Distribution Protection
M-7651A D-PAC

Application: DER Interconnection Protection

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BECKWITH ELECTRIC CO. INC.

BECKWITH ELECTRIC CO. INC.

Drew Welton

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Drew Welton is the Vice President of Sales & Creative Technical Solutions for Beckwith Electric and provides strategic leadership to the sales management team as well as creative technical solutions to our customers. Mr. Welton joined Beckwith Electric in 2016 as Director of Sales to provide strategic sales leadership and to further develop and execute sales channels.

- North American Regional Manager for OMICRON starting in 1997.
- Regional Sales Manager with Beckwith Electric. He also served as National Sales Director for Substation Automation with AREVA T&D.
- Written numerous articles on substation maintenance testing, and has conducted numerous training sessions for substation technicians and engineers at utilities and universities across North America.
- 20 year Senior Member of IEEE-PES, has been a contributor on a number of PSRC working groups, and presented at a number of industry conferences specific to power system protection and control.
- Graduate of Fort Lewis College, Durango, CO, with a Bachelor's degree in Business Administration.

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Wayne Hartmann

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Wayne is Beckwith Electric's top strategist for delivering innovative technology messages to the Electric Power Industry through technical forums and industry standard development.

- Before joining Beckwith Electric, performed in Application, Sales and Marketing Management capacities at PowerSecure, General Electric, Siemens Power T&D and Alstom T&D.
- Provides training and mentoring to Beckwith Electric personnel in Sales, Marketing, Creative Technical Solutions and Engineering.
- Key contributor to product ideation and holds a leadership role in the development of course structure and presentation materials for annual and regional Protection & Control Seminars.
- Senior Member of IEEE, serving as a Main Committee Member of the Power System Relaying and Control Committee for over 25 years.
  - Chair Emeritus of the IEEE PSRCC Rotating Machinery Subcommittee ('07-'10).
  - Contributed to numerous IEEE Standards, Guides, Reports, Tutorials and Transactions, delivered Tutorials IEEE Conferences, and authored and presented numerous technical papers at key industry conferences.
- Contributed to McGraw-Hill's "Standard Handbook of Power Plant Engineering."

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M-7651A D-PAC for DER Interconnection Protection

DER
Interconnection Protection
Overview

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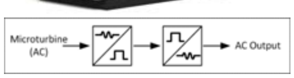
Conventional DER

Industrial Gas Turbine

Reciprocating Diesel

Microturbine Gaseous Fuel



Reciprocating Gaseous Fuel

Reciprocating aka: Internal Combustion Engine (ICE)

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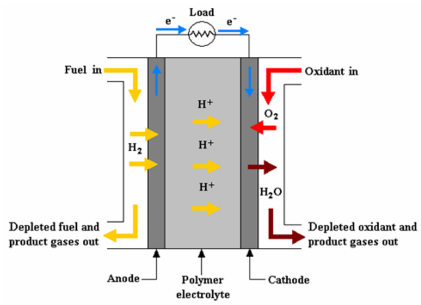
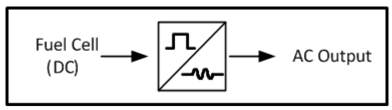
Conventional DER

Fuel Cell





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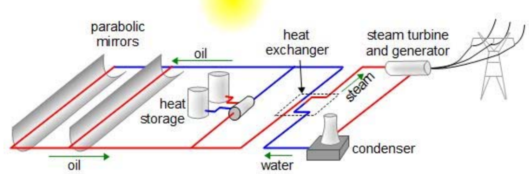
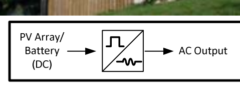
Renewable DER

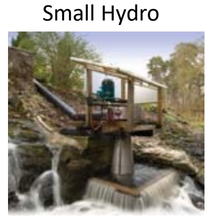
Solar (Thermal)



Solar (PV)



Small Hydro



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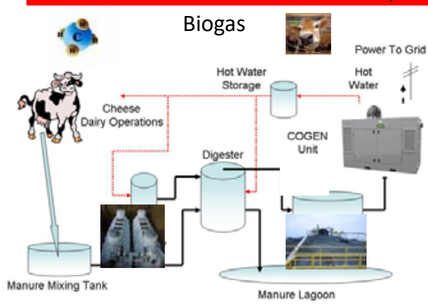
Renewable DER

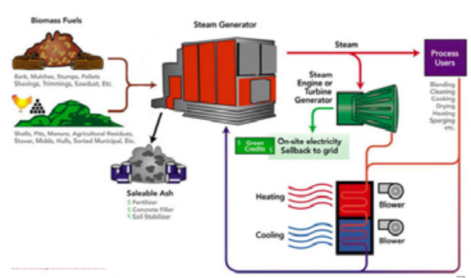
Wind

- May be induction or synchronous generator output
- May be mixture of generator and inverter output

Biogas



Biomass



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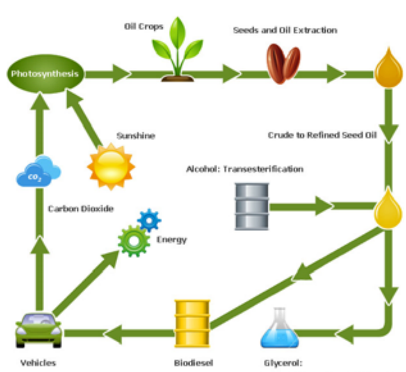
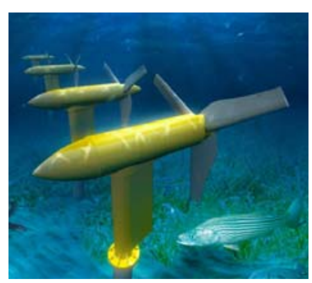
Renewable DER

Biodiesel



Tidal



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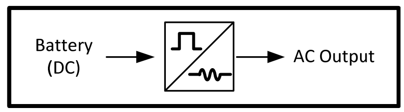
Renewable DER

Storage Battery



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Protection Elements and Use

– "The Five Food Groups"

- Loss of Parallel Operation (utility disconnected)
  - Anti-Islanding
- Abnormal Power Flow
  - Anti-Islanding
- Fault Backfeed Removal
- Detection of Damaging System Conditions
- Restoration

– Impact on interconnection protection

- Interconnection transformer configuration
- Various types of DERs
  – Induction, Synchronous, Asynchronous (Inverters)

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Interconnection Protection

"The Five Food Groups"

- Loss of Utility Parallel (Anti-Islanding)
  - Voltage and frequency (27, 59, 81-U, 81-O)
  - Rate-of-change of frequency (81R, aka ROCOF)
  - *Based on load (real and reactive) not equaling generation*
- Abnormal Power Flow (Anti-Islanding)
  - Power (32F, 32R-U)
  - *Based on power flow violations across the PCC*

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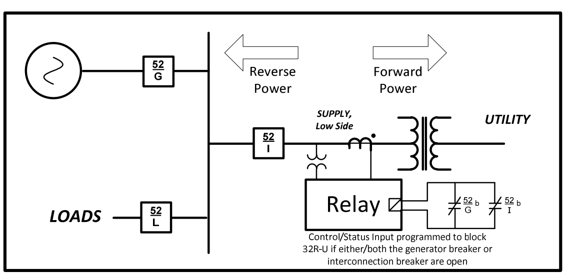
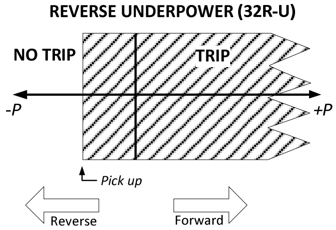
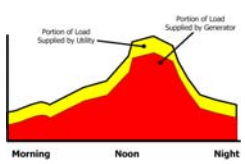
Low Import Power: *32R-U*



REVERSE UNDERPOWER (32R-U)





Load Following

- 32R-U Relay pickup set to at least 5% of total connected generator rated KVA
- 32R-U Relay programmed to trip when imported power falls <u>below</u> the pick-up level
- Switching off a large amount of facility load may cause nuisance tripping
- Generator Control should have proper bias power margin set

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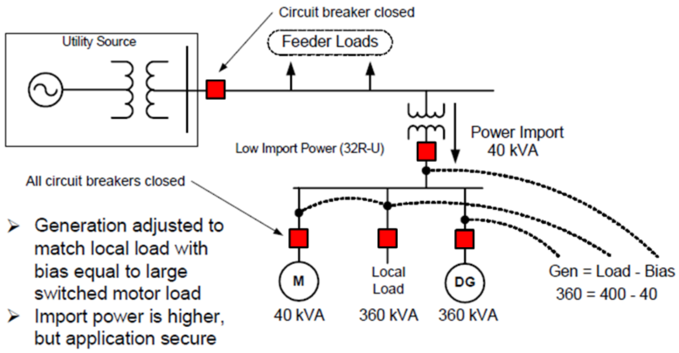
Low Import Power: *32R-U*



- Bias is made in the genset controller to ensure import of 40kW when paralleled
- 32R-U is set lower with appropriate margin (trips if import goes below genset control setpoint)

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Interconnection Protection

"The Five Food Groups"

- Fault Backfeed Detection
  - Phase and overcurrent (51V, 51), grounded systems
    - Directional overcurrent (67) or impedance (21) may be used
  - Ground overcurrent (50N/51N) for grounded systems
    - Directional ground overcurrent (67N) may be used
  - Ground over/under voltage (27N, 27N/59N) for ungrounded systems
  - Negative sequence overcurrent (46)
  - *Based on abnormally high current or abnormally low/high voltage as a result of faults*

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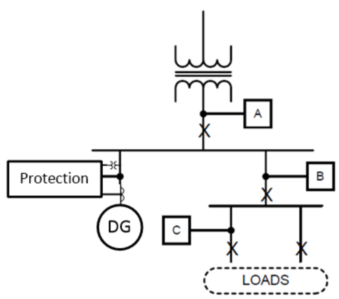
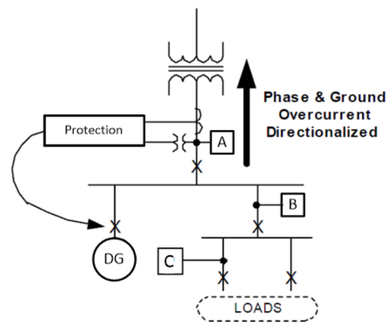
Direction vs. Non-Direction Elements at the PCC

- When applying non-directional phase or ground elements for fault backfeed protection (50P, 50N, 51P, 51N), they must be coordinated for faults in the facility and on the utility.
- This could lead to longer clearing times for utility faults.
- To speed up response of utility faults, use of directional elements (67, 67N, 21P), set to only trip in the utility's direction, will provide maximum trip speed.





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Issues with Inverter-Based DER Protection

- Inverter-based DER produces very little fault current
  - 1.0-1.3x rated current at full output
  - Fault current even less when output is lower then rated
    - Solar PV late in day; low irradiance = low output
- Fault backfeed protection (overcurrent) cannot be set below load for fear of nuisance tripping
- Resultant large NDZ (non-detection zone)
  - Transfer Trip anyone $$$$$$$?????

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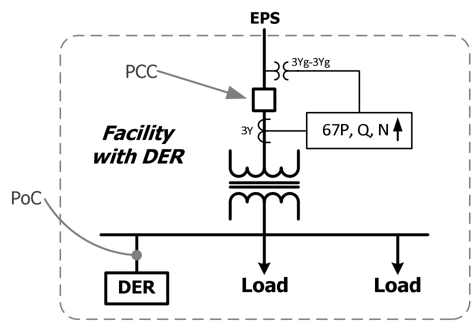
Focused Directional Overcurrent (FDO) Concept

- Use of focused directional overcurrent (FDO) elements (67P, 67Q, 67N) for Distributed Energy Resource (DER) Interconnection Protection (IP)
- Applicable at the PCC



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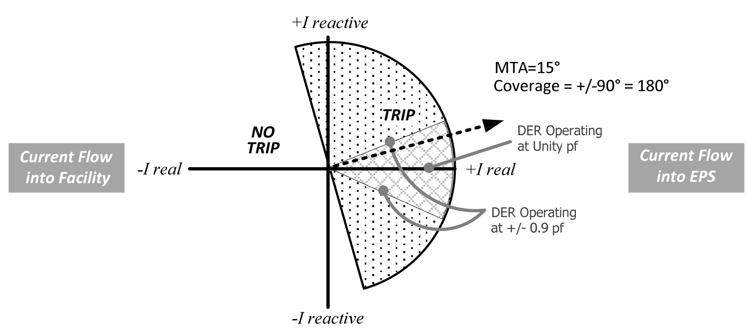
Traditional Directional Element

- For DER IP, directionalization is a reliability and security enhancement to control phase and ground overcurrent elements
- Used at the PCC, directionalization *to the EPS* blinds the overcurrent elements for load and faults *in the DER's facility*, thereby *increasing* the DER IP security
- In traditional 180° forward/reverse directional control, the overcurrent elements are subject to tripping on the DER's real power output.



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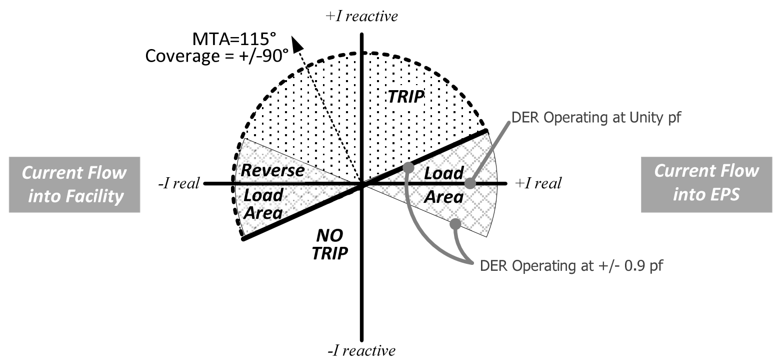
Traditional Directional Element

- Increasing the MTA from 15° to 115° so the forward real power load region is ignored exposes the overcurrent element to trip for load flow and faults in the facility (reverse load area).



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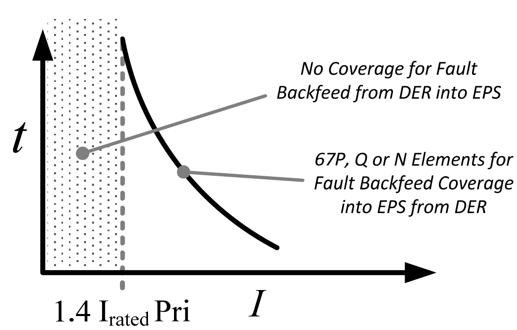
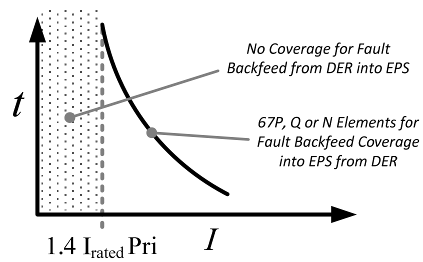
Inverter Fault Current Level

- Inverters typically develop fault current of 1.1-1.3x rated current
- To avoid tripping on normal power output, the overcurrent elements may be set above the DER's rated output current
- For an inverter-based DER, this overcurrent pickup value is typically 1.2–1.4x the DER's rated output current



Inverter Fault Current Level

- This tactic decreases sensitivity to detect DER fault infeed into the EPS
- This current value is essentially the same as load with margin for overload
- If the inverter-based DER is supplied by some variable source, such as a PV array, and as the PV output decreases below rated, the output current for both load and faulted EPS conditions also decreases below rated, making fault detection even more difficult.



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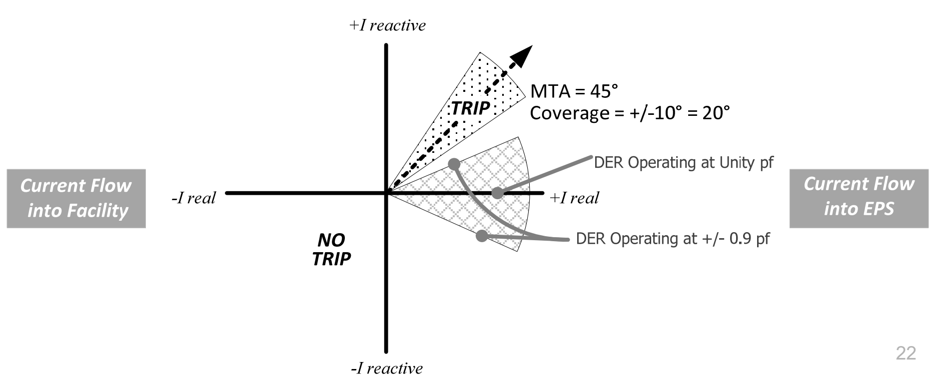
Focused Directionality

- FDO allows the directional characteristic of overcurrent element to be tunable to other than the traditional 180° forward/reverse decision
- Ex., the overcurrent element response angle may be restricted to 45° forward, plus or minus 10°, for an effective response angle of 35° to 55°



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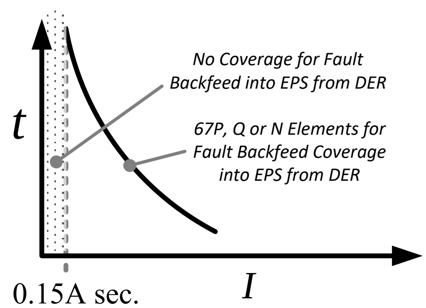
FDO and Current Setting

- FDO elements allow settings as low as 0.15A secondary which should greatly improve the sensitivity of the overcurrent elements
- The actual minimum primary current level detectable depends on the applied CT ratio
- Ex., DER IP using a 500:5 CT and by employing a setting of 0.15 secondary amps on the FDO element yields a sensitivity of 15A primary amps



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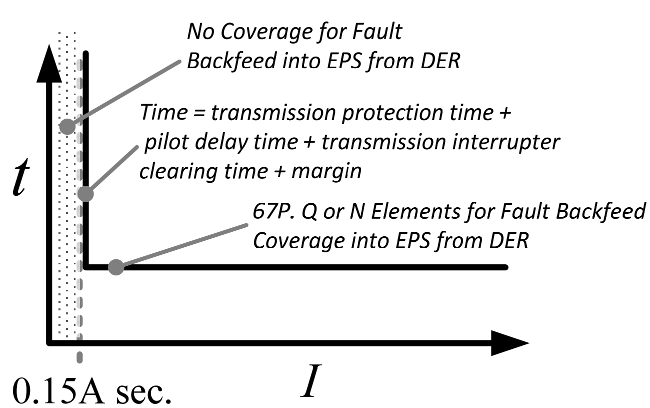
FDO and Current Setting

- Sensitive overcurrent element pickup setting with a definite time characteristic will coordinate with transmission protection and allow ride-through.
  - Transmission protection is typically definite time Z with transfer trip aided clearing times of 20-25 with 50BF margin



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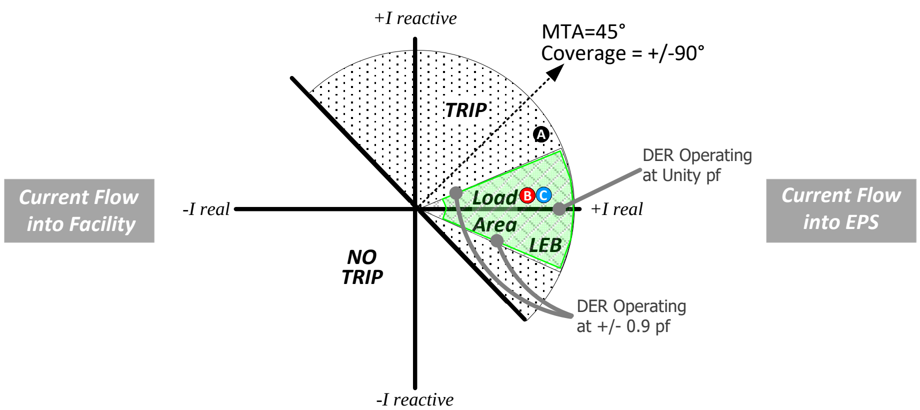
What about LEB?



LEB is *not* a proxy for FDO.

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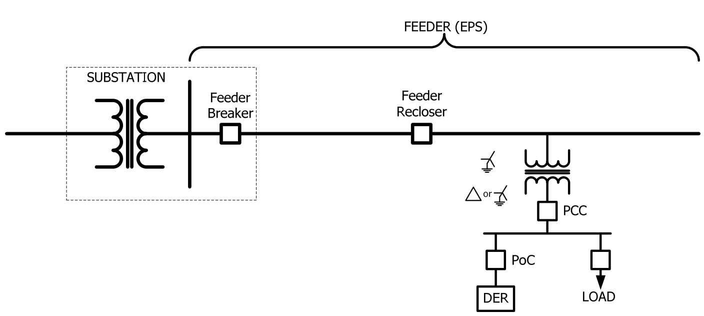
Application Considerations

- An inverter, at its terminals, can only provide positive sequence current.
- Transformer winding and grounding at the PCC and EPS energization status at the DER IP play pivotal roles in directionalization and application of FDO.
- **Ground Faults (67N):**
  - In order to apply FDO for ground faults, the interconnection transformer winding at the Utility-side of the point-of-common coupling must be a grounded wye



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Interconnection Protection

"The Five Food Groups"

- Damaging System Conditions
  - Open phase condition or load imbalance (46, 47), negative sequence current and voltage
  - Phase sequence reversal (47), negative sequence voltage
  - Loss of synchronism (78)
  - Instantaneous overvoltage (59I)
  - ➢ *Based on current or voltage imbalance (including reverse phase rotation), power system and DER going out-of-step, or ferroresonance*
- Facilitate proper restoration
  - All elements reset, voltage and frequency within limits
  - Reconnect timer (79) (all DER)
  - Sync check (25)
    - Synchronous generators and some self-commutating inverters

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Conditions for Ferroresonance

- Feeder that DER is connected to must be isolated from the utility
  - (Islanded condition)
- KW load in the island must be less than 3 times DER rating
- Capacitance must be greater than 25% and less than 500% of DER rating
- There must be a transformer in the circuit to provide nonlinearity

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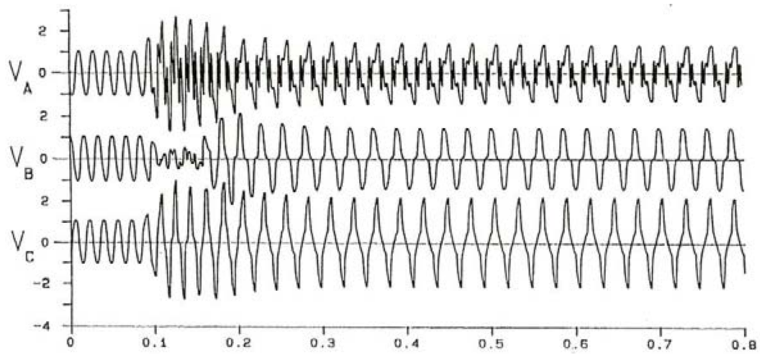
Ferroresonance: Test Circuit Setup

New York Field Tests- 1989

Field Test Circuit



Conditions:
Wye-Wye Transformers, 100kVAr capacitance, 60kW generator, 12kW load

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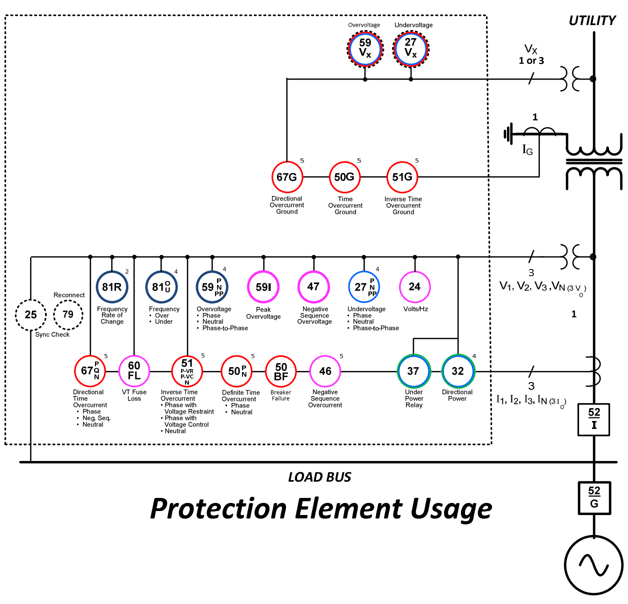
Advanced Convergent Protection Application



Protection Element Usage

- Fault Backfeed Removal
- Damaging Conditions
- Loss of Utility Parallel (Anti-Islanding)
- Abnormal Power Flow
- Restoration

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7651A D-PAC & 7679 Recloser Control

- Usage:
  - Feeder/Switchgear Protection
  - Recloser Control
  - DER Interconnection Protection
- Protection Applications (example):
  - *Reverse Interlock* (Fast Bus Protection)
  - *Maintenance Mode* (fast, sensitive tripping of the Mains/Tie when personnel are working on the switchgear; decreases arc flash incident energy)
  - *Breaker Failure* (Trip Mains/Tie when Feeder CB fails)
  - *Breaker Circuit Monitoring* (Trip and Close Circuits)
  - *Alternate Settings* for Backfeeding
  - *Directional Protection* (Ph. & Gnd.) to prevent motor fault backfeed nuisance tripping

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7651A D-PAC & 7679 Recloser Control

- Metering, PQ Monitoring & Protection Applications:
  - All measure quantities
  - Complex calculated quantities (W, VAR, kVA, kVAR)
  - Energy and Demands (+W/Hr, -W/Hr, Min., Max.)
  - Harmonic Spectra Recording to 63rd (Graphic and Tabular)
  - THD Alarm (%)
  - THD Trip (%)
  - TDD Alarm (%)
  - TDD Trip (%)
  - ITIC Curve Plotting for all Trips
- Communication Based Protection Solutions
  - Peer-to-Peer for Transfer Trip, Breaker Failure, Interlocking
  - DMS to Relay for Profile Changes, Setpoint Changes
  - IEC 61850, DNP, MODBUS

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Why New Protection and Why Now?

Key Reasons:

1. **Information for Operations and Analysis** made possible thanks to technological advances in software microprocessors and memory.
   - Advanced Metering, PQ, DME DFR Records, High Visibility SOE, Data Storage, Data Filtering, Data Presentation, etc.
2. **Demand for Advanced Communications**
   - True Ethernet, Dual MAC, IEC 61850, SD, USB
3. **Regulatory Compliance**
   - NERC & IEEE Cyber Security Compliance
4. **Simplicity to Execute Complex Applications**

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7651A D-PAC & 7679 Recloser Control

Applications: Feeder, Switchgear, Recloser, DER

- Provide Full Suite of Voltage, Current, Directional Current, Directional Power, Load Shed and Restoration Elements
- Simple to Apply Preprogrammed Distribution Protection Schemes
- Complex Scheme Graphical Logic for Custom Applications
- Seamless Integration into Existing and Future Practices

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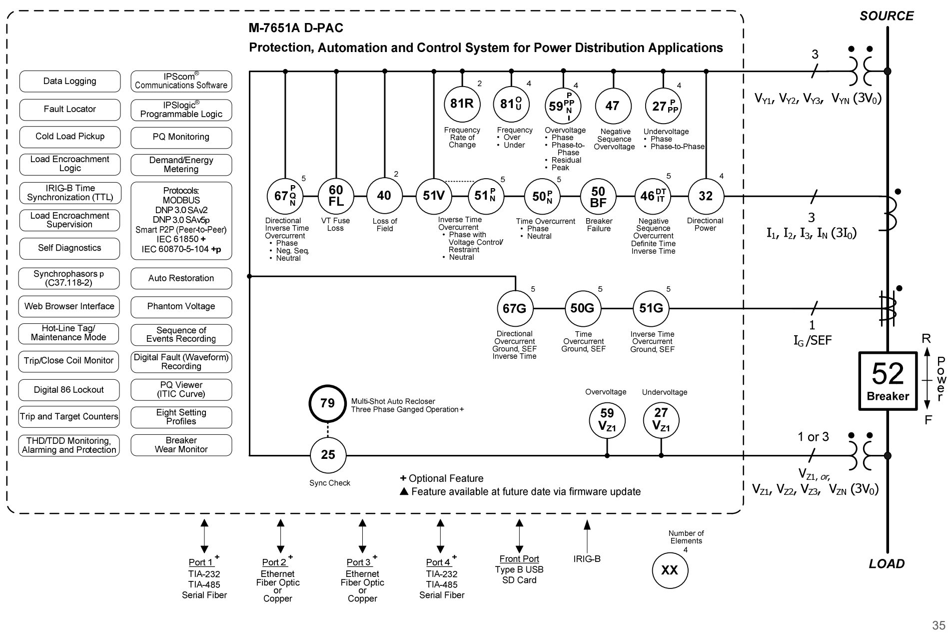
7651A Protection Functions



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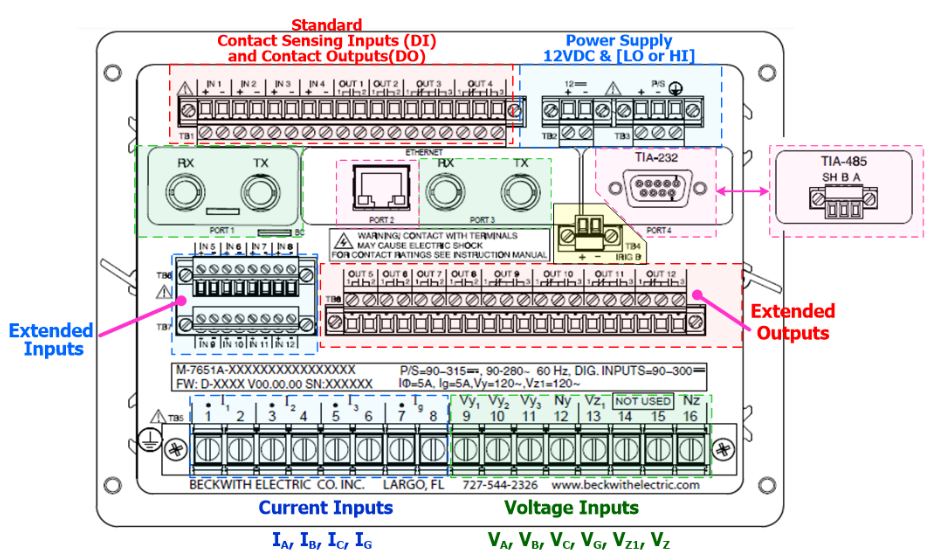
7651A Connections



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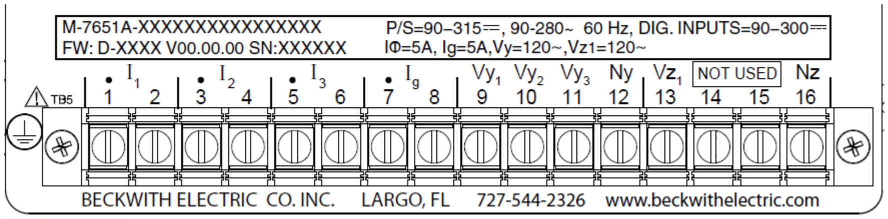
7651A CT/VT Inputs

- Voltage/Current Inputs available on the M-7651A:

SMART MODEL NUMBER: M-7651A - * * * * * * * * * * * * *

VOLTAGE INPUTS	
(4) LEA-High or VT Voltage Inputs (300 Vac Max)	**H4**
(4) LEA-Low Voltage Inputs (12 Vac Max)	L4
(3) LEA-Low Voltage Inputs (12 Vac Max) + (1) LEA-High or VT Voltage Input (300 Vac Max)	X4
(6) LEA-High or VT Voltage Inputs (300 Vac Max)	H6
(6) LEA-Low Voltage Inputs(12 Vac Max)	L6
(3) LEA-Low Voltage Inputs (12 Vac Max) + (3) LEA-High or VT Voltage Inputs (300 Vac Max)	X6



PHASE CURRENT INPUTS	
1A Current Inputs (3)	1
5A Current Inputs (3)	**5**

GROUND CURRENT INPUTS	
1A Ig Current Input	1
5A Ig Current Input	**5**
200mA SEF Ig Current Input **Note 1*	H
50mA SEF Ig Current Input	M
10mA SEF Ig Current Input	L

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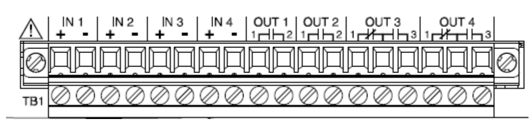
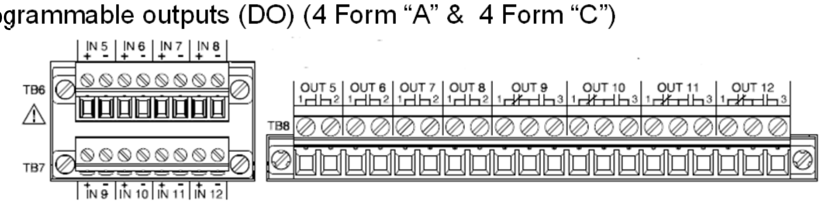
Contact Sensing Inputs & Contact Outputs

- Four programmable inputs (DI) and four programmable outputs (DO) (2 Form "A" & 2 Form "C")
  - Inputs are <u>externally wetted</u> and can be individually configured for high or low voltage
  - Low Voltage, 18~60V, or, High Voltage, 80~300V



- Extended I/O (optional) adds additional 8 programmable inputs (DI) plus 8 programmable outputs (DO) (4 Form "A" & 4 Form "C")



SMART MODEL NUMBER: M-7651A - * * * * * * * * * * * * *

I/O OPTIONS	
Standard I/O – (4) LV (9~60 Vdc) Inputs and (4) Dry Type Outputs	SL
Standard I/O - (4) HV (90~300 Vdc) Inputs and (4) Dry Type Outputs	**SH**
Expanded I/O – Standard I/O plus additional (8) LV (9~60 Vdc) Inputs and (8) Dry Type Outputs	EL
Expanded I/O – Standard I/O plus additional (8) HV (90~300 Vdc) Inputs and (8) Dry Type Outputs	EH

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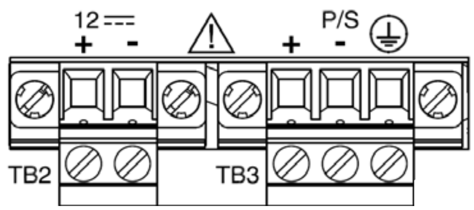
Power Supply



SMART MODEL NUMBER: M-7651A - * * * * * * * * * * * * *

POWER SUPPLY	
Low Voltage (18-60 Vdc)	L
High Voltage (90-280 Vac / 90-315 Vdc)	H

- Two power inputs
- Main power supply (P/S) available in two ranges
  - Low V: 18~62V DC
  - High V: 80~325V AC/DC
- Independent backup power input: 12V DC
  - Common voltage employed in radios used for communications

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BECKWITH ELECTRIC CO. INC.

Power Supply, V/I, DI/DO : Ratings

Power Supply	Range	Burden
24/48 Vdc	18-60 Vdc	12 VA
125/220 Vdc/Vac (Optional)	90-280 Vac 90-315 Vdc	15 VA

*Rides through 12V for 1 sec.

Table 5 Power Supply Specifications

*Additional 12VDC Input, operates in parallel ("best of")

AC Voltage Inputs

Voltage	Nominal	Maximum Continuous	Max Short Duration	Burden
Line to Neutral	120 Vac	300 Vac	600 Vac for 10 s	1MΩ
Low Energy Analog	4 Vac	12 Vac	300 Vac for 10 s	1MΩ

Table 6 AC Voltage Input Specifications

AC Current Inputs

AC Current	I Nominal	I Continuous	I Short duration	Burden
Phase Current	1 A 5 A	3 A 15 A	100 A for 1 second 500 A for 1 second	< 0.021 VA < 0.20 VA
Ground Current	1 A 5 A	3 A 15 A	100 A for 1 second 500 A for 1 second	< 0.021 VA < 0.20 VA
Sensitive Earth Fault (SEF)	10 mA 50 mA 200 mA	0.3 A 1.5 A 6 A	100 A for 1 second 100 A for 1 second 100 A for 1 second	< 0.001 VA < 0.002 VA < 0.01 VA

Table 7 AC Current Input Specifications

Wetting Voltage	
Input	DC Pickup Range
Low	9 – 60 Vdc
High	90 – 300 Vdc

Table 8 Digital Input Specifications

Output Contacts

IEEE C37.90
30 A make for 0.2 seconds at 250 Vdc Resistive
8 A carry at 120 Vac, 50/60 Hz
6 A break at 120 Vac, 50/60 Hz
0.5 A break at 48 Vdc, 24 VA
0.3 A break at 125 Vdc, 37.5 VA
0.2 A break at 250 Vdc, 50 VA

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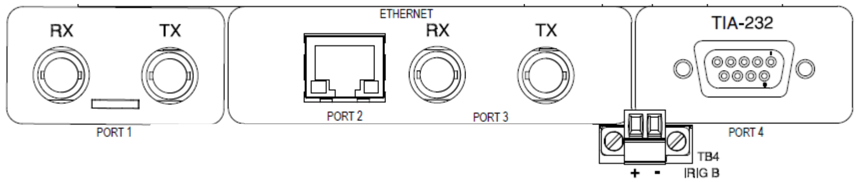
Advanced Communications



- Up to 4 rear ports available:
  - Port1 Serial (Std)
    - RS-232 or RS-485 or Serial Fiber
  - Port2 Ethernet (Optional)
    - RJ-45 Ethernet (Copper) or FO
  - Port3 Ethernet (Optional)
    - RJ-45 Ethernet (Copper) or FO
  - Port4 Serial (Optional)
    - RS-232 or RS-485 or Serial Fiber or Bluetooth
- Protocols Supported:
  - Modbus, Modbus over TCP/IP
  - DNP3.0, DNP over TCP & UDP
  - IEC-61850 (Optional)
  - IEC-60870-5-104 (Optional)
  - 2179 (Optional)
- Dual MAC Ethernet port offers full auto-negotiable 10/100Mbps auto-detect communication with multi user and multi protocol support
- IRIG-B; Demodulated, TTL Level, Isolation 1,500V

Protocols
Serial Ports – MODBUS®, DNP3.0
Ethernet Ports – MODBUS over TCP/IP and UDP, DNP3.0 over TCP/IP and UDP; IEC 61850, SmartP2P (Peer to Peer)▲, IEC 60870-5-104/101▲ (optional)

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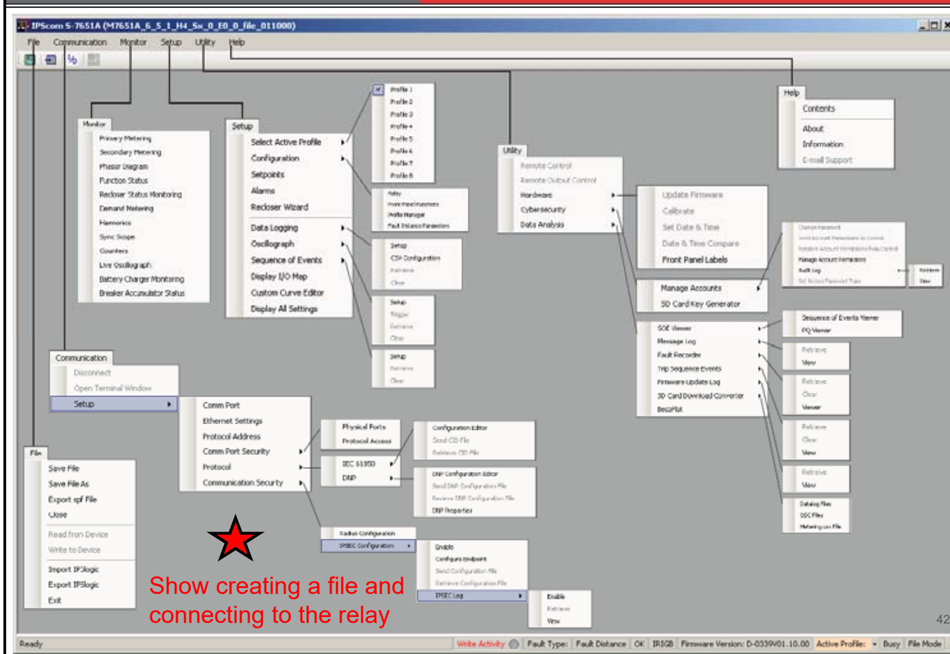
Overall Software Flow



Show creating a file and connecting to the relay

42

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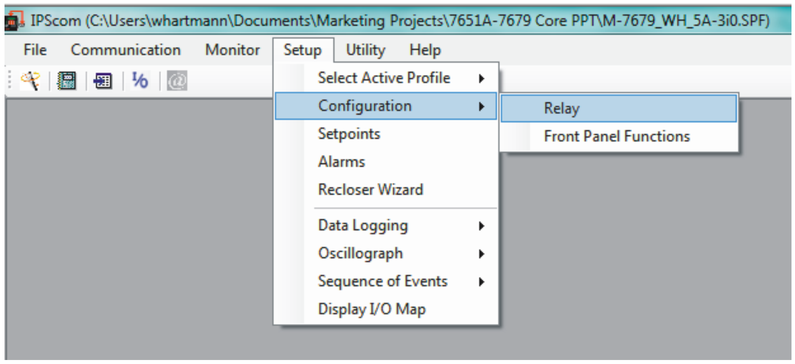
Set Up



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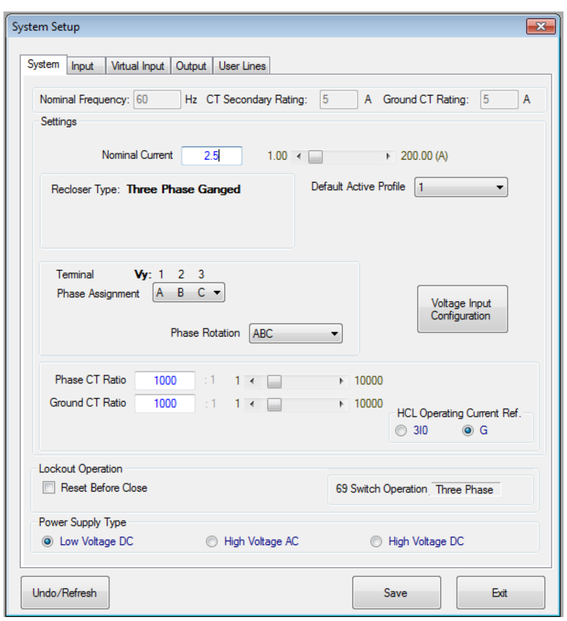
Set Up



“Relay’s Environment”

44

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Set Up

"Relay's Environment"

45

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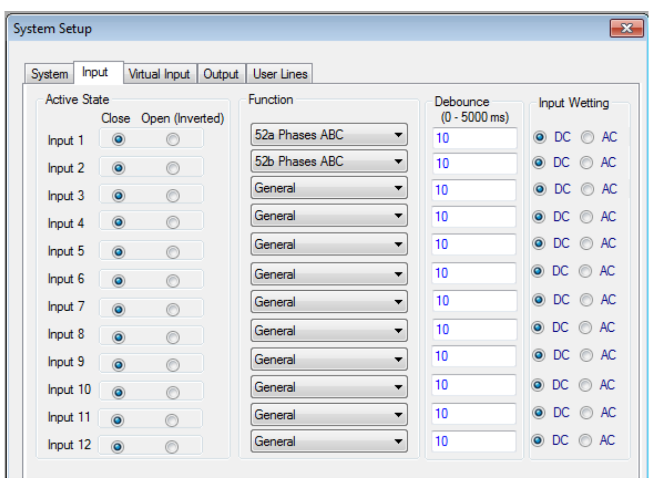
Contact (Voltage) Sensing Inputs



Can mix high and low voltages

46

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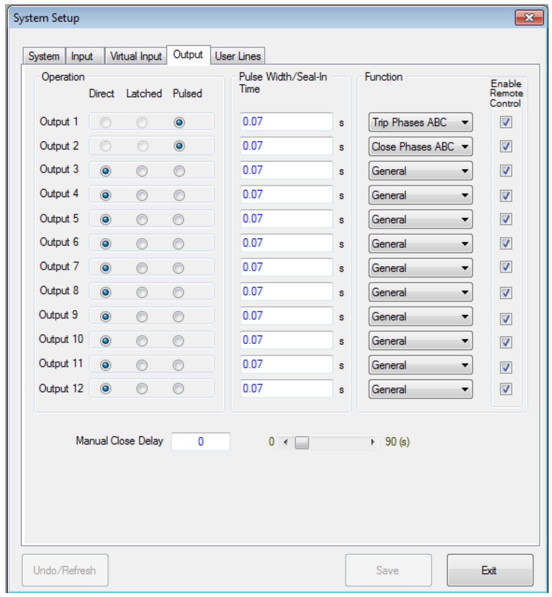
Outputs



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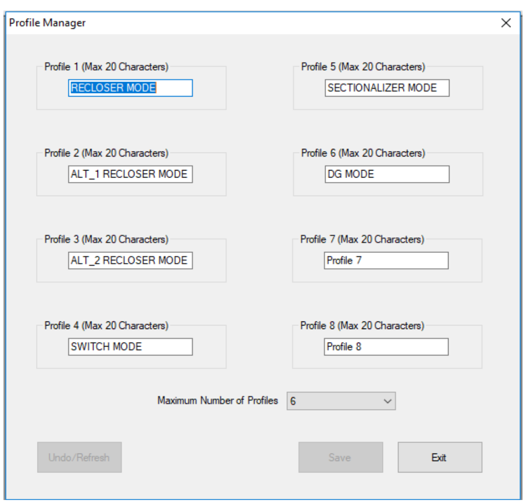
Profiles



User Profile Identification

Setting Profiles: 8

- These can be invoked by contact input, communication input, button input or measured parameter levels (ex., 32F vs. 32R)
- Each profile may be labeled for Operator and Technician use
- 7679 only; When role modes are changed, protection menus change to match the role
  - Recloser
  - Switch
  - Sectionalizer

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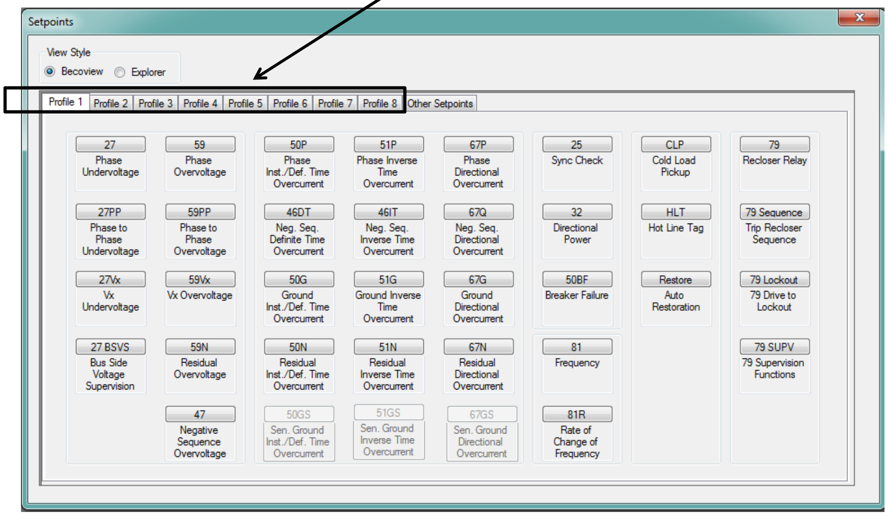
Elements in a Profile

Profile and Elements

8 Profiles
User manes will be displayed here



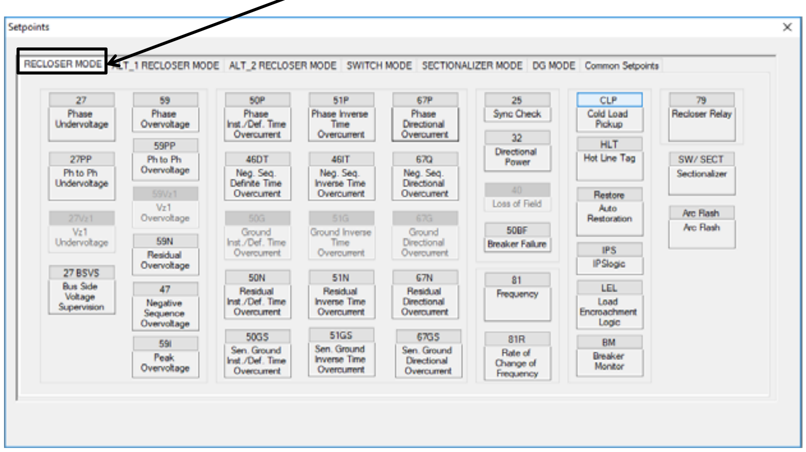
Element Programming by Clicking Element Number

BECKWITH ELECTRIC CO. INC.

Operating Modes

7679 Profiles to Change Operating Modes

8 Profiles
User manes will be displayed here



Roles include Recloser, Switch, Sectionalizer
Elements available to match mode selected

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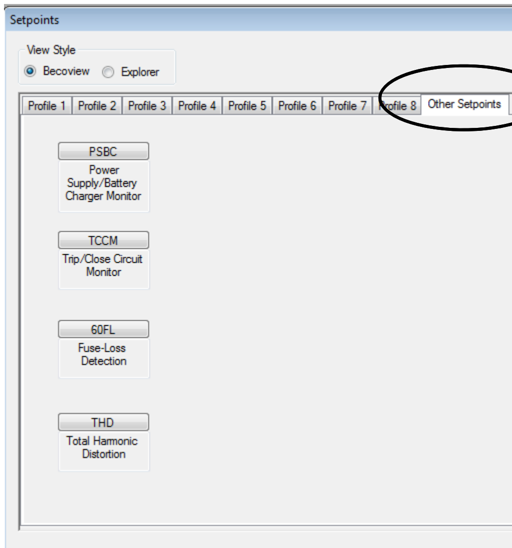
Common Settings



Global Settings

Programming

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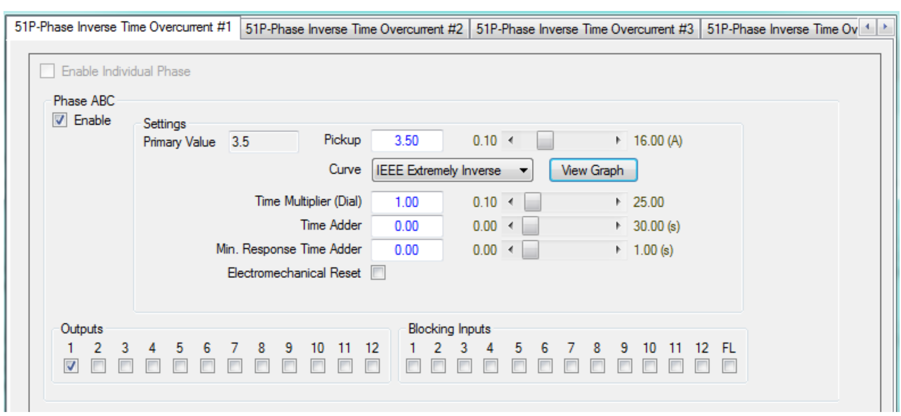
Element: 51P



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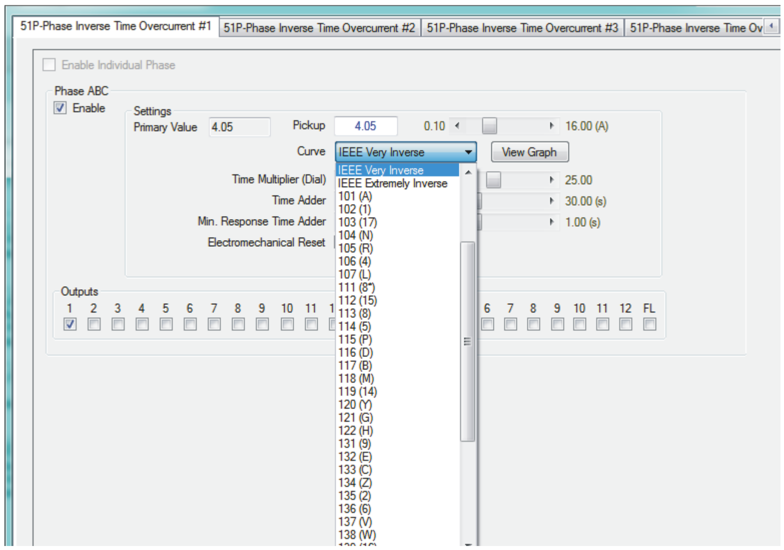
51P TOC



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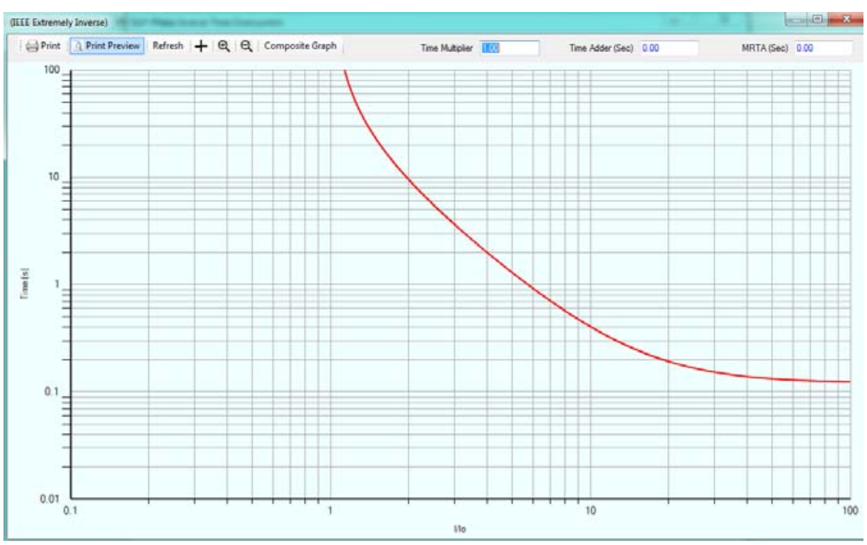
TOC Curve Display



Show setting 51P

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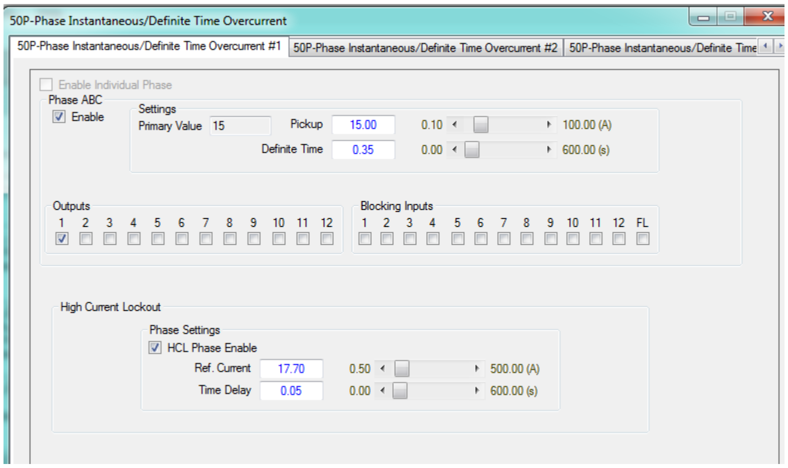
50P



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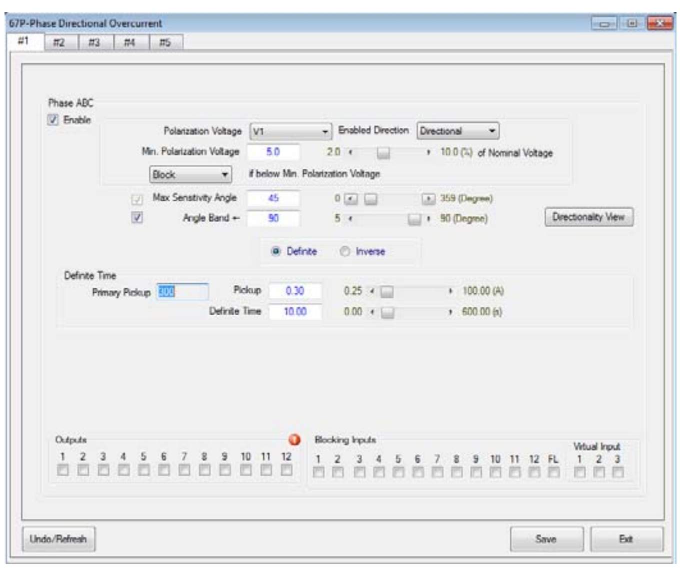
Directional Overcurrent

67P, 67Q, 67N (67P shown below)



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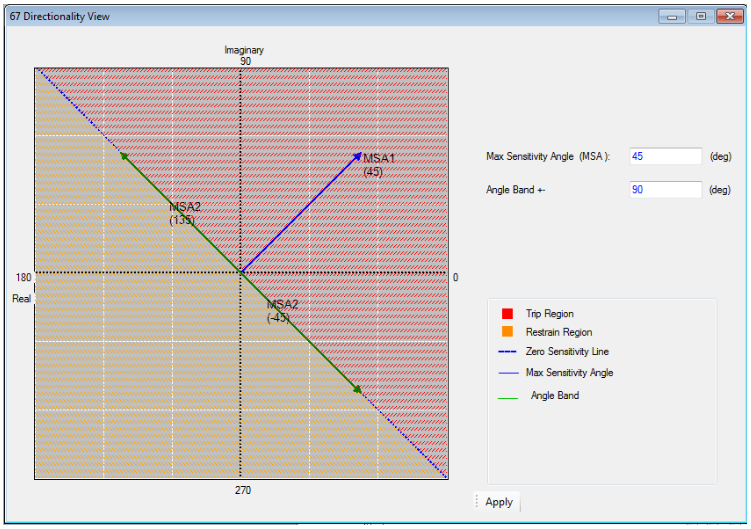
BECKWITH ELECTRIC CO. INC.

Directional Overcurrent

67P, 67Q, 67N (67P shown below)



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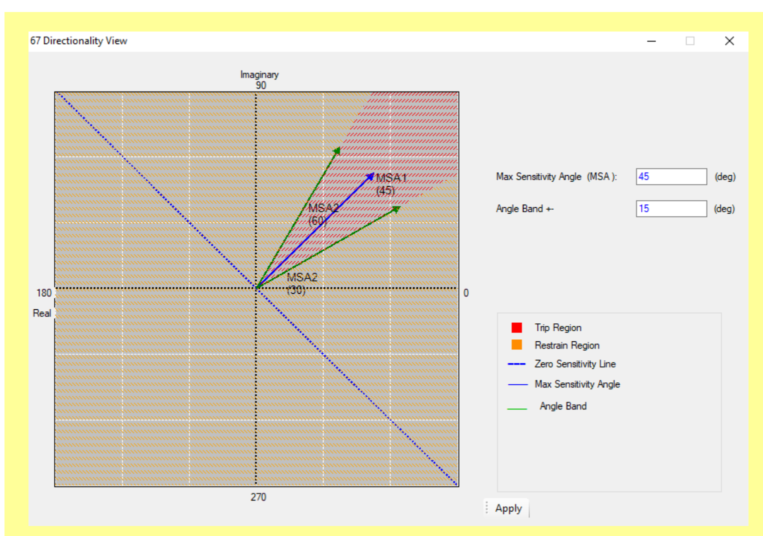
Directionalization

Phase Directional Characteristic



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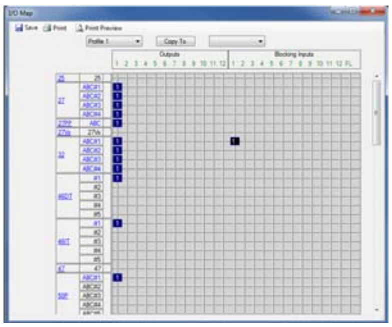
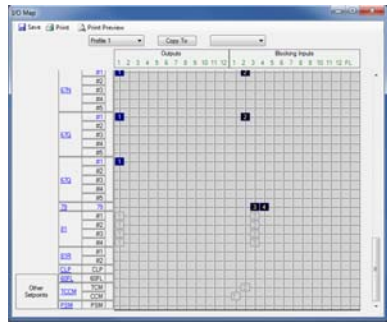
Output I/O Map

- Output I/O Map helps minimize logic programing by visually displaying which function and which setpoints are programmed to each output and which inputs are programmed to block
- I/O Map tool allow copying of logics to other profiles
- For testing purposes individual protection elements can be disabled without deleting its programming. In this case the functions will be greyed out.
- Custom IPSlogics also appear here.





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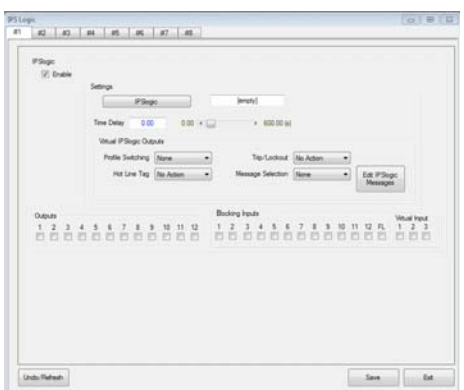
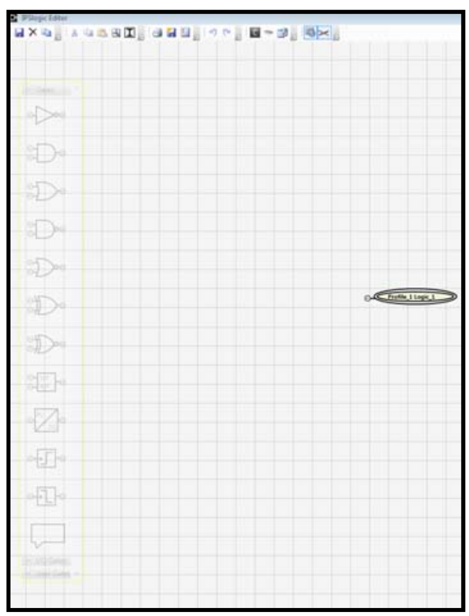
Custom Schemes: IPSlogic





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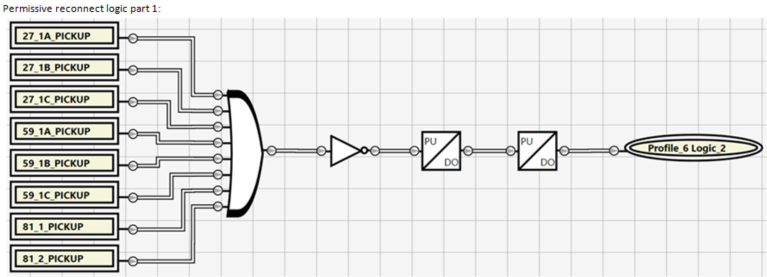
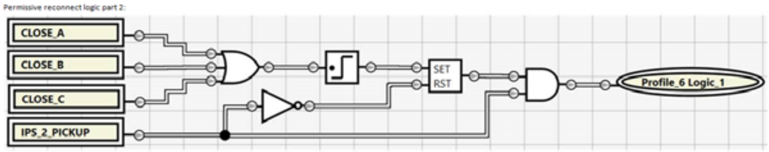
BECKWITH ELECTRIC CO. INC.

Custom Schemes: IPSlogic

Permissive reconnect logic part 1:



Permissive reconnect logic part 2:



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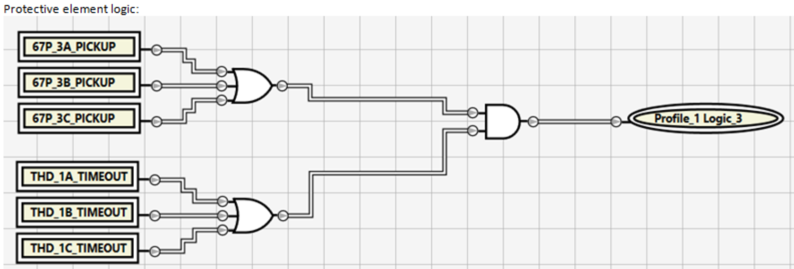
Custom Schemes: IPSlogic

Protective element logic:



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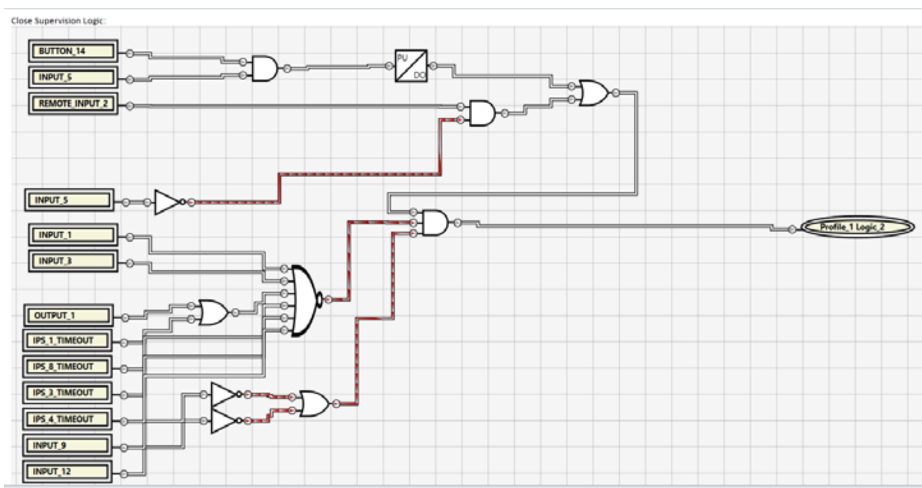
BECKWITH ELECTRIC CO. INC.

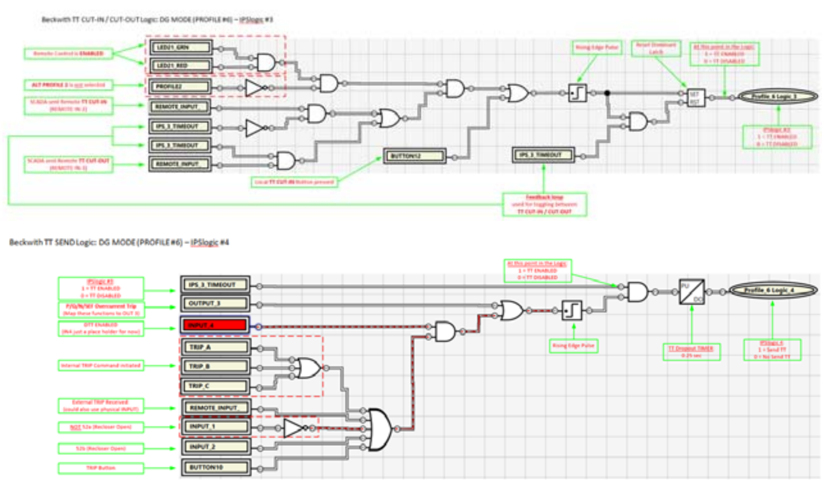
Custom Schemes: IPSlogic



63

BECKWITH ELECTRIC CO. INC.

Custom Schemes: IPSlogic



Open IPSlogic, add gate, show state simulator

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Monitoring

Primary

Secondary

★ Show loadflow metering

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Monitor Pickups and Trips

Real-time for Testing/Commissioning

Backstory:

- Four 27 elements are set
- 27/4 is set at 0.7pu, 20 cycles
- 27/1, 2, 3 are set closer to nominal, but with longer time delays
- Voltage on Phase A is dropped to 0.5pu.
- 27/4 trips; all other 27s in pickup on Phase A as long as low voltage is present and CB status indicates closed

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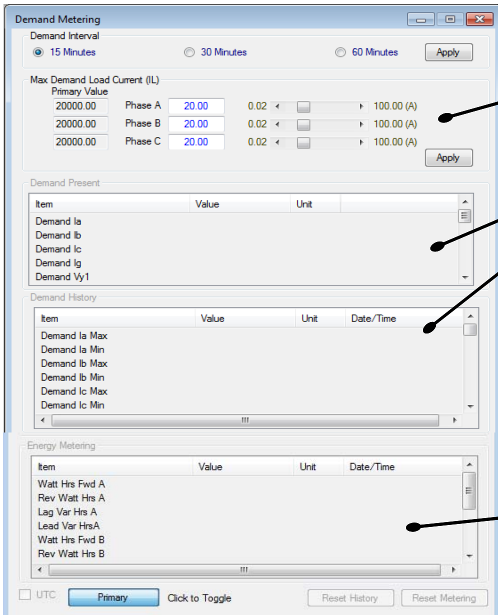
Demand & Energy Metering



Set Rated Load for TDD Metering

Demand

- **Demand and Energy**
  - **Present**
  - **Historical**
  - **Min/Max**
  - **All with date and time stamping**

Energy
(Bidirectional Registers)

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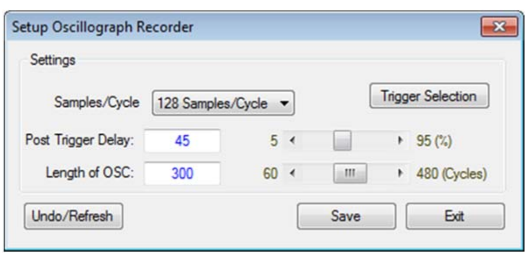
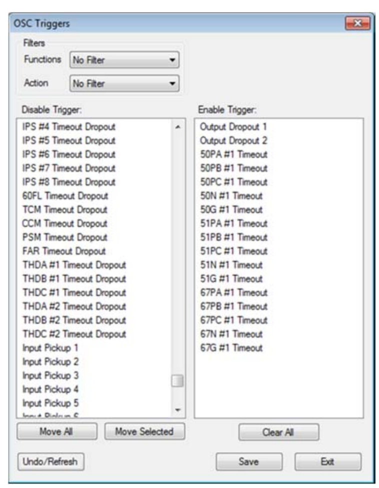
Set Up Oscillography Triggers

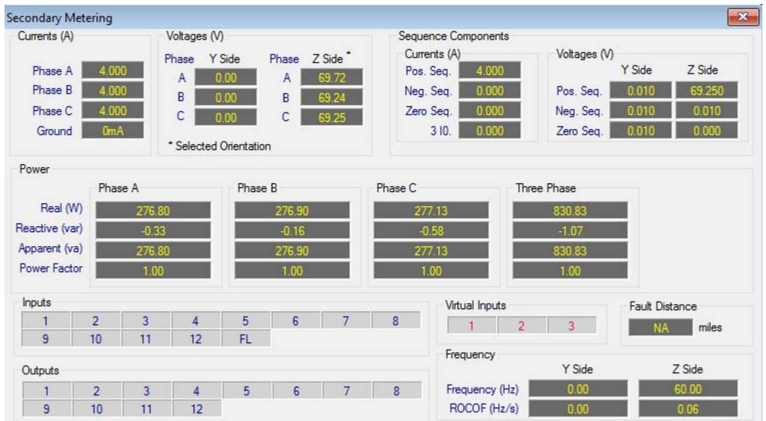




BECKWITH ELECTRIC CO. INC.

Metering & Phasor Diagram

- Secondary Metering: Loadflow at 1.0pf



- Note V Sequence sets:
  - V1=Total Current
  - V2 = 0
  - V0 = 3
- Note I Sequence sets:
  - I1=Total Current
  - I2 = 0
  - I0 = 3
- Powers
  - Watts = KVA
  - VAR = 0

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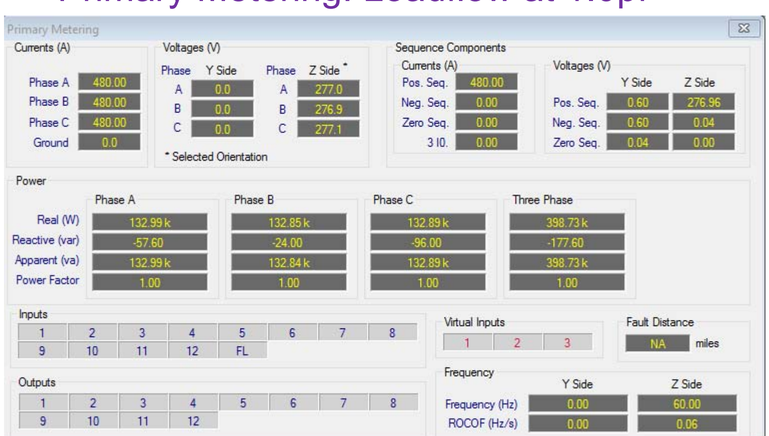
BECKWITH ELECTRIC CO. INC.

Metering & Phasor Diagram

- Primary Metering: Loadflow at 1.0pf



- Note V Sequence sets:
  - V1=Total Current
  - V2 = 0
  - V0 = 3
- Note I Sequence sets:
  - I1=Total Current
  - I2 = 0
  - I0 = 3
- Powers
  - Watts = KVA
  - VAR = 0

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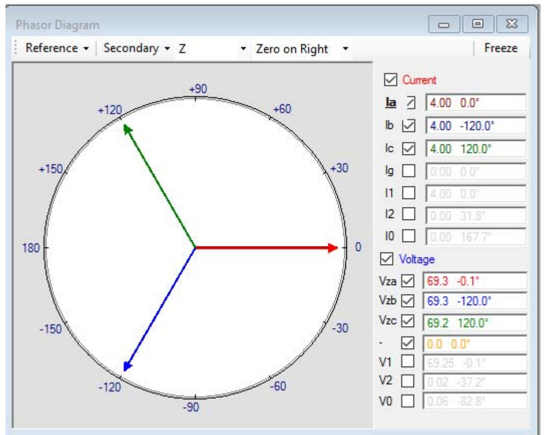
Metering & Phasor Diagram

- Vector Diagram: Loadflow at 1.0pf

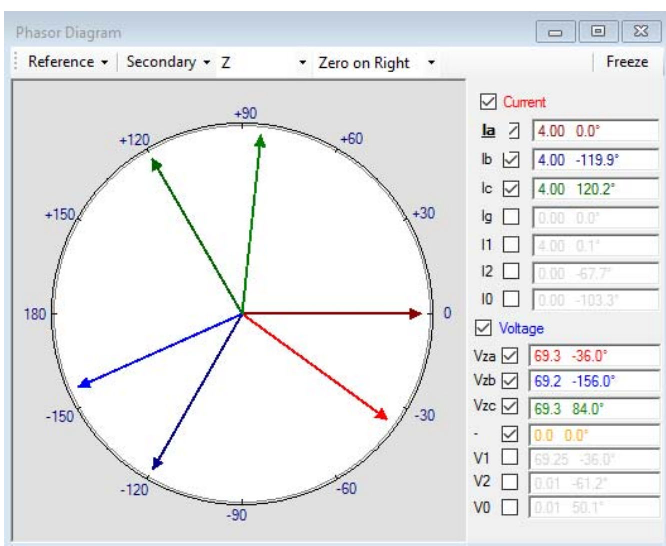


Show loadflow vector diagram

BECKWITH ELECTRIC CO. INC.

Metering & Phasor Diagram

- Vector Diagram: Loadflow at 0.8 pf lag



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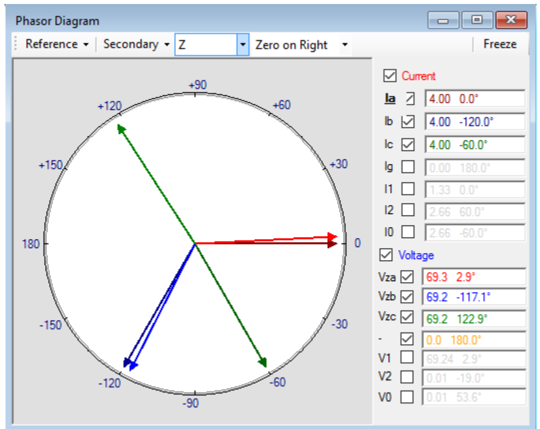
Metering & Phasor Diagram

- Vector Diagram: Loadflow at 1.0pf,
  - “C” Phase Current Rolled



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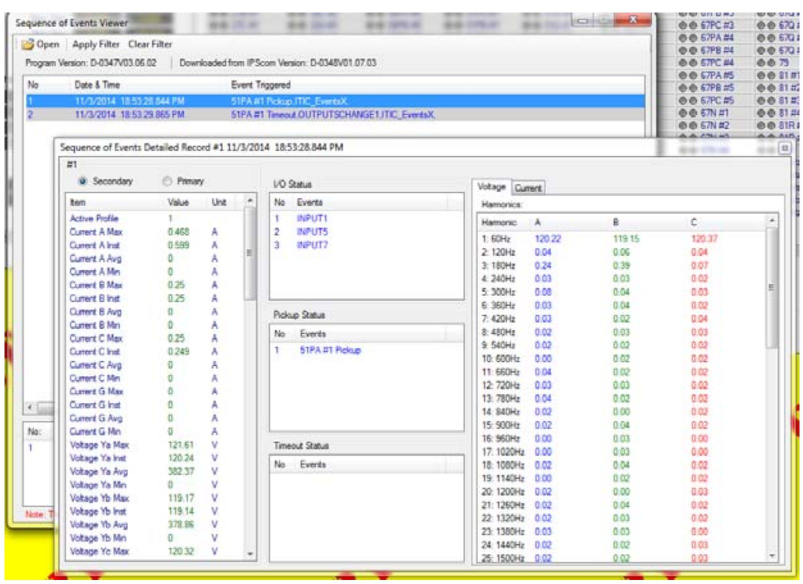
SOE

SOE Showing Trip



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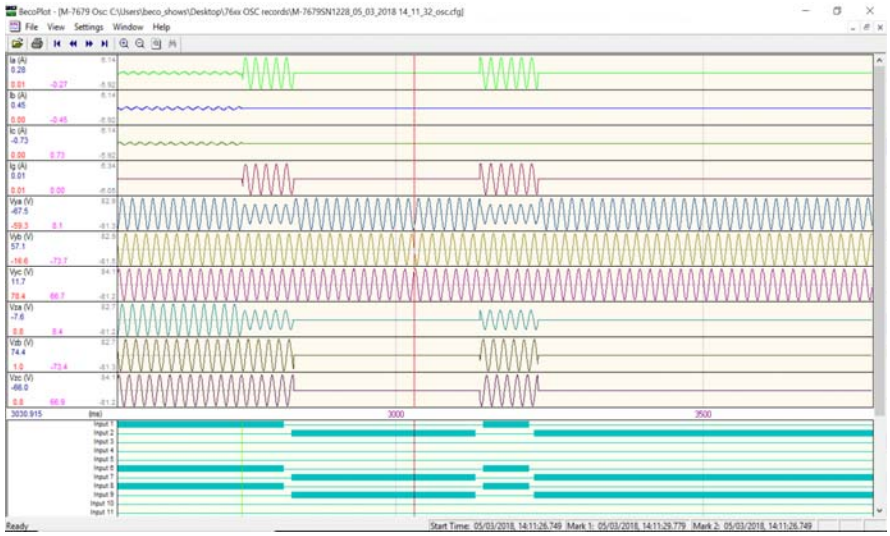
Oscillography

Up to 8 Seconds per Record



100 Records

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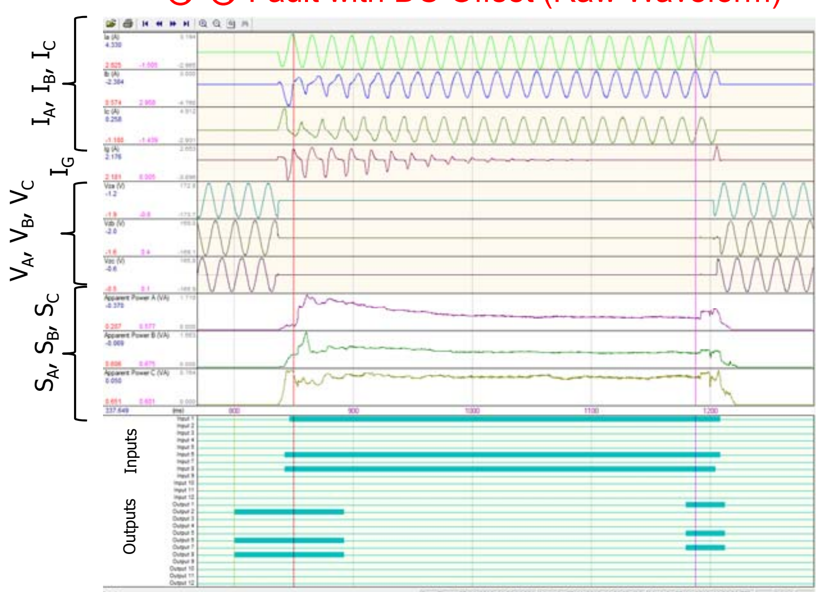
Oscillography

ϕ-ϕ Fault with DC Offset (Raw Waveform)



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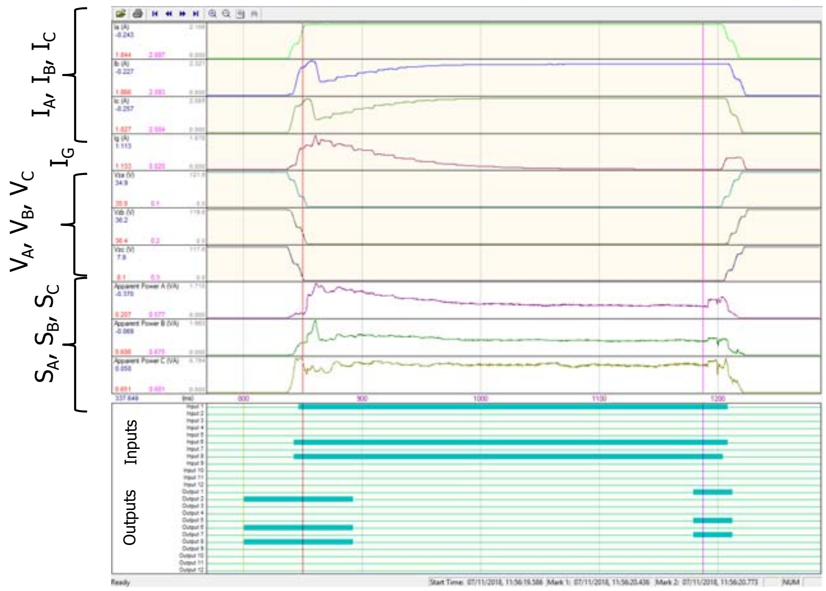
BECKWITH ELECTRIC CO. INC.

Oscillography

⊘-⊘ Fault with DC Offset (Fundamental View)



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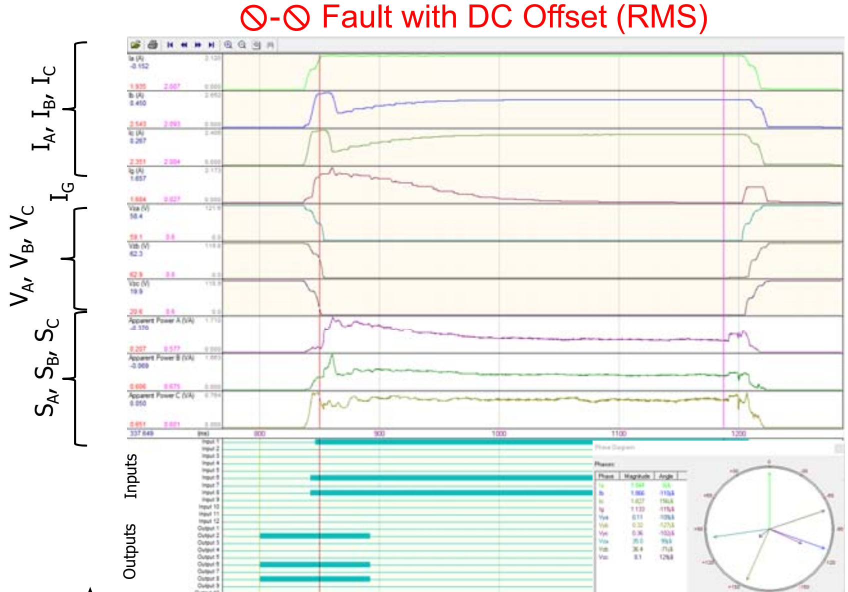
BECKWITH ELECTRIC CO. INC.

Oscillography

⊘-⊘ Fault with DC Offset (RMS)



Show Ph-Ph-G Fault with DC Offset: PG&E

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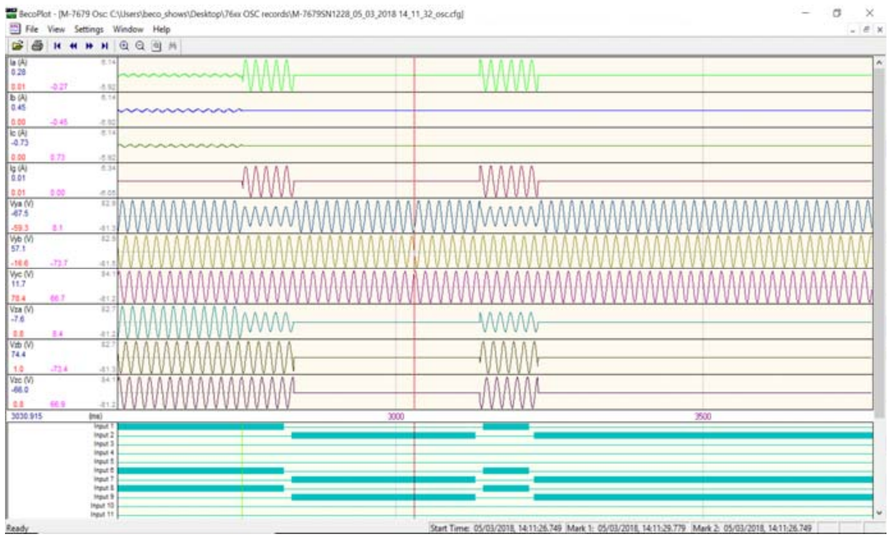
Oscillography

Up to 8 Seconds per Record



100 Records

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M-7651A for DER

Element Testing

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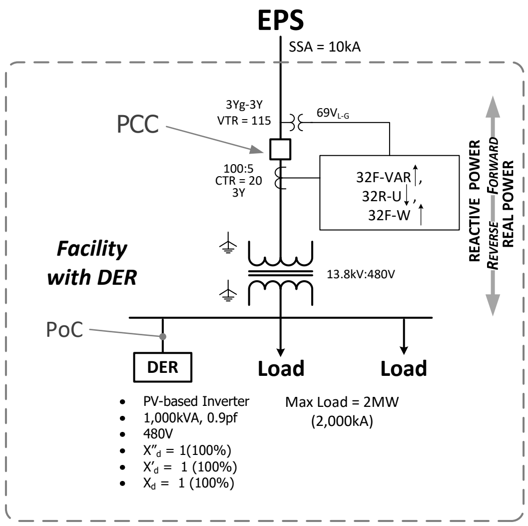
BECKWITH ELECTRIC CO. INC.

M-7651A: DER Interconnection Application



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M-7651A: DER Interconnection Application

"Elements of Distinction"

- 32F-VAR: Inadvertent VAR Export for Exporting DER
- 32R-U: Minimal Import Power for Non-Exporting DER
- 32F-Watt: Inadvertent Forward Overpower

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M-7651A Settings: DER Interconnection Application

- VTR = 115:1
- VT Type: 3Y-3Y
- Rated Secondary Voltage = $69V_{LG}$
- CTR = 100:5 = 20 (3Y)
- Inverter Power = 1,000kVA
- Inverter FRA = I = kVA/1.73*kV
  = I = 1,000/1.73* 13.8
  = I = 41.88A = 42A

Note: "FRA" = Full Rated Amps

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M-7651A Settings: 32F-VAR DER Interconnection Application

- I_{FRA} = 42A
- I_{NOM} = I_{FRA} / CTR
- = 42 /20
- = 2.1A
- V_{NOM} = 69V
- Formula for "Relay P_{NOM}"
  - 3 * 69 * 2.1 = $434.7W_R$ = $435W_R$ = 1pu

Line-to-Ground Voltage:

$P_{NOM} = 3 \cdot V_{NOM} \cdot I_{NOM}$ (Secondary Nominal Power)

$\text{Pickup} = \pm \frac{\text{Primary Power}}{P_{NOM} \cdot VTR \cdot CTR}$ (Three-Phase)

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M-7651A Settings: 32F-VAR DER Interconnection Application

Relay W=	435Wr	1pu	2.1	A
INV "S" Out	pu	Seconday Current @ pu		
1000	1.00	2.1		
900	0.90	1.89		
800	0.80	1.68		
700	0.70	1.47		
600	0.60	1.26		
500	0.50	1.05		
400	0.40	0.84		
300	0.30	0.63		
200	0.20	0.42		
100	0.10	0.21		
0	0.00	0		

- Minimum sensitivity of relay is 0.01A
- We are good to 15% of inverter power

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M-7651A: CT Dimensioning

- CT Limitations

Device Number	Function	Setpoint Ranges	Increment	Accuracy†
	Directional Instantaneous/Definite Time Overcurrent (Cont'd.)			
	Inverse Time:			
	Pickup			
	1 A CT/Gnd CT	0.02 to 3.20 A	0.01 A	±0.02 A or ±3%
	5 A CT/Gnd CT	0.10 to 16.00 A	0.01 A	±0.1 A or ±3%

- Minimum Sensitivity of Inverse Time Element: 67Q, N, P
- 5A CT, $0.1A_{sec}$
- The relay in this application can detect faults to 10% of inverter rating (10% rating = $0.21A_{sec}$)

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M-7651A:
CT Dimensioning

- CT Limitations

AC Current Inputs

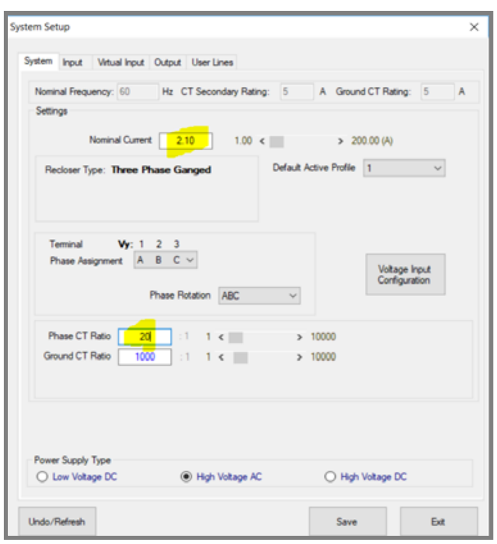
AC Current	I Nominal	I Continuous	I Short duration	Burden
Phase Current	1 A 5 A	3 A 15 A	100 A for 1 second 500 A for 1 second	< 0.021 VA < 0.20 VA
Ground Current	1 A 5 A	3 A 15 A	100 A for 1 second 500 A for 1 second	< 0.021 VA < 0.20 VA

- SSA = 10kA (10,000A)
  - System SSA contribution is greater than Facility with DER
  - 10,000/40 = 250; <500A; OK
- Max. Load of Facility with DER (DER off) = 2MW
  - 2MW = kVA/(1.73 * kV) = 2,000 / (1.73 * 13.8) = 83.8
  - 83.8 / 100 = 0.83A; OK

87

BECKWITH ELECTRIC CO. INC.

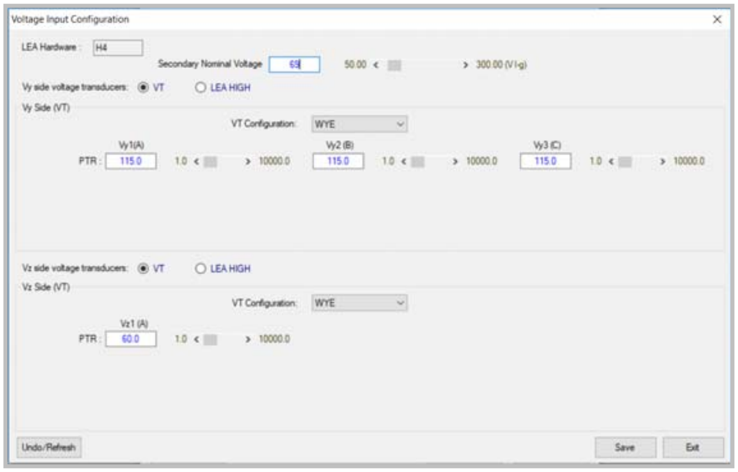
System Setup



88

BECKWITH ELECTRIC CO. INC.

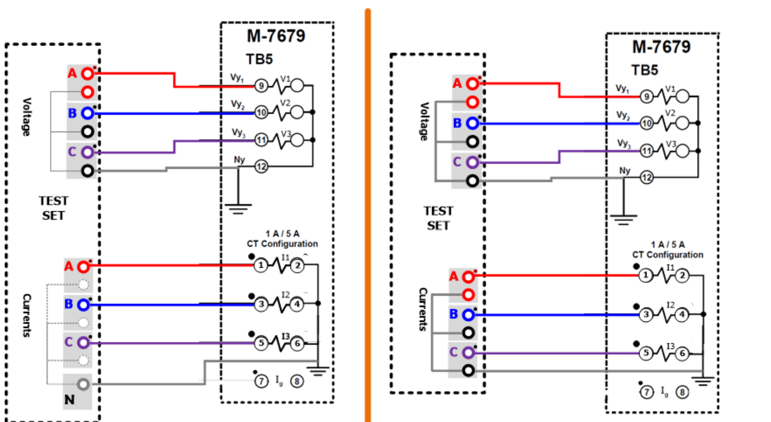
System Setup



BECKWITH ELECTRIC CO. INC.

M-7651A Test Connections

For both connections,
VA@0° with IA@0° & VB@-120 with IB@-120° & VC@-240° with IC@-240°
= 100% forward real power flow



Test Set Notes:
- Each phase's neutral connected together internally.
- One common neutral for all phases available for external connection

Test Set Notes:
- Each phase's neutral available for connection.
- Neutrals should be externally commoned together.

M-7651A D-PAC for DER Interconnection Protection

32F-VAR Element Application

M-7651A Settings: 32F-VAR DER Interconnection Application

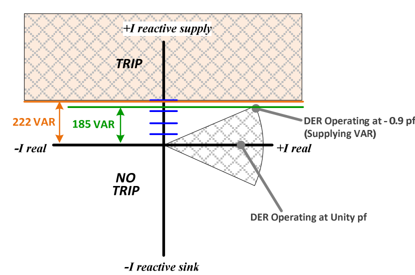
Line-to-Ground Voltage:

$P_{NOM} = 3 \bullet V_{NOM} \bullet I_{NOM}$ (Secondary Nominal Power)

$$\text{Pickup} = \pm \frac{\text{Primary Power}}{P_{NOM} \bullet VTR \bullet CTR} \text{ (Three-Phase)}$$

RELAY POWER

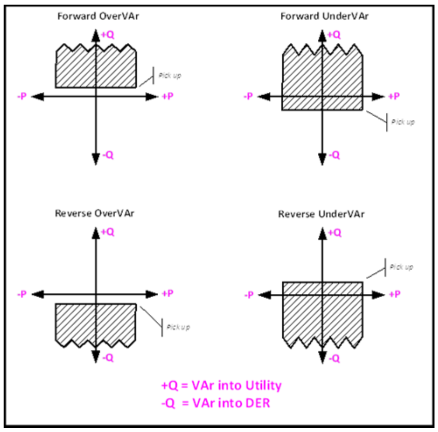
- P_{NOM} = 3 * 69 * 2.10
  = 438 VA = 1pu
- Normal pf = +/- 0.9 (25 degrees)
  - Sin 25° = 0.4226
  - Cos 25° = 0.9
- kW at 0.9 = 438 * cos 25
  - = 394W
- VARs at 0.9 = 438 * sin 25
  - = 185 VAR

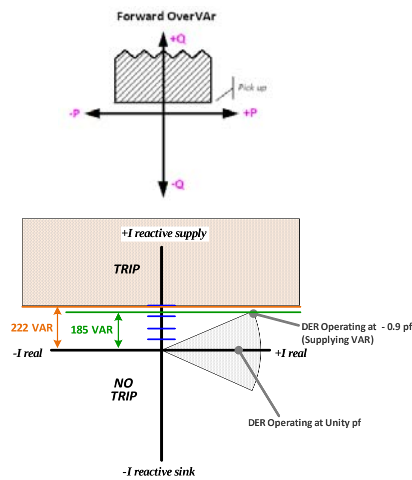


- Normal VAR Export Max. = 185 VAR
- 20% Margin = 185 * 1.2 = 222 VAR
- Setting = VAR / 1pu VA
  = 222 / 438 = 0.5077 = 0.51 pu

BECKWITH ELECTRIC CO. INC.

M-7651A Settings: 32F-VAR DER Interconnection Application

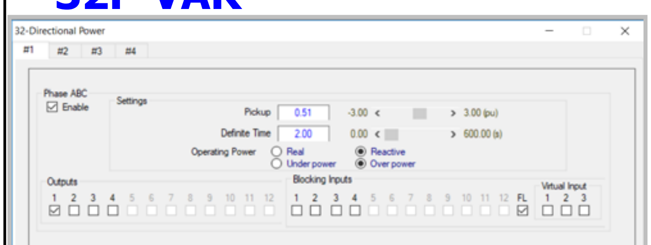


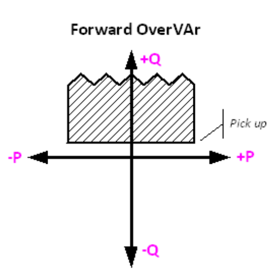


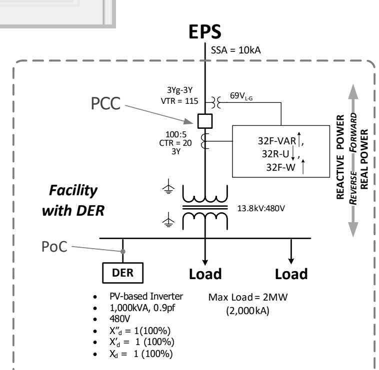
93

BECKWITH ELECTRIC CO. INC.

32F-VAR Setpoints





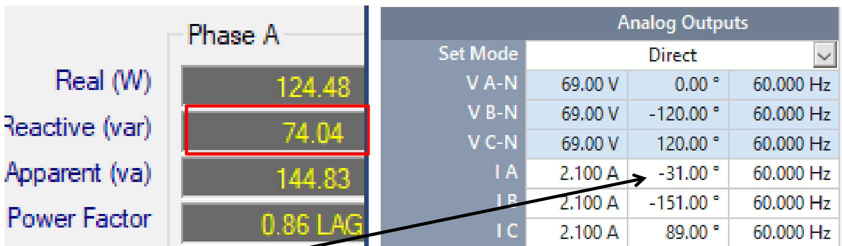


94

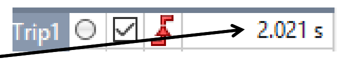
BECKWITH ELECTRIC CO. INC.

Testing the 32F-VAR Element

Inom (2.1) X Vnom (69) = 144.9W
144.9 X .51 (PU) Pick up = 73.9W



Rotate 3-ph currents
Meter reactive VAR's in Secondary Metering
Check pick up and trip time
Output 1 will pulse



BECKWITH ELECTRIC CO. INC.

M-7651A D-PAC for DER Interconnection Protection

32R-U Element Application

96

BECKWITH ELECTRIC CO. INC.

M-7651A Settings: 32R-U DER Interconnection Application

RELAY POWER

- P_{NOM} = 3 * 69 * 2.1
  = 438 VA = 1pu
- W_{NOM} = 3 * 69 * 2.1 * (Cos 0°)
  = 438 VA = 1pu
- W_{NOM}10% = 3 * 69 * 2.1 * (Cos 0°) * (0.1)
  = 43.5W
- $I_{(W10\%)}$ at 1.0pf = 43.5 / (3 * 69 * Cos 0°)
  = 0.21A

Line-to-Ground Voltage:

$P_{NOM} = 3 \bullet V_{NOM} \bullet I_{NOM}$ (Secondary Nominal Power)

$$\text{Pickup} = \pm \frac{\text{Primary Power}}{P_{NOM} \bullet VTR \bullet CTR} \text{ (Three-Phase)}$$

- Desire to trip if real power imported into the Facility with DER is less then 10% of the DER's rated output
- At unity pf, minimal amps coming into facility with DER must be equal or greater than 0.21A, or 21mA

97

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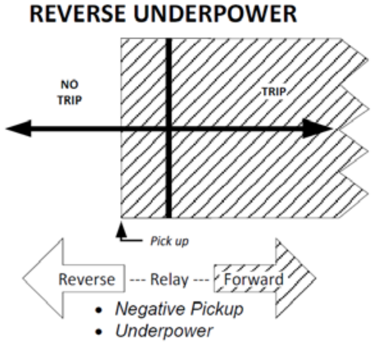
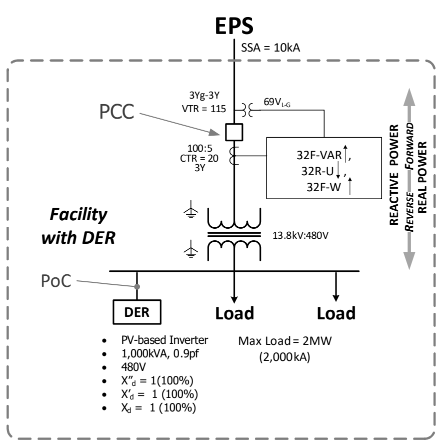
M-7651A Settings: 32R-U DER Interconnection Application

REVERSE UNDERPOWER



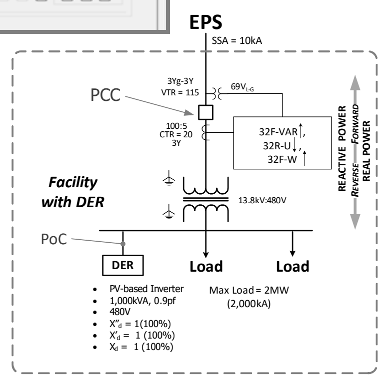


98

32R-U

Setpoints

Note:
Blocking Inputs 1 and 2 are used to block the 32R-U element if either the PPC CB or DER CBs are opened. Do not select blocking for "element only" testing.



99

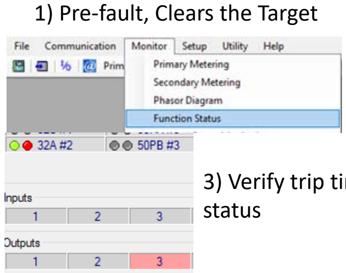
M-7651A Settings: 32R-U Test Procedure

Analog Outputs			
Set Mode	Direct		
V A-N	69.00 V	0.00 °	60.000 Hz
V B-N	69.00 V	-120.00 °	60.000 Hz
V C-N	69.00 V	120.00 °	60.000 Hz
I A	250.0 mA	-180.00 °	60.000 Hz
I B	250.0 mA	-300.00 °	60.000 Hz
I C	250.0 mA	-60.00 °	60.000 Hz

1) Pre-fault, Clears the Target

Analog Outputs			
Set Mode	Direct		
V A-N	69.00 V	0.00 °	60.000 Hz
V B-N	69.00 V	-120.00 °	60.000 Hz
V C-N	69.00 V	120.00 °	60.000 Hz
I A	210.0 mA	-180.00 °	60.000 Hz
I B	210.0 mA	-300.00 °	60.000 Hz
I C	210.0 mA	-60.00 °	60.000 Hz

2) Ramp 3 ph. Currents down on 10mA steps



3) Verify trip time and function status

Trip3	2.016 s

100

BECKWITH ELECTRIC CO. INC.

M-7651A D-PAC for DER Interconnection Protection

32F-Watt Element Application

101

BECKWITH ELECTRIC CO. INC.

M-7651A Settings: 32F-W DER Interconnection Application

RELAY POWER

- P_{NOM} = 3 * 69 * 2.1
  = 438 VA = 1pu
- W_{NOM} = 3 * 69 * 2.1 * (Cos 0°)
  = 438 VA = 1pu
- W_{NOM}25% = 3 * 69 * 2.1 * (Cos 0°) * (0.25)
  = 108.6W
- $I_{(W25\%)}$ at 1.0pf = 108.6 / (3 * 69 * Cos 0°)
  = 0.525A

Line-to-Ground Voltage:

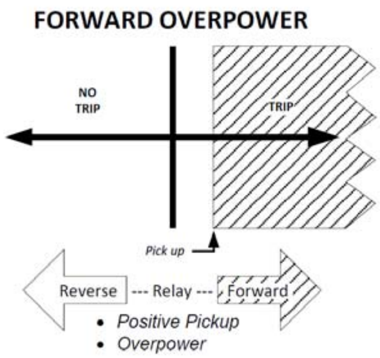
$P_{NOM} = 3 \cdot V_{NOM} \cdot I_{NOM}$ (Secondary Nominal Power)

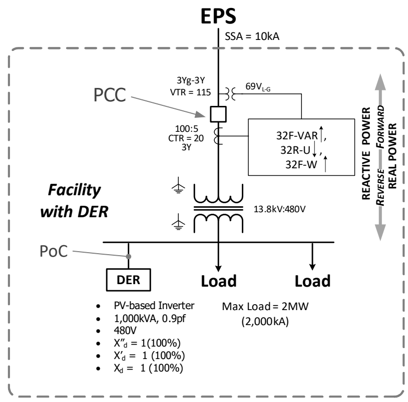
$$\text{Pickup} = \pm \frac{\text{Primary Power}}{P_{NOM} \cdot VTR \cdot CTR} \text{ (Three-Phase)}$$

- Desire to trip if real power exported out of the Facility with DER is greater than 25% of the DER's rated output
- At unity pf, maximum amps flowing into the EPS at unity pf must be equal or greater than 0.525A, or 525mA

102

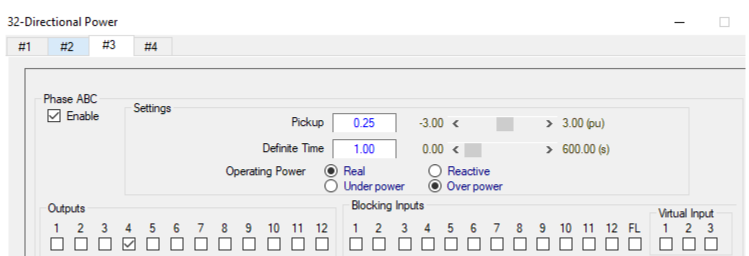
M-7651A Settings: 32F-W
DER Interconnection Application



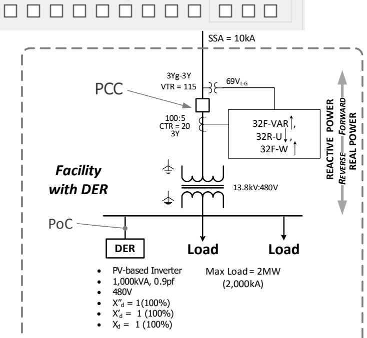


32F-W

Setpoints



Setting is 25% of In (2.1)



BECKWITH ELECTRIC CO. INC.

32F-W

Test

Analog Outputs			
Set Mode	Direct		
V A-N	69.00 V	0.00 °	60.000 Hz
V B-N	69.00 V	-120.00 °	60.000 Hz
V C-N	69.00 V	120.00 °	60.000 Hz
I A	500.0 mA	0.00 °	60.000 Hz
I B	500.0 mA	-120.00 °	60.000 Hz
I C	500.0 mA	120.00 °	60.000 Hz

Pre-fault values

Ramp up in 50mA steps, . > 2 sec. per step
Verify trip time and pick-up

In (2.1) x .25 = .525mA

Analog Outputs			
Set Mode	Direct		
V A-N	69.00 V	0.00 °	60.000 Hz
V B-N	69.00 V	-120.00 °	60.000 Hz
V C-N	69.00 V	120.00 °	60.000 Hz
I A	525.0 mA	0.00 °	60.000 Hz
I B	525.0 mA	-120.00 °	60.000 Hz
I C	525.0 mA	120.00 °	60.000 Hz

Trip 4 1.009 s

105

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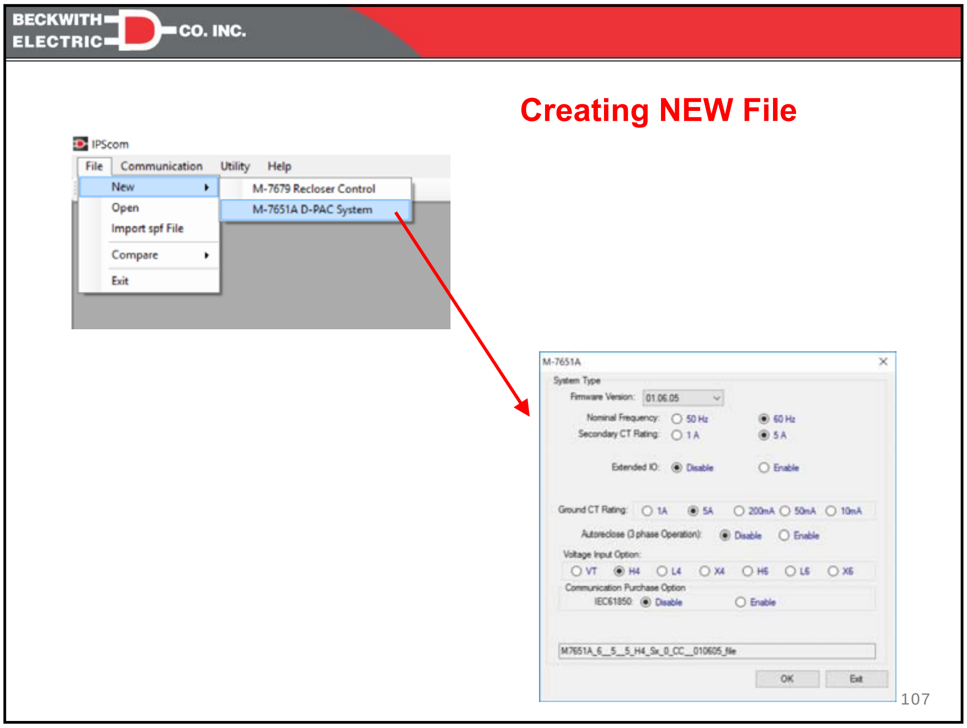
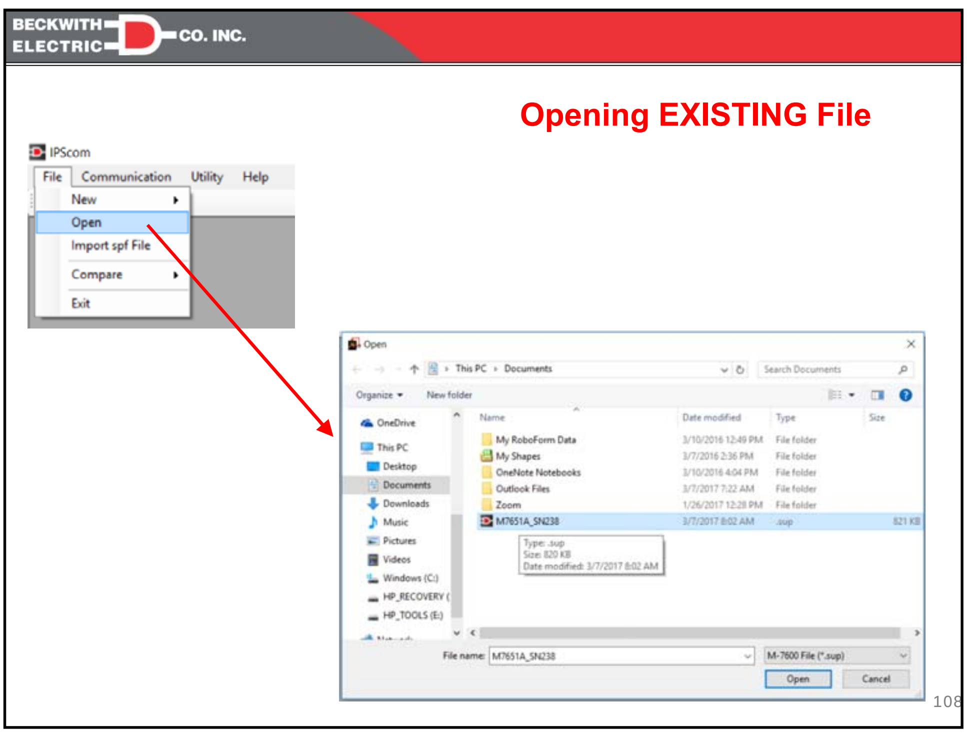
Annex: Software Navigation Overview

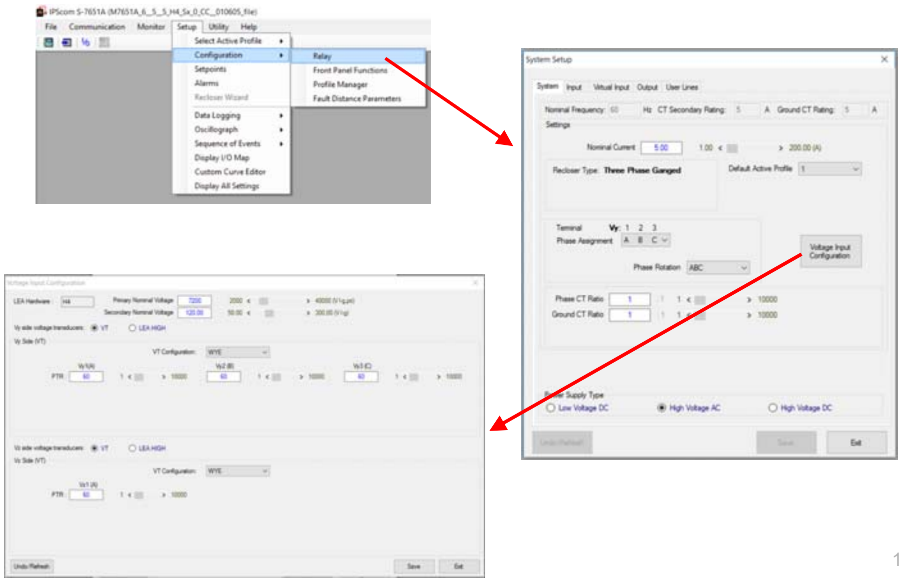
106


BECKWITH ELECTRIC CO. INC.
Creating NEW File
IPScom
File Communication Utility Help
New
Open
Import spf File
Compare
Exit
M-7679 Recloser Control
M-7651A D-PAC System
M-7651A
System Type
Firmware Version: 01.06.05
Nominal Frequency: 50 Hz 60 Hz
Secondary CT Rating: 1 A 5 A
Extended IO: Disable Enable
Ground CT Rating: 1A 5A 200mA 50mA 10mA
Autoreclose (3 phase Operation): Disable Enable
Voltage Input Option:
VT H4 L4 X4 H6 L6 X6
Communication Purchase Option
IEC61850: Disable Enable
M7651A_6__5__5_H4_Sx_0_CC__010605_file
OK Exit
107


BECKWITH ELECTRIC CO. INC.
Opening EXISTING File
IPScom
File Communication Utility Help
New
Open
Import spf File
Compare
Exit
Open
This PC › Documents
Search Documents
Organize New folder
OneDrive
This PC
Desktop
Documents
Downloads
Music
Pictures
Videos
Windows (C:)
HP_RECOVERY (
HP_TOOLS (E:)
Name Date modified Type Size
My RoboForm Data 3/10/2016 12:49 PM File folder
My Shapes 3/7/2016 2:36 PM File folder
OneNote Notebooks 3/10/2016 4:04 PM File folder
Outlook Files 3/7/2017 7:22 AM File folder
Zoom 1/26/2017 12:28 PM File folder
M7651A_SN238 3/7/2017 8:02 AM .sup 821 KB
Type: .sup
Size: 820 KB
Date modified: 3/7/2017 8:02 AM
File name: M7651A_SN238
M-7600 File (*.sup)
Open Cancel
108

BECKWITH ELECTRIC CO. INC.

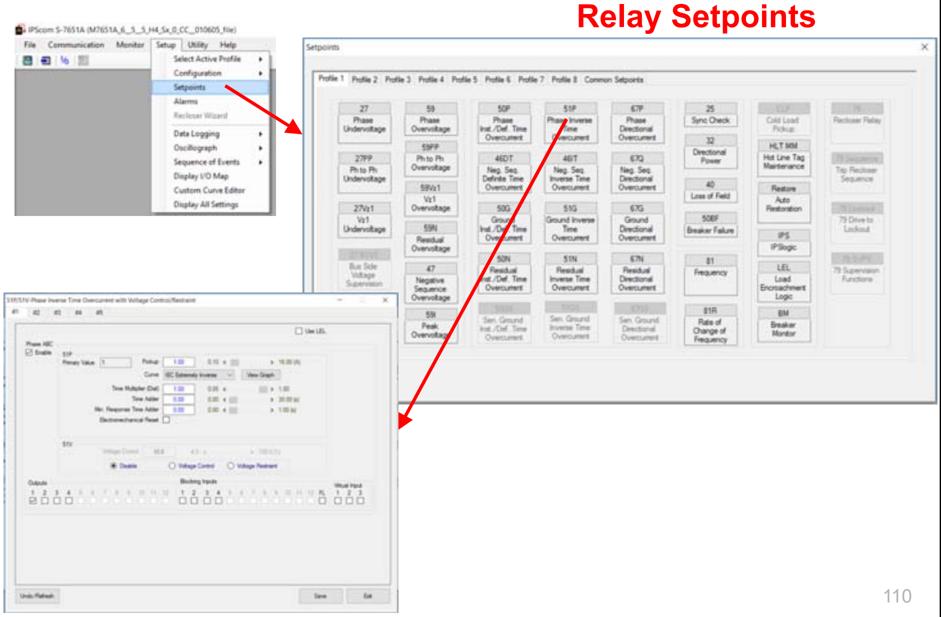
Set Up System



109

BECKWITH ELECTRIC CO. INC.

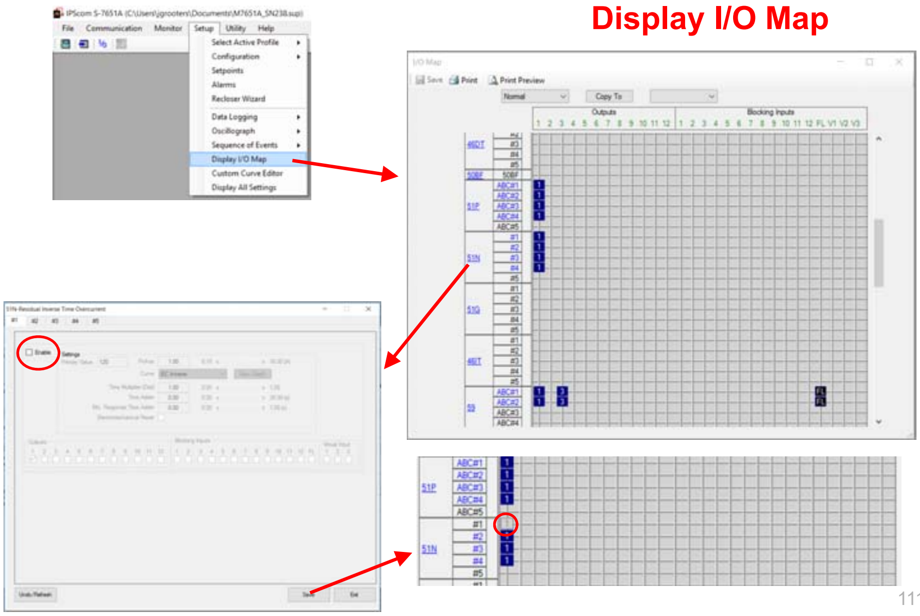
Relay Setpoints



110

BECKWITH ELECTRIC CO. INC.

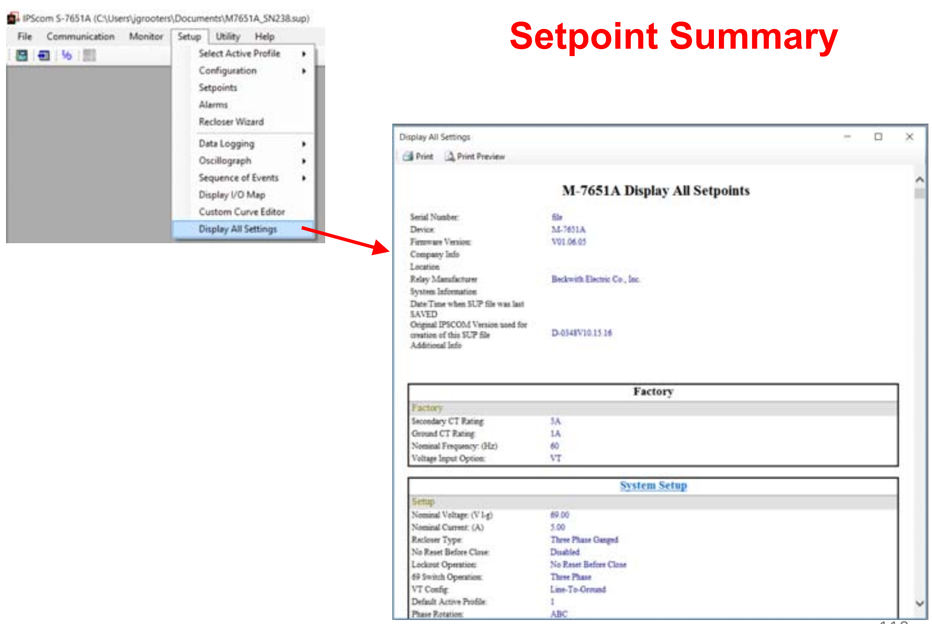
Display I/O Map



111

BECKWITH ELECTRIC CO. INC.

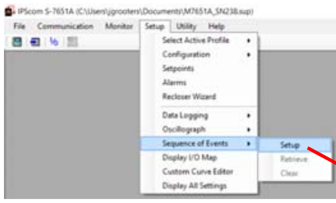
Setpoint Summary

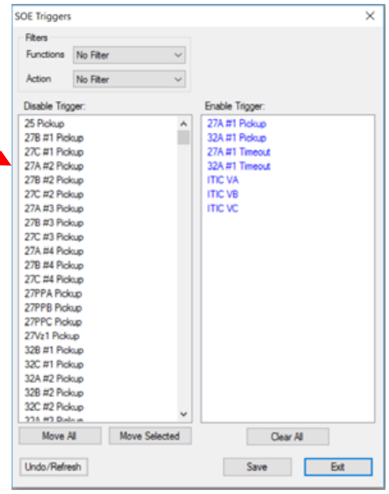


112

BECKWITH ELECTRIC CO. INC.

SOE Set Up



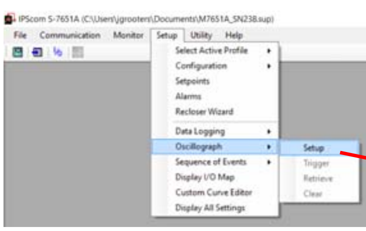


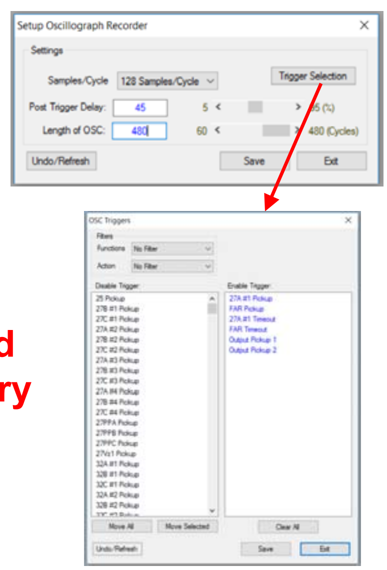
3500 SOE stored in nonvolatile memory

113

BECKWITH ELECTRIC CO. INC.

Oscillography Set Up

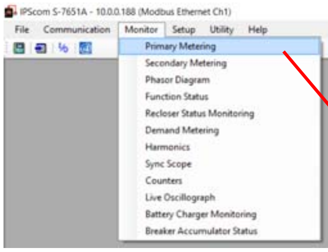




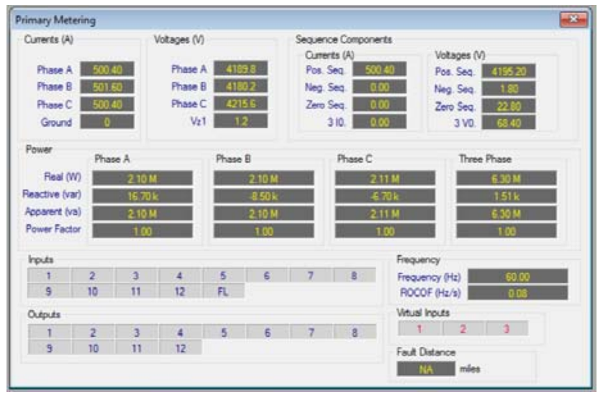
100 OSC files stored in nonvolatile memory

114

BECKWITH ELECTRIC CO. INC.

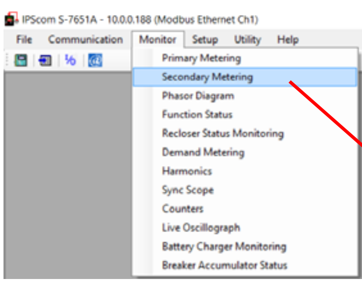


Primary Metering And Component Metering

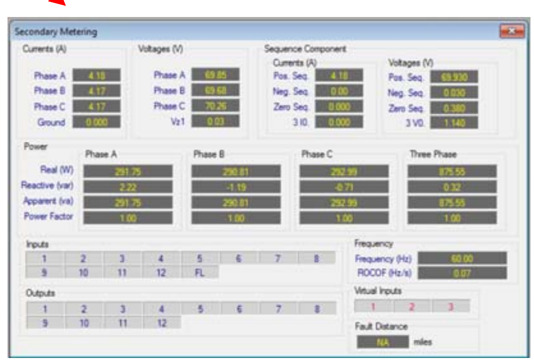


115

BECKWITH ELECTRIC CO. INC.



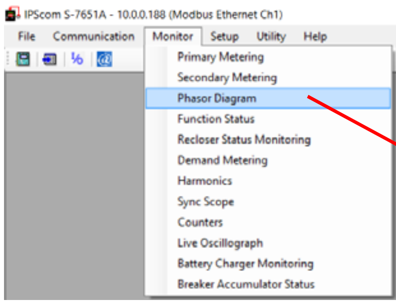
Secondary Metering, Components Metering, and Status

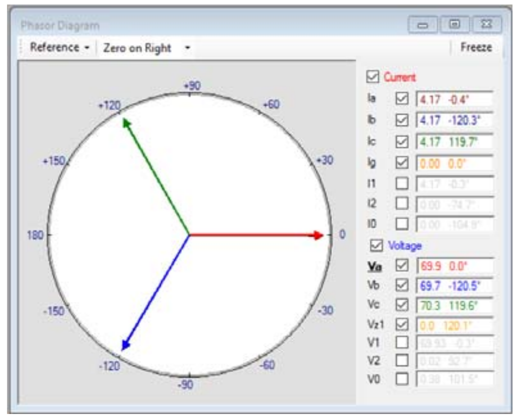


116

BECKWITH ELECTRIC CO. INC.

Phasor Diagram



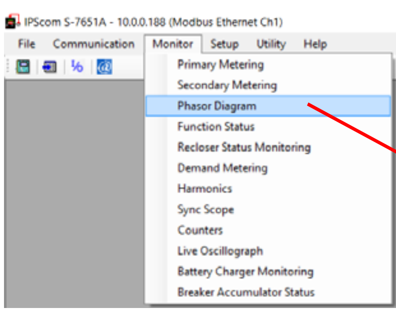


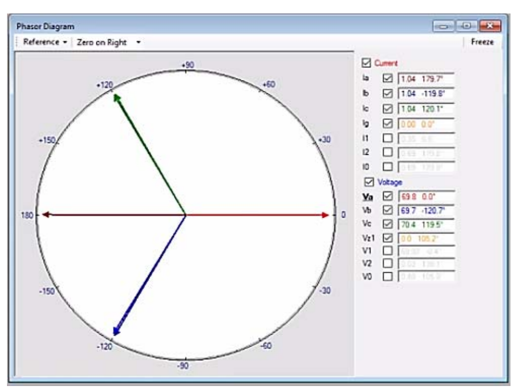
All corresponding voltages and currents in phase (loadflow at unity pf)

117

BECKWITH ELECTRIC CO. INC.

Phasor Diagram

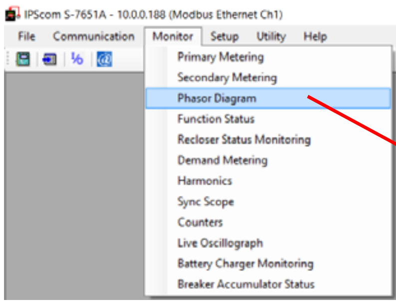




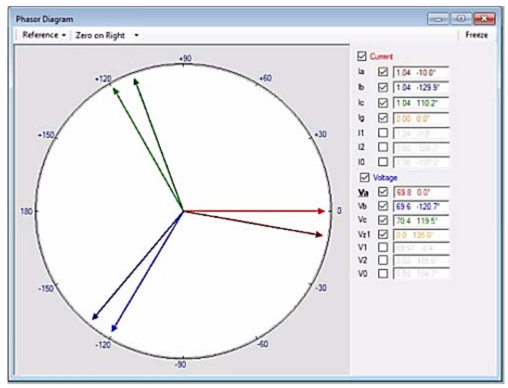
- All corresponding voltages and currents in phase (loadflow at unity pf)
- Phase A current wired 180° from Phase A voltage

118

BECKWITH ELECTRIC CO. INC.



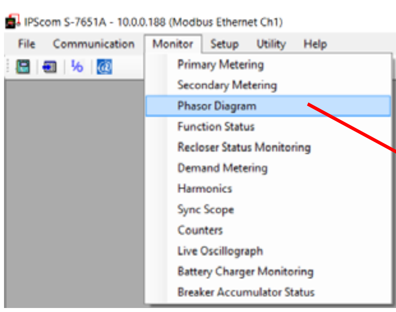
Phasor Diagram



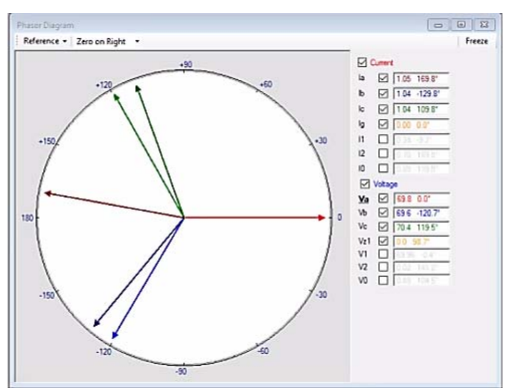
- All currents lag corresponding voltage by 10°
- Loadflow with lagging power factor

119

BECKWITH ELECTRIC CO. INC.



Phasor Diagram

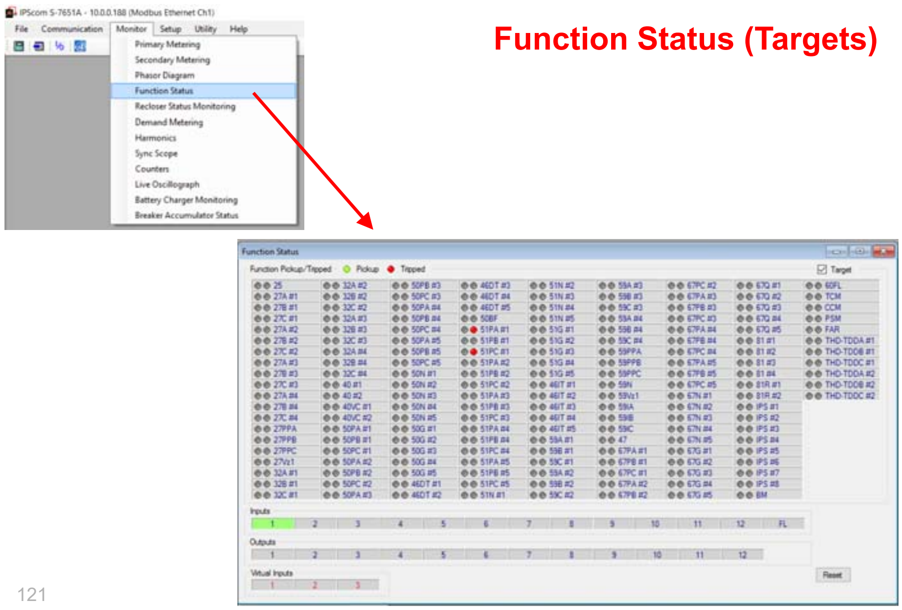


- All currents lag corresponding voltages by 10°
- Phase A current is wired 180° out-of-phase with Phase A voltage
- Representative of balanced load at lagging pf

120

BECKWITH ELECTRIC CO. INC.

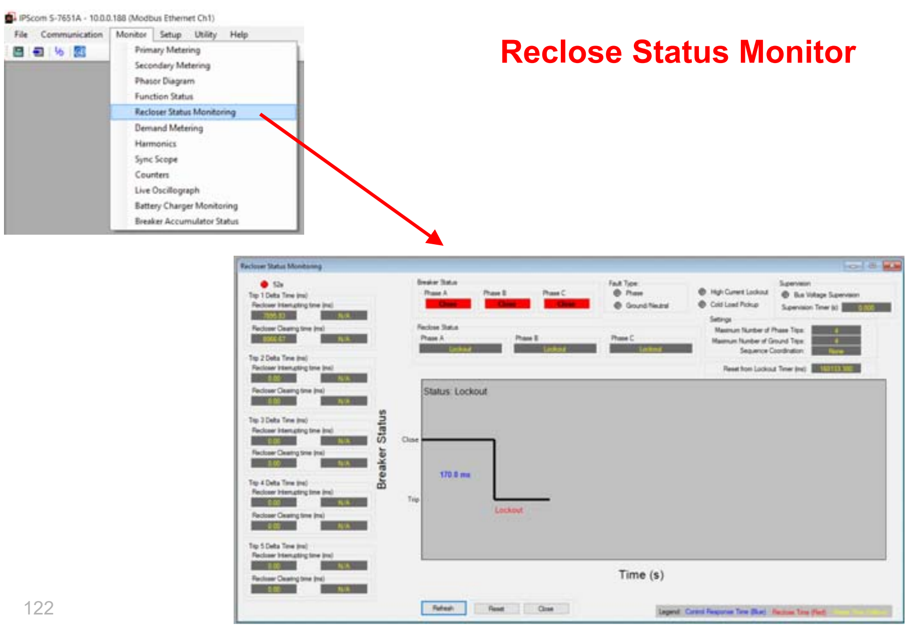
Function Status (Targets)



121

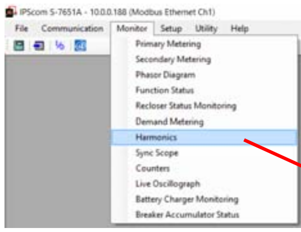
BECKWITH ELECTRIC CO. INC.

Reclose Status Monitor

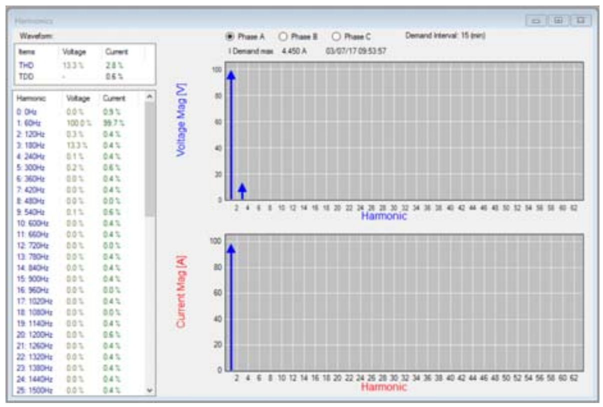


122

BECKWITH ELECTRIC CO. INC.

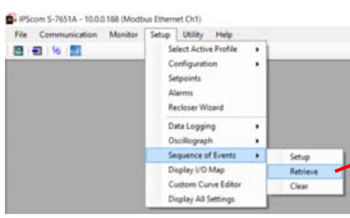


Harmonics Monitoring

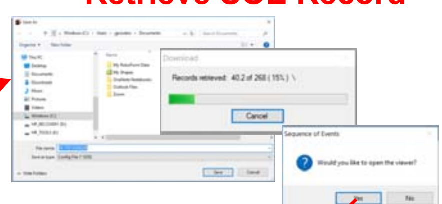


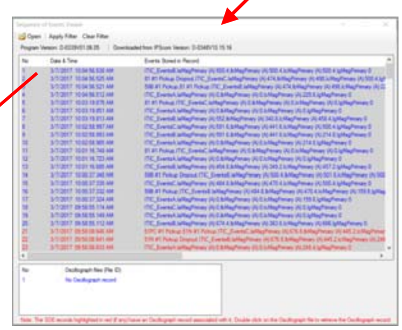
123

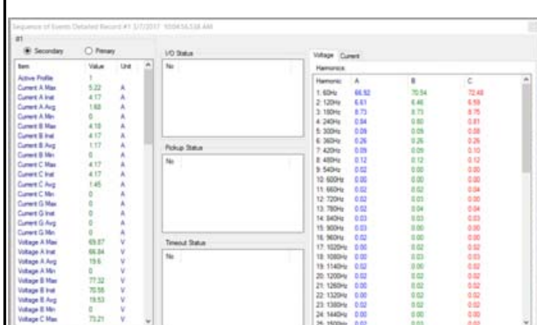
BECKWITH ELECTRIC CO. INC.



Retrieve SOE Record







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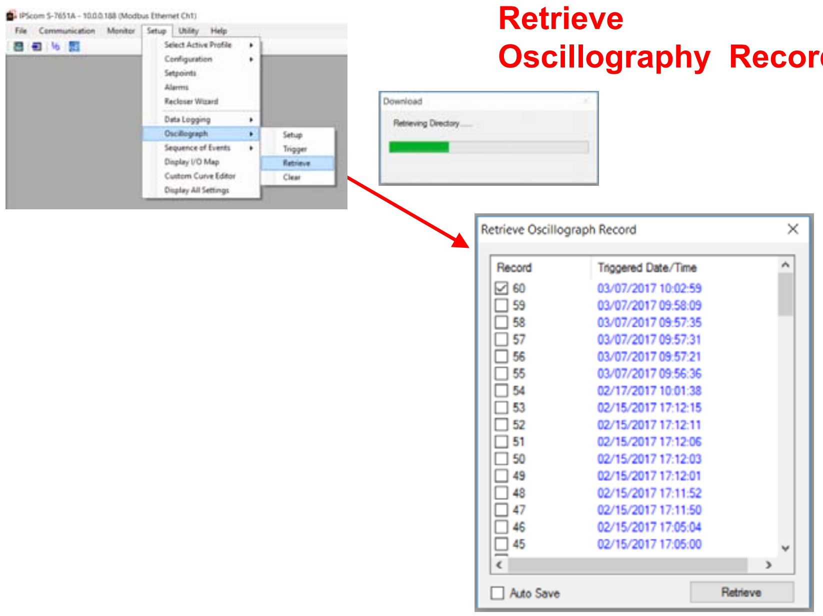
Retrieve Oscillography Record



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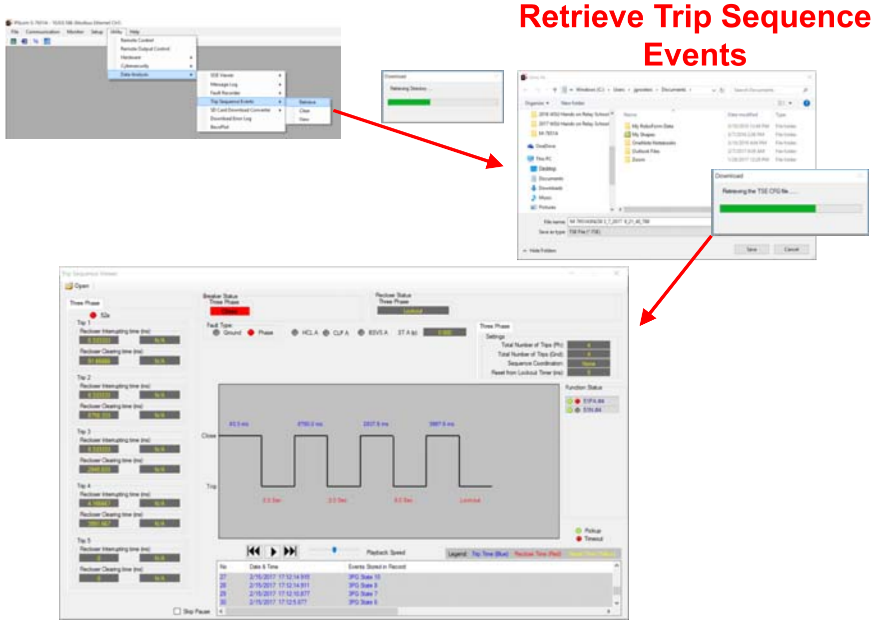
Retrieve Trip Sequence Events



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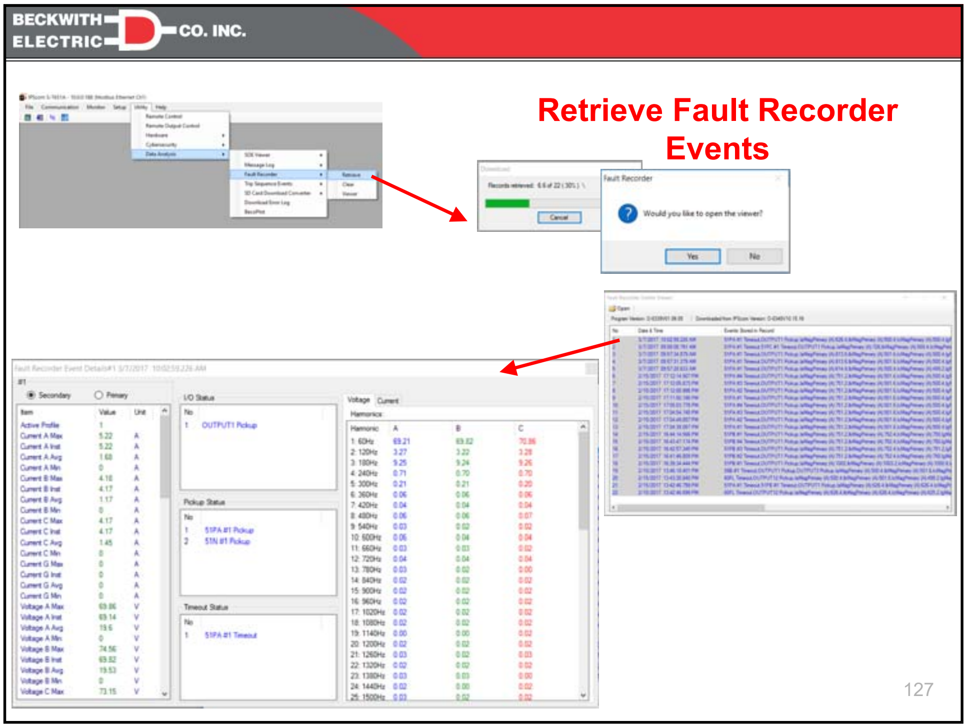
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Retrieve Fault Recorder Events
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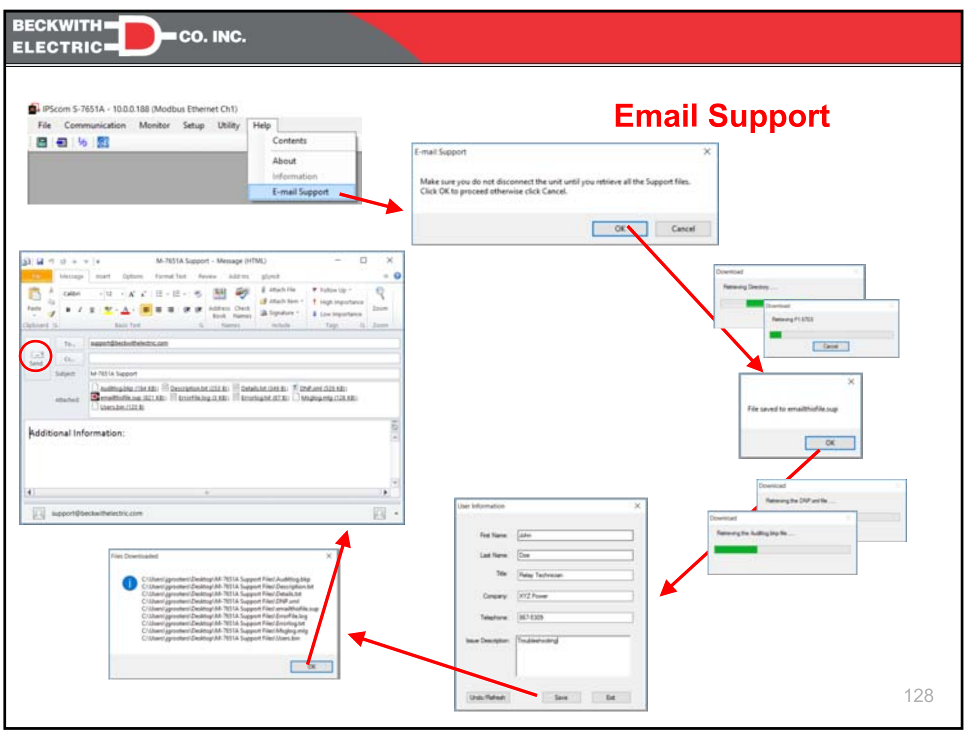
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Email Support
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