

Modern Capacitor Bank Protection Methods

Modern Capacitor Bank Protection Methods

Ryan Bowersox, Joe Schaefer - Florida Power and Light

Daniel Ransom - GE Grid Solutions

Presenter: Mike Ramlachan - GE Grid Solutions

Our discussion today

Capacitor and capacitor bank fundamentals and operation

Capacitor-bank protection

Real-world examples

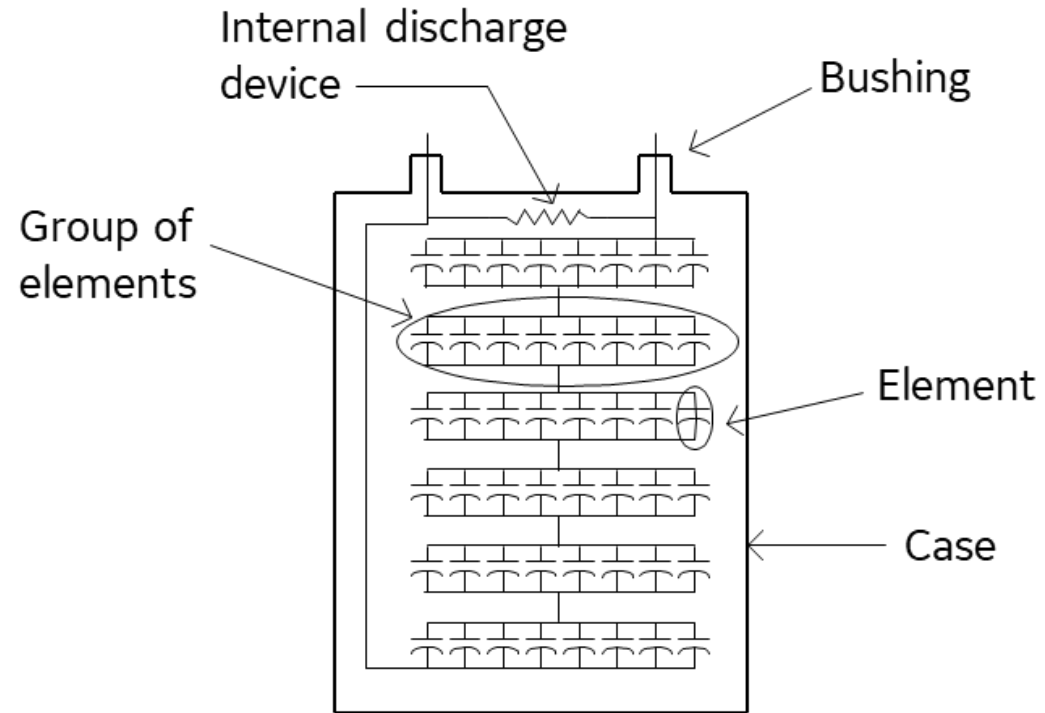
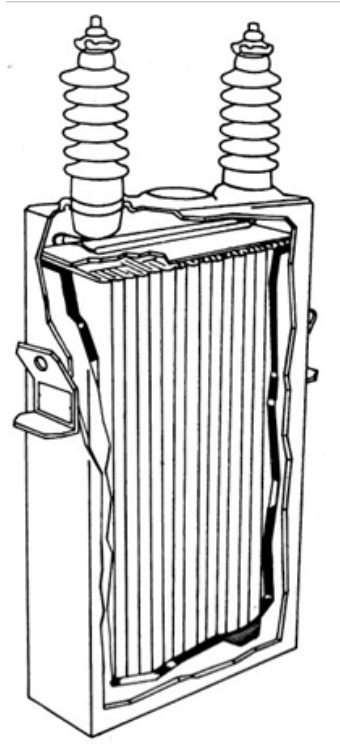


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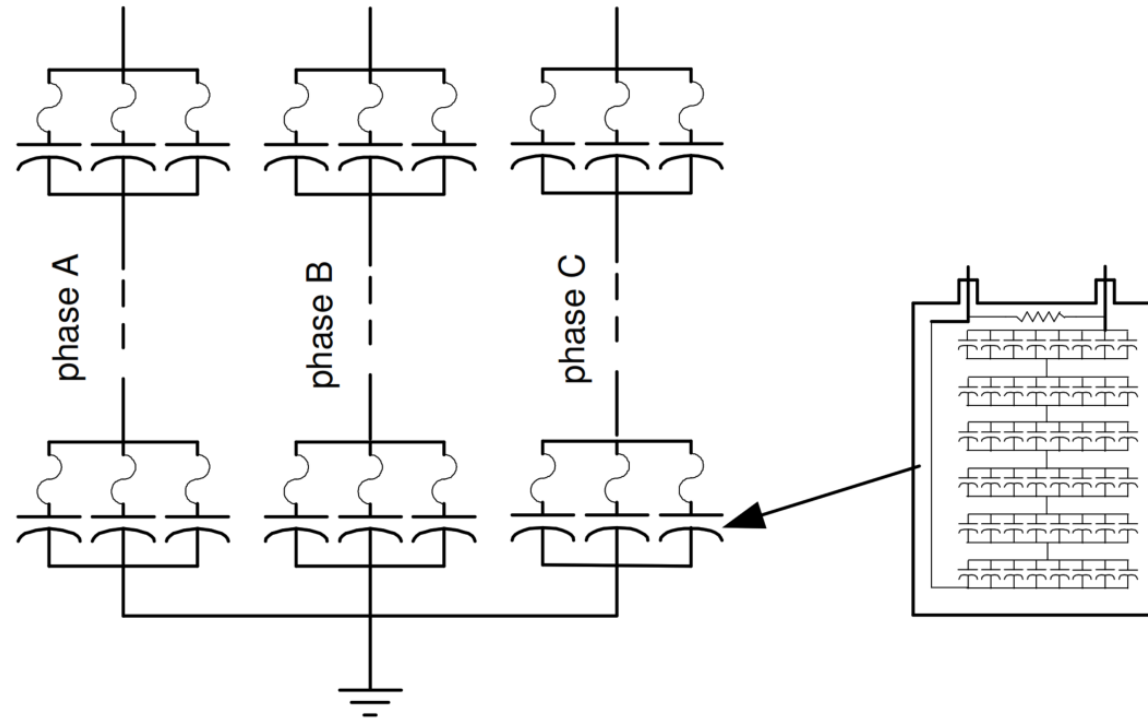
Capacitor and capacitor-bank fundamentals and operation



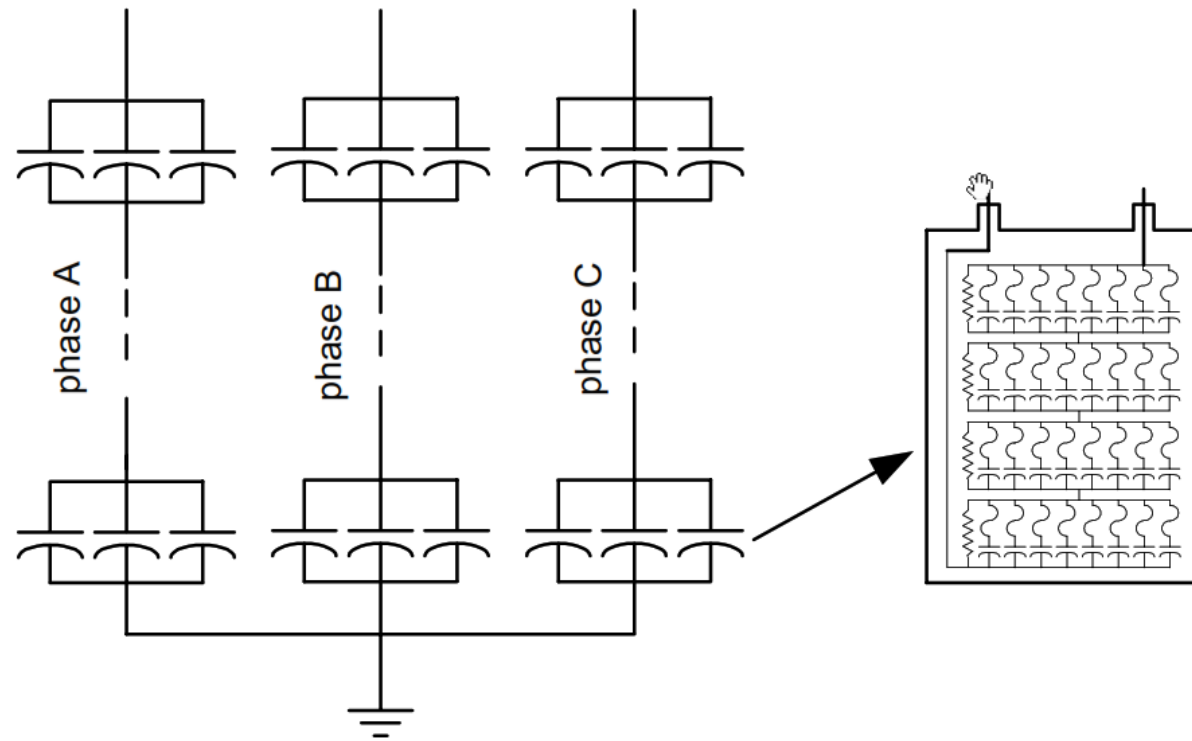
Capacitor unit



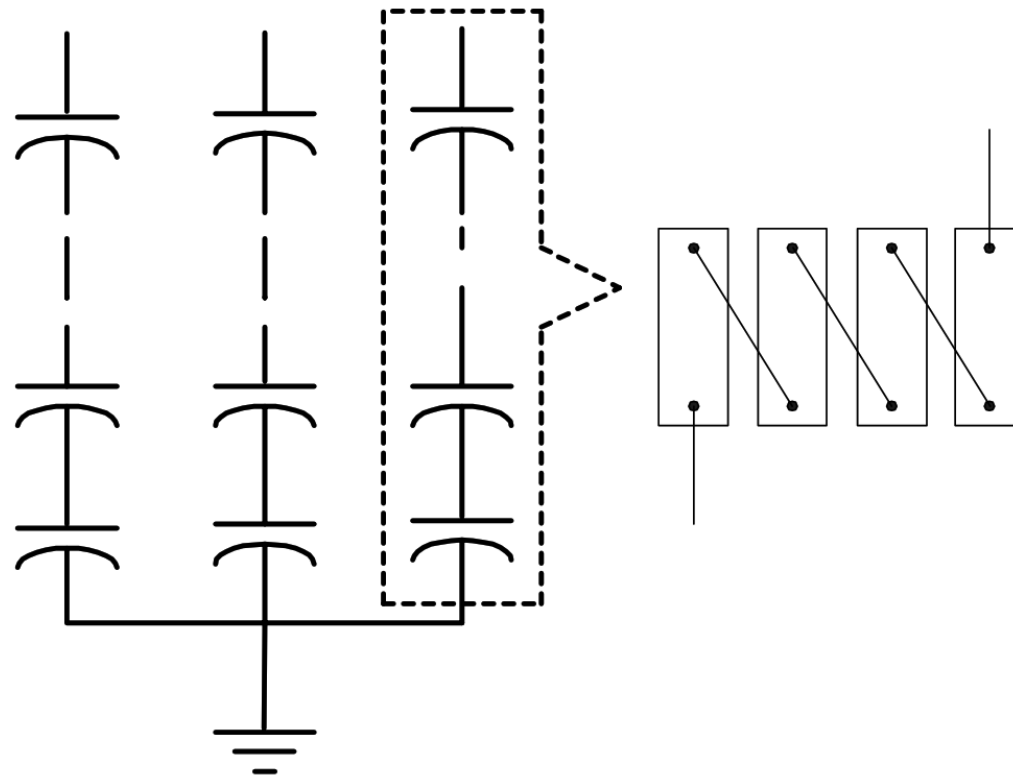
Externally fused shunt capacitor bank and capacitor unit



Internally fused shunt capacitor bank and capacitor unit



Fuseless shunt capacitor bank and series string

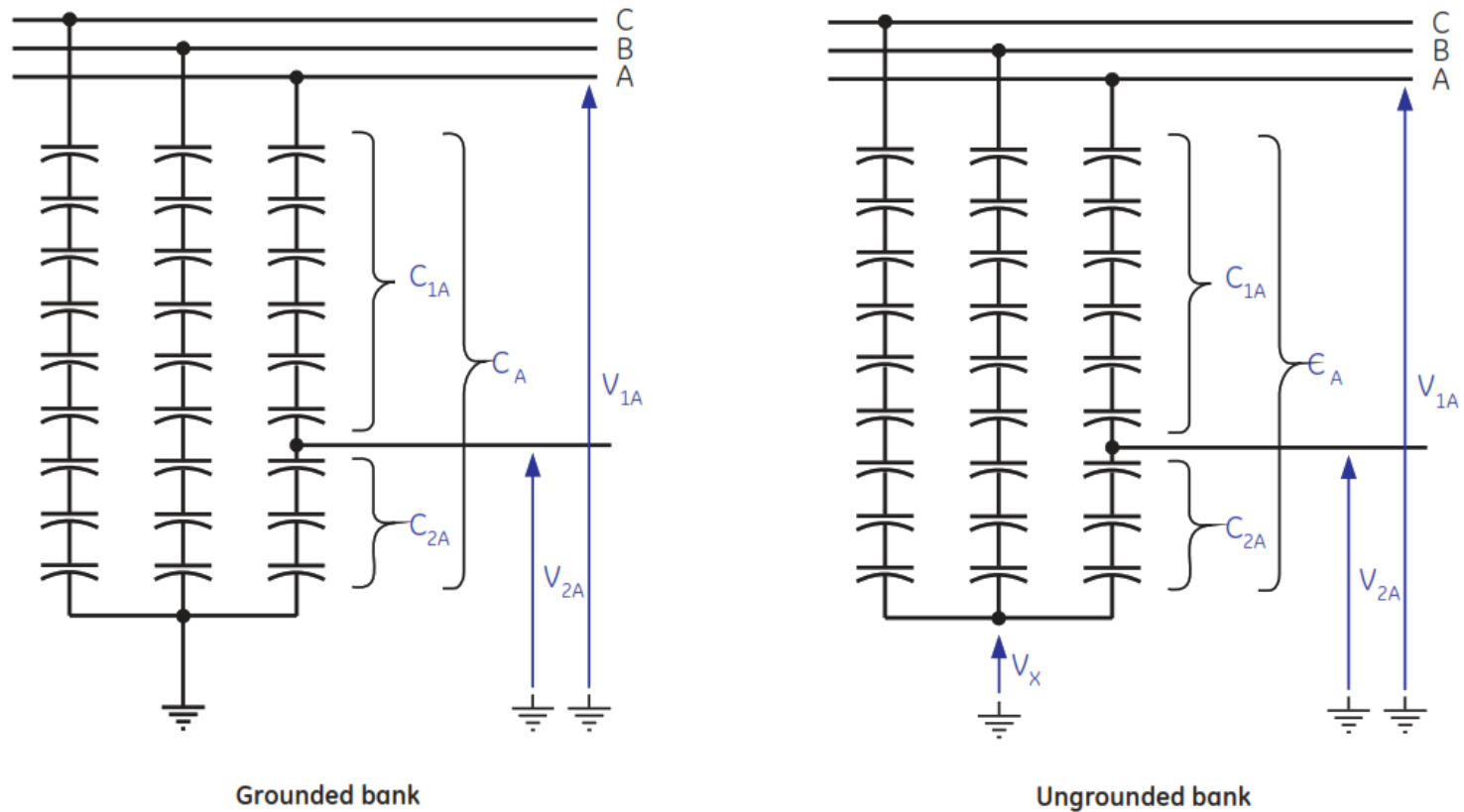


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Capacitor bank protection

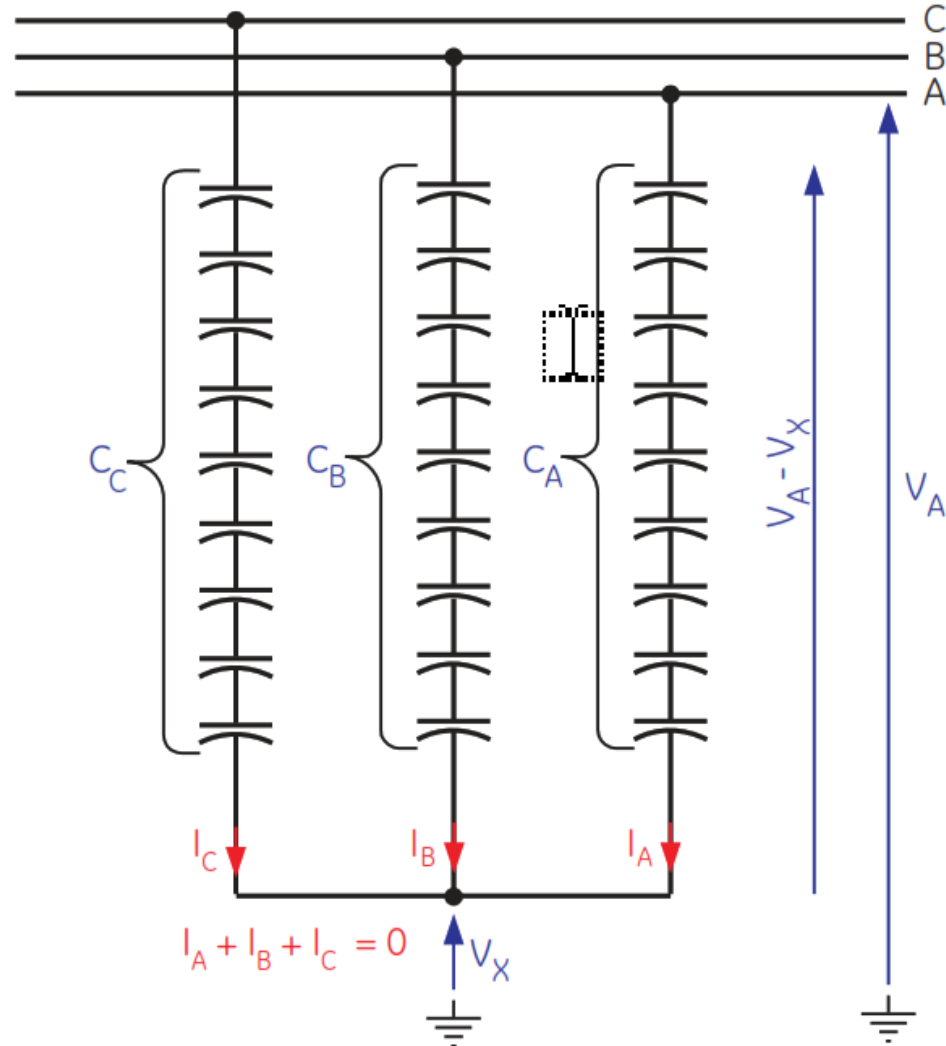


Measuring points for voltage differential 87V protection

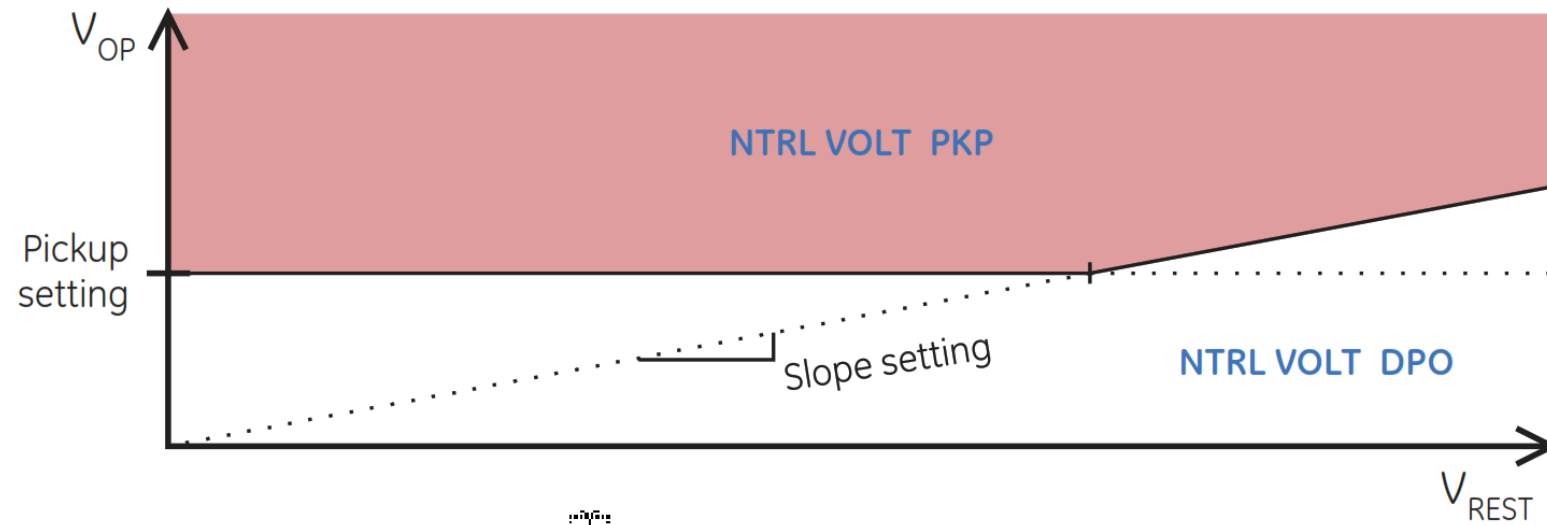


834750A1.CDR

Compensated bank neutral overvoltage 59NU

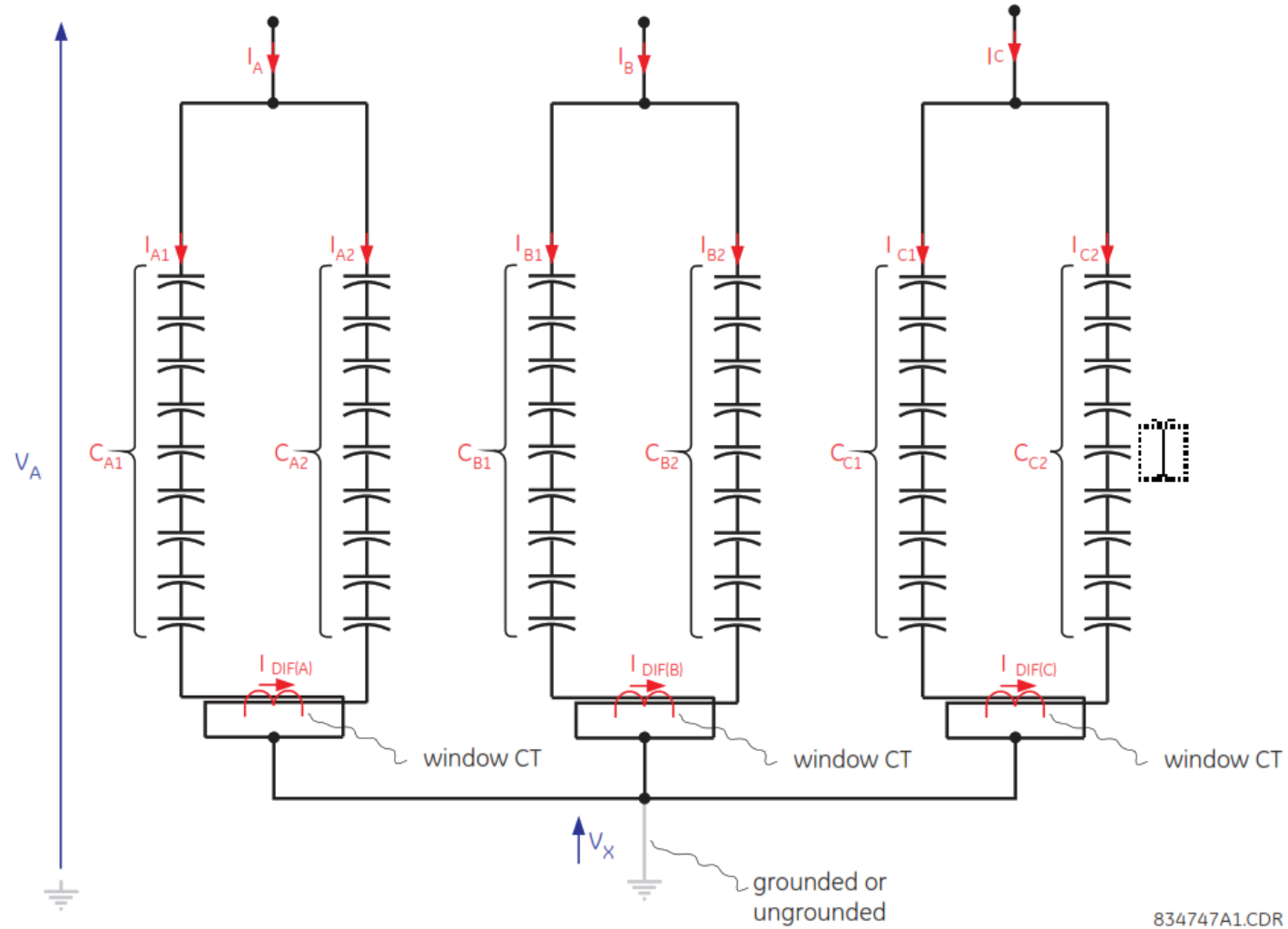


Neutral overvoltage 59NU restraint

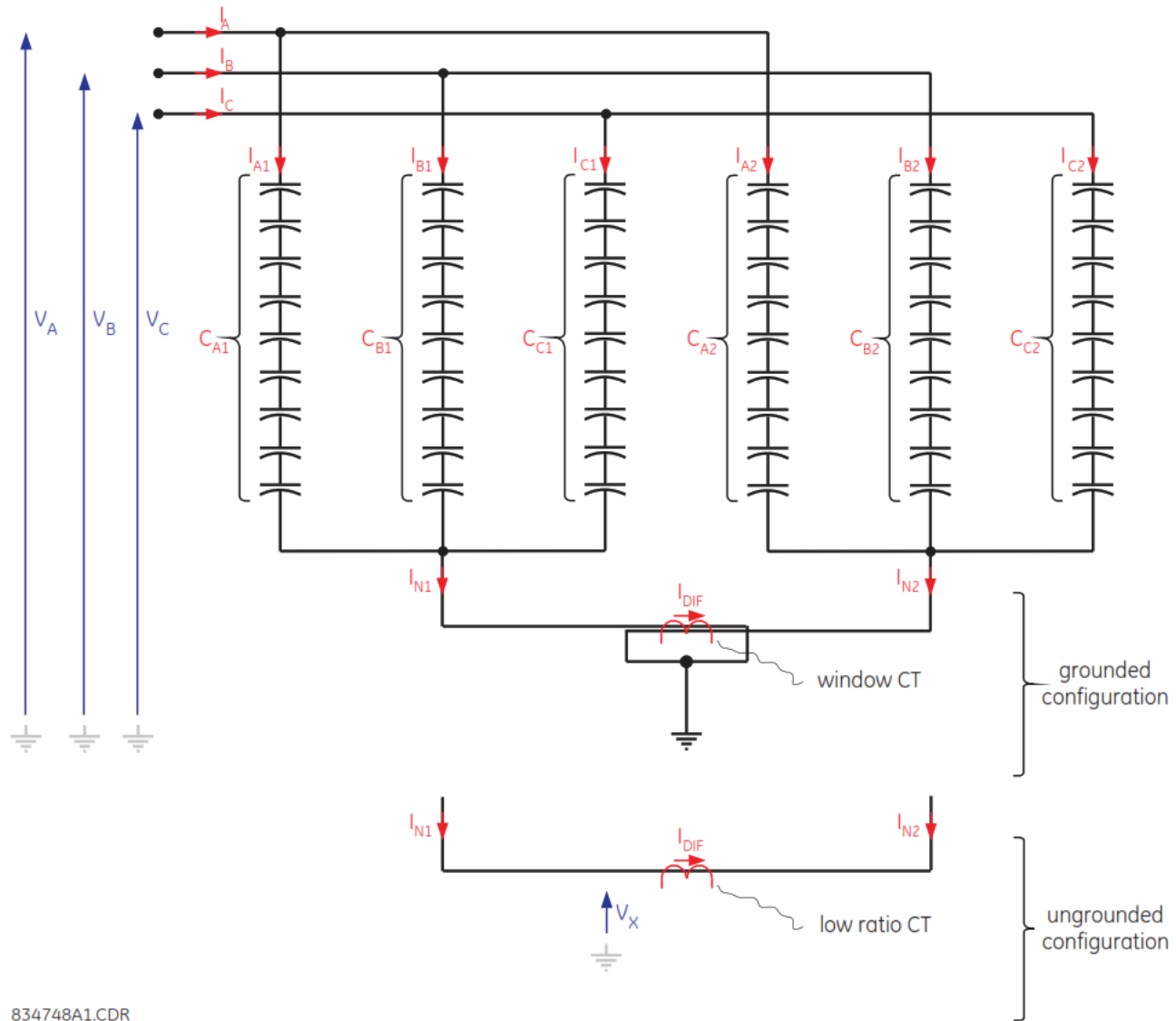


834746A1.CDR

Phase current unbalance 60P

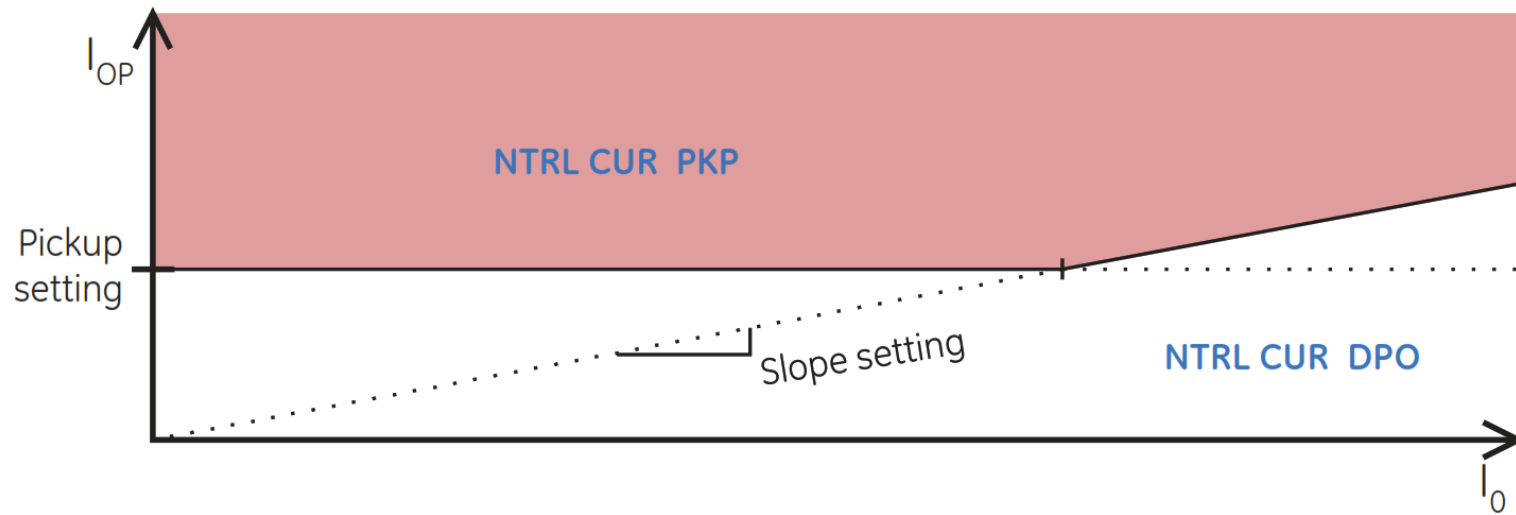


Neutral current unbalance 60N



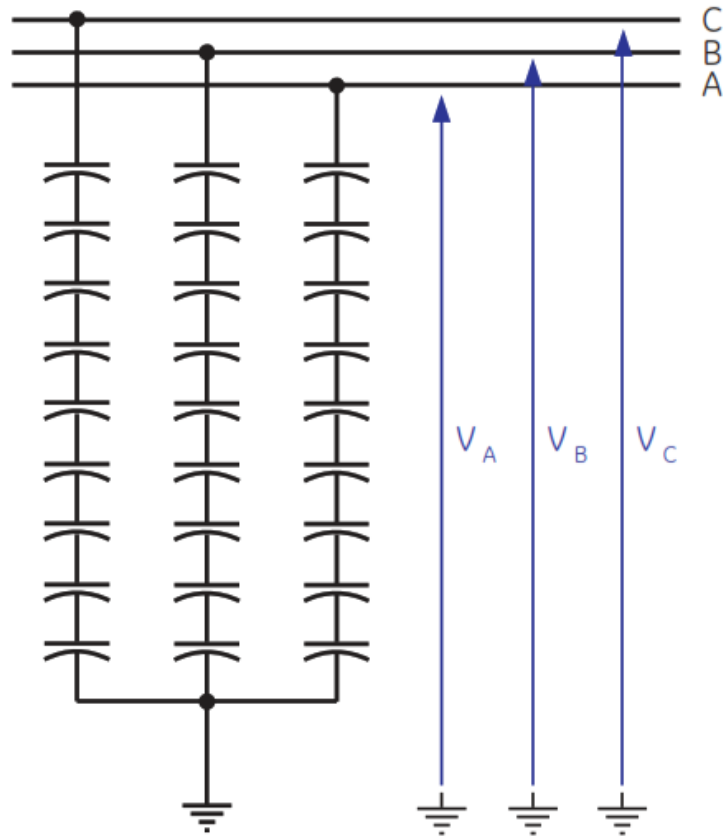
834748A1.CDR

Neutral current unbalance 60N restraint

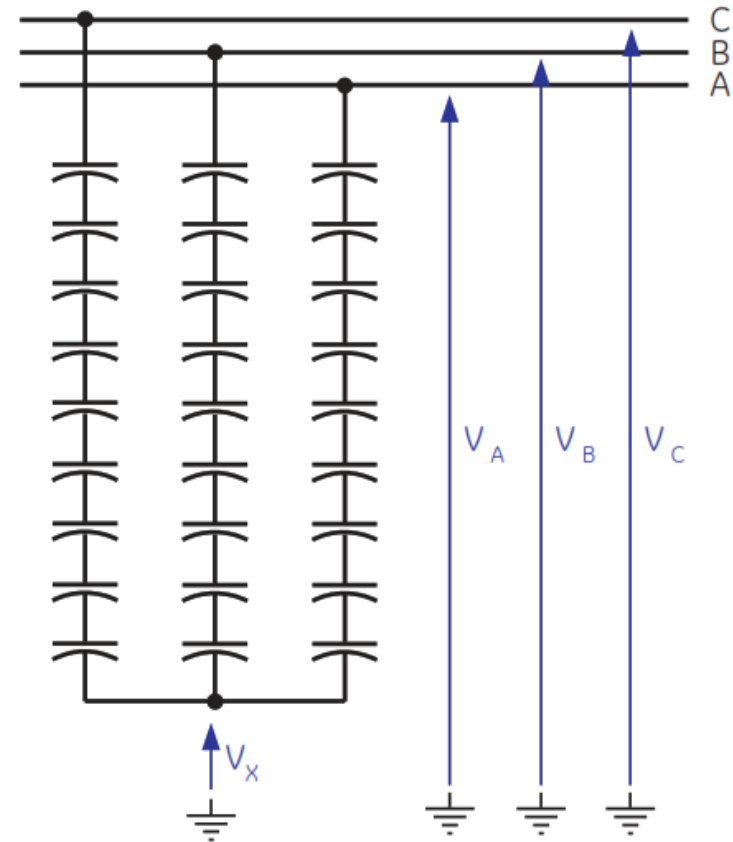


834749A1.CDR

Bank overvoltage 59B for grounded and ungrounded banks



Grounded bank



Ungrounded bank

834744A1.CDR

Sensitivity stages

Set relay elements in multiple stages

Provides sensitivity across large voltage or current range

Complies with standards or manufacturer specifications

Example, manufacturer spec

- 1.25 pu overvoltage for 5 minutes (300 s)
- 1.5 pu overvoltage for 15 seconds
- 2 pu overvoltage for 0.25 second

59B	Amplitude calculation	Pickup setting	50 percent of maximum time (s)
Stage 1	$0.9 \cdot 1.25$	1.125 pu	150
Stage 2	$0.9 \cdot 1.5$	1.35 pu	7.5
Stage 3	$0.9 \cdot 2$	1.80 pu	0.125

SETTING	PARAMETER
Bank OV 1 Function	Enabled
Bank OV 1 Bus Source	Bank (SRC 1)
Bank OV 1 Ntrl Source	Bank (SRC 1)
Bank OV 1 Bank Ground	Grounded
Bank OV 1 Curve	Flexcurve A
Bank OV 1 Curve Time Multiplier	1.00
Bank OV 1 STG 1A Pickup	1.125 pu
Bank OV 1 STG 2A Pickup	1.350 pu
Bank OV 1 STG 3A Pickup	1.800 pu
Bank OV 1 STG 4A Pickup	1.050 pu
Bank OV 1 STG 1B Pickup	1.125 pu
Bank OV 1 STG 2B Pickup	1.350 pu
Bank OV 1 STG 3B Pickup	1.800 pu
Bank OV 1 STG 4B Pickup	1.050 pu
Bank OV 1 STG 1C Pickup	1.125 pu
Bank OV 1 STG 2C Pickup	1.350 pu
Bank OV 1 STG 3C Pickup	1.800 pu
Bank OV 1 STG 4C Pickup	1.050 pu
Bank OV 1 STG 1 Pickup Delay	150.00 s
Bank OV 1 STG 2 Pickup Delay	7.50 s
Bank OV 1 STG 3 Pickup Delay	0.12 s
Bank OV 1 Dropout Delay	0.25 s
Bank OV 1 BLock	OFF
Bank OV 1 Target	Self-reset
Bank OV 1 Events	Enabled

Auto-setting / self-tuning

Relay measures unbalance on-service capacitor bank

Relay calculates unbalance k-factor settings per phase, determining “zero-ed” point

Apply with manual supervision, or automatically apply calculated factors

After auto-set, relay measures changes to issue alarms and trips

VOLTAGE DIF1 AUTO
SETTING: Enabled

VDIF1A k=0.0249
APPLY IN PHS A? Yes

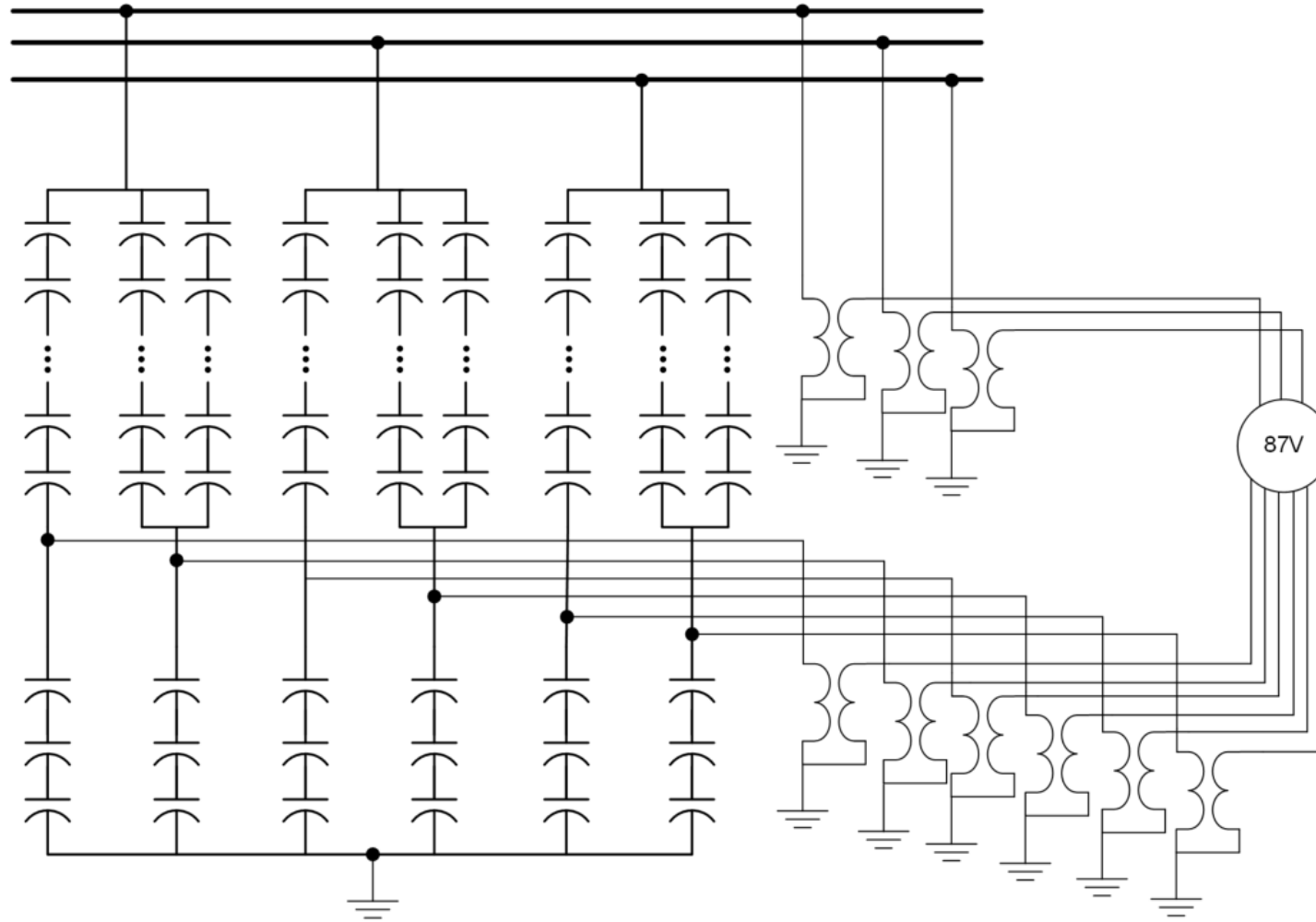
VDIF1A k=0.0249
APPLY IN PHS B? Yes

VDIF1A k=0.0249
APPLY IN PHS C? Yes

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Voltage differential trip upon switching

87V differential connections, grounded wye bank



87V operation event record

Event Recorder - [C:\Users\212762995\Docume...]

File Name: C:\Users\212762995\Documents\GE Renew

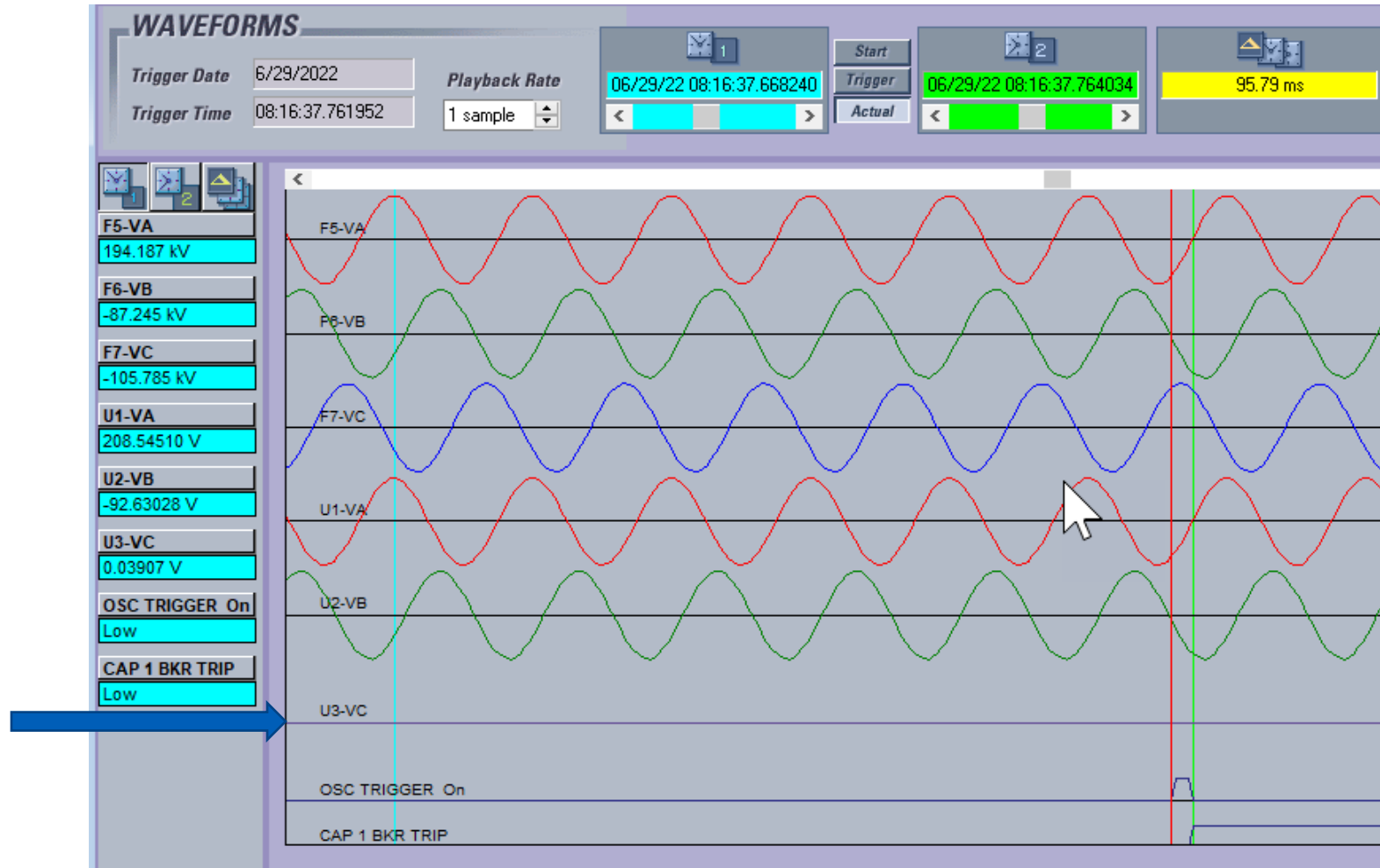
Shown Number of Events

0 days 0 h : 0 m : 2.009419 s

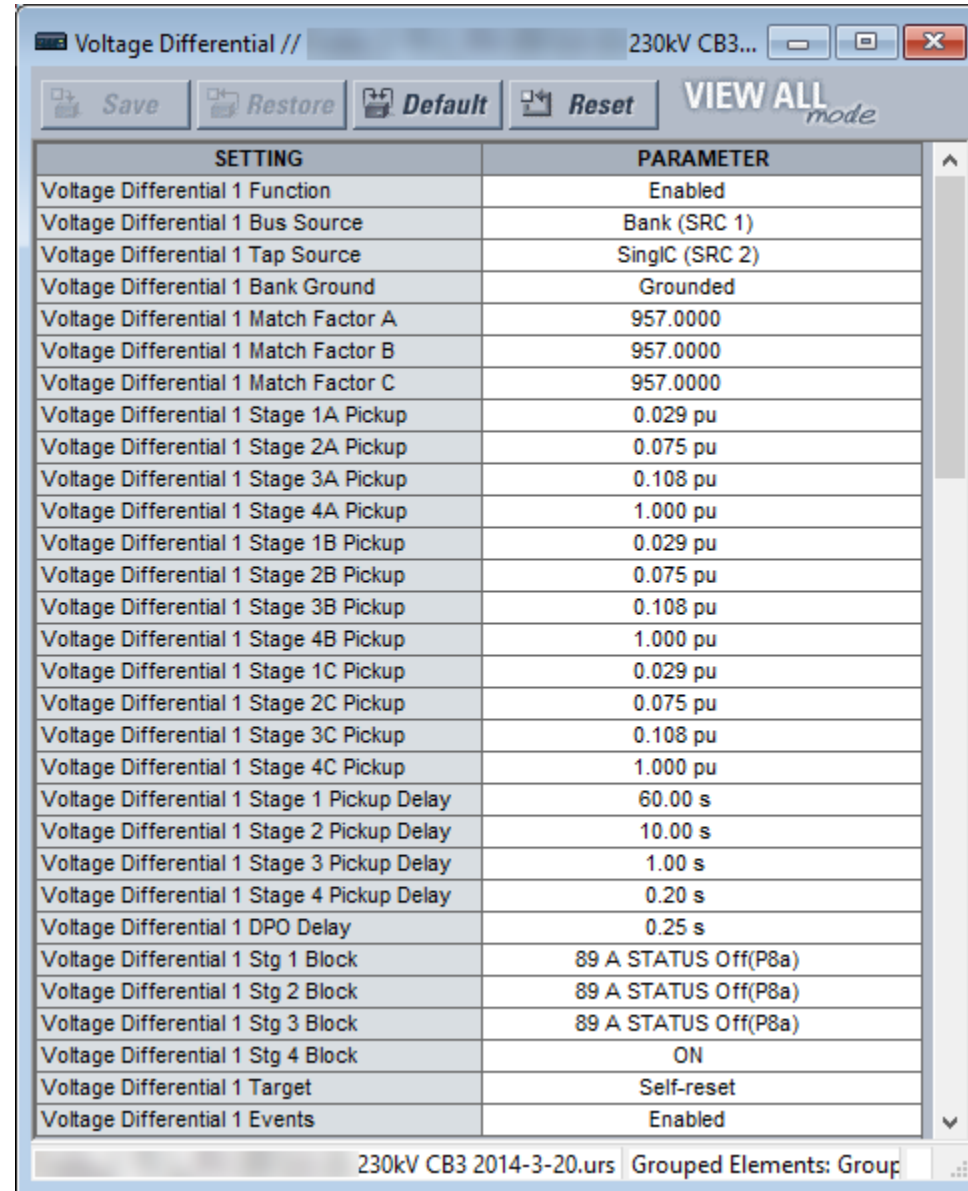
Date/Time	Cause	Data
Jun 29 2022 08:16:37.764035	CAP 1 BKR TRIP	
Jun 29 2022 08:16:37.761952	LATCH 1 ON	
Jun 29 2022 08:16:37.761952	DFR 86CB TRP On	
Jun 29 2022 08:16:37.761952	89 OPEN On	
Jun 29 2022 08:16:37.761952	OSCILLOGRAPHY TRIG'D	
Jun 29 2022 08:16:37.761952	V DIF2 STG3 On	
Jun 29 2022 08:16:37.761952	V DIF 1 STG3 On	
Jun 29 2022 08:16:37.761952	DIF TRIP On	
Jun 29 2022 08:16:37.761952	DIF1 On	
Jun 29 2022 08:16:37.761952	DIF2 On	
Jun 29 2022 08:16:37.761952	VOLT DIF 2 STG3C OP	
Jun 29 2022 08:16:37.761952	VOLT DIF 1 STG3C OP	
Jun 29 2022 08:16:36.761944	VOLT DIF 2 STG3C PKP	
Jun 29 2022 08:16:36.761944	VOLT DIF 2 STG2C PKP	
Jun 29 2022 08:16:36.761944	VOLT DIF 2 STG1C PKP	
Jun 29 2022 08:16:36.761944	VOLT DIF 1 STG3C PKP	
Jun 29 2022 08:16:36.761944	VOLT DIF 1 STG2C PKP	
Jun 29 2022 08:16:36.761944	VOLT DIF 1 STG1C PKP	
Jun 29 2022 08:16:36.681477	SUPV CLOSE Off	
Jun 29 2022 08:16:36.666113	CLOSE CAP BK Off	
Jun 29 2022 08:16:36.664031	89 BLK CLS Off	
Jun 29 2022 08:16:36.664031	89 CLOSE Off	
Jun 29 2022 08:16:36.664031	89BLK CLOSE Off	
Jun 29 2022 08:16:36.664031	89 A CONT Off	
Jun 29 2022 08:16:36.664031	CAP 1 DISCHARGING	
Jun 29 2022 08:16:36.661462	89 A STATUS On	
Jun 29 2022 08:16:36.551531	NEUTRAL TOC1 DPO	
Jun 29 2022 08:16:36.543197	NEUTRAL TOC1 PKP	
Jun 29 2022 08:16:36.509860	NEUTRAL TOC1 DPO	
Jun 29 2022 08:16:36.501522	NEUTRAL TOC1 PKP	
Jun 29 2022 08:16:35.759841	89 CLOSE On	
Jun 29 2022 08:16:35.759841	CAP 1 BKR CLOSE	
Jun 29 2022 08:16:35.757756	CLOSE CAP BK On	
Jun 29 2022 08:16:35.754616	SUPV CLOSE On	



87V operation from lack of source VC



87V settings



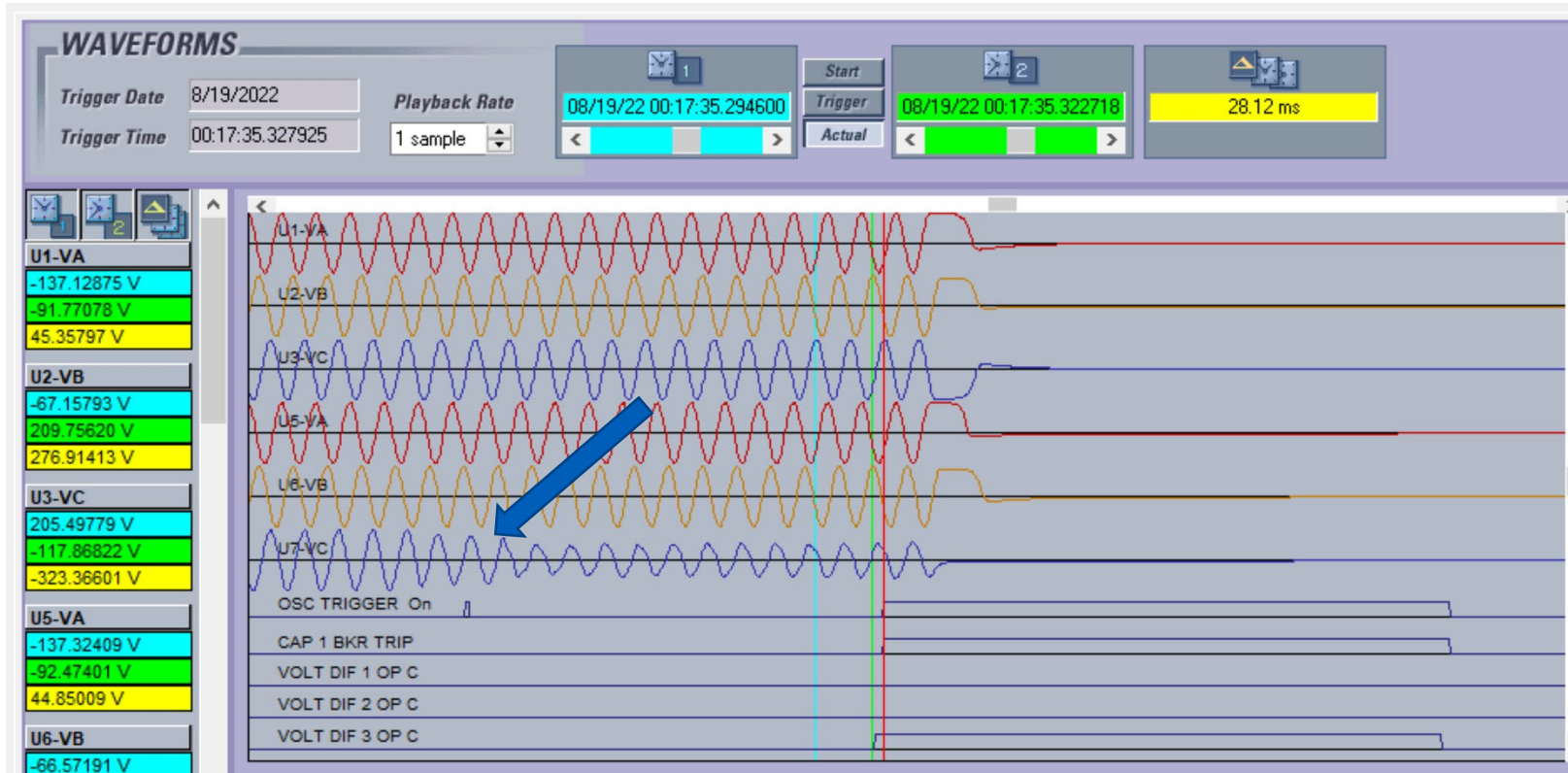
SETTING	PARAMETER
Voltage Differential 1 Function	Enabled
Voltage Differential 1 Bus Source	Bank (SRC 1)
Voltage Differential 1 Tap Source	SingIC (SRC 2)
Voltage Differential 1 Bank Ground	Grounded
Voltage Differential 1 Match Factor A	957.0000
Voltage Differential 1 Match Factor B	957.0000
Voltage Differential 1 Match Factor C	957.0000
Voltage Differential 1 Stage 1A Pickup	0.029 pu
Voltage Differential 1 Stage 2A Pickup	0.075 pu
Voltage Differential 1 Stage 3A Pickup	0.108 pu
Voltage Differential 1 Stage 4A Pickup	1.000 pu
Voltage Differential 1 Stage 1B Pickup	0.029 pu
Voltage Differential 1 Stage 2B Pickup	0.075 pu
Voltage Differential 1 Stage 3B Pickup	0.108 pu
Voltage Differential 1 Stage 4B Pickup	1.000 pu
Voltage Differential 1 Stage 1C Pickup	0.029 pu
Voltage Differential 1 Stage 2C Pickup	0.075 pu
Voltage Differential 1 Stage 3C Pickup	0.108 pu
Voltage Differential 1 Stage 4C Pickup	1.000 pu
Voltage Differential 1 Stage 1 Pickup Delay	60.00 s
Voltage Differential 1 Stage 2 Pickup Delay	10.00 s
Voltage Differential 1 Stage 3 Pickup Delay	1.00 s
Voltage Differential 1 Stage 4 Pickup Delay	0.20 s
Voltage Differential 1 DPO Delay	0.25 s
Voltage Differential 1 Stg 1 Block	89 A STATUS Off(P8a)
Voltage Differential 1 Stg 2 Block	89 A STATUS Off(P8a)
Voltage Differential 1 Stg 3 Block	89 A STATUS Off(P8a)
Voltage Differential 1 Stg 4 Block	ON
Voltage Differential 1 Target	Self-reset
Voltage Differential 1 Events	Enabled

230kV CB3 2014-3-20.urs Grouped Elements: Group

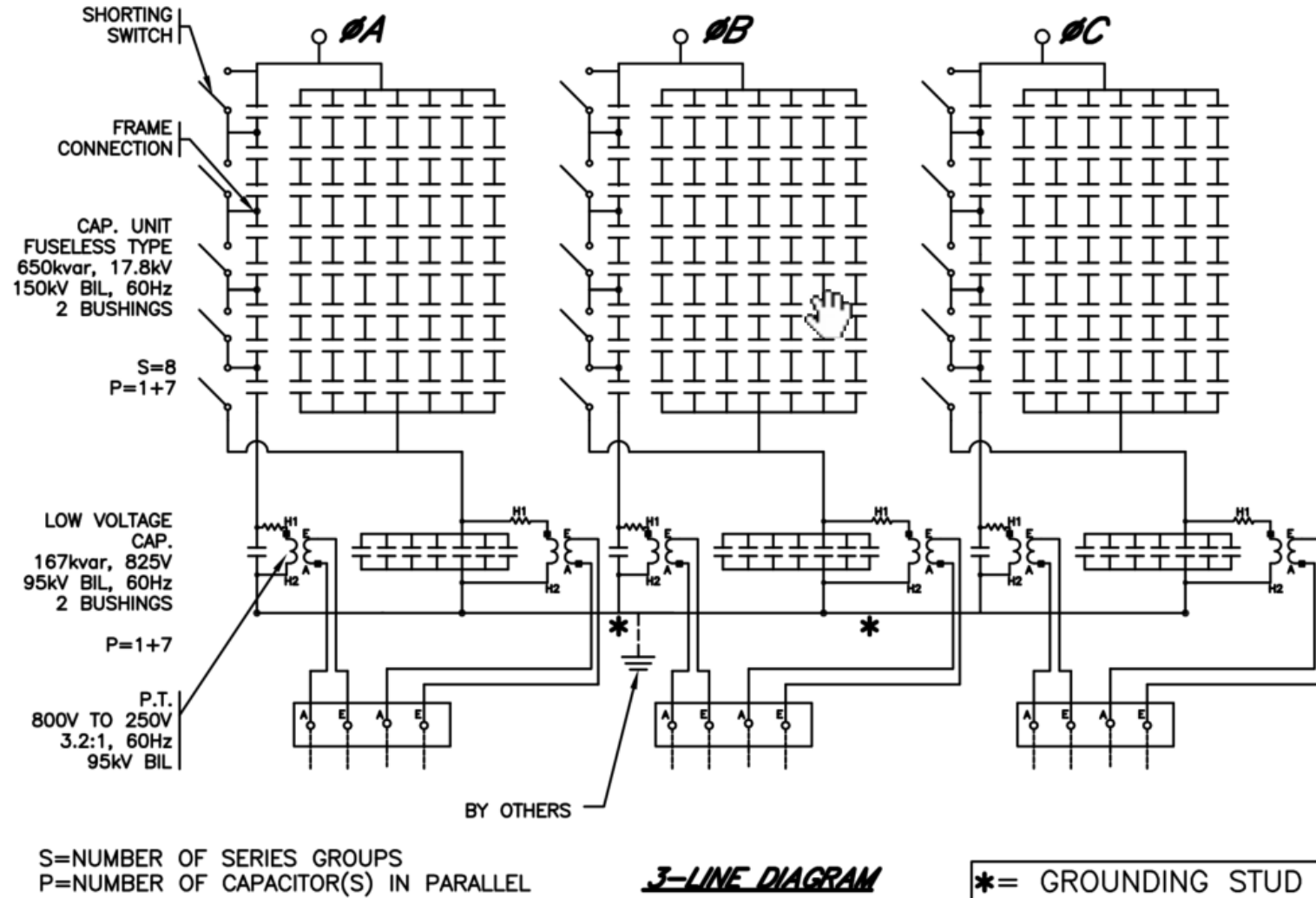
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Voltage differential trip while in service

Phase C voltage drop during operation



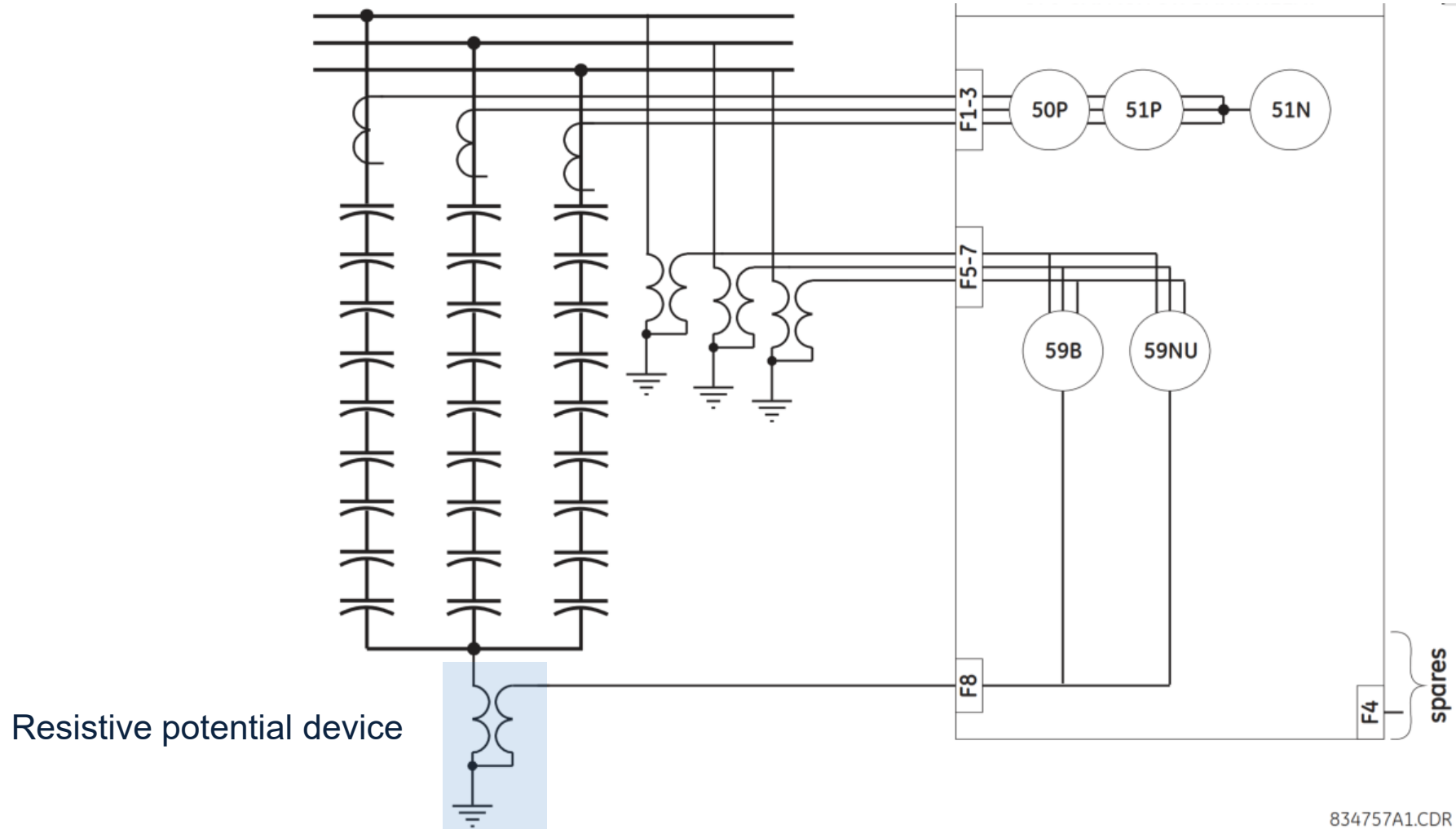
Grounded-wye bank detail



Modern Capacitor Bank Protection Methods

Compensated bank neutral
voltage unbalance (ANSI 59NU)
upon closing

Ungrounded SCB and neutral voltage sensing



Neutral voltage unbalance 59NU settings

SETTING	PARAMETER
Neutral Current Unbalance 1 Function	Enabled
Neutral Current Unbalance 1 Bank Source	NeutUn (SRC 2)
Neutral Current Unbalance 1 k MAG	0.0000
Neutral Current Unbalance 1 k ANG	0 deg
Neutral Current Unbalance 1 STG1 PKP	0.048 pu
Neutral Current Unbalance 1 STG1 SLOPE	0.0 %
Neutral Current Unbalance 1 STG2 PKP	0.072 pu
Neutral Current Unbalance 1 STG2 SLOPE	0.0 %
Neutral Current Unbalance 1 STG3 PKP	0.072 pu
Neutral Current Unbalance 1 STG3 SLOPE	0.0 %
Neutral Current Unbalance 1 STG4 PKP	0.072 pu
Neutral Current Unbalance 1 STG4 SLOPE	0.0 %
Neutral Current Unbalance 1 STG1 DEL	1.00 s
Neutral Current Unbalance 1 STG2 DEL	0.17 s
Neutral Current Unbalance 1 STG3 DEL	0.17 s
Neutral Current Unbalance 1 STG4 DEL	0.17 s
Neutral Current Unbalance 1 DPO DEL	0.25 s
Neutral Current Unbalance 1 STG1 Block	89H-a2 Off(P8a)
Neutral Current Unbalance 1 STG2 Block	89H-a2 Off(P8a)
Neutral Current Unbalance 1 STG3 Block	ON
Neutral Current Unbalance 1 STG4 Block	ON
Neutral Current Unbalance 1 Target	Self-reset
Neutral Current Unbalance 1 Events	Enabled

Grouped Elements: G

Events for neutral unbalance 59NU

Event Recorder - [C:\Users\212762995\Documents\GE...]

File Name: C:\Users\212762995\Documents\GE Renewable E

Shown Number of Events: 0 days 0 h : 0 m : 1.608632 s

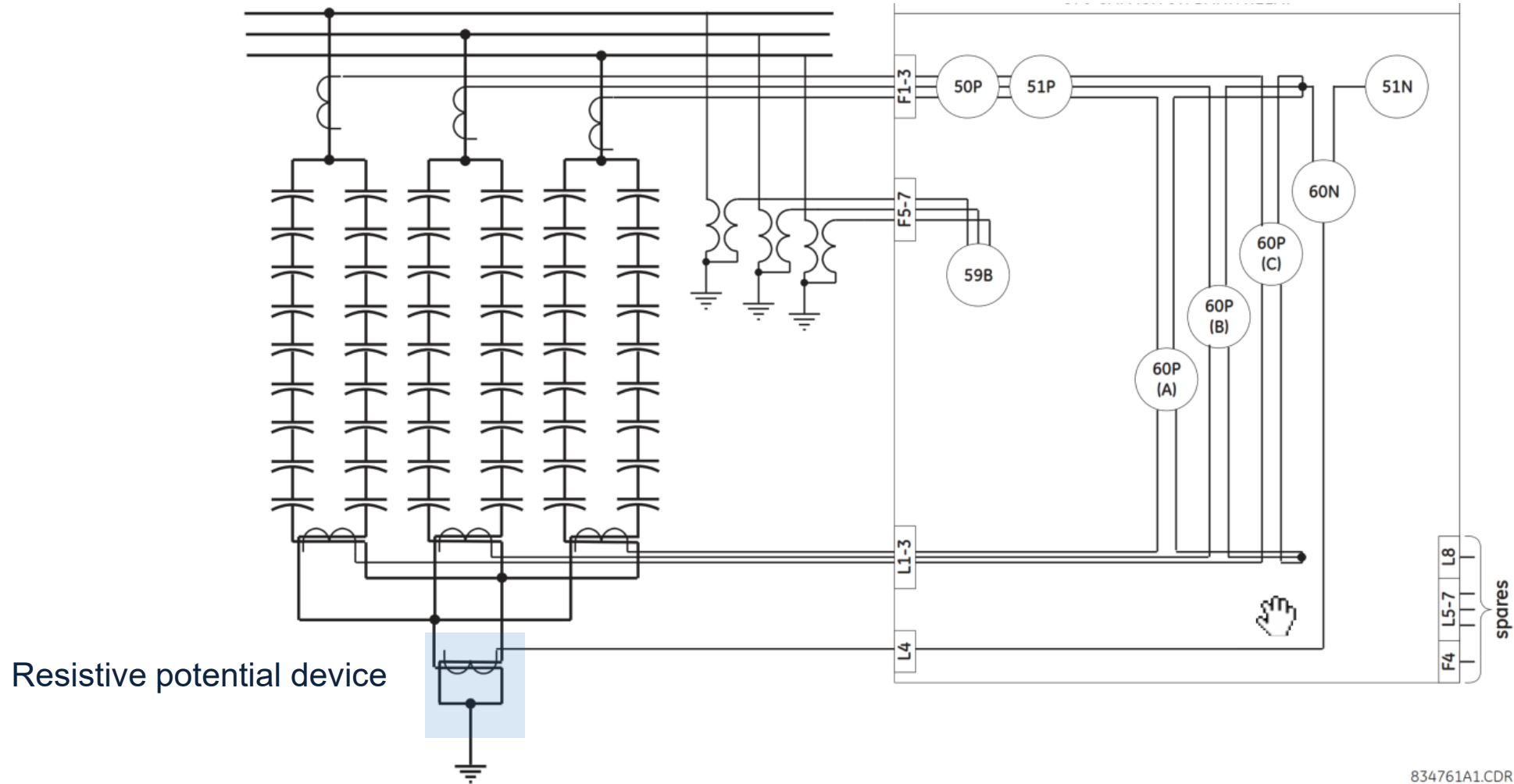
Event Nu	Date/Time	Cause	Da
49594	Sep 29 2022 16:33:14.515970	CAP 1 BKR TRIP	
49593	Sep 29 2022 16:33:14.515970	LATCH 1 ON	
49592	Sep 29 2022 16:33:14.515970	USER FAULT RPT TRIG	
49591	Sep 29 2022 16:33:14.513888	89 SHNT TRIP On	
49590	Sep 29 2022 16:33:14.513888	OSCILLOGRAPHY TRIG'D	
49589	Sep 29 2022 16:33:14.513888	TRIP On	
49588	Sep 29 2022 16:33:14.513888	VLT UNBAL TR On	
49587	Sep 29 2022 16:33:14.513888	NTRL VOLT 1 OP	
49586	Sep 29 2022 16:33:14.513888	NTRL VOLT 1 STG4 OP	
49585	Sep 29 2022 16:33:13.782610	NTRL VOLT 1 STG3 PKP	
49584	Sep 29 2022 16:33:13.782610	NTRL VOLT 1 STG2 PKP	
49583	Sep 29 2022 16:33:13.782610	NTRL VOLT 1 STG1 PKP	
49582	Sep 29 2022 16:33:13.712903	SUPV CLOSE Off	
49581	Sep 29 2022 16:33:13.693026	89 BLK CLS Off	
49580	Sep 29 2022 16:33:13.693026	89 CLOSE Off	
49579	Sep 29 2022 16:33:13.693026	BLK CLS LED On	
49578	Sep 29 2022 16:33:13.693026	89BLK CLOSE Off	
49577	Sep 29 2022 16:33:13.693026	CLOSE CAP BK Off	
49576	Sep 29 2022 16:33:13.693026	89 A CONT Off	
49575	Sep 29 2022 16:33:13.693026	CAP 1 DISCHARGING	
49574	Sep 29 2022 16:33:13.689403	89H-a2 On	
49573	Sep 29 2022 16:33:13.513861	OSCILLOGRAPHY TRIG'D	
49572	Sep 29 2022 16:33:13.513861	NTRL VOLT 1 PKP	
49571	Sep 29 2022 16:33:13.513861	NTRL VOLT 1 STG4 PKP	
49570	Sep 29 2022 16:33:12.911743	89 CLOSE On	
49569	Sep 29 2022 16:33:12.911743	CAP 1 BKR CLOSE	
49568	Sep 29 2022 16:33:12.909660	CLOSE CAP BK On	
49567	Sep 29 2022 16:33:12.907338	SUPV CLOSE On	
49566	Sep 29 2022 16:33:12.907338	AVR 1 CLOSE Off	



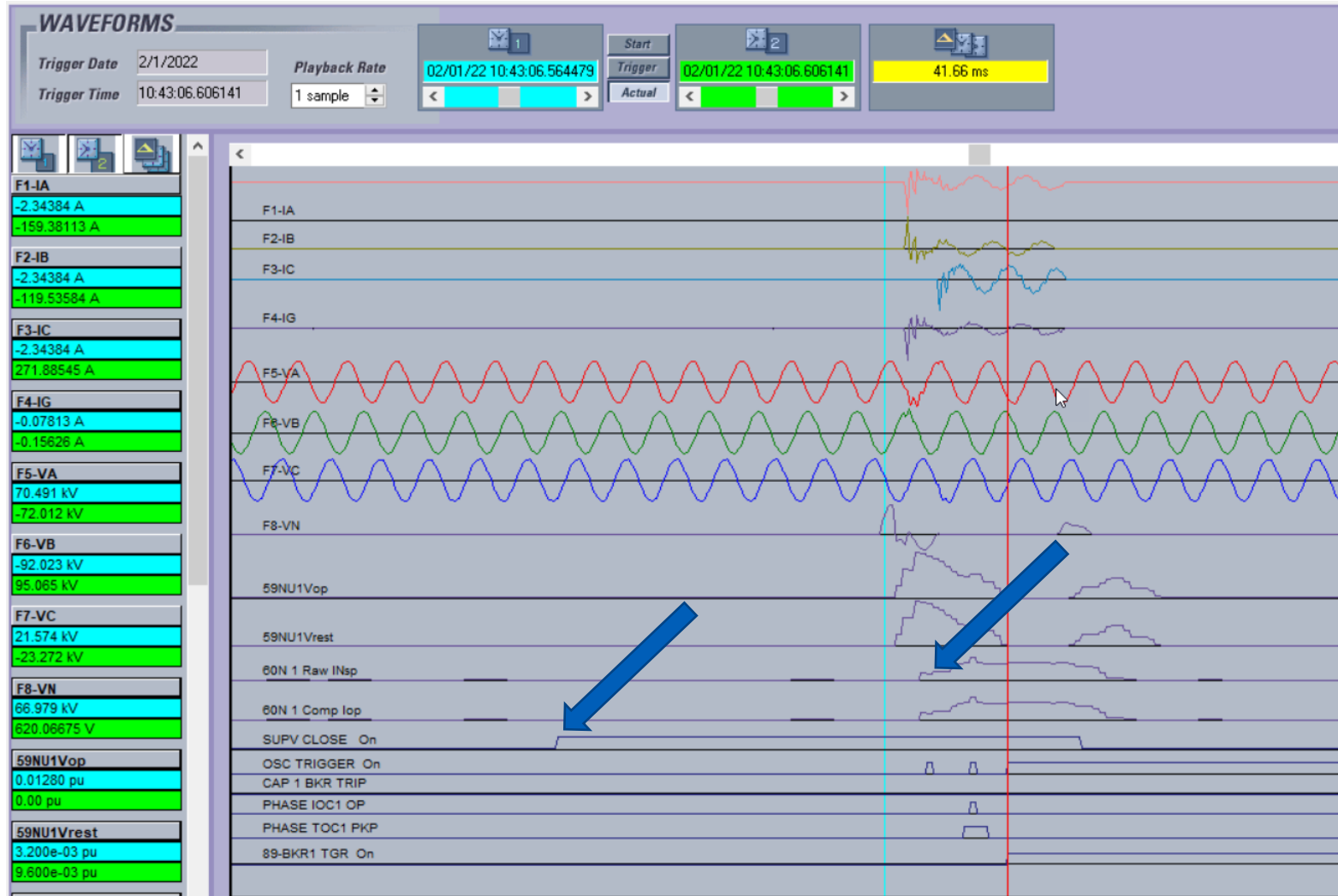
Modern Capacitor Bank Protection Methods

Bank overcurrent 60N
upon closing

Current balance protection 60N and 60P



Closing SCB event



Conclusions

Protecting capacitor banks is challenging

Effective protection methods

- Voltage differential (87V)
- Neutral-voltage unbalance (59NU)
- Phase-current unbalance (60P)
- Neutral-current unbalance (60N)
- Bank phase overvoltage (59B)

Compensate for unbalances through auto setting and self-tuning

Real-world examples showed applications of protection methods

Questions?