolution	13 bits, 8192 counts full scale	
Input & Output:		
Analog Input Channels	15 currents and 3 voltages transformer protection and recording	Rating: In = 5 A or 1 A Vn = 69 V Continuous: 3x In, 2x Vn One Second: 20x In without distortion
Temperature Inputs, Ambient and Top Oil	Capable of receiving 2 sets of isolated 4-20 mA current loops for ambient and top oil temperatures	No damage for 3x nominal for 1 minute/hour for Vn External temperature transducers can be powered from relay. Unregulated 30 Vdc supply output, 24 Vdc load at 40 mA.
Sampling Resolution	12 bits plus sign, amplitude measurement accuracy: +/-0.5% for 54 to 66 Hz	
Burden	ac input voltage: < 0.15 VA @ 67 V, ac input current: < 0.25 VA @ 5 A	

T-PRO Model 8700 Specifications		
Analog Input Sampling	Sample rate: 96 samples/cycle for protection algorithm 8x/cycle for protection	
External Inputs	9 isolated inputs Optional 48/125 or 125/250 Vdc	Optional 48 to 125 or 125 to 250 Vdc nominal, externally wetted
Burden	Burden resistance: > 10 k ohms	
Isolation	Internal optical isolation 1 ms resolution	
Sample rate	1 ms resolution	
Output Relays (contacts)	14 programmable outputs plus relay inoperative contact	Make: 30 A as per IEEE C37.90 Carry: 8 A Break: 0.9 A at 125 Vdc resistive 0.35 A at 250 Vdc resistive
Interface & Communication:		
Front Display	2 lines x 24 characters, fluorescent	Exceptional visibility in all ambient light conditions
Front Panel Indicators	6 LEDs	Target, Relay Functional, IRIG-B Functional, Service Required, Test Mode, Alarm
Serial User Interface	Front and rear RS-232 ports to 115 K baud	Rear port can support an external modem
Internal Modem	33.6 Kbps, V.32 bis	Optional internal modem
Network	10BaseT Ethernet port	Optional Ethernet card
SCADA Interface	DNP3 (RS-232 or Ethernet) or Modbus (RS-232)	Rear port
Time Sync	IRIG-B, BNC connector	Modulated or unmodulated, auto-detect
Self Checking/Relay Inoperative	1 contact	closed when relay inoperative
Terminal User Interface	VT100 terminal emulation	Accessible via serial, modem or network interface
Environmental:		
Ambient Temperature Range	-40°C to 85°C	IEC 60068-2-1/IEC 60068-2-2
Humidity	Up to 95% without condensation	IEC 60068-2-30
Insulation Test (Hi-Pot)	Power supply, analog inputs, external inputs, output contacts at 1.5 kV, 50/60 Hz, 1 minute (isolated 30 Vdc supply at 1 kV)	IEC 60255-5
Electrical Fast Transient		ANSI/IEEE C37.90.1 - 1989
Oscillatory Transient		ANSI/IEEE C37.90.1 - 1989
RFI Susceptibility		ANSI/IEEE C37.90.2, IEC 255-22-3
Shock and Bump		IEC 60255-21-2 Class 1

T-PRO Model 8700 Specifications		
Sinusoidal Vibration	10 Hz to 150 Hz, 0.15 mm or 20 m/s^2, 10 sweep cycles	IEC 60068-2-6
Physical:		
Weight	11.8 kg	26 lbs
Dimensions	13.3 cm 48.3 cm rack mount 30.5 cm deep	3U high, 5.25" 19" rack mount 12" deep
Time Synchronization and Accuracy		
External Time Source	The relay is synchronized using IRIG-B input (modulated or unmodulated) auto detect.	Free Running Accuracy: In the absence of an external time source, the relay maintains time with a maximum ±15 minutes drift per year over the full operating temperature range, and maximum ±90 seconds drift per year at a constant temperature of 25°C. The relay detects loss or re-establishment of external time source and automatically switch between internal and external time.
Synchronization Accuracy	Sampling clocks synchronized with the time source (internal or external).	
Overall T-PRO Accuracies		
Current	± 2.5% of inputs from 0.1 to 1.0 x nominal current (In)	
	± 1.0% of inputs from 1.0 to 20.0 x nominal current (In)	
Voltage	± 1.0% of inputs from 0.01 to 2.0 x nominal voltage (Vn)	
Differential element	± 5.0% of set value IOmin from 0.10 to 1.0 per unit (pu)	
Directional Phase Angle	± 2.5% or >± 2.0° of set value from 0.01° to 360.0°	
Frequency Elements	±0.001 Hz (fixed level)	
	±0.05 Hz (df/dt)	
Timers		
Inverse Overcurrent Timers	± 2.5% or ± 1 cycle of selected curve	
Definite Overcurrent Timers	±2.5% or ±1 cycle non-directional	
Frequency Timer	±2.5% of set value plus 1.25 cycles to 1.75 cycles of inherent delay (fixed level) at 2x pickup, error <40 ms (df/dt) at 0.1 Hz/s above pickup, error <100 ms	
Timers	± 3 ms of set value	
Burden	AC Voltage Inputs, < 0.15 VA @ 67 volts	
	AC Current Inputs, < 0.50 VA @ 5 amps	

Frequency Element Operating Time Curves

Figure A.1: Time delay Error at .2 Seconds, Figure A.2: Time Delay Error at 1 Second and Figure A.3: Time Delay Error at 10 Seconds show operating times for the T-PRO frequency rate of change elements at different time delay settings and rate of change settings.

The diagrams show operating times at each test point including output contact operate time. Operating times are the same for both 50 Hz and 60 Hz.

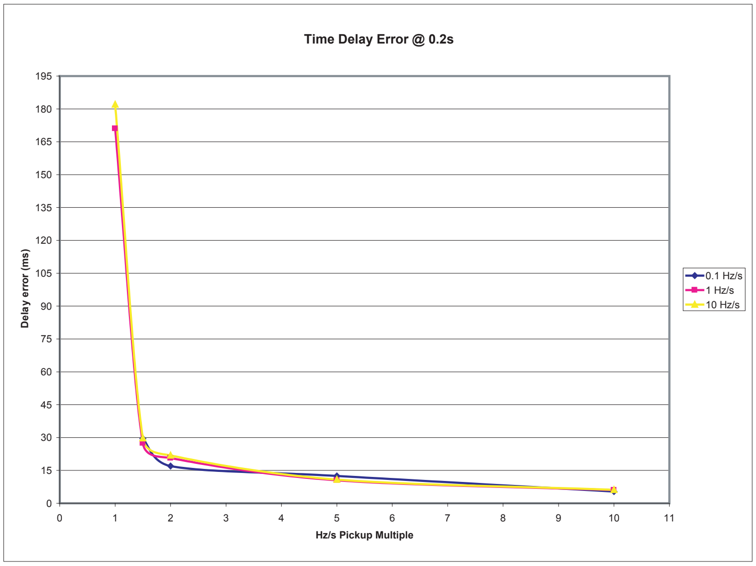


Figure A.1: Time delay Error at .2 Seconds

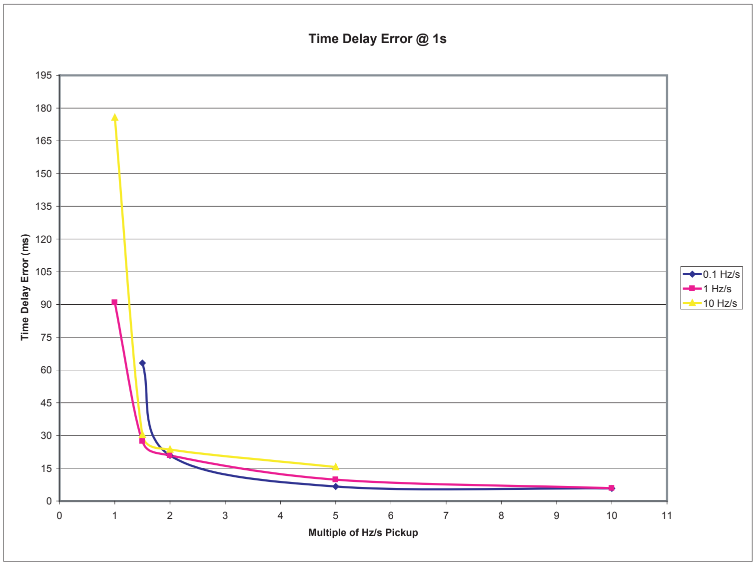


Figure A.2: Time Delay Error at 1 Second

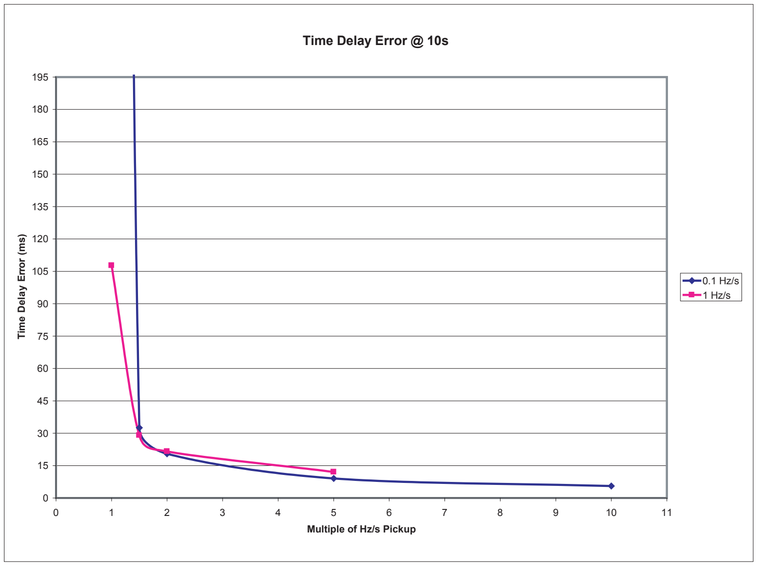


Figure A.3: Time Delay Error at 10 Seconds

Appendix B IED Settings and Ranges

When a setting has been completed in *Offliner* Settings software, it can be printed along with the ranges available for these settings. This is a view only option; to change the settings you must go back into the particular setting that you wish to change. The summary is a quick way to view all the settings in a compact form.

The top part of the settings summary contains all the information from the Relay Identification screen.

The setting summary provides a list of all the current and voltage analog input quantity names used for protection and recording. External Inputs and Output contact names are also identified on this summary.

T-PRO Settings Summary

Name	Symbol/Value	Unit	Range
Relay Identification			
Settings Version	6		
Ignore Serial Number	No		
Serial Number	TPRO-8700-980130-06		
Unit ID	UnitID		
Nominal CT Secondary Current	5 A		
Nominal System Frequency	60 Hz		
Comments	Comments		
Setting Name	Default Settings		
Date Created-Modified	1999-03-22 11:50:00		
Station Name	Station Name		
Station Number	1		
Location	Location		
Bank Name	TB3		
Analog Input Names			
VA	Voltage A		
VB	Voltage B		
VC	Voltage C		
IA1	IA1		
IB1	IB1		
IC1	IC1		
IA2	IA2		
IB2	IB2		
IC2	IC2		
IA3	IA3		
IB3	IB3		

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
IC3	IC3		
IA4	IA4		
IB4	IB4		
IC4	IC4		
IA5	IA5		
IB5	IB5		
IC5	IC5		
Temp1	DC1		
Temp2	DC2		
External Input Names			
1	Spare 1		
2	Spare 2		
3	Spare 3		
4	Spare 4		
5	Spare 5		
6	Spare 6		
7	Spare 7		
8	Spare 8		
9	Spare 9		
Output Contact Names			
Output 1	Spare 1		
Output 2	Spare 2		
Output 3	Spare 3		
Output 4	Spare 4		
Output 5	Spare 5		
Output 6	Spare 6		
Output 7	Spare 7		
Output 8	Spare 8		
Output 9	Spare 9		
Output 10	Spare 10		
Output 11	Spare 11		
Output 12	Spare 12		
Output 13	Spare 13		
Output 14	Spare 14		
Nameplate Data			
Transformer 3 Phase Capacity	100.0	MVA	1.0 to 2000.0
Transformer Winding	3	-	
Tap Changer Range	0	%	-100 to 100

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
Normal Loss of Life Hot Spot Temp.	110.0	°C	70.0 to 200.0
Transformer Temperature Rise	65	°C	-
Transformer Cooling Method	Self cooled		
Temp. Rise Hot Spot (TRiseHS)	25.00	°C	-
Temp. Rise Top Oil (TRiseTop)	55.00	°C	-
Temp. Rise Time Const. Hot Spot (TauHS)	0.08	hours	-
Temp. Rise Time Const. Top Oil (TauTop)	3.00	hours	-
Ratio of Load Loss to Iron Loss (R)	3.20	-	-
Hot Spot Temp. Exponent (m)	0.80	-	-
Top Oil Temp. Exponent (n)	0.80	-	-
Winding			
Voltage Input Connection			
PT Turns Ratio	2000.0	-	1.0 to 10000.0
Location	HV	-	
Transformer NamePlate			
HV: (as PT Source)			
Voltage	230.0	kV	115.0 to 1000.0
Connection	Y		
Phase	0°		
LV:			
Voltage	115.0	kV	13.8 to 230.0
Connection	Y		
Phase	0°		
TV:			
Voltage	13.8	kV	1.0 to 115.0
Connection	Y		
Phase	0°		
CT Connections			
Current Input 1			
Winding	HV		
Connection	Y		
Phase	0°		
Turns Ratio	100.00	:1	1.00 to 10000.00
External Input Selection	<Not Used>		
Current Input 2			
Winding	LV		
Connection	Y		
Phase	0°		

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
Turns Ratio	200.00	:1	1.00 to 10000.00
External Input Selection	<Not Used>		
Current Input 3			
Winding	TV		
Connection	Y		
Phase	0°		
Turns Ratio	1667.00	:1	1.00 to 10000.00
External Input Selection	<Not Used>		
Current Input 4			
Winding	NC		
Connection	Y		
Phase	0°		
Turns Ratio	450.00	:1	1.00 to 10000.00
External Input Selection	<Not Used>		
Current Input 5			
Winding	51N/87N		
Connection	Y		
Phase	0°		
Turns Ratio	4000.00	:1	1.00 to 10000.00
External Input Selection	<Not Used>		
Ambient Temperature Scaling			
Max Valid Temperature	50.0	°C	-40.0 to 50.0
Min Valid Temperature	-50.0	°C	-50.0 to 40.0
Max Correlating Current Value	20.00	mA	5.00 to 20.00
Min Correlating Current Value	4.00	mA	4.00 to 19.00
Top Oil Temperature Scaling			
Top Oil	Calculated		
Max Valid Temperature	200.0	°C	-30.0 to 200.0
Min Valid Temperature	-40.0	°C	-50.0 to 190.0
Max Correlating Current Value	20.00	mA	5.00 to 20.00
Min Correlating Current Value	4.00	mA	4.00 to 19.00
Protection Summary			
87	Enabled		
87N-HV	Enabled		
87N-LV	Enabled		
87N-TV	Enabled		

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
TOEWS	Enabled		
24INV	Enabled		
24DEF	Enabled		
59N	Enabled		
27-1	Enabled		
27-2	Enabled		
60	Enabled		
81-1	Fixed Level		
81-2	Rate of Change		
81-3	Fixed Level		
81-4	Rate of Change		
50-HV	Enabled		
51-HV	Enabled		
50-LV	Enabled		
51-LV	Enabled		
50-TV	Enabled		
51-TV	Enabled		
51ADP	Enabled		
50N-HV	Enabled		
51N-HV	Enabled		
50N-LV	Enabled		
51N-LV	Enabled		
50N-TV	Enabled		
51N-TV	Enabled		
67	Enabled		
THD	Enabled		
87 - Differential			
87	Enabled		
IOmin	0.30	pu	0.10 to 1.00
IRs	5.00	pu	1.50 to 50.00
S1	20.00	%	6.00 to 40.00
S2	40.00	%	20.00 to 200.00
High Current Settings	10.00	pu	0.90 to 100.00
I2 Cross Blocking	Enabled		
I2Setting	0.30	pu	0.05 to 1.00
I5	Disabled		
I5 Setting	0.30	pu	0.05 to 1.00
87N - Neutral Differential			

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
87N-HV	Enabled		
IOmin	0.30	pu	0.10 to 1.00
IRs	5.00	pu	1.50 to 50.00
S1	20.00	%	6.00 to 40.00
S2	40.00	%	20.00 to 200.00
CT Turns Ratio	100.00	:1	1.00 to 10000.00
87N-LV	Enabled		
IOmin	0.30	pu	0.10 to 1.00
IRs	5.00	pu	1.50 to 50.00
S1	20.00	%	6.00 to 40.00
S2	40.00	%	20.00 to 200.00
CT Turns Ratio	200.00	:1	1.00 to 10000.00
87N-TV	Enabled		
IOmin	0.30	pu	0.10 to 1.00
IRs	5.00	pu	1.50 to 50.00
S1	20.00	%	6.00 to 40.00
S2	40.00	%	20.00 to 200.00
CT Turns Ratio	1000.00	:1	1.00 to 10000.00
49-1 - Thermal Overload			
Current Input Switch	OFF	-	
Pickup	1.20	pu	0.10 to 20.00
Hysteresis	0.10	pu	0.00 to 1.00
Pickup Delay (Tp1)	0.10	s	0.00 to 1800.00
Dropout Delay (Td1)	0.00	s	0.00 to 1800.00
Temperature Input Switch	OFF	-	
Pickup	120.0	°C	70.0 to 200.0
Hysteresis	1.0	°C	0.0 to 10.0
Pickup Delay (Tp2)	0.01	hours	0.00 to 24.00
Dropout Delay (Td2)	0.00	hours	0.00 to 24.00
Logic Gate Switch	OR	-	
LED Switch	Target LED	-	
49-2 - Thermal Overload			
Current Input Switch	OFF	-	
Pickup	1.00	pu	0.10 to 20.00
Hysteresis	0.10	pu	0.00 to 1.00
Pickup Delay (Tp1)	0.00	s	0.00 to 1800.00
Dropout Delay (Td1)	0.00	s	0.00 to 1800.00

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
Temperature Input Switch	OFF	-	
Pickup	120.0	°C	70.0 to 200.0
Hysteresis	1.0	°C	0.0 to 10.0
Pickup Delay (Tp2)	0.02	hours	0.00 to 24.00
Dropout Delay (Td2)	0.00	hours	0.00 to 24.00
Logic Gate Switch	OR	-	
LED Switch	Target LED	-	
49-3 - Thermal Overload			
Current Input Switch	OFF	-	
Pickup	1.00	pu	0.10 to 20.00
Hysteresis	0.10	pu	0.00 to 1.00
Pickup Delay (Tp1)	0.00	s	0.00 to 1800.00
Dropout Delay (Td1)	0.00	s	0.00 to 1800.00
Temperature Input Switch	OFF	-	
Pickup	120.0	°C	70.0 to 200.0
Hysteresis	1.0	°C	0.0 to 10.0
Pickup Delay (Tp2)	0.03	hours	0.00 to 24.00
Dropout Delay (Td2)	0.00	hours	0.00 to 24.00
Logic Gate Switch	OR	-	
LED Switch	Target LED	-	
49-4 - Thermal Overload			
Current Input Switch	OFF	-	
Pickup	1.00	pu	0.10 to 20.00
Hysteresis	0.10	pu	0.00 to 1.00
Pickup Delay (Tp1)	0.00	s	0.00 to 1800.00
Dropout Delay (Td1)	0.00	s	0.00 to 1800.00
Temperature Input Switch	OFF	-	
Pickup	120.0	°C	70.0 to 200.0
Hysteresis	1.0	°C	0.0 to 10.0
Pickup Delay (Tp2)	0.04	hours	0.00 to 24.00
Dropout Delay (Td2)	0.00	hours	0.00 to 24.00
Logic Gate Switch	OR	-	
LED Switch	Alarm LED	-	
49-5 - Thermal Overload			
Current Input Switch	OFF	-	
Pickup	1.00	pu	0.10 to 20.00
Hysteresis	0.10	pu	0.00 to 1.00
Pickup Delay (Tp1)	0.00	s	0.00 to 1800.00

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
Dropout Delay (Td1)	0.00	s	0.00 to 1800.00
Temperature Input Switch	OFF	-	
Pickup	120.0	°C	70.0 to 200.0
Hysteresis	1.0	°C	0.0 to 10.0
Pickup Delay (Tp2)	0.05	hours	0.00 to 24.00
Dropout Delay (Td2)	0.00	hours	0.00 to 24.00
Logic Gate Switch	OR	-	
LED Switch	Alarm LED	-	
49-6 - Thermal Overload			
Current Input Switch	OFF	-	
Pickup	1.00	pu	0.10 to 20.00
Hysteresis	0.10	pu	0.00 to 1.00
Pickup Delay (Tp1)	0.00	s	0.00 to 1800.00
Dropout Delay (Td1)	0.00	s	0.00 to 1800.00
Temperature Input Switch	OFF	-	
Pickup	120.0	°C	70.0 to 200.0
Hysteresis	1.0	°C	0.0 to 10.0
Pickup Delay (Tp2)	0.00	hours	0.00 to 24.00
Dropout Delay (Td2)	0.00	hours	0.00 to 24.00
Logic Gate Switch	OR	-	
LED Switch	Alarm LED	-	
49-7 - Thermal Overload			
Current Input Switch	OFF	-	
Pickup	1.00	pu	0.10 to 20.00
Hysteresis	0.10	pu	0.00 to 1.00
Pickup Delay (Tp1)	0.00	s	0.00 to 1800.00
Dropout Delay (Td1)	0.00	s	0.00 to 1800.00
Temperature Input Switch	OFF	-	
Pickup	120.0	°C	70.0 to 200.0
Hysteresis	1.0	°C	0.0 to 10.0
Pickup Delay (Tp2)	0.00	hours	0.00 to 24.00
Dropout Delay (Td2)	0.00	hours	0.00 to 24.00
Logic Gate Switch	OR	-	
LED Switch	Alarm LED	-	
49-8 - Thermal Overload			
Current Input Switch	OFF	-	
Pickup	1.00	pu	0.10 to 20.00
Hysteresis	0.10	pu	0.00 to 1.00

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
Pickup Delay (Tp1)	0.00	s	0.00 to 1800.00
Dropout Delay (Td1)	0.00	s	0.00 to 1800.00
Temperature Input Switch	OFF	-	
Pickup	120.0	°C	70.0 to 200.0
Hysteresis	1.0	°C	0.0 to 10.0
Pickup Delay (Tp2)	0.00	hours	0.00 to 24.00
Dropout Delay (Td2)	0.00	hours	0.00 to 24.00
Logic Gate Switch	OR	-	
LED Switch	Alarm LED	-	
49-9 - Thermal Overload			
Current Input Switch	OFF	-	
Pickup	1.00	pu	0.10 to 20.00
Hysteresis	0.10	pu	0.00 to 1.00
Pickup Delay (Tp1)	0.00	s	0.00 to 1800.00
Dropout Delay (Td1)	0.00	s	0.00 to 1800.00
Temperature Input Switch	OFF	-	
Pickup	120.0	°C	70.0 to 200.0
Hysteresis	1.0	°C	0.0 to 10.0
Pickup Delay (Tp2)	0.00	hours	0.00 to 24.00
Dropout Delay (Td2)	0.00	hours	0.00 to 24.00
Logic Gate Switch	OR	-	
LED Switch	Alarm LED	-	
49-10 - Thermal Overload			
Current Input Switch	OFF	-	
Pickup	1.00	pu	0.10 to 20.00
Hysteresis	0.10	pu	0.00 to 1.00
Pickup Delay (Tp1)	0.00	s	0.00 to 1800.00
Dropout Delay (Td1)	0.00	s	0.00 to 1800.00
Temperature Input Switch	OFF	-	
Pickup	120.0	°C	70.0 to 200.0
Hysteresis	1.0	°C	0.0 to 10.0
Pickup Delay (Tp2)	0.00	hours	0.00 to 24.00
Dropout Delay (Td2)	0.00	hours	0.00 to 24.00
Logic Gate Switch	OR	-	
LED Switch	Alarm LED	-	
49-11 - Thermal Overload			
Current Input Switch	OFF	-	
Pickup	1.00	pu	0.10 to 20.00

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
Hysteresis	0.10	pu	0.00 to 1.00
Pickup Delay (Tp1)	0.00	s	0.00 to 1800.00
Dropout Delay (Td1)	0.00	s	0.00 to 1800.00
Temperature Input Switch	OFF	-	
Pickup	120.0	°C	70.0 to 200.0
Hysteresis	1.0	°C	0.0 to 10.0
Pickup Delay (Tp2)	0.00	hours	0.00 to 24.00
Dropout Delay (Td2)	0.00	hours	0.00 to 24.00
Logic Gate Switch	OR	-	
LED Switch	Alarm LED	-	
49-12 - Thermal Overload			
Current Input Switch	OFF	-	
Pickup	1.00	pu	0.10 to 20.00
Hysteresis	0.10	pu	0.00 to 1.00
Pickup Delay (Tp1)	0.00	s	0.00 to 1800.00
Dropout Delay (Td1)	0.00	s	0.00 to 1800.00
Temperature Input Switch	OFF	-	
Pickup	120.0	°C	70.0 to 200.0
Hysteresis	1.0	°C	0.0 to 10.0
Pickup Delay (Tp2)	0.00	hours	0.00 to 24.00
Dropout Delay (Td2)	0.00	hours	0.00 to 24.00
Logic Gate Switch	OR	-	
LED Switch	Alarm LED	-	
TOEWS (Transformer Overload Early Warning System)			
TOEWS	Enabled		
THS (Temperature Hot Spot) Trip Setting	150.0	°C	70.0 to 200.0
THS To Start LOL (Loss of Life) Calculation	140.0	°C	70.0 to 200.0
LOL Trip Setting	2.0	days	0.5 to 100.0
24INV - Inverse Time			
24INV	Enabled		
K	0.10	-	0.10 to 100.00
Pickup	1.20	pu	1.00 to 2.00
Reset Time	0.50	s	0.05 to 100.00
24DEF - Definite Time Delay			
24DEF	Enabled		
Pickup	1.20	pu	1.00 to 2.00
Pickup Delay	0.05	s	0.05 to 99.99
59N - Zero Sequence Overvoltage			

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
59N	Enabled		
3V0 Pickup	80.00	V	75.00 to 150.00
Curve Type	IEC very inverse		
TMS	0.50	-	0.01 to 10.00
A	13.5000	-	-
B	0.0000	-	-
p	1.00	-	-
TR	47.30	-	0.10 to 100.00
27 - Undervoltage			
27-1	Enabled		
Gate Switch	AND		
Pickup	10.0	V	1.0 to 120.0
Pickup Delay	0.00	s	0.00 to 99.99
27-2	Enabled		
Gate Switch	AND		
Pickup	10.0	V	1.0 to 120.0
Pickup Delay	0.00	s	0.00 to 99.99
60 - Loss of Potential Alarm			
60	Enabled		
81 - Over/Under Frequency			
81-1	Fixed Level		
Pickup	61.000	Hz	[50.000, 59.995] or [60.005, 70.000]
Pickup Delay	2.00	s	0.05 to 99.99
81-2	Rate of Change		
Pickup	10.0	Hz/s	[-10.0, -0.1] or [0.1, 10.0]
Pickup Delay	2.00	s	0.20 to 99.99
81-3	Fixed Level		
Pickup	61.000	Hz	[50.000, 59.995] or [60.005, 70.000]
Pickup Delay	2.00	s	0.05 to 99.99
81-4	Rate of Change		
Pickup	10.0	Hz/s	[-10.0, -0.1] or [0.1, 10.0]
Pickup Delay	2.00	s	0.20 to 99.99
50/51 - Phase Overcurrent: HV			
50-HV	Enabled		
Pickup	1.50	pu	0.10 to 20.00

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
Pickup Delay	1.00	s	0.00 to 99.99
51-HV	Enabled		
Pickup	1.50	pu	0.50 to 2.10
Curve Type	IEC very inverse		
TMS	0.50	-	0.01 to 10.00
A	13.5000	-	-
B	0.0000	-	-
p	1.00	-	-
TR	47.30	-	0.10 to 100.00
51ADP	Enabled		
Multiple of Normal Loss of Life	1.0	-	0.5 to 512.0
50/51 - Phase Overcurrent: LV			
50-LV	Enabled		
Pickup	1.50	pu	0.10 to 20.00
Pickup Delay	1.00	s	0.00 to 99.99
51-LV	Enabled		
Pickup	1.50	pu	0.10 to 5.00
Curve Type	IEC very inverse		
TMS	0.50	-	0.01 to 10.00
A	13.5000	-	-
B	0.0000	-	-
p	1.00	-	-
TR	47.30	-	0.10 to 100.00
50/51 - Phase Overcurrent: TV			
50-TV	Enabled		
Pickup	1.50	pu	0.10 to 20.00
Pickup Delay	1.00	s	0.00 to 99.99
51-TV	Enabled		
Pickup	1.50	pu	0.10 to 5.00
Curve Type	IEC very inverse		
TMS	0.50	-	0.01 to 10.00
A	13.5000	-	-
B	0.0000	-	-
p	1.00	-	-
TR	47.30	-	0.10 to 100.00
50N/51N - Neutral Overcurrent: HV			
50N-HV	Enabled		
Pickup	10.00	A	0.50 to 50.00

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
Pickup Delay	1.00	s	0.00 to 99.99
51N-HV	Enabled		
Pickup	10.00	A	0.50 to 50.00
Curve Type	IEC very inverse		
TMS	0.50	-	0.01 to 10.00
A	13.5000	-	-
B	0.0000	-	-
p	1.00	-	-
TR	47.30	-	0.10 to 100.00
50N/51N - Neutral Overcurrent: LV			
50N-LV	Enabled		
Pickup	10.00	A	0.50 to 50.00
Pickup Delay	1.00	s	0.00 to 99.99
51N-LV	Enabled		
Pickup	10.00	A	0.50 to 50.00
Curve Type	IEC very inverse		
TMS	0.50	-	0.01 to 10.00
A	13.5000	-	-
B	0.0000	-	-
p	1.00	-	-
TR	47.30	-	0.10 to 100.00
50N/51N - Neutral Overcurrent: TV			
50N-TV	Enabled		
Pickup	10.00	A	0.50 to 50.00
Pickup Delay	1.00	s	0.00 to 99.99
51N-TV	Enabled		
Pickup	10.00	A	0.50 to 50.00
Curve Type	IEC very inverse		
TMS	0.50	-	0.01 to 10.00
A	13.5000	-	-
B	0.0000	-	-
p	1.00	-	-
TR	47.30	-	0.10 to 100.00
67 - Directional Overcurrent			
67	Enabled		
Pickup	1.50	A	0.05 to 1.95
Curve Type	IEC very inverse		
TMS	0.50	-	0.01 to 10.00

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
A	13.5000	-	-
B	0.0000	-	-
p	1.00	-	-
TR	47.30	-	0.10 to 100.00
Alpha	0.0	-	-179.9 to 180.0
Beta	180.0	-	0.1 to 360.0
THD - Total Harmonic Distortion			
THD	Enabled		
Pickup	10.0	%	5.0 to 100.0
Through Fault Monitor			
Through Fault Monitor	Enabled		
Input Current	HV		
Pickup Level	1.20	Pu	0.10 to 20.00
Hysteresis	0.10	Pu	0.00 to 1.00
Pickup Delay	0.00	S	0.00 to 99.99
Dropout Delay	0.00	S	0.00 to 99.99
I*I*t Alarm Limit	1000.0	*A*A.S	0.1 to 9999.9
2nd Harmonic Blocking	Disabled		
Pickup Delay	0.02	S	0.00 to 99.99
Dropout Delay	0.02	S	0.00 to 99.99
PL 1 [ProLogic 1]			
ProLogic 1	Disabled		
Target	Enabled		
Pickup Delay	0.00	s	0.00 to 999.00
Dropout Delay	0.00	s	0.00 to 999.00
Operator 1			
Input A	<Unused = 0>		
Operator 2			
Input B	<Unused = 0>		
Operator 3			
Input C	<Unused = 0>		
Operator 4			
Input D	<Unused = 0>		
Operator 5			
Input E	<Unused = 0>		
PL 2 [ProLogic 2]			
ProLogic 2	Disabled		
Target	Enabled		

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
Pickup Delay	0.00	s	0.00 to 999.00
Dropout Delay	0.00	s	0.00 to 999.00
Operator 1			
Input A	<Unused = 0>		
Operator 2			
Input B	<Unused = 0>		
Operator 3			
Input C	<Unused = 0>		
Operator 4			
Input D	<Unused = 0>		
Operator 5			
Input E	<Unused = 0>		
PL 3 [ProLogic 3]			
ProLogic 3	Disabled		
Target	Enabled		
Pickup Delay	0.00	s	0.00 to 999.00
Dropout Delay	0.00	s	0.00 to 999.00
Operator 1			
Input A	<Unused = 0>		
Operator 2			
Input B	<Unused = 0>		
Operator 3			
Input C	<Unused = 0>		
Operator 4			
Input D	<Unused = 0>		
Operator 5			
Input E	<Unused = 0>		
PL 4 [ProLogic 4]			
ProLogic 4	Disabled		
Target	Enabled		
Pickup Delay	0.00	s	0.00 to 999.00
Dropout Delay	0.00	s	0.00 to 999.00
Operator 1			
Input A	<Unused = 0>		
Operator 2			
Input B	<Unused = 0>		
Operator 3			
Input C	<Unused = 0>		

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
Operator 4			
Input D	<Unused = 0>		
Operator 5			
Input E	<Unused = 0>		
PL 5 [ProLogic 5]			
ProLogic 5	Disabled		
Target	Enabled		
Pickup Delay	0.00	s	0.00 to 999.00
Dropout Delay	0.00	s	0.00 to 999.00
Operator 1			
Input A	<Unused = 0>		
Operator 2			
Input B	<Unused = 0>		
Operator 3			
Input C	<Unused = 0>		
Operator 4			
Input D	<Unused = 0>		
Operator 5			
Input E	<Unused = 0>		
PL 6 [ProLogic 6]			
ProLogic 6	Disabled		
Target	Enabled		
Pickup Delay	0.00	s	0.00 to 999.00
Dropout Delay	0.00	s	0.00 to 999.00
Operator 1			
Input A	<Unused = 0>		
Operator 2			
Input B	<Unused = 0>		
Operator 3			
Input C	<Unused = 0>		
Operator 4			
Input D	<Unused = 0>		
Operator 5			
Input E	<Unused = 0>		
PL 7 [ProLogic 7]			
ProLogic 7	Disabled		
Target	Enabled		
Pickup Delay	0.00	s	0.00 to 999.00

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
Dropout Delay	0.00	s	0.00 to 999.00
Operator 1			
Input A	<Unused = 0>		
Operator 2			
Input B	<Unused = 0>		
Operator 3			
Input C	<Unused = 0>		
Operator 4			
Input D	<Unused = 0>		
Operator 5			
Input E	<Unused = 0>		
PL 8 [ProLogic 8]			
ProLogic 8	Disabled		
Target	Enabled		
Pickup Delay	0.00	s	0.00 to 999.00
Dropout Delay	0.00	s	0.00 to 999.00
Operator 1			
Input A	<Unused = 0>		
Operator 2			
Input B	<Unused = 0>		
Operator 3			
Input C	<Unused = 0>		
Operator 4			
Input D	<Unused = 0>		
Operator 5			
Input E	<Unused = 0>		
PL 9 [ProLogic 9]			
ProLogic 9	Disabled		
Target	Enabled		
Pickup Delay	0.00	s	0.00 to 999.00
Dropout Delay	0.00	s	0.00 to 999.00
Operator 1			
Input A	<Unused = 0>		
Operator 2			
Input B	<Unused = 0>		
Operator 3			
Input C	<Unused = 0>		
Operator 4			

T-PRO Settings Summary			
Name	**Symbol/Value**	**Unit**	**Range**
Input D	<Unused = 0>		
Operator 5			
Input E	<Unused = 0>		
PL 10 [ProLogic 10]			
ProLogic 10	Disabled		
Target	Enabled		
Pickup Delay	0.00	s	0.00 to 999.00
Dropout Delay	0.00	s	0.00 to 999.00
Operator 1			
Input A	<Unused = 0>		
Operator 2			
Input B	<Unused = 0>		
Operator 3			
Input C	<Unused = 0>		
Operator 4			
Input D	<Unused = 0>		
Operator 5			
Input E	<Unused = 0>		
Record Length			
Fault Record Length	0.5	s	0.2 to 2.0
Thermal Logging	Disabled		
Trend Sample Rate	3	minutes/sample	3 to 60

Appendix C Hardware Description

The T-PRO is a sophisticated transformer protection relay with integral high-quality fault recording.

External Input and Comm Board

The T-PRO Relay has 9 channels of external inputs provided by the External Input and Comm Board. Inputs are optically isolated, factory pre-set to the customer's requested voltage level. Two dual-range user-selectable external-input voltage-level model of the External Input and Comm Board are available. This allows you to select between 48 Vdc and 125 Vdc or 125 Vdc and 250 Vdc (nominal) on a per input basis.

The External Input and Comm Board also provides the relay with two rear-panel RS-232 ports, IRIG-B time synchronization input, and optional network or telephone connection. The RS-232 ports are female DB-9S connectors, IRIG-B is a male BNC, and network or telephone is a female RJ-45 modular jack.

Relay Output and DC Analog Input Board

The Relay Output Board provides 14 normally open contact outputs for relaying, alarms and control, one normally closed output contact for indicating proper relay operation. This board also provides two 4-20mA current inputs and one unregulated 30 Vdc supply.

Power Supply Board

The power supply operates from 40 to 300 Vdc or 120 Vac +- 20% at 50/60 Hz. This wide operating range provides easier installation by eliminating power supply ordering options.

AC Analog Input Board

The AC Analog Input Board has 15 current transformer inputs and 3 potential transformer inputs for ac current and voltage inputs. On-board anti-aliasing filters provide accurate and secure digitization of the ac input signals.

Main Processor Board (MPB)

The MPB has analog data acquisition, high-speed digital signal processing for triggering and data conversion, communications, and interface logic to perform the core functions of the relay.

The Digital Signal Processor (DSP) on a MPB performs the protective relaying functions of the relay, separate from the 486 CPU. It has its own flash memory and self-checking for fully independent operation.

The Main Processor Board has:

- 24 channels of high-speed 12 bit-plus-sign analog-to-digital conversion
- Re-programmable flash memory for the DSP allows independent relay operation and field software upgrades
- Floating point DSP for fast capture and manipulation of data
- Standard RS-232 serial communications ports
- High speed link between DSP and 486 processors
- Time synchronism processor with automatic detection of modulated and unmodulated IRIG-B
- Sophisticated fault detection and “watchdog” recovery hardware

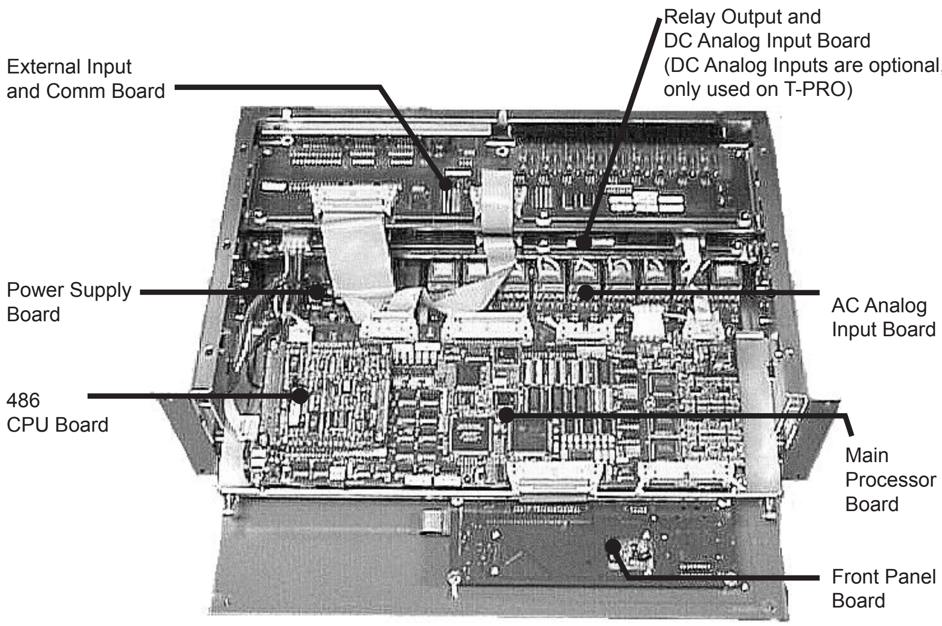
486 CPU Board

A 486-class CPU provides data storage, information management, housekeeping, and communications for the relay. The 486 runs a real-time operating system optimized for high speed, high precision computing. The 486 provides sophisticated facilities for communications and field software updates. Local and wide area networking is supported by providing the relay with a path to future networking capability.

A highly reliable solid-state flash disk on the CPU board provides the operating software for the 486, and stores the relay's recordings.

Front Panel Board

The Front Panel Board provides visual indication of the status of the relay, an alphanumeric display and keypad for system monitoring, and a front-panel RS-232 port.



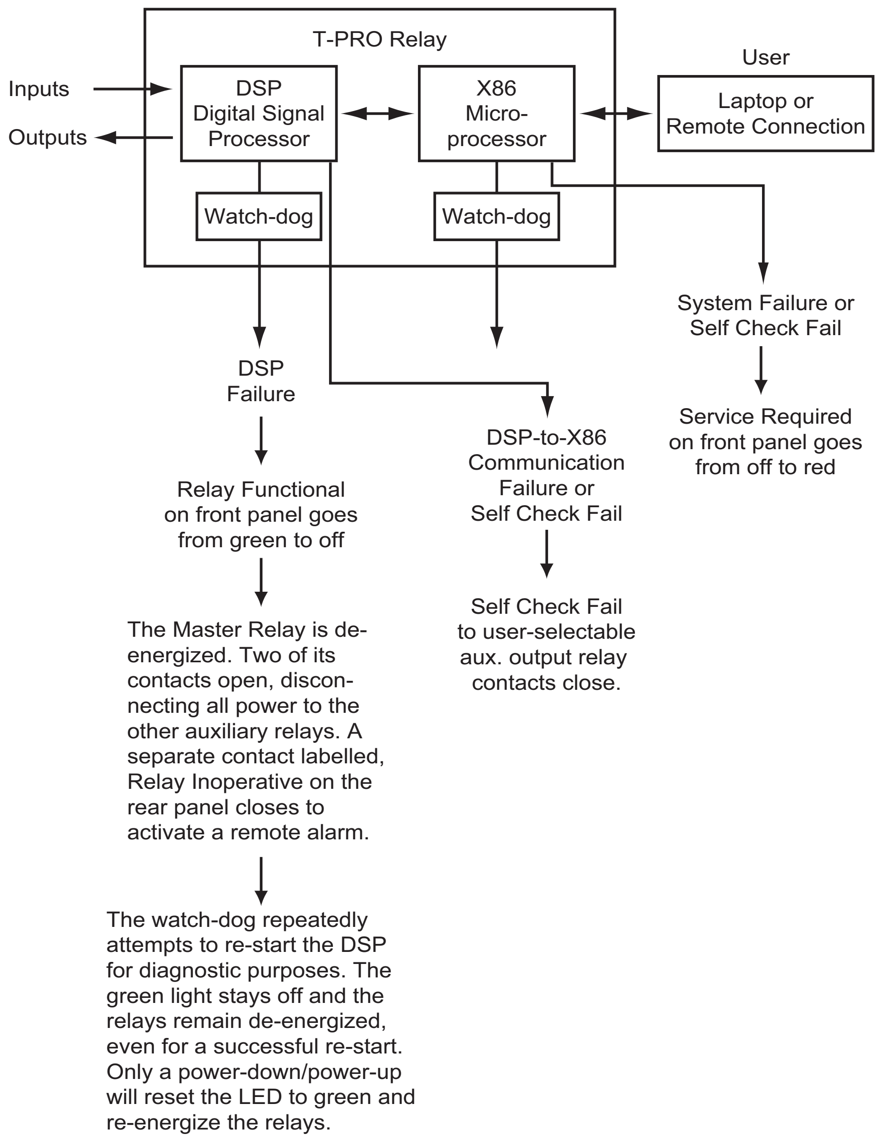
Appendix D Event Messages

T-PRO Event Messages	
Event Log Message	**Notes**
87: Trip on ABC	The possible phase information is: • A • B • C • N • AB • BC • CA • ABC
87N-HV: Trip	
87N-LV: Trip	
87N-TV: Trip	
51-HV: Trip	
50-HV: Trip	
51-LV: Trip	
50-LV: Trip	
51-TV: Trip	
50-TV: Trip	
51N-HV: Trip	
50N-HV: Trip	
51N-LV: Trip	
50N-LV: Trip	
51N-TV: Trip	
50N-TV: Trip	
67: Trip	
24INV: Trip	
24DEF: Trip	
59N Trip	
60: Alarm	
51-HV: Alarm	
51-LV: Alarm	
51-TV: Alarm	
51N-HV: Alarm	
51N-LV: Alarm	
51N-TV: Alarm	
67: Alarm	
24INV: Alarm	
59N: Alarm	
THD Exceeds Limit: Alrm	

T-PRO Event Messages	
Ambient (P1) - Range: Alrm	P1 - could be Over or Under
Top Oil (P1) - Range: Alrm	P1 - could be Over or Under
TOEWS: 15 min Alarm	
TOEWS: 30 min Alarm	
TOEWS: Trip	
49-1: Trip/Alarm	
49-2: Trip/Alarm	
49-3: Trip/Alarm	
49-4: Trip/Alarm	
49-5: Trip/Alarm	
49-6: Trip/Alarm	
49-7: Trip/Alarm	
49-8: Trip/Alarm	
49-9: Trip/Alarm	
49-10: Trip/Alarm	
49-11: Trip/Alarm	
49-12: Trip/Alarm	
81-1: Trip	
81-2: Trip	
81-3: Trip	
81-4: Trip	
27-1: Trip on ABC 27-2: Trip on ABC	The possible phase information is: • A • B • C • N • AB • BC • CA • ABC
I*I*t Alarm on ABC	The possible phase information is: • A • B • C • N • AB • BC • CA • ABC
ProLogic Name: PLn	ProLogic outputs names are user-assigned Where n = 1 to 10
External Input Name: EIn: High	External input names are user-assigned Where n = 1 to 9
External Input Name: EIn Low	External Input names are user-assigned Where n = 1 to 9
Output Contacts name: Out n: Open	Output contact names are user-assigned Where n= 1 to 14
Output Contact name: Out n = Closed	Output contact names are user-assigned Where n= 1 to 14
Self Check: DC Ch.n: Alarm	Continuous dc level on Ch. n, where n = 1 to 18.

T-PRO Event Messages	
Self Check: DC Alarm Reset	Continuous dc level, condition has reset.
Self Check: DC Ch.n: O/P Block	Continuous dc level on Ch. n, where n = 1 to 18.
New Setting Loaded	
Manual settings load request completed	Completion of user-initiated settings change
Unit recalibrated	
Unit restarted	
User logged in	

Details of Failure Modes



> Note: For either of the above cases the DSP controller functions continue with normal auxiliary relay outputs provided that DSP failure or Self Check Fail: Block has not occurred.

Self Check Fail due to DC Offset Detector

The DSP has an algorithm that detects continuous dc levels on the analog inputs and initiates alarms and relay output contact blocking when the measured dc level exceeds the Alarm or Block level. The Alarm level is intended to provide an early indication of a problem. The Block level blocks the relay from false-tripping by preventing any output contact from closing. The Relay Functional LED turns off, but the protection functions will operate normally, with the exception that the output contacts will not be allowed to close. The Relay Inoperative contact will close for a Block condition. The following table describes all the Alarm/Block indication functions.

Action	Condition	
	Alarm	Block
Relay Functional LED off		X
Service Required LED on	X	X
Self Check Fail Signal high	X	X
Relay Inoperative Contact closed		X
Output Contacts held open		X
Event Log Message	X	X
Status available through SCADA	X	X

The Self Check Fail signal, which is available in the Output Matrix, TUI metering and SCADA, can be used to signal an alarm. Note that if this signal is mapped to an output contact, the contact which it is mapped to will only be closed for an alarm condition. If the relay is in the Block condition, the Relay Inoperative contact must be used to signal an alarm.

The status of the Self Check Fail is available through the SCADA services provided by the T-PRO. The digital signal Self Check Fail will indicate that DSP has detected a continuous dc level and the analog metering value Self Check Fail Parameter is used to indicate which condition, Alarm or Block. The failure types and which analog values they are associated with are described in the table below. Both signals are available in DNP and Modbus.

Point Value	**Condition**
0	Normal
1	Alarm
2	Block
3	Alarm has evolved to block

The Alarm condition is allowed to reset if the continuous dc level drops below the pickup level. The Block condition has no reset level. If power is cycled to the relay it will go into its normal state until the continuous dc level is detected again.

Appendix E Modbus RTU Communication Protocol

The SCADA port supports DNP3 and Modicon Modbus protocols. All metering values available through the terminal user interface are also available through the Modbus protocol. Additionally, the Modbus protocol supports the reading of unit time and time of the readings, and provides access to trip and alarm events, including fault location information.

A "Hold Readings" function is available to freeze all metering readings into a snapshot (see Force Single Coil function, address 0).

Read Coil Status			
Channel	**Address**	**Value**	
Hold Readings	00001	0: Readings not held	1: Readings held
Reserved	00257	Reserved	Reserved
Output Contact 1	00513	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 2	00514	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 3	00515	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 4	00516	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 5	00517	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 6	00518	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 7	00519	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 8	00520	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 9	00521	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 10	00522	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 11	00523	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 12	00524	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 13	00525	0: Contact Open (inactive)	1: Contact Closed (active)
Output Contact 14	00526	0: Contact Open (inactive)	1: Contact Closed (active)
Dev 87 Trip	00769	0: Off (inactive)	1: On (active)
Dev 87 Restrain	00770	0: Off (inactive)	1: On (active)
Dev 87 Fast Trip	00771	0: Off (inactive)	1: On (active)
Dev 51HV Trip	00772	0: Off (inactive)	1: On (active)
Dev 51HV Alarm	00773	0: Off (inactive)	1: On (active)
Dev 50HV Trip	00774	0: Off (inactive)	1: On (active)
Dev 51LV Trip	00775	0: Off (inactive)	1: On (active)
Dev 51LV Alarm	00776	0: Off (inactive)	1: On (active)
Dev 50LV Trip	00777	0: Off (inactive)	1: On (active)
Dev 51TV Trip	00778	0: Off (inactive)	1: On (active)

Dev 51TV Alarm	00779	0: Off (inactive)	1: On (active)
Dev 50TV Trip	00780	0: Off (inactive)	1: On (active)
Dev 51NHV Trip	00781	0: Off (inactive)	1: On (active)
Dev 51NHV Alarm	00782	0: Off (inactive)	1: On (active)
Dev 50NHV Trip	00783	0: Off (inactive)	1: On (active)
Dev 51NLV Trip	00784	0: Off (inactive)	1: On (active)
Dev 51NLV Alarm	00785	0: Off (inactive)	1: On (active)
Dev 50NLV Trip	00786	0: Off (inactive)	1: On (active)
Dev 51NTV Trip	00787	0: Off (inactive)	1: On (active)
Dev 51NTV Alarm	00788	0: Off (inactive)	1: On (active)
Dev 50NTV Trip	00789	0: Off (inactive)	1: On (active)
Dev 67 Trip	00790	0: Off (inactive)	1: On (active)
Dev 67 Alarm	00791	0: Off (inactive)	1: On (active)
Dev 24INV Trip	00792	0: Off (inactive)	1: On (active)
Dev 24INV Alarm	00793	0: Off (inactive)	1: On (active)
Dev 24DEF Trip	00794	0: Off (inactive)	1: On (active)
Dev 59N Trip	00795	0: Off (inactive)	1: On (active)
Dev 59N Alarm	00796	0: Off (inactive)	1: On (active)
Dev 60 Alarm	00797	0: Off (inactive)	1: On (active)
THD Alarm	00798	0: Off (inactive)	1: On (active)
Self Check Fail	00799	0: Off (inactive)	1: On (active)
Ambient Temp Alarm	00800	0: Off (inactive)	1: On (active)
Top Oil Temp Alarm	00801	0: Off (inactive)	1: On (active)
Dev 49-1 Trip/Alarm	00802	0: Off (inactive)	1: On (active)
Dev 49-2 Trip/Alarm	00803	0: Off (inactive)	1: On (active)
Dev 49-3 Trip/Alarm	00804	0: Off (inactive)	1: On (active)
Dev 49-4 Trip/Alarm	00805	0: Off (inactive)	1: On (active)
Dev 49-5 Trip/Alarm	00806	0: Off (inactive)	1: On (active)
Dev 49-6 Trip/Alarm	00807	0: Off (inactive)	1: On (active)
Dev 49-7 Trip/Alarm	00808	0: Off (inactive)	1: On (active)
Dev 49-8 Trip/Alarm	00809	0: Off (inactive)	1: On (active)
Dev 49-9 Trip/Alarm	00810	0: Off (inactive)	1: On (active)
Dev 49-10 Trip/Alarm	00811	0: Off (inactive)	1: On (active)
Dev 49-11 Trip/Alarm	00812	0: Off (inactive)	1: On (active)
Dev 49-12 Trip/Alarm	00813	0: Off (inactive)	1: On (active)
Dev 87NHV Trip	00814	0: Off (inactive)	1: On (active)
Dev 87NLV Trip	00815	0: Off (inactive)	1: On (active)
Dev 87NTV Trip	00816	0: Off (inactive)	1: On (active)
TOEWS 15 Minute Alarm	00817	0: Off (inactive)	1: On (active)
TOEWS 30 Minute Alarm	00818	0: Off (inactive)	1: On (active)

TOEWS Trip	00819	0: Off (inactive)	1: On (active)
ProLogic 1 Trip	00820	0: Off (inactive)	1: On (active)
ProLogic 2 Trip	00821	0: Off (inactive)	1: On (active)
ProLogic 3 Trip	00822	0: Off (inactive)	1: On (active)
ProLogic 4 Trip	00823	0: Off (inactive)	1: On (active)
ProLogic 5 Trip	00824	0: Off (inactive)	1: On (active)
ProLogic 6 Trip	00825	0: Off (inactive)	1: On (active)
ProLogic 7 Trip	00826	0: Off (inactive)	1: On (active)
ProLogic 8 Trip	00827	0: Off (inactive)	1: On (active)
ProLogic 9 Trip	00828	0: Off (inactive)	1: On (active)
ProLogic 10 Trip	00829	0: Off (inactive)	1: On (active)
81-1 Trip	00830	0: Off (inactive)	1: On (active)
81-2 Trip	00831	0: Off (inactive)	1: On (active)
81-1 Trip	00832	0: Off (inactive)	1: On (active)
81-2 Trip	00833	0: Off (inactive)	1: On (active)
27-1 Trip	00834	0: Off (inactive)	1: On (active)
27-2 Trip	00835	0: Off (inactive)	1: On (active)
I*I*t Alarm	00836	0: Off (inactive)	1: On (active)

Read Input Status		
Channel	**Address**	**Value**
External I/P 1	10001	0: off (inactive), 1: on (active)
External I/P 2	10002	0: off (inactive), 1: on (active)
External I/P 3	10003	0: off (inactive), 1: on (active)
External I/P 4	10004	0: off (inactive), 1: on (active)
External I/P 5	10005	0: off (inactive), 1: on (active)
External I/P 6	10006	0: off (inactive), 1: on (active)
External I/P 7	10007	0: off (inactive), 1: on (active)
External I/P 8	10008	0: off (inactive), 1: on (active)
External I/P 9	10009	0: off (inactive), 1: on (active)

Read Holding register table			
Channel	**Address**	**Units**	**Scale**
T-PRO Clock Time (UTC). Read all in same query to ensure consistent time reading data.			
Milliseconds Now	40001	0-999	1
Seconds Now	40002	0-59	1

Minutes Now	40003	0-59	1
Hours Now	40004	0-23	1
Day of Year Now	40005	1-365 (up to 366 if leap year)	1
Years since 1900	40006	90-137	1
Sync'd to IRIG-B	40007	0: No 1: Yes	1
Time of Acquisition (UTC). Read all in same query to ensure consistent time reading data.			
Milliseconds Now	40008	0-999	1
Seconds Now	40009	0-59	1
Minutes Now	40010	0-59	1
Hours Now	40011	0-23	1
Day of Year Now	40012	1-365 (up to 366 if leap year)	1
Years since 1900	40013	90-137	1
Sync'd to IRIG-B	40014	0: No 1: Yes	1
Offset of UTC to IED local time.	40015	2's complement half hours, North America is negative	1

Read Holding register table			
Channel	**Address**	**Units**	**Scale**
Va Magnitude	257	KV	10
Va Angle	258	Degrees	10
Vb Magnitude	259	kV	10
Vb Angle	260	Degrees	10
Vc Magnitude	261	kV	10
Vc Angle	262	Degrees	10
Positive Sequence Voltage	263	kV	10
Positive Sequence Current	264	A	1
Instantaneous Watts	265	MW	10
Instantaneous VARs	266	MVAR	10
I1a Magnitude	267	A	1
I1a Angle	268	Degrees	10
I1b Magnitude	269	A	1
I1b Angle	270	Degrees	10
I1c Magnitude	271	A	1
I1c Angle	272	Degrees	10
I2a Magnitude	273	A	1
I2a Angle	274	Degrees	10
I2b Magnitude	275	A	1
I2b Angle	276	Degrees	10
I2c Magnitude	277	A	1
I2c Angle	278	Degrees	10
I3a Magnitude	279	A	1
I3a Angle	280	Degrees	10
I3b Magnitude	281	A	1
I3b Angle	282	Degrees	10
I3c Magnitude	283	A	1
I3c Angle	284	Degrees	10
I4a Magnitude	285	A	1
I4a Angle	286	Degrees	10
I4b Magnitude	287	A	1
I4b Angle	288	Degrees	10
I4c Magnitude	289	A	1
I4c Angle	290	Degrees	10
I5a Magnitude	291	A	1
I5a Angle	292	Degrees	10

I5b Magnitude	293	A	1
I5b Angle	294	Degrees	10
I5c Magnitude	295	A	1
I5c Angle	296	Degrees	10
HVa Current Magnitude	297	A	1
HVa Current Angle	298	Degrees	10
HVb Current Magnitude	299	A	1
HVb Current Angle	300	Degrees	10
HVc Current Magnitude	301	A	1
HVc Current Angle	302	Degrees	10
LVa Current Magnitude	303	A	1
LVa Current Angle	304	Degrees	10
LVb Current Magnitude	305	A	1
LVb Current Angle	306	Degrees	10
LVc Current Magnitude	307	A	1
LVc Current Angle	308	Degrees	10
TVa Current Magnitude	309	A	1
TVa Current Angle	310	Degrees	10
TVb Current Magnitude	311	A	1
TVb Current Angle	312	Degrees	10
TVc Current Magnitude	313	A	1
TVc Current Angle	314	Degrees	10
Ia Operating	315	A	1
Ib Operating	316	A	1
Ic Operating	317	A	1
Ia Restraint	318	A	1
Ib Restraint	319	A	1
Ic Restraint	320	A	1
Frequency	321	Hz	100
DC1	322	mA	100
DC2	323	mA	100
HV Current	324	p.u.	100
LV Current	325	p.u.	100
TV Current	326	p.u.	100
TOEWS Minutes to trip	327	Minutes	1
Self Check Fail Parameter	328	N/A	1
Ambient Temperature	513	c	10
Top Oil Temperature	514	c	10
Hot Spot Temperature	515	c	10
Loss of Life	516	p.u.	100

Pickup Level	517	p.u.	100
THD	518	%	100
Accumulated IA*Ia*t	519	KA*KA*S	10
Accumulated IB*IB*t	520	KA*KA*S	10
Accumulated IC*IC*t	521	KA*KA*S	10
Accumulated Through Fault Count	522	N/A	1

Read Input Register (Function Code 04)
No input registers supported. Response from IED indicates “ILLEGAL FUNCTION.”

Force Single Coil (Function Code 05)			
Only the “hold readings” coil can be forced. When active, this coil locks all coil, input and holding register readings simultaneously at their present values. When inactive, coil, input and holding register values read their most recently available state.			
Channel	**Type**	**Address**	**Value**
Hold Readings	Read/Write	01	0000: Readings update normally (inactive) FF00: Hold readings (active)

Preset Single Register (Function Code 06)			
Channel	**Address**	**Value**	**Scaled Up By**
Event Message Control (See below for details of use)			
Refresh event list	40769	No data required	N/A
Acknowledge the current event and get the next event	40770	No data required	N/A
Get the next event (without acknowledge)	40771	No data required	N/A

Diagnostic Subfunctions (Function Code 08)	
Return Query Data (Subfunction 00)	This provides an echo of the submitted message.
Restart Comm. Option (Subfunction 01)	This restarts the Modbus communications process.
Force Listen Only Mode (Subfunction 04)	No response is returned. IED enters “Listen Only” mode. This mode can only be exited by the “Restart Comm. Option” command.

Report Slave ID (Function Code 17/0x11)			
A fixed response is returned by the IED, including system model, version and issue numbers.			
Channel	**Type**	**Bytes**	**Value**
Model Number	Read Only	0 and 1	0 x 21FC = 8700 decimal
Version Number	Read Only	2 and 3	Version number
Issue Number	Read Only	4 and 5	Issue number

- The T-PRO IED model number is 8700.
- Version and issue will each be positive integers, say X and Y.
- The T-PRO is defined by as “Model 8700, Version X Issue Y”.

Accessing T-PRO Event Information	
All T-PRO detector event messages displayed in the Event Log are available through Modbus. The following controls are available.	
Refresh Event List	(Function Code 6, address 40769): Fetches the latest events from the T-PRO’s event log and makes them available for Modbus access. The most recent event becomes the current event available for reading.
Acknowledge Current Event and Get Next Event	(Function Code 6, address 40770): Clears the current event from the read registers and places the next event into them. An acknowledged event is no longer available for reading.
Get Next Event	(Function Code 6, address 40771): Places the next event in the read registers without acknowledging the current event. The current event reappears in the list when Refresh Event List is used.
Size of Current Event Message	(Function Code 3, address 40772): Indicates the number of 16 bit registers used to contain the current event. Event data is stored with two characters per register. A reading of zero indicates that there are no unacknowledged events available in the current set. (N.B. The Refresh Event List function can be used to check for new events that have occurred since the last Refresh Event List.)
Read Event Message	(Function Code 3, addresses 40774 - 40832): Contains the current event message. Two ASCII characters are packed into each 16 bit register. All unused registers in the set are set to 0.

Modbus Event Message Example			
" 2000 Sep21 20:16:16.966: Diff. (87) on ABC: Trip			
Register	**Value**	**Meaning**	
	High Byte	**Low Byte**	
40772	0x00	0x1D	Event text size = 29 (0x1D hex)
40773	0x20	0x20	’<sp>’, ’<sp>’
40774	0x32	0x30	‘2’, ‘0’
40775	0x30	0x30	‘0’, ‘0’
40776	0x53	0x65	‘S’, ‘e’
40777	0x70	0x32	‘p’, ‘2’
40778	0x31	0x20	‘1’, ‘<sp>’
40779	0x32	0x30	‘2’, ‘0’
40780	0x3A	0x31	‘:’, ‘1’
40781	0x36	0x3A	‘6’, ‘:’
40782	0x31	0x36	‘1’, ‘6’
40783	0x2E	0x39	‘.’, ‘9’
40784	0x36	0x36	‘6’, ‘6’
40785	0x20	0x3A	‘<sp>’, ‘:’
40786	0x20	0x44	‘<sp>’, ‘D’
40787	0x69	0x66	‘ i’, ‘f’
40788	0x66	0x2E	‘f’, ‘. ‘
40789	0x20	0x28	‘<sp>’, ‘(’
40790	0x38	0x37	‘8’, ‘7’
40791	0x29	0x20	‘)’, ‘ ’
40792	0x6F	0x6E	‘o’, ‘ n‘
40793	0x20	0x41	‘<sp>’, ‘A’
40794	0x42	0x43	‘B ’, ‘C’
40795	0x3A	0x20	‘:’, ‘<sp>’
40796	0x54	0x72	’T’,’r’
40797	0x69	0x70	’i’, ’p’

Appendix F DNP3 Communication Protocol

The SCADA port supports DNP3. All metering values available through the terminal user interface are available by DNP3 protocol. Included are the device profile, implementation table and the point list for the DNP3 protocol.

Device Profile

Vendor Name: ERLPhase Power Technologies Ltd.	Device Name: Relay Model #
Highest DNP Level Supported: For Requests: 2 For Responses: 2	Device Function: _ Master x Slave
Maximum Data Link Frame Size (octets): Transmitted: 292 Received: 292	Maximum Application Frame Size (octets): Transmitted: 2048 Received: 2048
Maximum Data Link Re-tries: _ None x Fixed at 3 _ Configurable, range __ to __	Maximum Application Layer Re-tries: x None _ Configurable, range __ to __
Requires Data Link Layer Confirmation: _ Never _ Always _ Sometimes x Configurable, either always or never	Requires Application Layer Confirmation: _ Never _ Always (not recommended) x When reporting Event Data (Slave) x When sending multi-fragment responses (Slave) _ Sometimes _ Configurable

Timeouts (in seconds) while waiting for:				
Data Link Confirm	__None	x Fixed at 2	__Variable	__Configurable
Complete Application Fragment	x None	__Fixed at 2	__Variable	__Configurable
Application Confirm	__None	x Fixed at 5	__Variable	__Configurable
Complete Application Response	x None	__Fixed at 2	__Variable	__Configurable
Others________________________				
Select to execute delay	__None	x Fixed at 10	__Variable	__Configurable

Sends/Executes Control Operations:				
WRITE Binary Outputs	x Never	__Always	__Sometimes	__Configurable
SELECT/OPERATE	__Never	x Always	__Sometimes	__Configurable
DIRECT OPERATE	__Never	x Always	__Sometimes	__Configurable
DIRECT OPERATE No ACK	__Never	x Always	__Sometimes	__Configurable
Count > 1	x Never	__Always	__Sometimes	__Configurable
Pulse On	__Never	x Always	__Sometimes	__Configurable
Pulse Off	x Never	__Always	__Sometimes	__Configurable
Latch On	__Never	x Always	__Sometimes	__Configurable
Latch Off	__Never	x Always	__Sometimes	__Configurable
Queue	x Never	__Always	__Sometimes	__Configurable
Clear Queue	x Never	__Always	__Sometimes	__Configurable
Maximum number of control objects per request: 16				
Notes: Control Trip/Close - Code Combination supported: Latch On/NUL Latch Off/NUL Pulse On/NUL (Pulse duration fixed at 1 s)				

Report Binary Input Change Events when no specific variation requested: __Never __Only time-tagged x Only non-time-tagged _ Configurable to send both, one or the other	Reports time-tagged Binary Input Change Events when no specific variation requested __Never x Binary Input Change with Time _ Binary Input Change with Relative Time _ Configurable
Sends Unsolicited Response: x Never _ Configurable _Only certain objects _ Sometimes	Sends Static Data in Unsolicited Responses: x Never _ When Device Restarts _ When Status Flags Change No other options are permitted.

_ ENABLE/DISABLE UNSOLICITED Function codes supported			
Default Counter Object/Variation: x No Counter Reported _ Configurable _ Default Object ________ _ Default Variation ________ _ Point-by-point list attached		Counters Roll Over at: x No Counters Reported _ Configurable _ 16 Bits _ 32 Bits _ Other Value ________ _ Point-by-point list attached	

Implementation Table

Object			Request		Response	
Grp	**VAR**	**Description**	**Function Code**	**Qualifier Codes (hex)**	**Function Code**	**Qualifier Codes (hex)**
1	0	Binary Input - All Variations	1 (read)	0x00, 0x01, 0x06, 0x07, 0x08, 0x17, 0x28	129 (response)	0x00
1	1	Binary Input (default)	1 (read)	0x00, 0x01, 0x06, 0x07, 0x08, 0x17, 0x28	129 (response)	0x00
1	2	Binary Input with Status	1 (read)	0x00, 0x01, 0x06, 0x07, 0x08, 0x17, 0x28	129 (response)	0x00
2	0	Binary Input Change - All Variations	1 (read)	0x06, 0x07, 0x08	129 (response)	0x17
2	1	Binary Input Change without Time	1 (read)	0x06, 0x07, 0x08	129 (response)	0x17
2	2	Binary Input Change with Time (default)	1 (read)	0x06, 0x07, 0x08	129 (response)	0x17
2	3	Binary Input Change with Relative Time	1 (read)	0x06, 0x07, 0x08	129 (response)	0x17
10	0	Binary Output - All Variations	1 (read)	0x00, 0x01, 0x06, 0x07, 0x08, 0x17, 0x28	129 (response)	0x00
10	2	Binary Output Status (default)	1 (read)	0x00, 0x01, 0x06, 0x07, 0x08, 0x17, 0x28	129 (response)	0x00
30	0	Analog Input - All Variations	1 (read)	0x00, 0x01, 0x06, 0x07, 0x08, 0x17, 0x28	129 (response)	0x01
30	1	32-bit Analog Input	1 (read)	0x00, 0x01, 0x06, 0x07, 0x08, 0x17, 0x28	129 (response)	0x01
30	2	16-bit Analog Input	1 (read)	0x00, 0x01, 0x06, 0x07, 0x08, 0x17, 0x28	129 (response)	0x01
30	3	32-bit Analog Input without flag	1 (read)	0x00, 0x01, 0x06, 0x07, 0x08, 0x17, 0x28	129 (response)	0x01
30	4	16-bit Analog Input without flag (default)	1 (read)	0x00, 0x01, 0x06, 0x07, 0x08, 0x17, 0x28	129 (response)	0x01
32	0	Analog Input Change Event - All Variations	1 (read)	0x06, 0x07, 0x08	129 (response)	0x28
32	1	Analog Input Change Event - 32-bit without Time	1 (read)	0x06, 0x07, 0x08	129 (response)	0x28
32	2	Analog Input Change Event - 16-bit without Time (default)	1 (read)	0x06, 0x07, 0x08	129 (response)	0x28
32	3	Analog Input Change Event - 32-bit with Time	1 (read)	0x06, 0x07, 0x08	129 (response)	0x28
32	4	Analog Input Change Event - 16-bit with Time	1 (read)	0x06, 0x07, 0x08	129 (response)	0x28
51	1	Time and Data CTO			129 (response)	0x07, quantity=1
52	1	Time Delay Coarse			129 (response)	0x07, quantity=1
60	1	Class 0 Data	1 (read)	0x06		

60	2	Class 1 Data	1 (read)	0x06, 0x07, 0x08		
60	3	Class 2 Data	1 (read)	0x06, 0x07, 0x08		
80	1	Internal Indications	2 (write)	0x00, index=7		
110	0	Octet String	1 (read)	0x06	129 (response)	0x07
111	0	Octet String Change Event	1 (read)	0x06	129 (response)	0x07
		No Object	14 (warm restart)			

Point List

Binary Inputs (Obj 1, 2)		
	Static Points	**Change Event Points**
Object Group	1	2
Object Variation	1 – Binary Input (default)	1 – Binary Input Change without Time
	2 – Binary Input with Status	1 – Binary Input Change with Time (default)
		3 – Binary Input Change with Relative Time
Class	0	1
Note: Binary inputs are scanned with 1 ms resolution.		
Change event buffer size		100

Binary Inputs	**Point Index**	**Change Event Class**
External Input 1	0	1
External Input 2	1	1
External Input 3	2	1
External Input 4	3	1
External Input 5	4	1
External Input 6	5	1
External Input 7	6	1
External Input 8	7	1
External Input 9	8	1

Binary Outputs (Obj 10)		
	Static Points	**Change Event Points**
Object Group	10	Not Applicable
Object Variation	2 – Binary Output Status (default)	Not Applicable
Class	0	Not Applicable
Note: Binary outputs are scanned with 500 ms resolution.		
No change buffer		

Binary Outputs	**Point Index**	**Change Event Class**
Output Contact 1	0	N/A
Output Contact 2	1	N/A
Output Contact 3	2	N/A
Output Contact 4	3	N/A
Output Contact 5	4	N/A
Output Contact 6	5	N/A
Output Contact 7	6	N/A
Output Contact 8	7	N/A
Output Contact 9	8	N/A
Output Contact 10	9	N/A
Output Contact 11	10	N/A
Output Contact 12	11	N/A
Output Contact 13	12	N/A
Output Contact 14	13	N/A
Dev 87 Trip	14	N/A
Dev 87 Restrain	15	N/A
Dev 87 Fast Trip	16	N/A
Dev 51HV Trip	17	N/A
Dev 51HV Alarm	18	N/A
Dev 50HV Trip	19	N/A
Dev 51LV Trip	20	N/A
Dev 51LV Alarm	21	N/A
Dev 50LV Trip	22	N/A
Dev 51TV Trip	23	N/A
Dev 51TV Alarm	24	N/A
Dev 50TV Trip	25	N/A
Dev 51NHV Trip	26	N/A
Dev 51NHV Alarm	27	N/A
Dev 50NHV Trip	28	N/A
Dev 51NLV Trip	29	N/A
Dev 51NLV Alarm	30	N/A
Dev 50NLV Trip	31	N/A
Dev 51NTV Trip	32	N/A
Dev 51NTV Alarm	33	N/A
Dev 50NTV Trip	34	N/A
Dev 67 Trip	35	N/A
Dev 67 Alarm	36	N/A

Dev 24INV Trip	37	N/A
Dev 24INV Alarm	38	N/A
Dev 24DEFTrip	39	N/A
Dev 59N Trip	40	N/A
Dev 59N Alarm	41	N/A
Dev 60 Alarm	42	N/A
THD Alarm	43	N/A
Self Check Fail	44	N/A
Ambient Temp Alarm	45	N/A
Top Oil Temp Alarm	46	N/A
Dev 49-1 Trip/Alarm	47	N/A
Dev 49-2 Trip/Alarm	48	N/A
Dev 49-3 Trip/Alarm	49	N/A
Dev 49-4 Trip/Alarm	50	N/A
Dev 49-5 Trip/Alarm	51	N/A
Dev 49-6 Trip/Alarm	52	N/A
Dev 49-7 Trip/Alarm	53	N/A
Dev 49-8 Trip/Alarm	54	N/A
Dev 49-9 Trip/Alarm	55	N/A
Dev 49-10 Trip/Alarm	56	N/A
Dev 49-11 Trip/Alarm	57	N/A
Dev 49-12 Trip/Alarm	58	N/A
Dev 87NHV Trip	59	N/A
Dev 87NLV Trip	60	N/A
Dev 87NTV Trip	61	N/A
TOEWS 15 Minute Alarm	62	N/A
TOEWS 30 Minute Alarm	63	N/A
TOEWS Trip	64	N/A
ProLogic 1 Trip	65	N/A
ProLogic 2 Trip	66	N/A
ProLogic 3 Trip	67	N/A
ProLogic 4 Trip	68	N/A
ProLogic 5 Trip	69	N/A
ProLogic 6 Trip	70	N/A
ProLogic 7 Trip	71	N/A
ProLogic 8 Trip	72	N/A
ProLogic 9 Trip	73	N/A
ProLogic 10 Trip	74	N/A
81-1 Trip	75	N/A
812 Trip	76	N/A

81-1 Trip	77	N/A
81-2 Trip	78	N/A
27-1	79	N/A
27-2	80	N/A
I*I*t Alarm	81	N/A

Analog Inputs (Obj 30, 31)		
	Static Points	**Change Event Points**
Object Group	30	32
Object Variation	1 - 32-bit Analog Input	1 - Analog Input Change - 32-bit without Time
	2 - 16-bit Analog Input	2 - Analog Input Change - 16-bit without Time (default)
	3 - 32-bit Analog Input without flag	3 - Analog Input Change - 32-bit with Time
	4 - 16-bit Analog Input without flag (default)	4 - Analog Input Change - 16-bit with Time
Class	0	2
Note: Analog Inputs are scanned with 500 ms resolution. Note: Nominal is based on 69 V secondary voltage * PT ratio for voltage channels, and either 1A or 5A secondary current * CT ratio for current channels dependent upon the format of CT installed in the T-PRO.		
Change event buffer size		100

Analog Inputs	**Point Index**	**Units**	**Scale**	**Change Event Class**	**Deadband**
Va Magnitude	0	kV	10	2	2% Nominal
Va Angle	1	Degrees	10	2	0.5 Degrees
Vb Magnitude	2	kV	10	2	2% Nominal
Vb Angle	3	Degrees	10	2	0.5 Degrees
Vc Magnitude	4	kV	10	2	2% Nominal
Vc Angle	5	Degrees	10	2	0.5 Degrees
Positive Sequence Voltage	6	kV	10	2	2% Nominal
Positive Sequence Current	7	A	1	2	2% Nominal
Instantaneous Watts	8	MW	10	2	4% Nominal
Instantaneous VARs	9	MVAR	10	2	4% Nominal
I1a Magnitude	10	A	1	2	2% Nominal
I1a Angle	11	Degrees	10	2	0.5 Degrees
I1b Magnitude	12	A	1	2	2% Nominal
I1b Angle	13	Degrees	10	2	0.5 Degrees
I1c Magnitude	14	A	1	2	2% Nominal
I1c Angle	15	Degrees	10	2	0.5 Degrees

I2a Magnitude	16	A	1	2	2% Nominal
I2a Angle	17	Degrees	10	2	0.5 Degrees
I2b Magnitude	18	A	1	2	2% Nominal
I2b Angle	19	Degrees	10	2	0.5 Degrees
I2c Magnitude	20	A	1	2	2% Nominal
I2c Angle	21	Degrees	10	2	0.5 Degrees
I3a Magnitude	22	A	1	2	2% Nominal
I3a Angle	23	Degrees	10	2	0.5 Degrees
I3b Magnitude	24	A	1	2	2% Nominal
I3b Angle	25	Degrees	10	2	0.5 Degrees
I3c Magnitude	26	A	1	2	2% Nominal
I3c Angle	27	Degrees	10	2	0.5 Degrees
I4a Magnitude	28	A	1	2	2% Nominal
I4a Angle	29	Degrees	10	2	0.5 Degrees
I4b Magnitude	30	A	1	2	2% Nominal
I4b Angle	31	Degrees	10	2	0.5 Degrees
I4c Magnitude	32	A	1	2	2% Nominal
I4c Angle	33	Degrees	10	2	0.5 Degrees
I5a Magnitude	34	A	1	2	2% Nominal
I5a Angle	35	Degrees	10	2	0.5 Degrees
I5b Magnitude	36	A	1	2	2% Nominal
I5b Angle	37	Degrees	10	2	0.5 Degrees
I5c Magnitude	38	A	1	2	2% Nominal
I5c Angle	39	Degrees	10	2	0.5 Degrees
HVa Current Magnitude	40	A	1	2	2% Nominal
HVa Current Angle	41	Degrees	10	2	0.5 Degrees
HVb Current Magnitude	42	A	1	2	2% Nominal
HVb Current Angle	43	Degrees	10	2	0.5 Degrees
HVc Current Magnitude	44	A	1	2	2% Nominal
HVc Current Angle	45	Degrees	10	2	0.5 Degrees
LVa Current Magnitude	46	A	1	2	2% Nominal
LVa Current Angle	47	Degrees	10	2	0.5 Degrees
LVb Current Magnitude	48	A	1	2	2% Nominal
LVb Current Angle	49	Degrees	10	2	0.5 Degrees
LVc Current Magnitude	50	A	1	2	2% Nominal
LVc Current Angle	51	Degrees	10	2	0.5 Degrees
TVa Current Magnitude	52	A	1	2	2% Nominal
TVa Current Angle	53	Degrees	10	2	0.5 Degrees
TVb Current Magnitude	54	A	1	2	2% Nominal
TVb Current Angle	55	Degrees	10	2	0.5 Degrees

TVc Current Magnitude	56	A	1	2	2% Nominal
TVc Current Angle	57	Degrees	10	2	0.5 Degrees
Ia Operating	58	A	1	2	2% Nominal
Ib Operating	59	A	1	2	2% Nominal
Ic Operating	60	A	1	2	2% Nominal
Ia Restraint	61	A	1	2	2% Nominal
Ib Restraint	62	A	1	2	2% Nominal
Ic Restraint	63	A	1	2	2% Nominal
Frequency	64	Hz	100	2	0.05 Hz
DC1	65	mA	100	2	0.24mA
DC2	66	mA	100	2	0.24mA
HV Current	67	p.u.	100	2	0.02
LV Current	68	p.u.	100	2	0.02
TV Current	69	p.u.	100	2	0.02
Ambient Temperature	70	C	10	2	0.5
Top Oil Temperature	71	C	10	2	2
Hot Spot Temperature	72	C	10	2	3
Loss of Life	73	%	100	2	0.02
51 Pickup Level	74	p.u.	100	2	0.02
THD	75	%	100	2	0.25
TOEWS Minutes to trip	76	Minutes	1	2	0.5 Minutes
Self Check Fail Parameter	77	N/A	1	2	0.5
Accumulated IA*IA*t	78	kA*kAs	1000	2	0.001
Accumulated IB*IB*t	79	kA*kA*s	1000	2	0.001
Accumulated IC*IC*t	80	kA*kA*s	1000	2	0.001
Accumulated Through Fault count	81	N/A	1	2	1

Object 110, 111 - Octet String for Event Log access

Object 110 and Object 111 are Octet String objects provide access to the Event Log text of the relay. These objects are described in Technical Bulletin 9701-004.zip_71 available from the DNP user group web page (www.dnp.org). Object 110 always contains the most recent event in the relay. Object 111 is the corresponding change event object. As stated in the DNP technical bulletin, the variation of the response object represents the length of the string. The string represents the ASCII values of the event text. The following example shows an event returned through either of the octet string objects.

DNP Example: Event Message

" 2000Sep21 20:16:16.966 : Diff. (87) on ABC: Trip"

DNP Octet string object contents:					
0x46	0x4C	0x32	0x30	0x30	0x30
0x53	0x65	0x70	0x32	0x31	0x20
0x32	0x30	0x3A	0x31	0x36	0x3A
0x31	0x36	0x2E	0x39	0x36	0x36
0x20	0x3A	0x20	0x44	0x69	0x66
0x66	0x2E	0x20	0x28	0x38	0x37
0x29	0x20	0x6F	0x6E	0x20	0x41
0x42	0x43	0x3A	0x20	0x54	0x72
0x69	0x70				

Appendix G   Mechanical Drawings

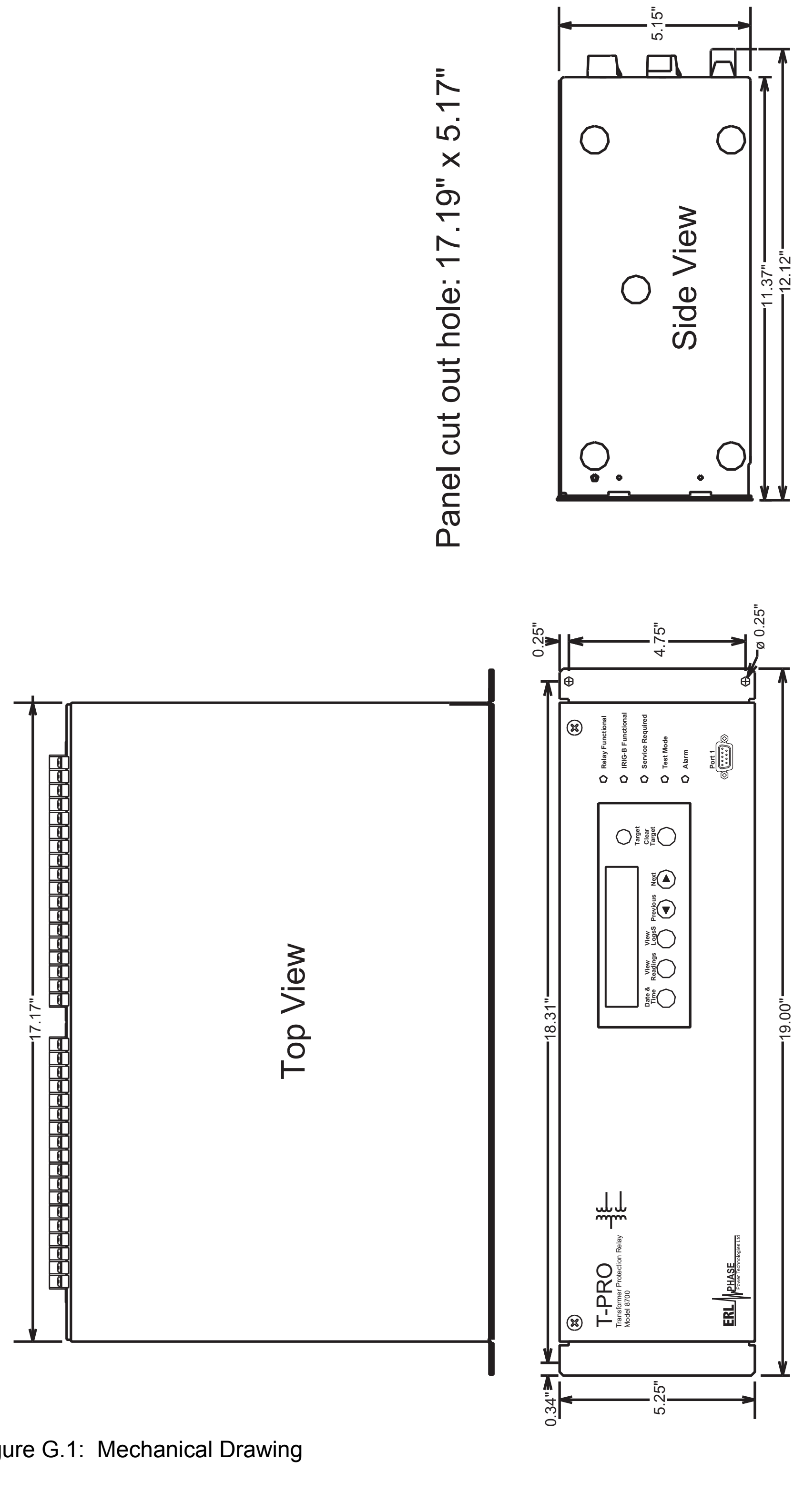


Figure G.1: Mechanical Drawing

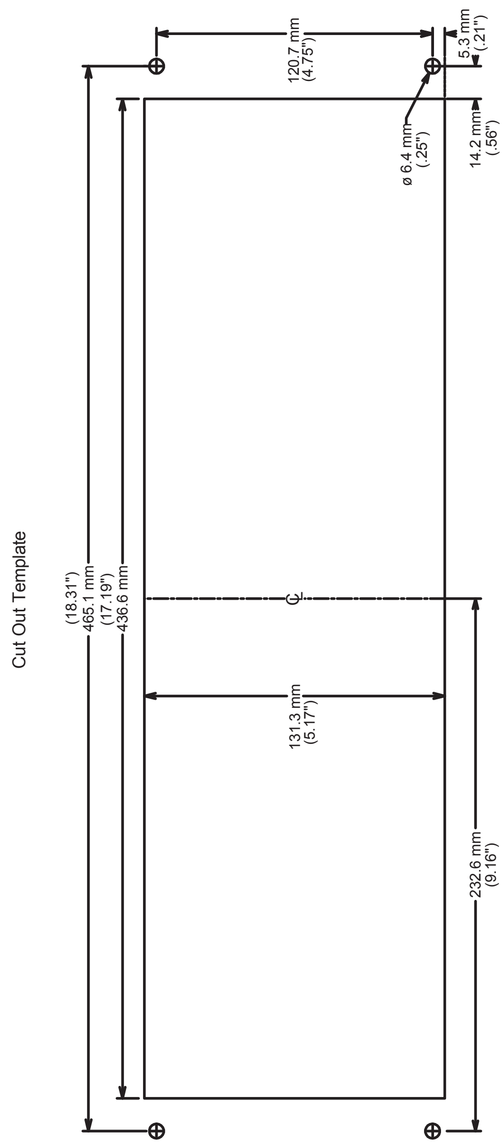


Figure G.2: Cut-out Template

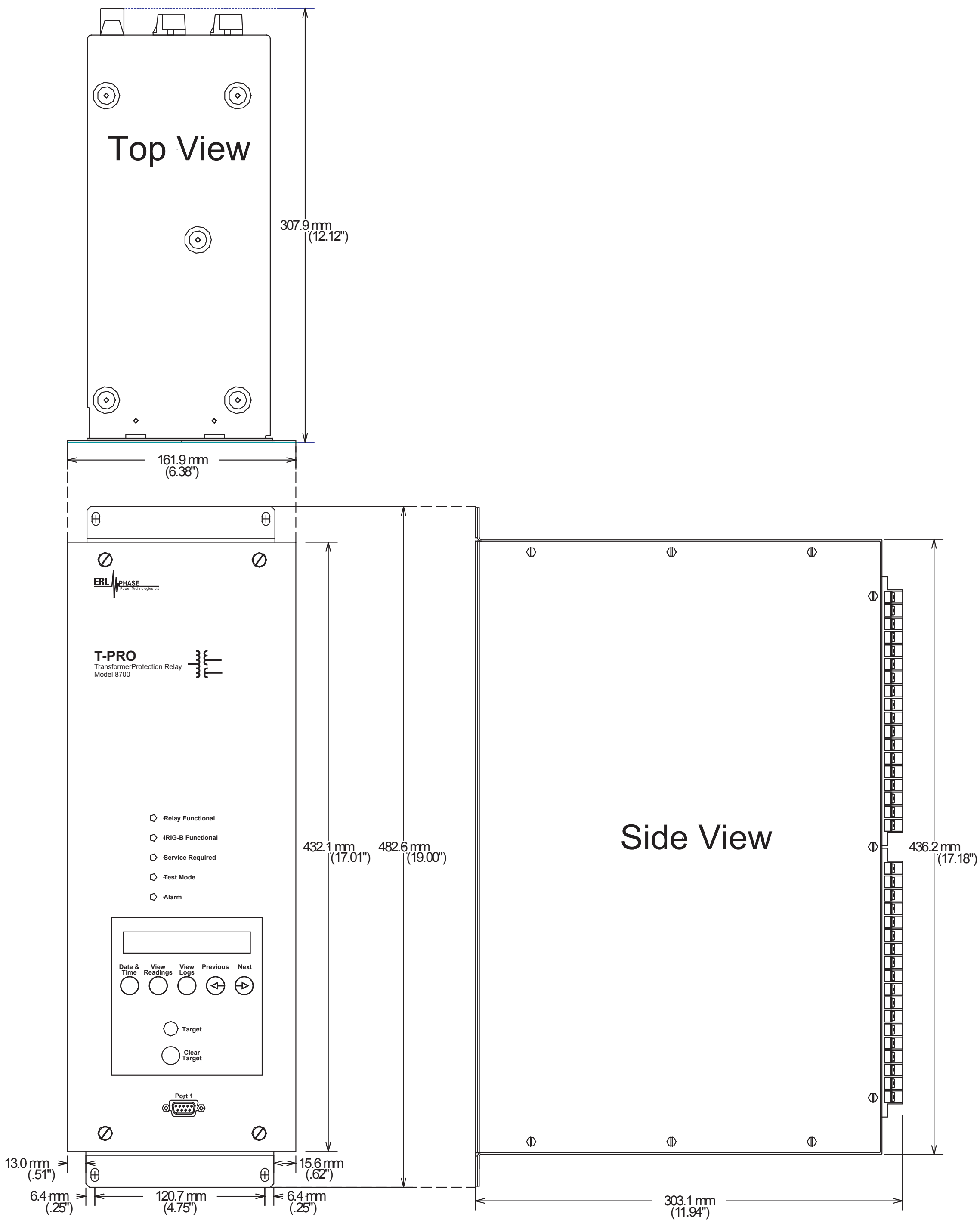


Figure G.3: Vertical Mount Mechanical Drawing

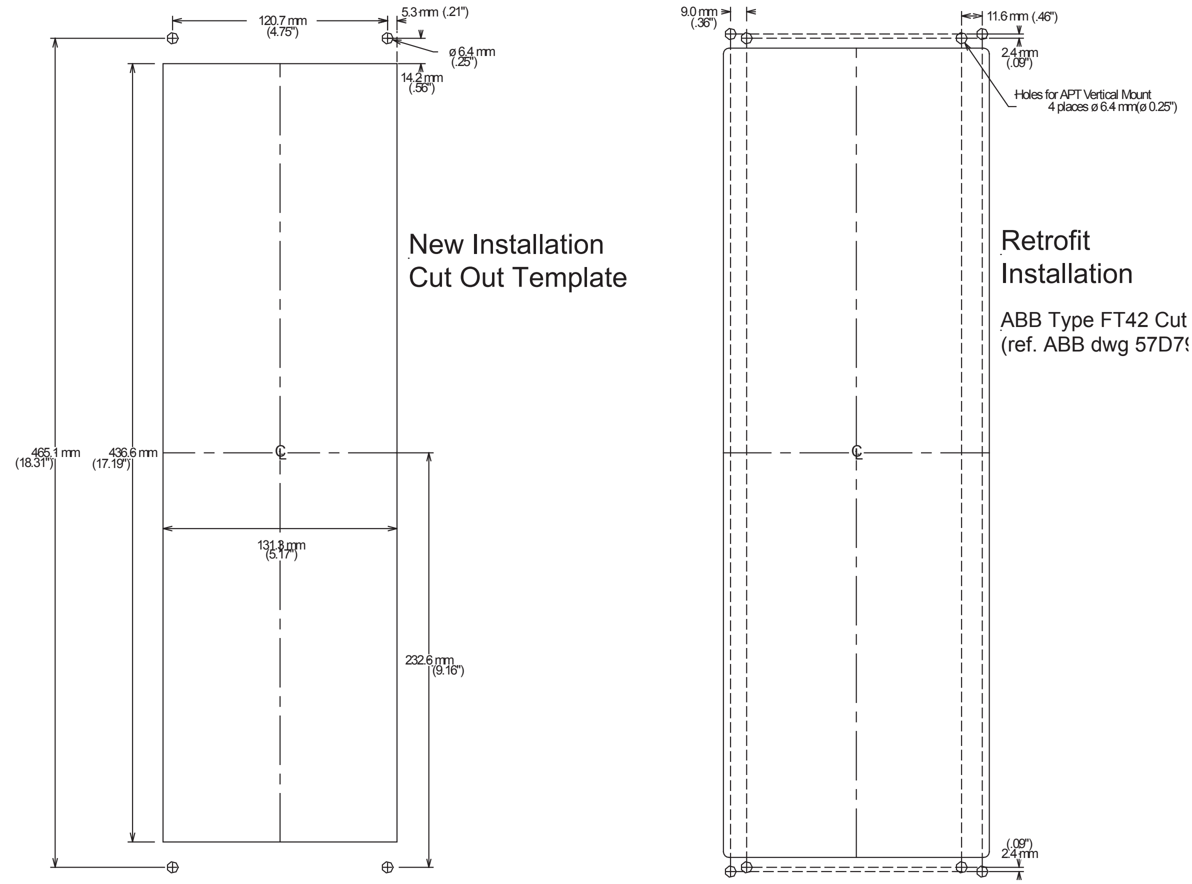


Figure G.4: Vertical Mount Cut-out Template

Appendix H Rear Panel Drawings

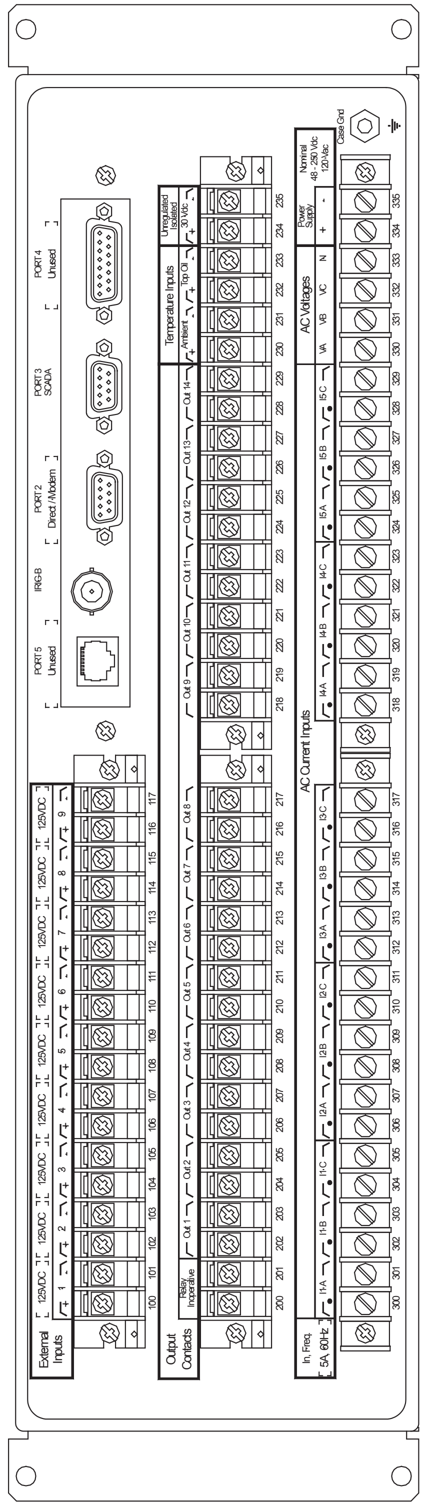


Figure H.1: Rear Panel

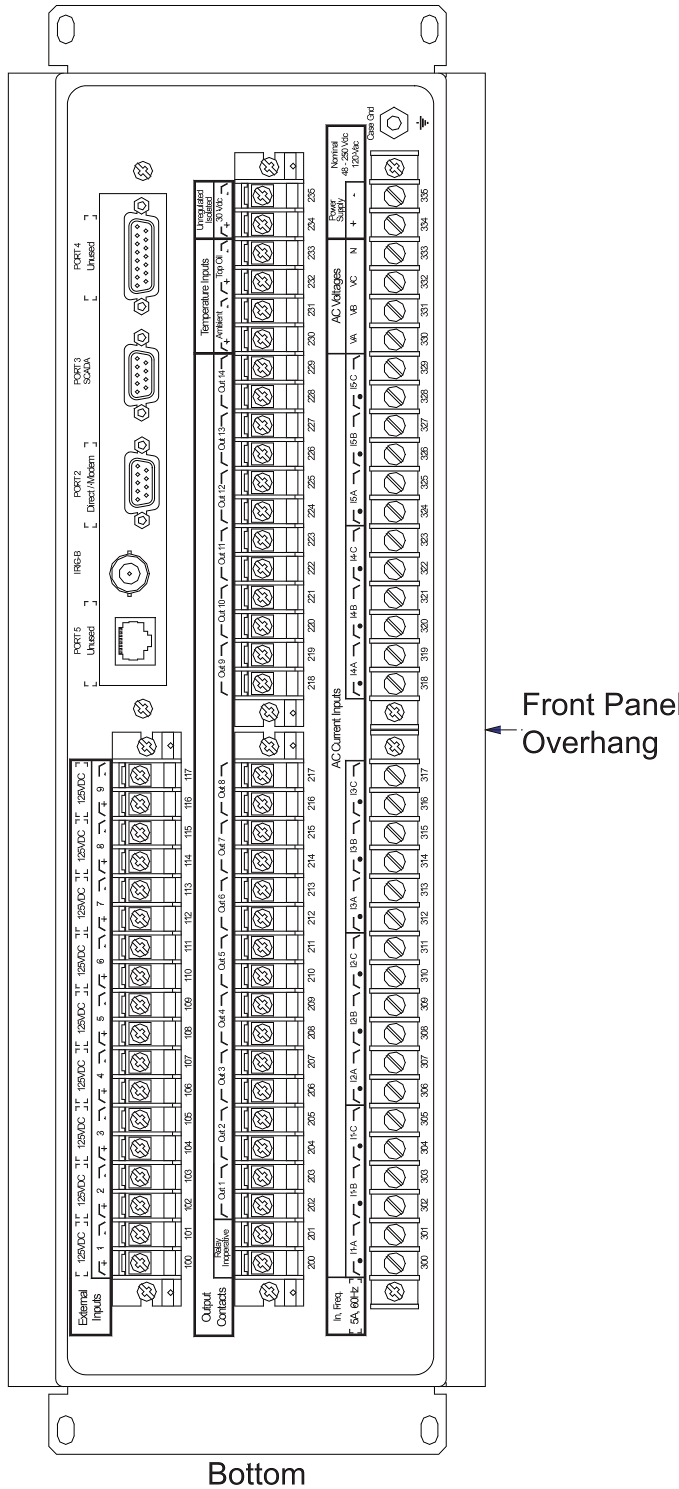


Figure H.2: Vertical Mount Rear Panel

Appendix I   AC Schematic Drawing

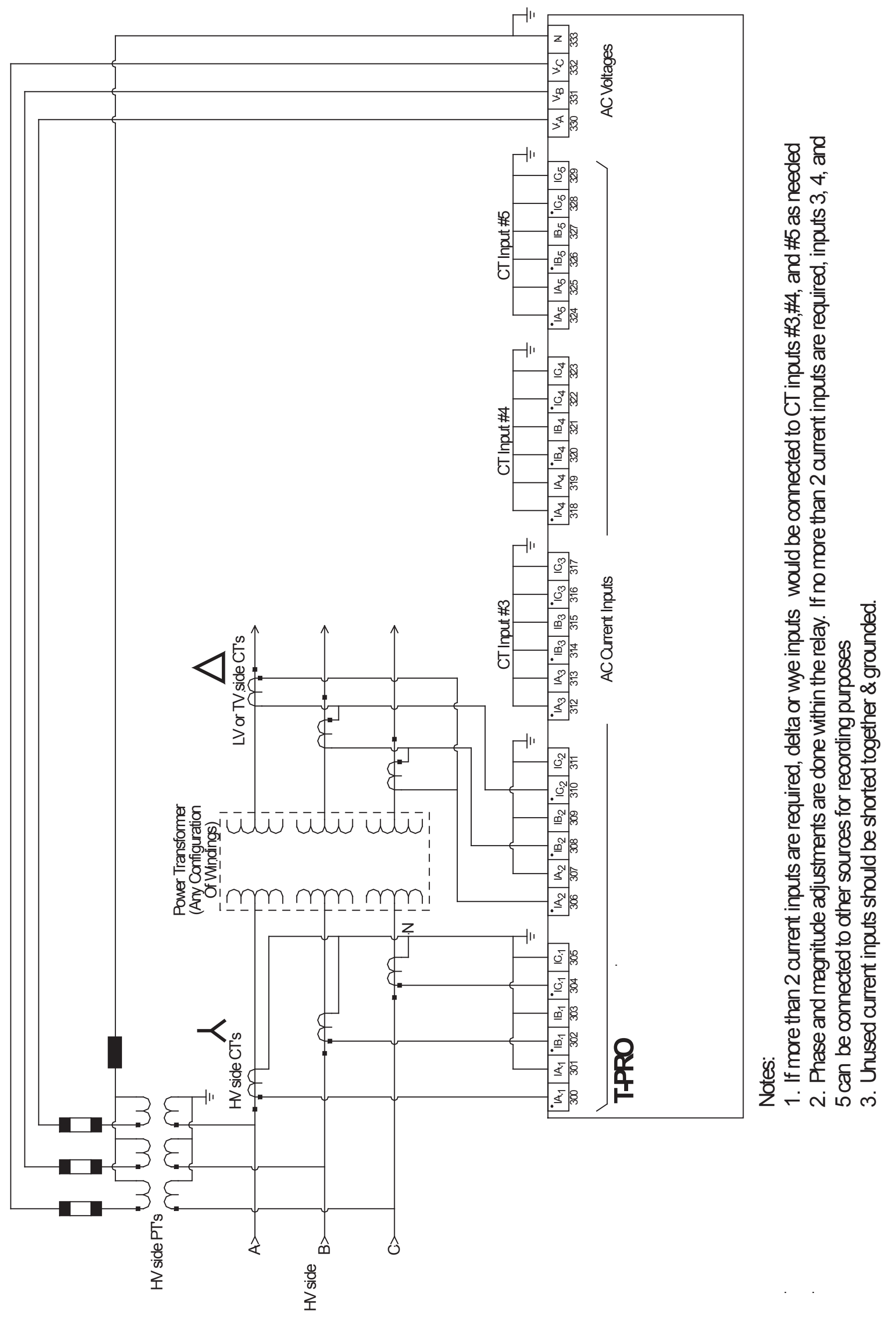


Figure I.1: T-PRO AC Schematic

Appendix J DC Schematic Drawing

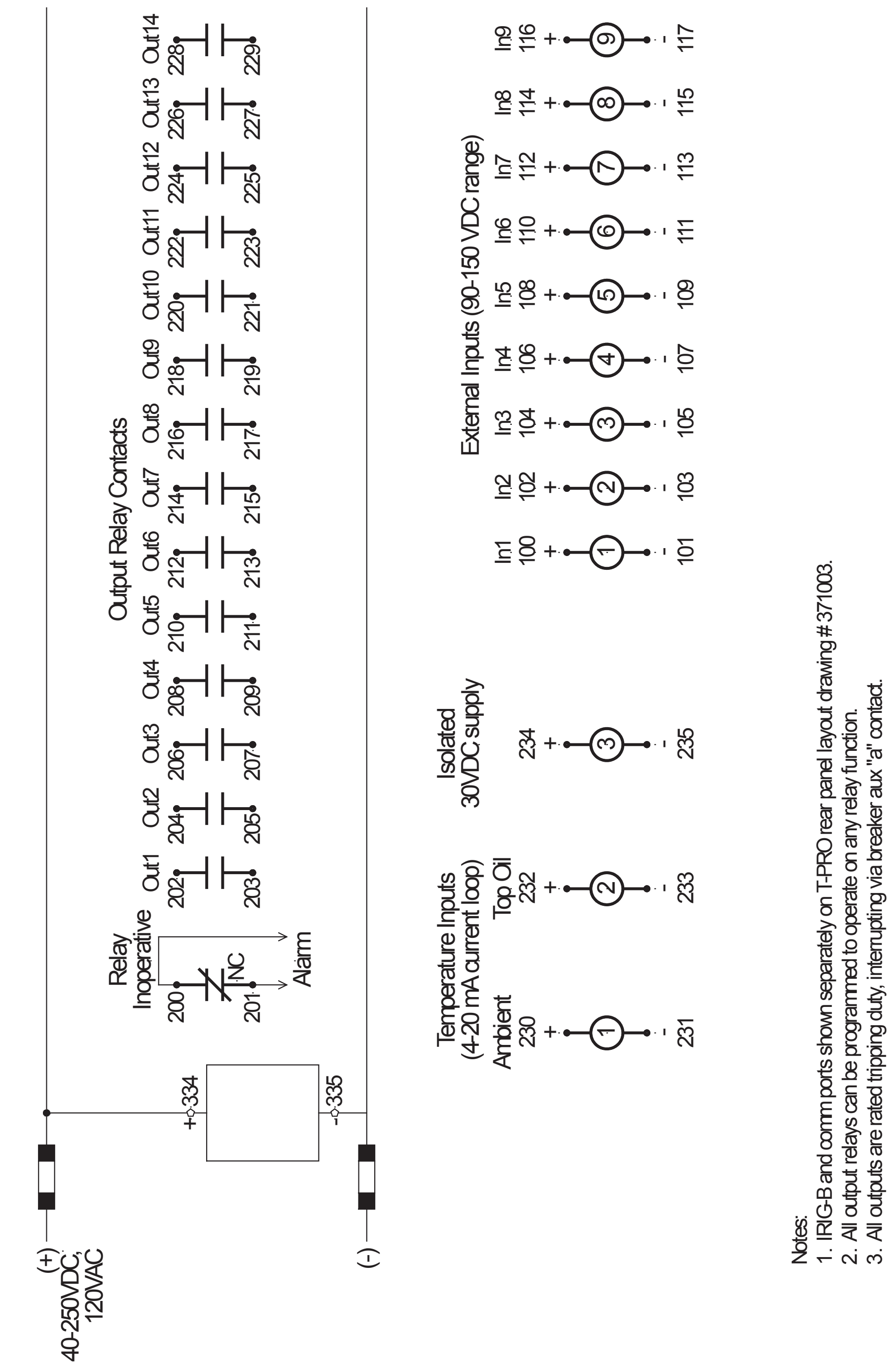


Figure J.1: T-PRO DC Schematic

Appendix K Function Logic Diagram

Diagram in plastic sleeve.

Appendix L Analog Phase Shift Table

+30°(-330°) Shift	+60°(-300°) Shift
$IA = \frac{Ia - Ib}{\sqrt{3}}$	$IA = \frac{Ia - 2Ib + Ic}{3}$
$IB = \frac{Ib - Ic}{\sqrt{3}}$	$IB = \frac{Ib - 2Ic + Ia}{3}$
$IC = \frac{Ic - Ia}{\sqrt{3}}$	$IC = \frac{Ic - 2Ia + Ib}{3}$

+90°(-270°) Shift	+120°(-240°) Shift
$IA = \frac{Ic - Ib}{\sqrt{3}}$	$IA = \frac{2Ic - Ia - Ib}{3}$
$IB = \frac{Ia - Ic}{\sqrt{3}}$	$IB = \frac{2Ia - Ib - Ic}{3}$
$IC = \frac{Ib - Ia}{\sqrt{3}}$	$IC = \frac{2Ib - Ic - Ia}{3}$

+150°(-210°) Shift	-30°(+330°) Shift
$IA = \frac{Ic - Ia}{\sqrt{3}}$	$IA = \frac{Ia - Ic}{\sqrt{3}}$
$IB = \frac{Ia - Ib}{\sqrt{3}}$	$IB = \frac{Ib - Ia}{\sqrt{3}}$
$IC = \frac{Ib - Ic}{\sqrt{3}}$	$IC = \frac{Ic - Ib}{\sqrt{3}}$

-60°(+300°) Shift	-90°(+270°) Shift
$IA = \frac{Ia - 2Ic + Ib}{3}$	$IA = \frac{Ib - Ic}{\sqrt{3}}$
$IB = \frac{Ib - 2Ia + Ic}{3}$	$IB = \frac{Ic - Ia}{\sqrt{3}}$
$IC = \frac{Ic - 2Ib + Ia}{3}$	$IC = \frac{Ia - Ib}{\sqrt{3}}$

-120°(+240°) Shift	-150°(+210°) Shift
$IA = \frac{2Ib - Ic - Ia}{3}$	$IA = \frac{Ib - Ia}{\sqrt{3}}$
$IB = \frac{2Ic - Ia - Ib}{3}$	$IB = \frac{Ic - Ib}{\sqrt{3}}$
$IC = \frac{2Ia - Ib - Ic}{3}$	$IC = \frac{Ia - Ic}{\sqrt{3}}$

0° Shift	±180° Shift
$IA = \frac{2Ia - Ib - Ic}{3}$	$IA = \frac{Ic - 2Ia + Ib}{3}$
$IB = \frac{2Ib - Ic - Ia}{3}$	$IB = \frac{Ia - 2Ib + Ic}{3}$
$IC = \frac{2Ic - Ia - Ib}{3}$	$IC = \frac{Ib - 2Ic + Ia}{3}$

Appendix M Loss of Life of Solid Insulation

The loss of life calculation equation is based on IEEE Standard C57.91-1995. The per unit rate of loss of life is called the aging acceleration factor (F_{AA}), given by

$$F_{AA} = e^{\frac{15000}{110 + 273} - \frac{15000}{\theta_H + 273}}$$

per unit. [Eq. (2) of C57.91-1995]

where θ_H is the hot spot temperature in degrees celsius.

For example, if $\theta_H = 110°C$, then $F_{AA} = 1$;

if $\theta_H = 117°C$, then $F_{AA} = 2$.

The definition of "normal lifetime" for a transformer was 65,000 hours (7.42 years) in C57.115-1991. In C57.91-1995 options were given including 65,000 hours, but suggesting that 180,000 (20.55 years) hours was more reasonable. This is really a judgment call. Since the 65,000 hour (7.42 years) figure appears in both versions of the Standard, it was decided to use 7.42 years in the T-PRO software, until a more definitive statement appears.

The above equation is the same, regardless of which "end of life" value is chosen.

For example, if F_{AA} is on average equal to 0.2 (not unusual) over a period of 20 years, then the loss of life over that period would be (0.2 x 20 years)/(7.42 years) = 54%.

The equation in the previous standard (C57.115-1991) is written differently, but is identical mathematically.

C57.91-1995 is under review, as of November 2001. A new version may be issued in the year 2002.

Adaptive Overcurrent Relay Pickup Level Feature

There are two basic ideas here, based on ANSI/IEEE Standards C57.92-1981 and C57.115-1991, for Mineral Oil Immersed Power Transformers:

1 When the ambient temperature is low, a transformer can carry more load, when high, less load.

2 It is OK to exceed the transformer rated (hot spot) winding temperature, for a limited time.

The T-PRO Relay implements these ideas as follows:

When Ambient Temperature Adaptation is selected, the pickup level of the overcurrent protection follows the Allowed Loading curves below, which are calculated in accordance with the Standards. An ambient temperature probe feeds information into the back of the relay. Five different cooling types are accommodated, in accordance with the Standard.

Example 1

Suppose the transformer is 65°C rise, cooling is type 5: Forced Air Cooled (OA/FA/FA) and a “relative rate of loss of life” of “1” has been selected. Then the overload characteristic pickup will automatically be one per unit when the Ambient Temperature is 30°C, because that is the design condition for the transformer.

As the ambient temperature deviates from 30°C, the relay pickup will track the lower curve in the diagram, so that for example at -30°C, the overcurrent relay pickup is automatically changed to 1.4 per unit. Conversely, the transformer is automatically de-rated to about 0.93 per unit, if the ambient temperature goes to 40°C.

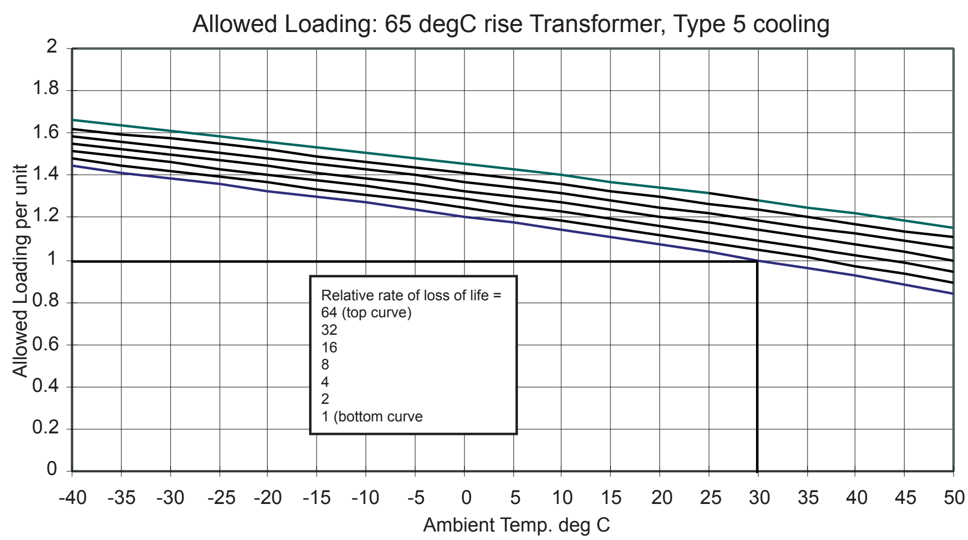


Figure M.1: Allowed Loading: 65°C Rise Transformer, Type 5 Cooling

If a “relative rate of loss of life” of “1” is chosen, and a loading just below pick-up were to persist for 24 hours, “normal” i.e. design loss of life would occur. However, loading is seldom this constant.

Thus it can be seen that higher rates of loss of life might be reasonably accepted (2, 4, 8, 16, 32). Under such conditions, the continued “trend logging” of internal temperatures and accumulated loss of life become valuable features of the T-PRO Relay.

Example 2

Refer to the same curve in “Example 1” in Appendix M. Suppose for the same transformer a “relative rate of loss of life” of “8” has been selected. First, note that this corresponds to a steady-state hot spot temperature of 130°C (see Table “65°C Rise Transformer” in Appendix M on page Appendix M-6), not a dangerous level. Suppose also that the ambient temperature is 35°C. From the curves, the Allowed Loading is 1.1 per unit. In other words, the inverse-time overcurrent relay pickup will adapt to 1.1 per unit. [At an ambient of -25°C, a 48% overload trip level would pertain.]

What does this mean? The meaning is that at just under this trip level, the transformer insulation is deteriorating at just under 8 times the normal rate. This is not a problem unless the situation is never ‘balanced’ by lower operating levels, as is usually the case.

Another way of looking at this is that the adaptive feature, with settings of rate of loss of life greater than normal, allows temporary overloads.

Note that the shape of the inverse-time curve above 2 per unit current is not affected, as shown in for details see Figure M.2: Adaptive Pickup Characteristic on page M-3.

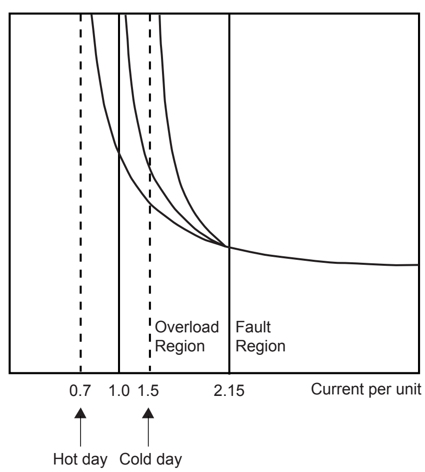


Figure M.2: Adaptive Pickup Characteristic

The “Trend Logging” feature of the T-PRO relay allows you to keep track of the accumulated loss of life to ensure that overloads are not causing a long term problem.

Overloading Curves for 65°C Rise Transformers

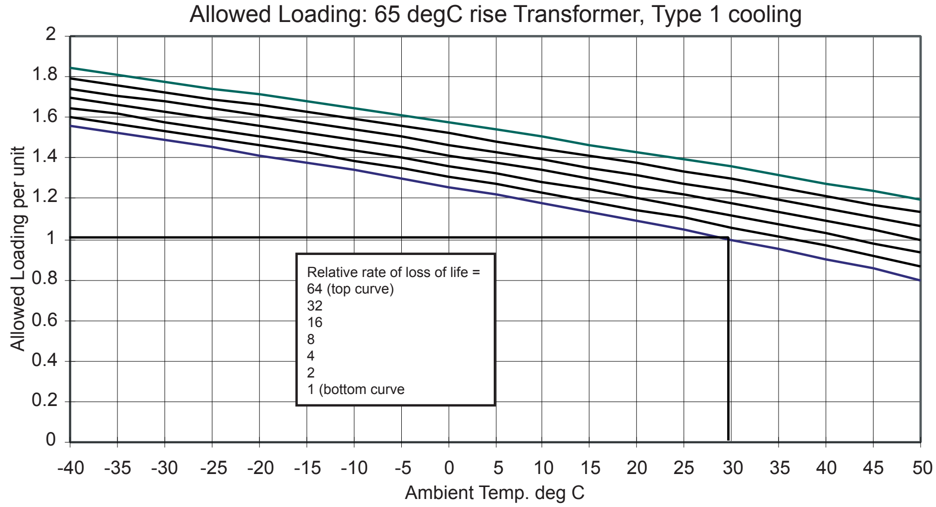


Figure M.3: Allowed Loading: 65°C Rise Transformer, Type 1 Cooling

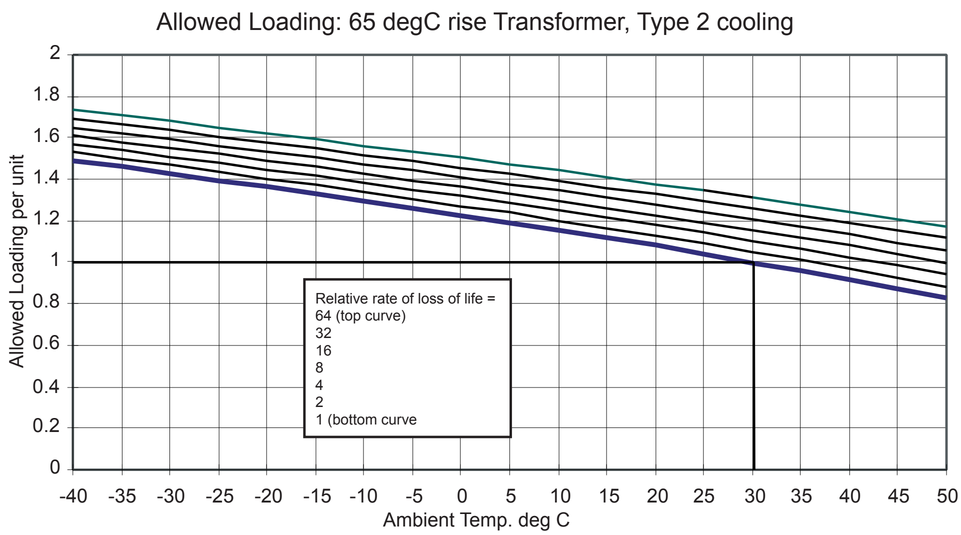


Figure M.4: Allowed Loading: 65°C Rise Transformer, Type 2 Cooling

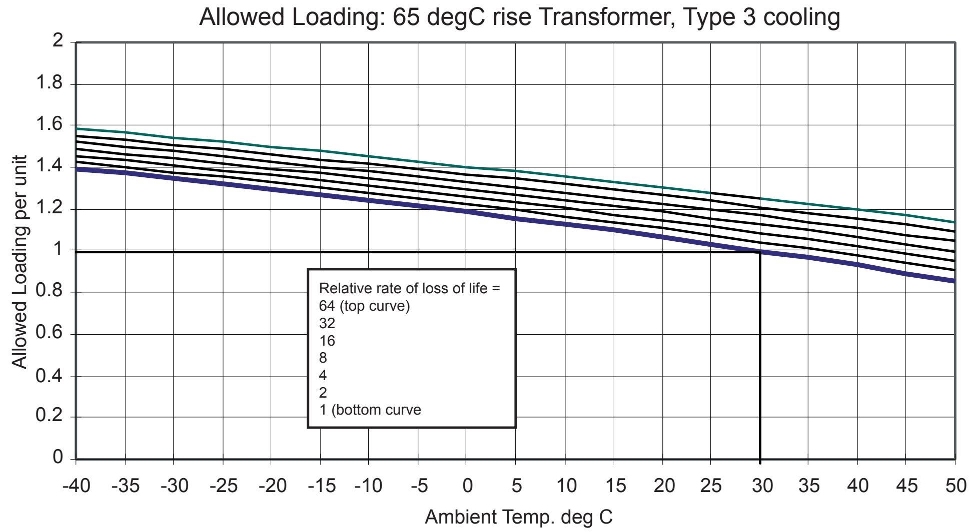


Figure M.5: Allowed Loading: 65°C Rise Transformer, Type 3 Cooling

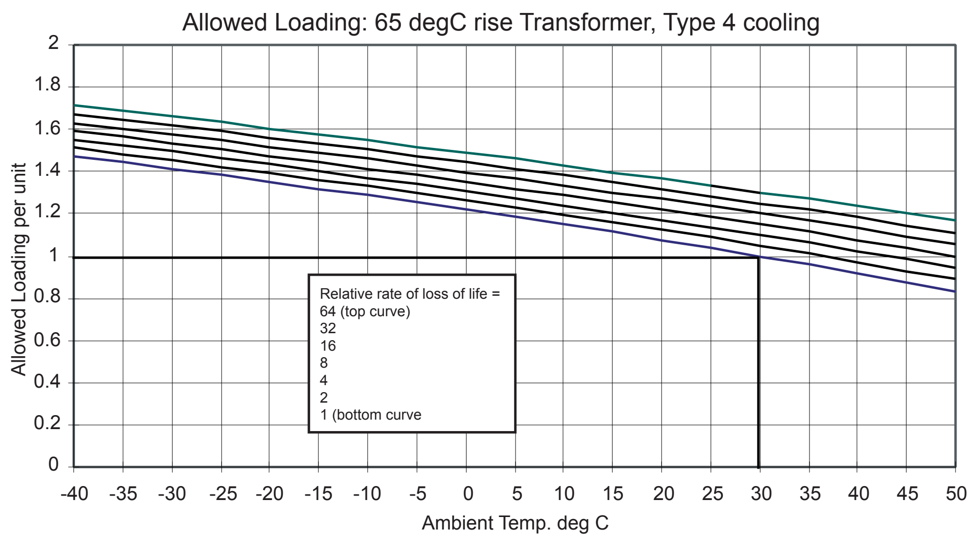


Figure M.6: Allowed Loading: 65°C Rise Transformer, Type 4 Cooling

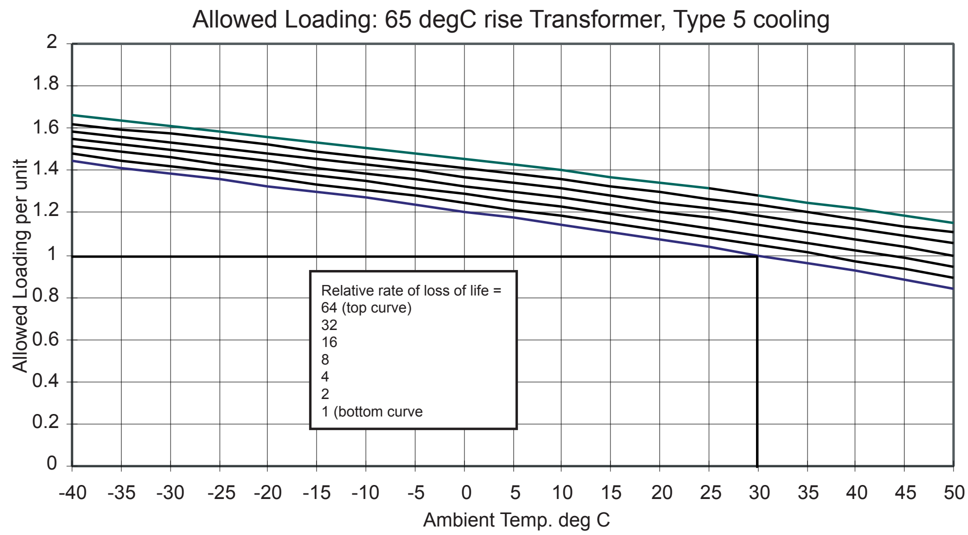


Figure M.7: Allowed Loading: 65°C Rise Transformer, Type 5 Cooling

The above curves are for 65°C rise transformers. Curves for 55°C rise transformers can be supplied on request.

Each "Relative rate of loss of life" curve is related directly to a specific hot spot temperature as follows:

65°C Rise Transformer						
Relative Rate of Loss of Life	1	2	4	8	16	32
Hot Spot Temperature °C	110	116	123	130	137	145

55°C Rise Transformer						
Relative Rate of Loss of Life	1	2	4	8	16	32
Hot Spot Temperature °C	95	101	107	113	120	127

Appendix N Top Oil and Hot Spot Temperature Calculation

The parameters used in calculating the Top Oil and Hot Spot (Winding) temperatures as functions of the ambient temperature and the load current, are as shown below [Based on IEEE/ANSI Standards C57.115-1991 and C57.92-1981].

Parameters for 65°C Rise Transformers					
Cooling Type	OA or OW (Type 1)*	FA 133% or less (Type 2)	FA more than 133% (Type 4)	Non-directed FOA or FOW (Type 5)	Directed FOA or FOW (Type 3)
$\Delta\theta_{H,R}$ °C	25	30	35	35	35
$\Delta\theta_{TO,R}$ °C	55	50	45	45	45
τ_{TO} hours	3.0	2.0	1.25	1.25	1.25
τ_{W} hours	0.08	0.08	0.08	0.08	0.08
R	3.2	4.5	6.5	6.5	6.5
m	0.8	0.8	0.8	0.8	1.0
n	0.8	0.9	0.9	1.0	1.0

Parameters for 55°C Rise Transformers					
Cooling Type	OA or OW	FA 133% or less	FA more than 133%	Non-directed FOA or FOW	Directed FOA or FOW
$\Delta\theta_{H,R}$ °C	20	25	28	28	28
$\Delta\theta_{TO,R}$ °C	45	40	37	37	37
τ_{TO} hours	3.0	2.0	1.25	1.25	1.25
τ_{W} hours	0.08	0.08	0.08	0.08	0.08
R	3.0	3.5	5.0	5.0	5.0
m	0.8	0.8	0.8	0.8	1.0
n	0.8	0.9	0.9	1.0	1.0

The meanings of the symbols, and the equations used are as follows:

$\Delta\theta_{H,R}$	rated hot spot rise over top oil in °C
$\Delta\theta_{TO,R}$	rated top oil rise over ambient in °C
τ_{TO}	top oil rise time constant in hours
τ_{W}	hot spot (winding) rise time constant in hours
R	ratio of full load (rated) copper loss to rated iron loss, dimension-less
m	exponent relating load level to hot spot rise, dimensionless
n	exponent relating load level to top oil rise, dimensionless

The newest version of this Standard, at the time of writing (1998), is C57.91-1995. The only numerical difference in the new table is for Non-Directed FOA or FOW cooling: n = 0.9 (rather than 1.0).

Also, in the new standard, it is recommended that all parameters in the table except m and n should be found "from test." Of course, this is not usually possible, especially if the transformer is already in service.

The temperature calculation equations are most concisely described in block diagram form, for details see for details see Figure N.1: Block Diagram of Top Oil and Hot Spot Temperature Calculation Method on page N-3 (Inputs: per unit load and Ambient Temperature.) and for details see Figure N.2: Block Diagram of Top Oil and Hot Spot Temperature Calculation Method on page N-3 (Inputs: per unit load and Top Oil Temperature.).

The two situations are

1 Top Oil temperature not sensed. For this case, the Top Oil temperature is calculated as a rise above the Ambient temperature, and the Hot Spot temperature as a rise above Top Oil temperature.

2 Top Oil temperature is sensed (an electrical analog input to the relay). For this case, the Hot Spot temperature is calculated as a rise above the measured Top Oil temperature.

Those parameters not already defined for the equations are as follows:

$\Delta\theta_{H,U}$	ultimate hot spot rise over top oil, in °C
$\Delta\theta_{H}$	time-varying hot spot rise over top oil, in °C
$\Delta\theta_{TO,U}$	ultimate top oil rise over ambient, in °C
$\Delta\theta_{TO}$	time-varying top oil rise over ambient, in °C
θ_{A}	ambient temperature, in °C

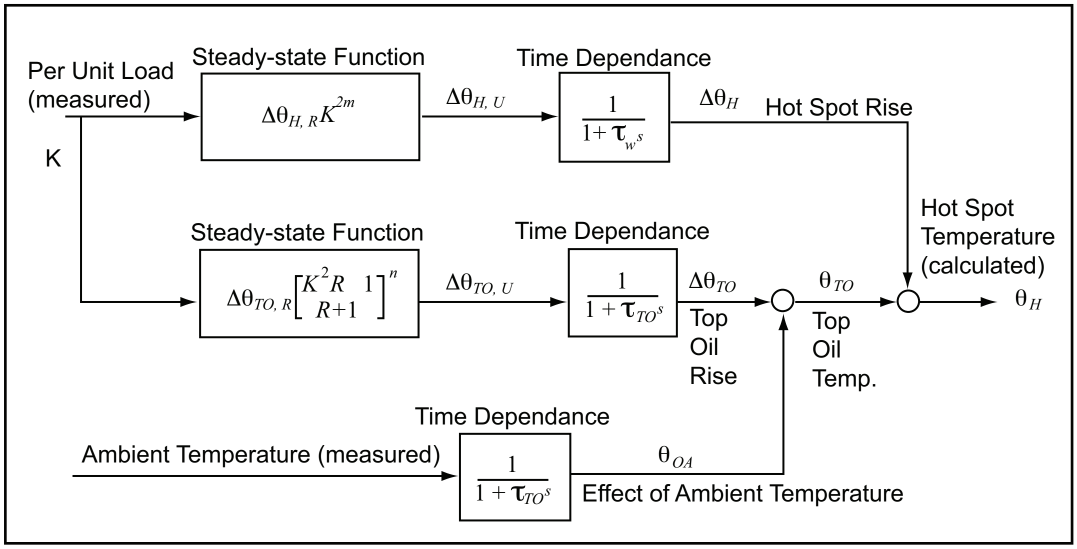


Figure N.1: Block Diagram of Top Oil and Hot Spot Temperature Calculation Method

Inputs: per unit load and Ambient Temperature.

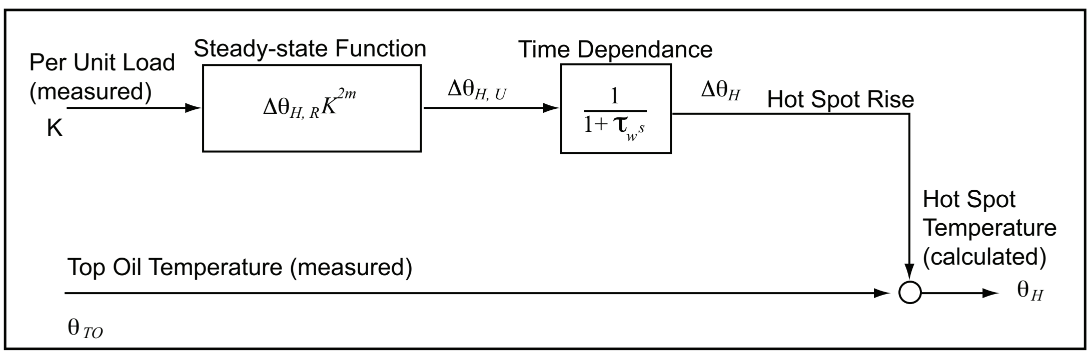


Figure N.2: Block Diagram of Top Oil and Hot Spot Temperature Calculation Method

Inputs: per unit load and Top Oil Temperature.

Appendix O Temperature Probe Connections

Example 1

Using one top oil probe and one ambient temperature probe with one T-PRO A, both powered from the T-PRO A.

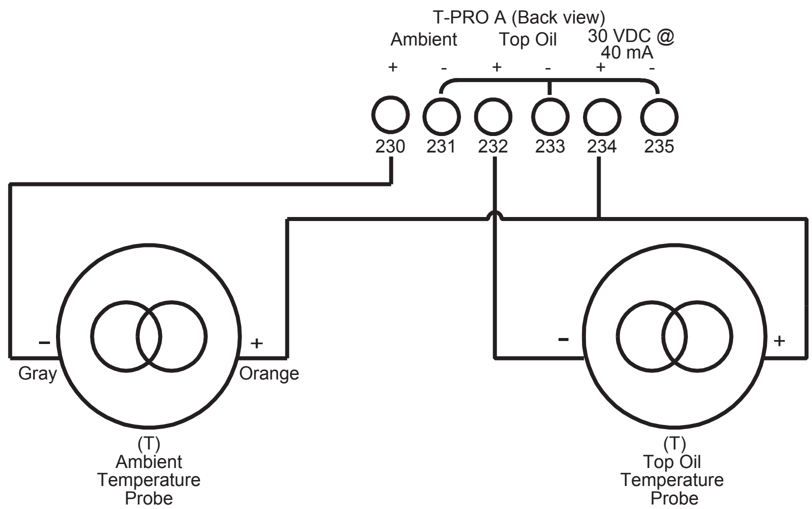


Figure O.1: T-PRO A (Back view)

Example 2

Using two top oil probes powered by two T-PRO relays (B and C) and one ambient temperature probe powered by T-PRO C.

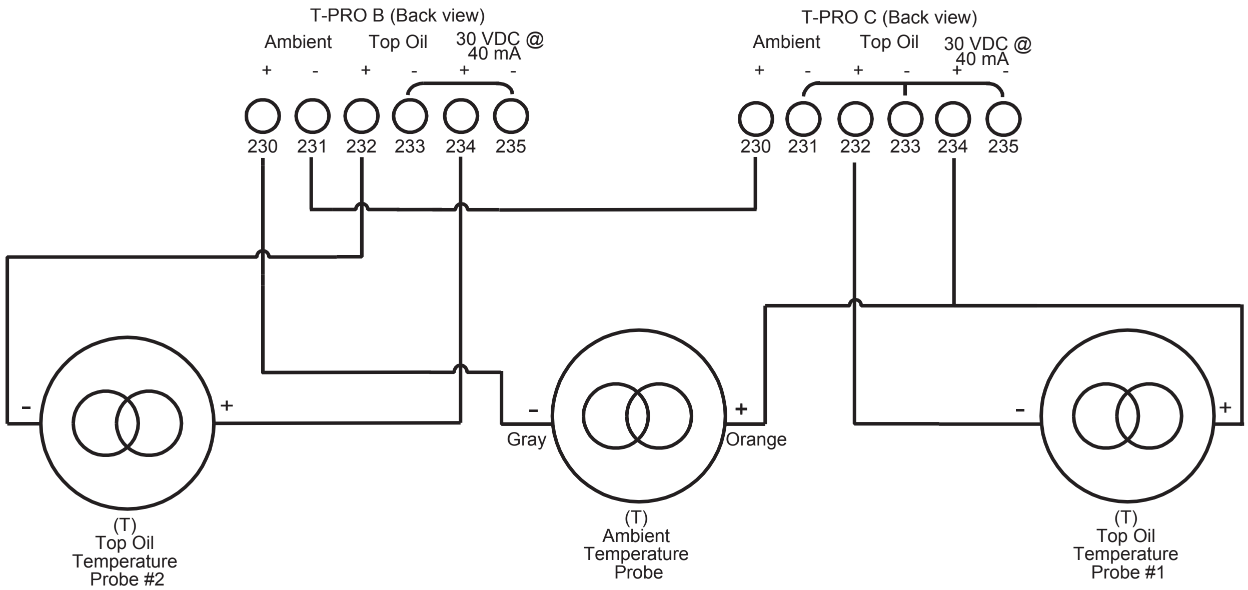


Figure O.2: T-PRO B (Back view) and T-PRO C (Back view)

Index