FDA Conference April 30 to May 1, 2018

Gregg 230 kV SS Shunt Capacitor Bank Failure and Cascading Area Disturbances

Leo B. Hisugan, P.E., Supervising Protection Engineer, PG&E

Aaron M. Feathers, P.E., Principal Protection Engineer, PG&E

GREGG 230 KV SWITCHING STATION

(8) - 230 KV PILOT TRANSMISSION LINES
(2) – 230 KV SHUNT CAPACITOR BANKS, 150.28 MVAR TOTAL
(2) – 230 KV SHUNT INDUCTOR BANKS, 100 MVAR TOTAL

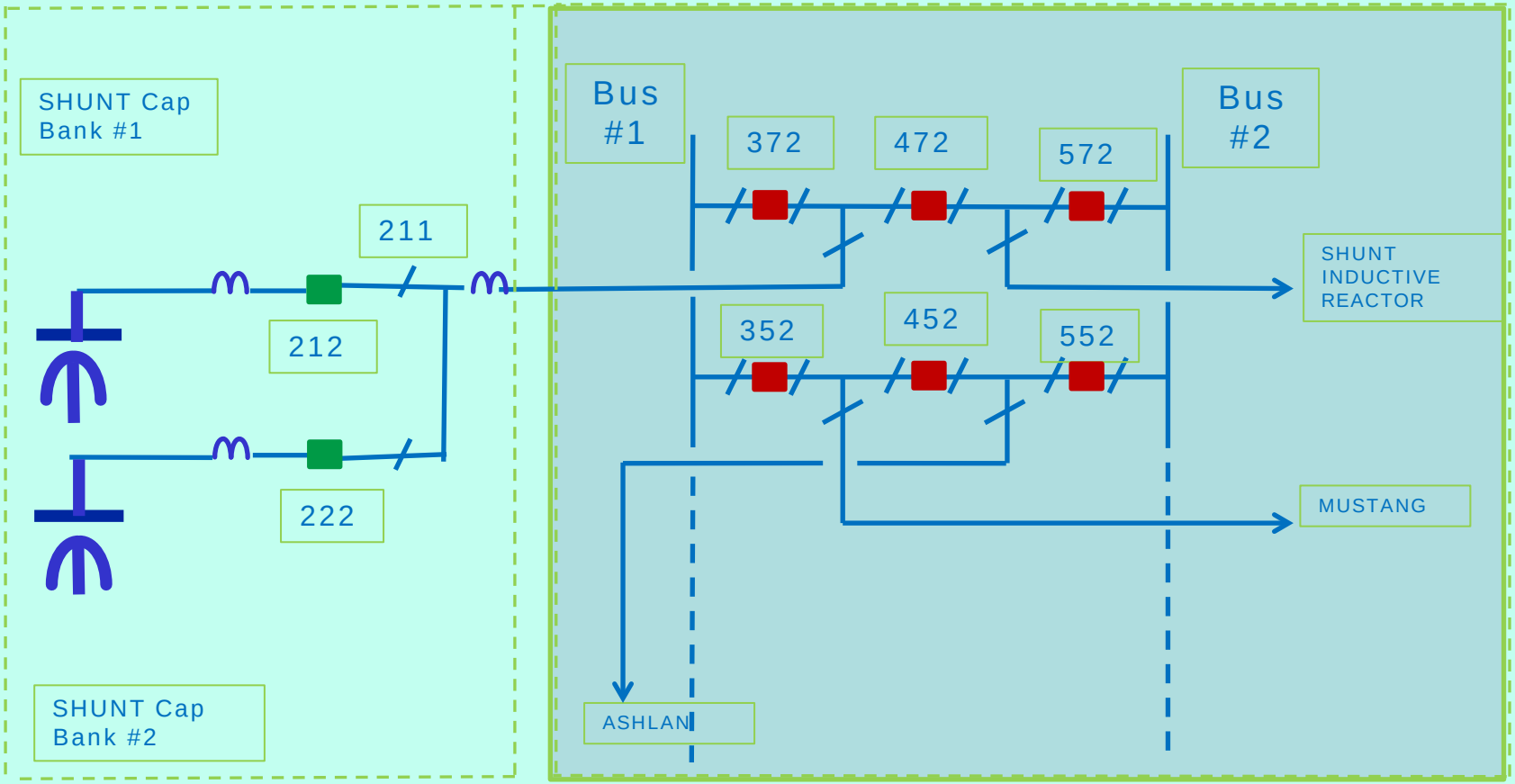
GREGG 230 KV SHUNT REACTOR BANKS
100 MVAR

GREGG 230 KV SHUNT CAPACITOR BANKS
150.28 MVAR TOTAL

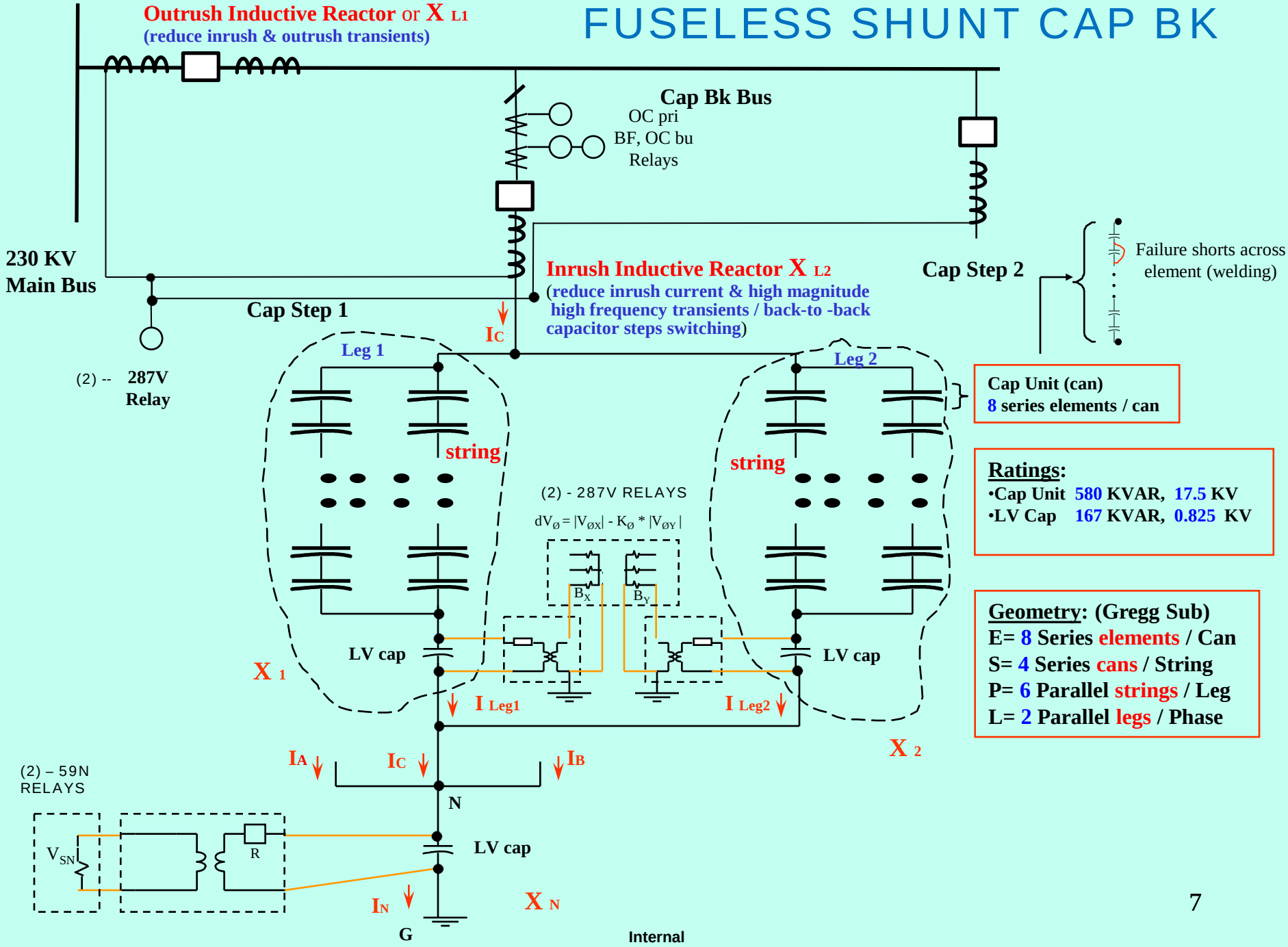
Gregg SS Events Outline

- Gregg SS background
- What cascading events transpired?
- Review and analysis of events
- Findings
- Corrective action plan and execution
- Lessons learned and recommendation
- Questions

Gregg 230 kV SS Partial Single Line Diagram



FUSELESS SHUNT CAP BK

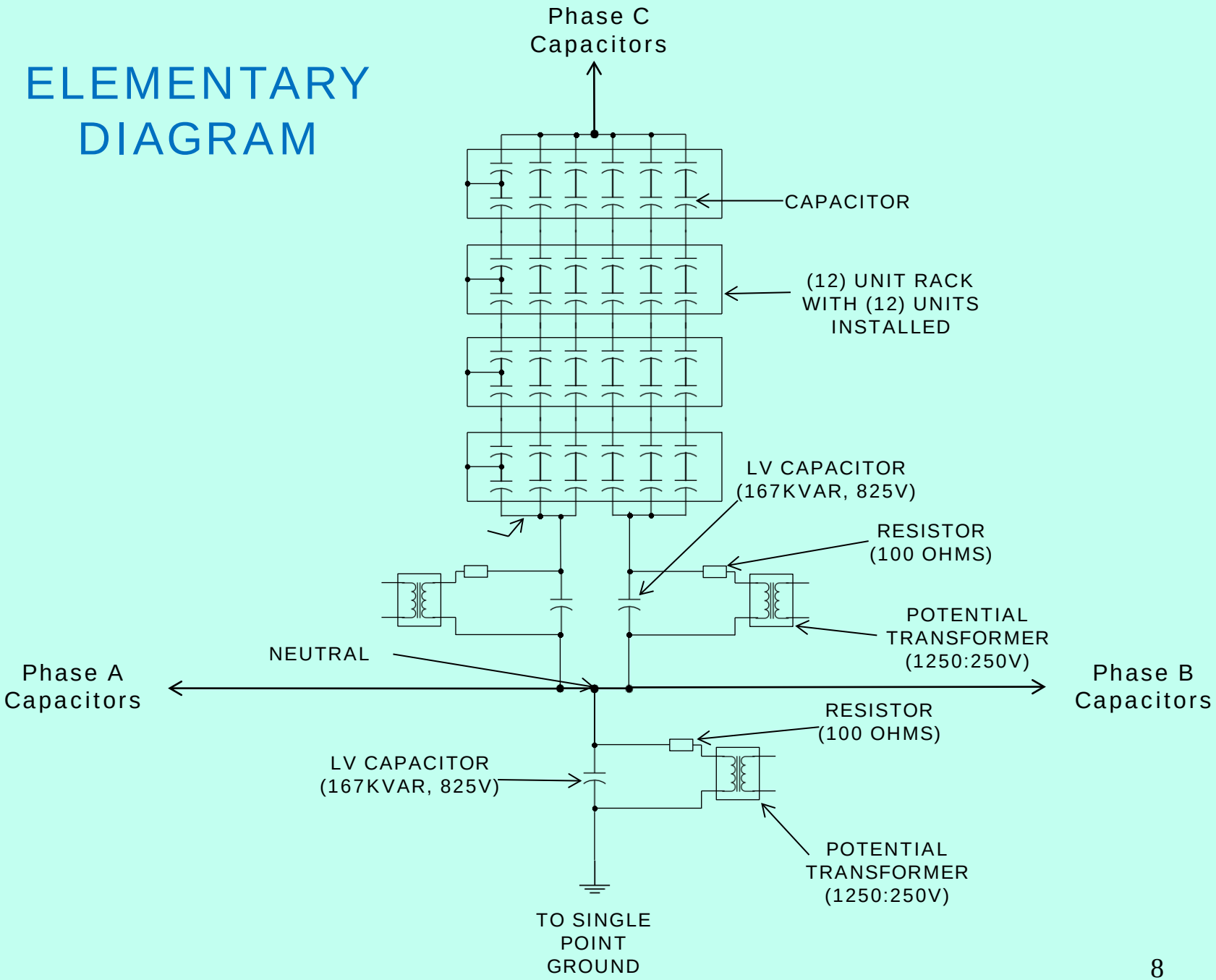


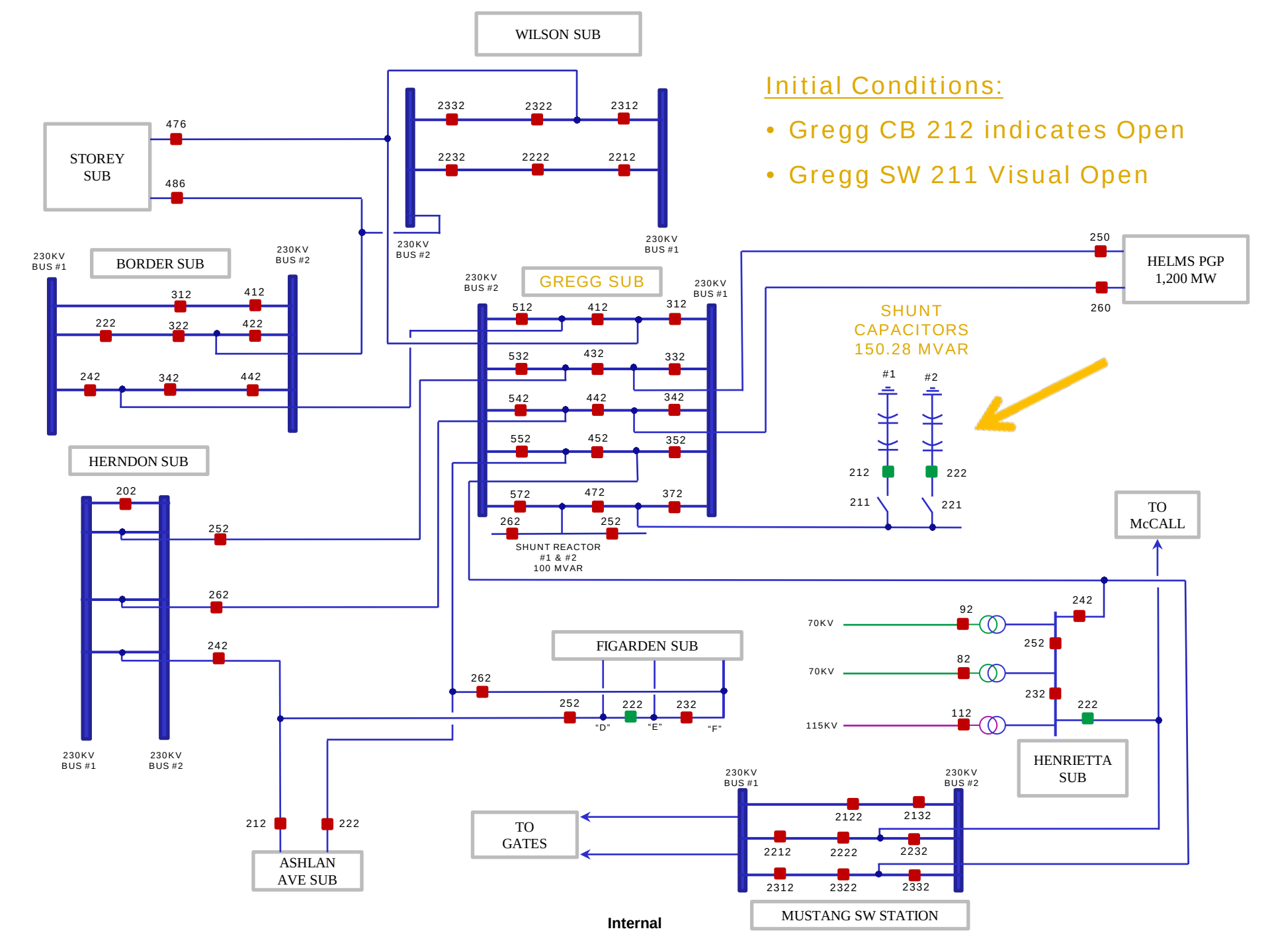
Cap Unit (can)
8 series elements / can

Ratings:
- Cap Unit 580 KVAR, 17.5 KV
- LV Cap 167 KVAR, 0.825 KV

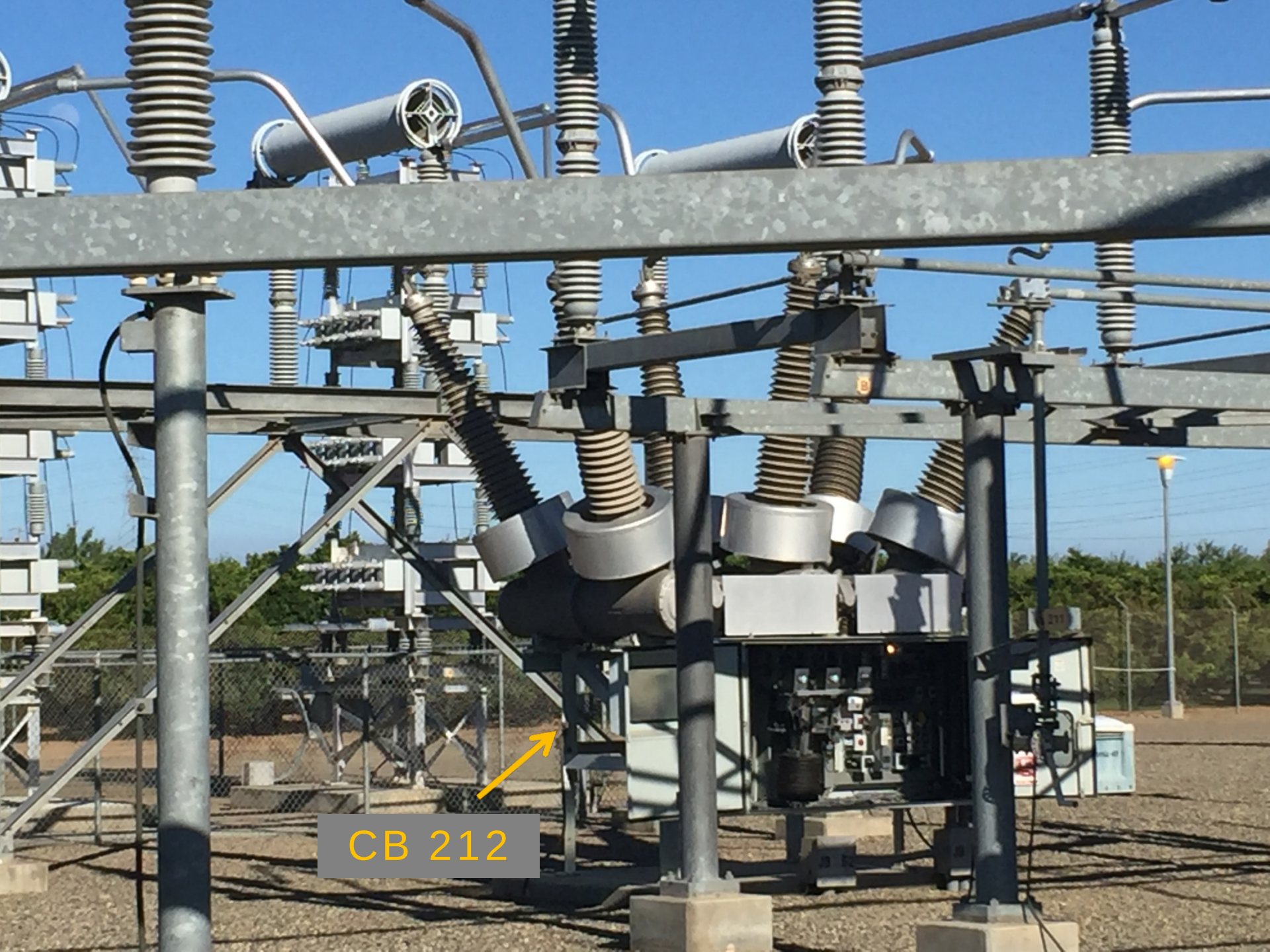
Geometry: (Gregg Sub)
E= 8 Series elements / Can
S= 4 Series cans / String
P= 6 Parallel strings / Leg
L= 2 Parallel legs / Phase

ELEMENTARY DIAGRAM

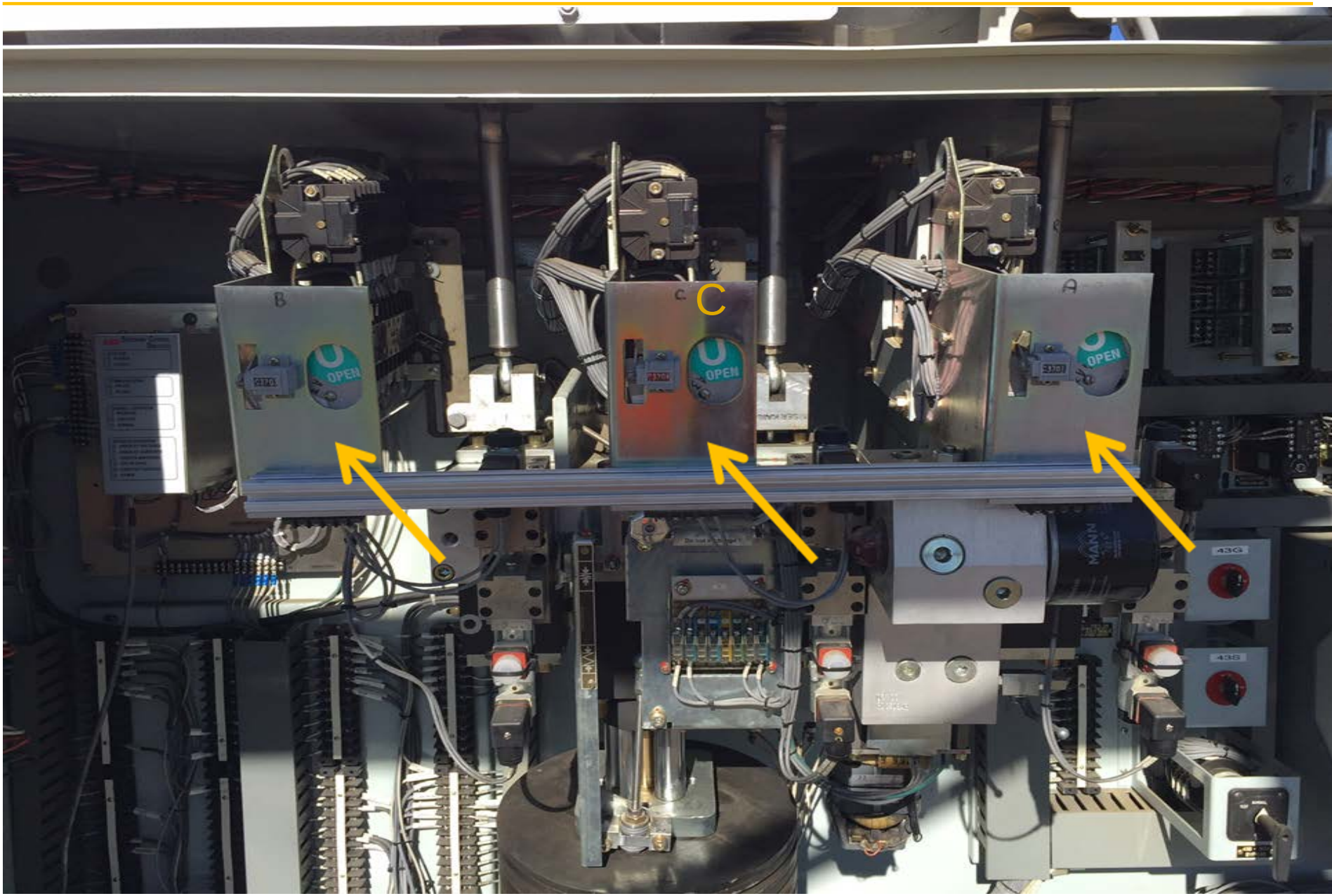



WILSON SUB
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
STOREY SUB
476
486
230KV BUS #1
BORDER SUB
230KV BUS #2
312
412
222
322
422
242
342
442
230KV BUS #2
GREGG SUB
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
250
260
HELMS PGP 1,200 MW
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
TO McCALL
FIGARDEN SUB
262
252
222
232
"D"
"E"
"F"
70KV
92
242
252
70KV
82
232
222
115KV
112
HENRIETTA SUB
212
222
ASHLAN AVE SUB
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Initial Conditions:
• Gregg CB 212 indicates Open
• Gregg SW 211 Visual Open
Internal


230 KV SWITCH 211
HVCB 212

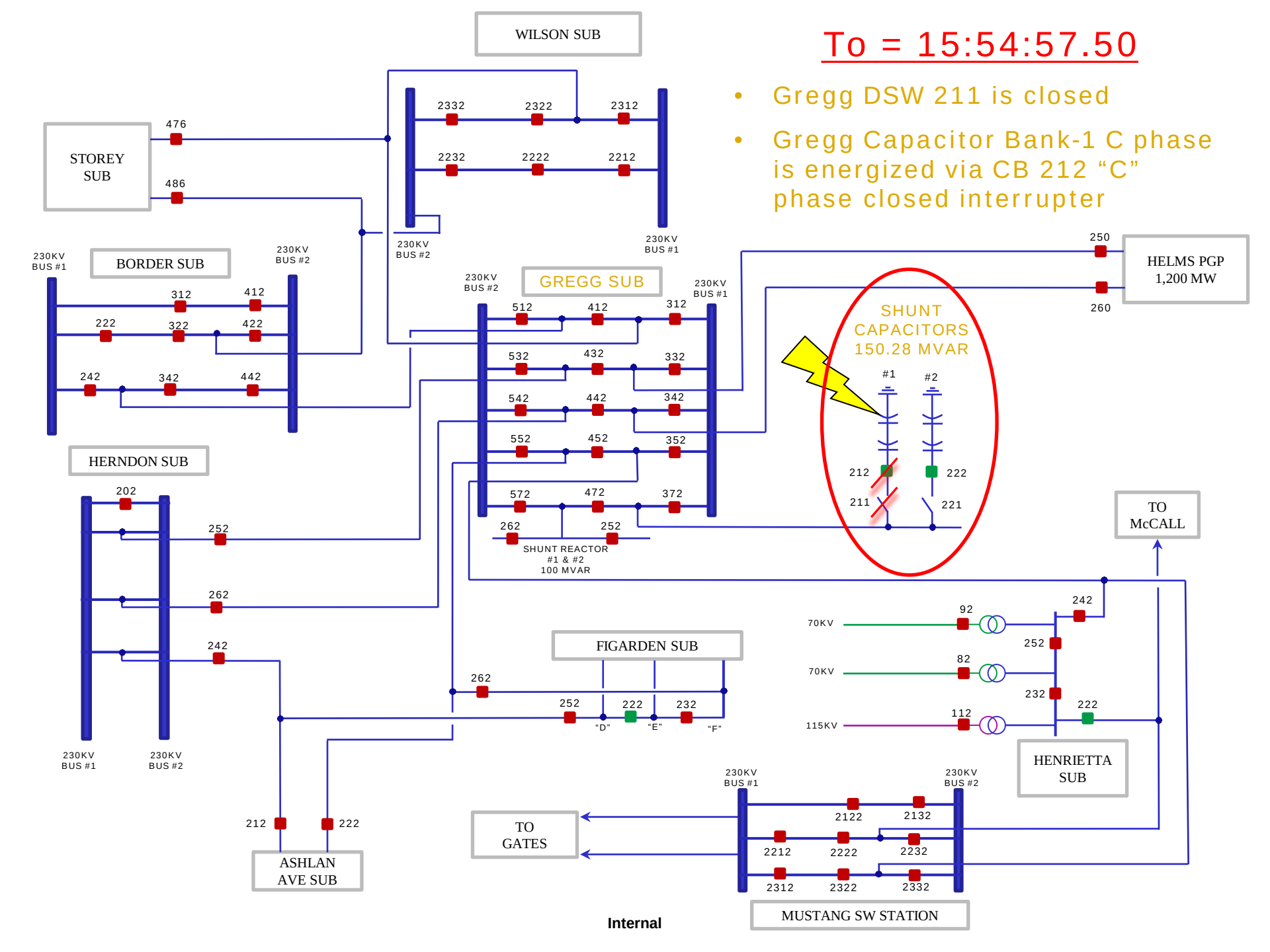

CB 212

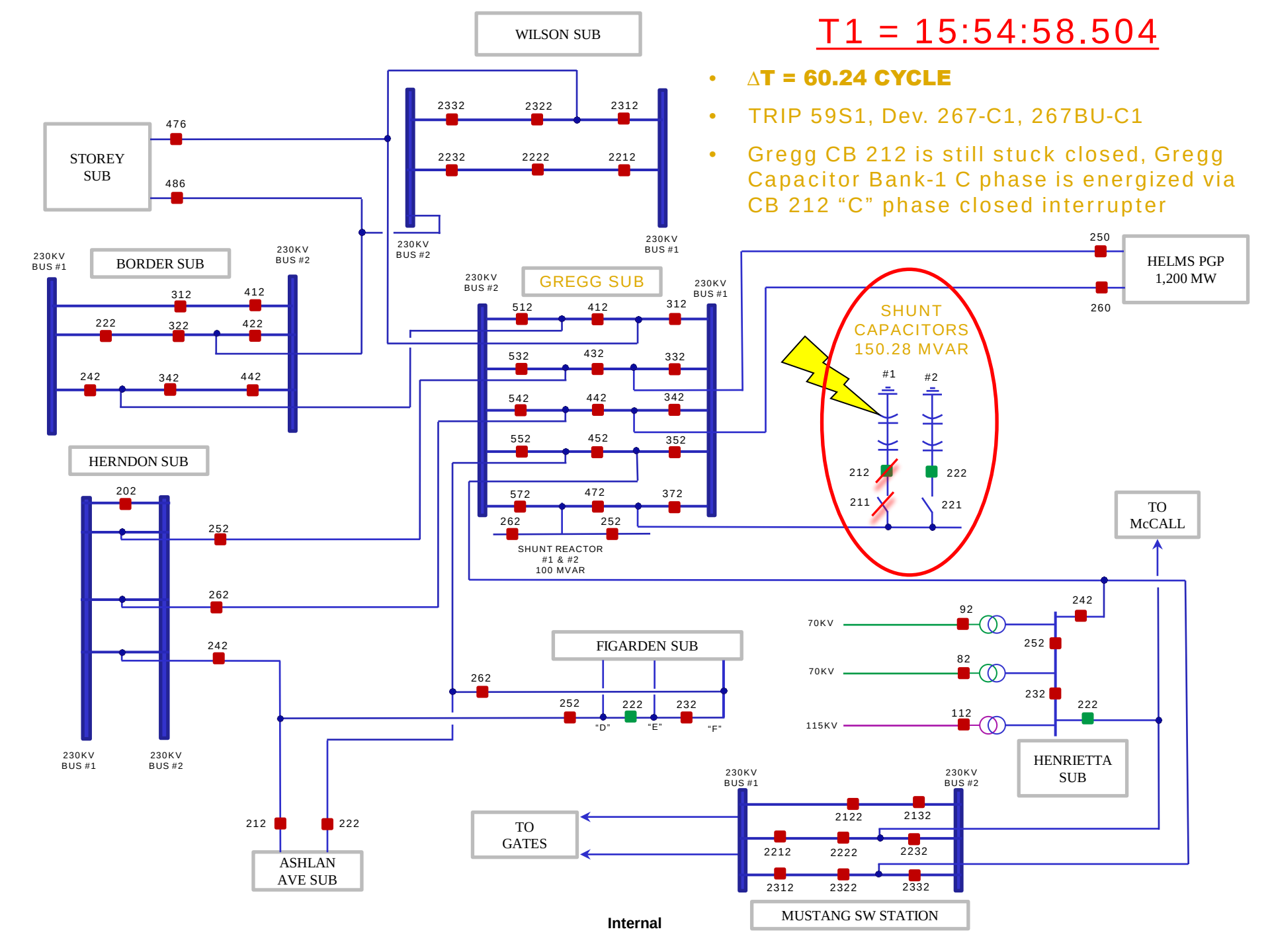
CB 212 SEMAPHORE INDICATION PER PHASE

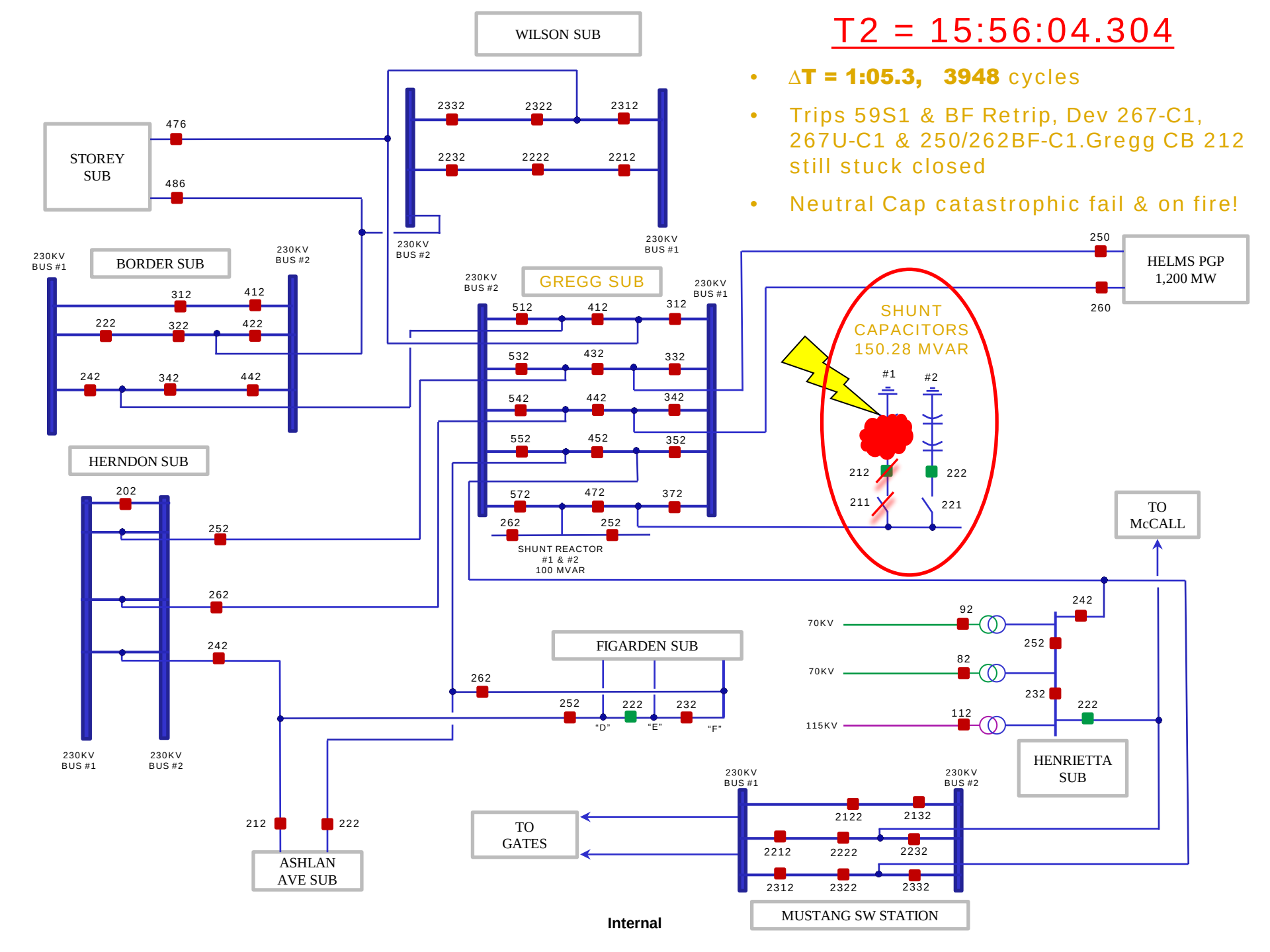



SERIES SWITCHING
INRUSH REACTOR, 0.0283 Ω
DANGER


SERIES OUTRUSH
REACTOR, 0.75 Ω

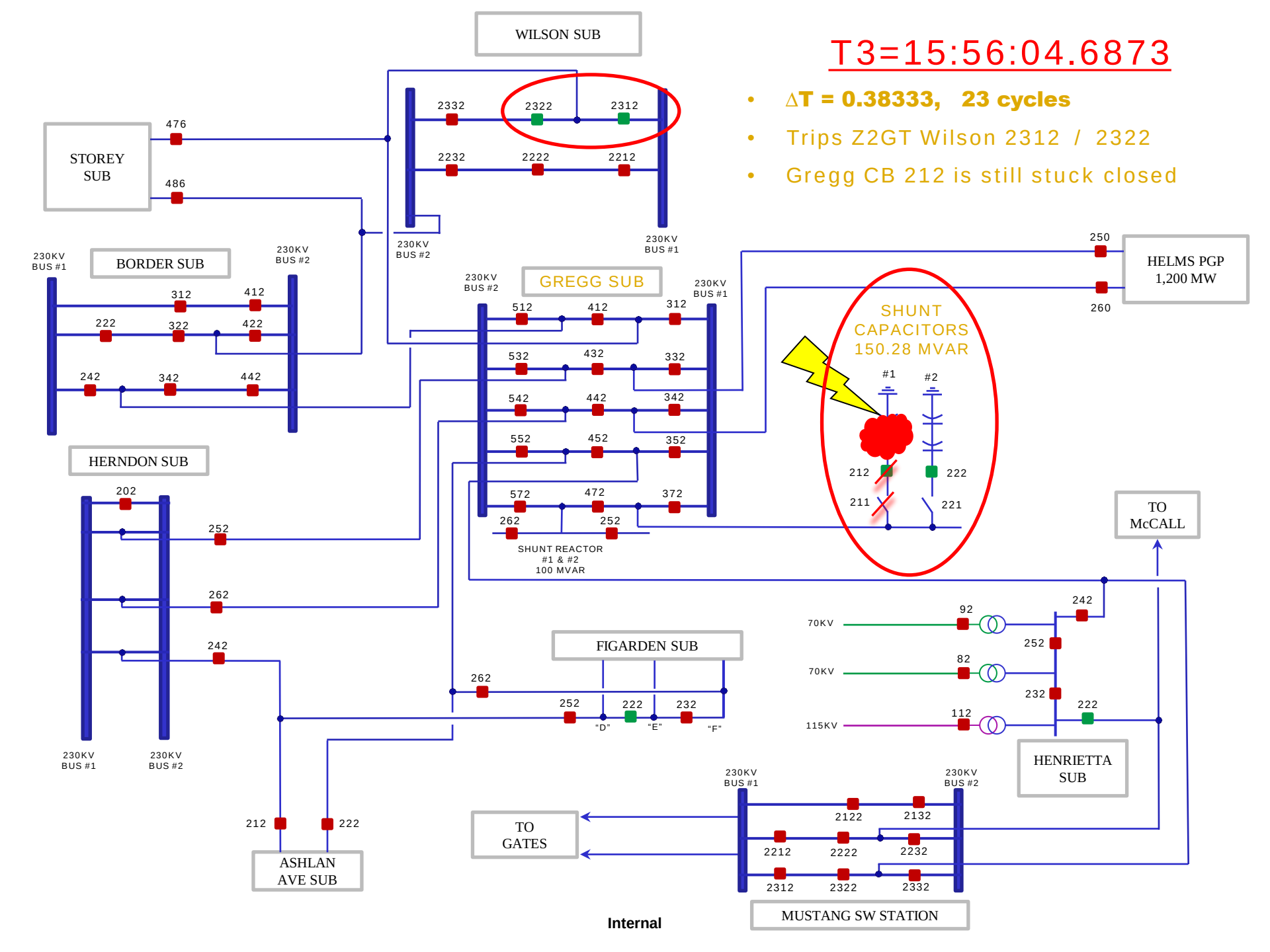

To = 15:54:57.50
Gregg DSW 211 is closed
Gregg Capacitor Bank-1 C phase is energized via CB 212 “C” phase closed interrupter
WILSON SUB
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
STOREY SUB
476
486
230KV BUS #1
BORDER SUB
230KV BUS #2
312
412
222
322
422
242
342
442
230KV BUS #2
GREGG SUB
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
250
260
HELMS PGP 1,200 MW
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
FIGARDEN SUB
262
252
222
232
“D”
“E”
“F”
TO McCALL
70KV
92
242
252
70KV
82
232
222
115KV
112
HENRIETTA SUB
212
222
ASHLAN AVE SUB
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Internal

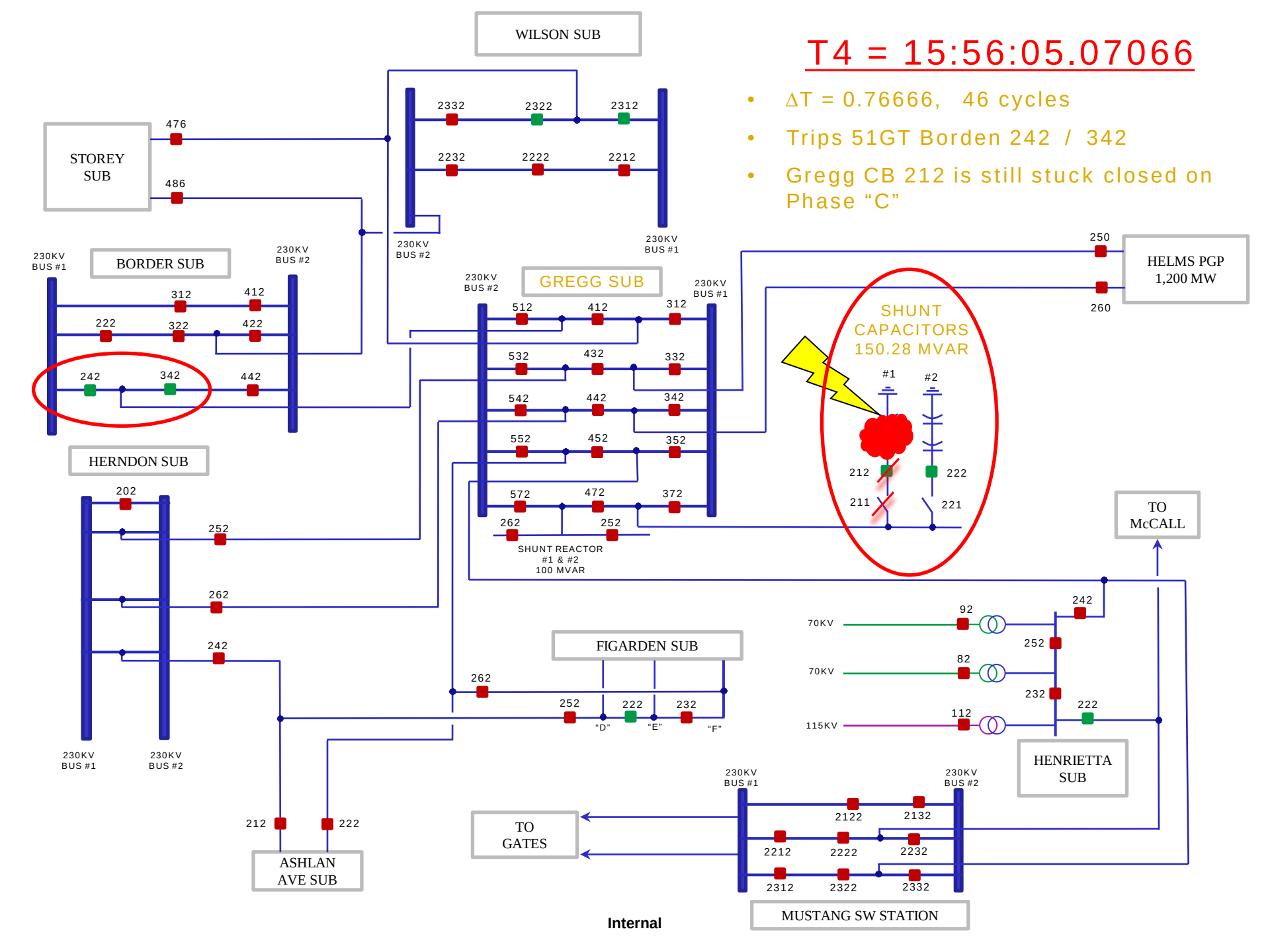

T1 = 15:54:58.504
ΔT = 60.24 CYCLE
TRIP 59S1, Dev. 267-C1, 267BU-C1
Gregg CB 212 is still stuck closed, Gregg Capacitor Bank-1 C phase is energized via CB 212 "C" phase closed interrupter
WILSON SUB
STORY SUB
476
486
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
BORDER SUB
230KV BUS #1
230KV BUS #2
312
412
222
322
422
242
342
442
GREGG SUB
230KV BUS #2
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
250
260
HELMS PGP 1,200 MW
TO McCALL
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
FIGARDEN SUB
262
252
222
232
"D"
"E"
"F"
70KV
92
242
252
70KV
82
232
222
115KV
112
HENRIETTA SUB
212
222
ASHLAN AVE SUB
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Internal

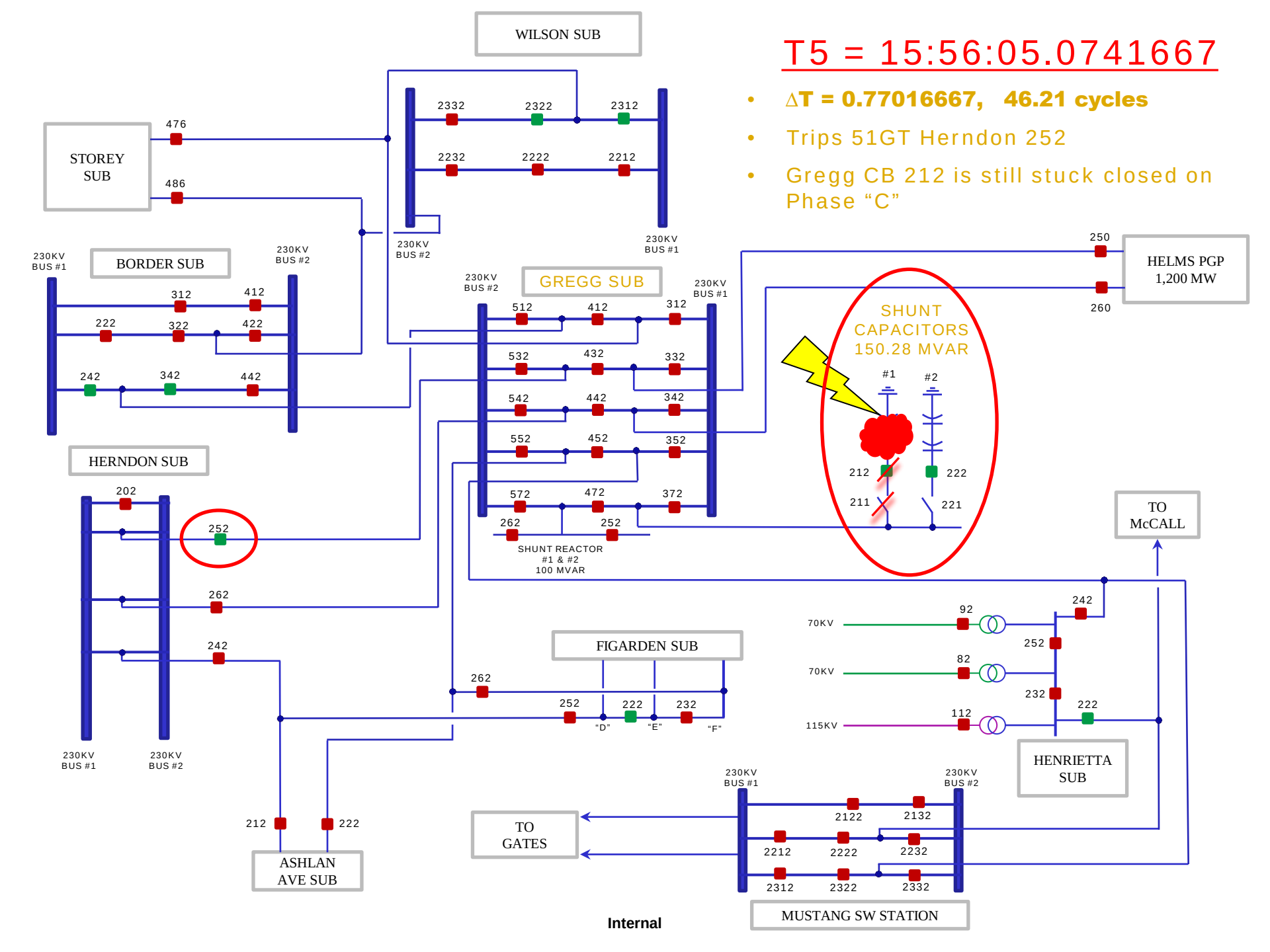

T2 = 15:56:04.304
ΔT = 1:05.3, 3948 cycles
Trips 59S1 & BF Retrip, Dev 267-C1, 267U-C1 & 250/262BF-C1.Gregg CB 212 still stuck closed
Neutral Cap catastrophic fail & on fire!
WILSON SUB
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
STORIEY SUB
476
486
230KV BUS #1
BORDER SUB
230KV BUS #2
312
412
222
322
422
242
342
442
GREGG SUB
230KV BUS #2
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
250
260
HELMS PGP 1,200 MW
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
TO McCALL
FIGARDEN SUB
262
252
222
232
"D"
"E"
"F"
70KV
92
242
252
70KV
82
232
222
115KV
112
HENRIETTA SUB
212
222
ASHLAN AVE SUB
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Internal

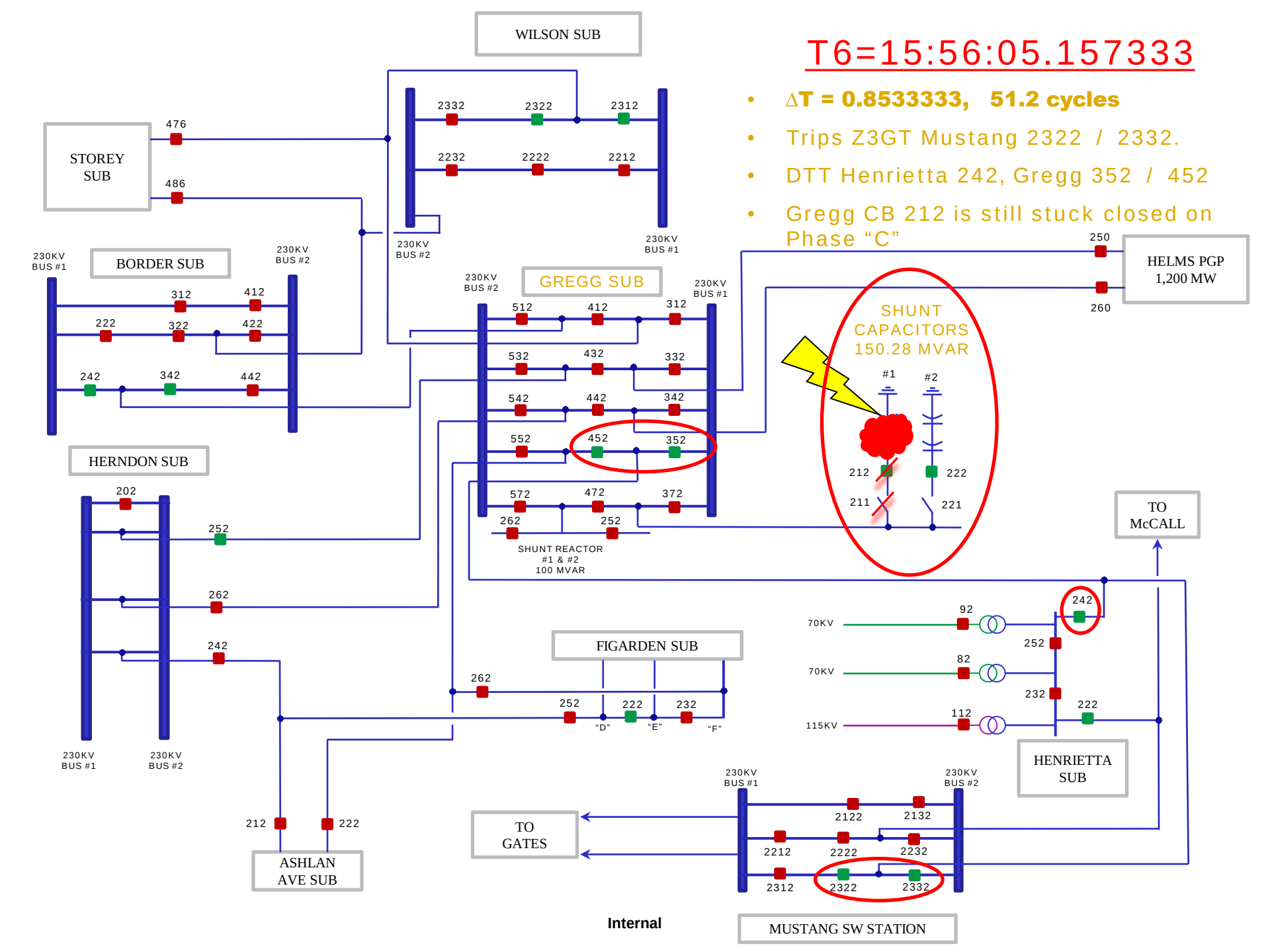
Gregg Shunt Capacitor Bank 1 on Fire Video

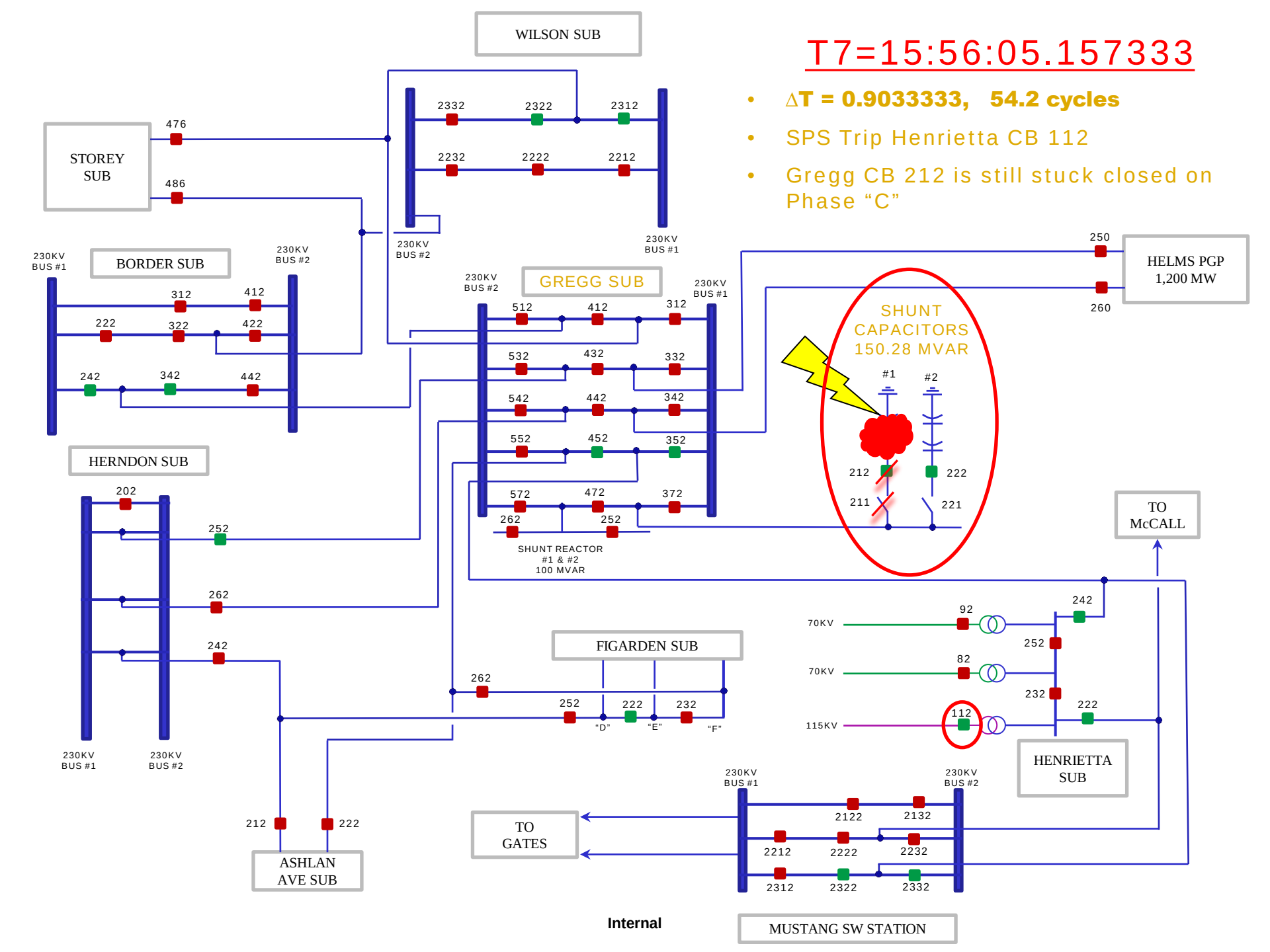
20160616_155608.mp4

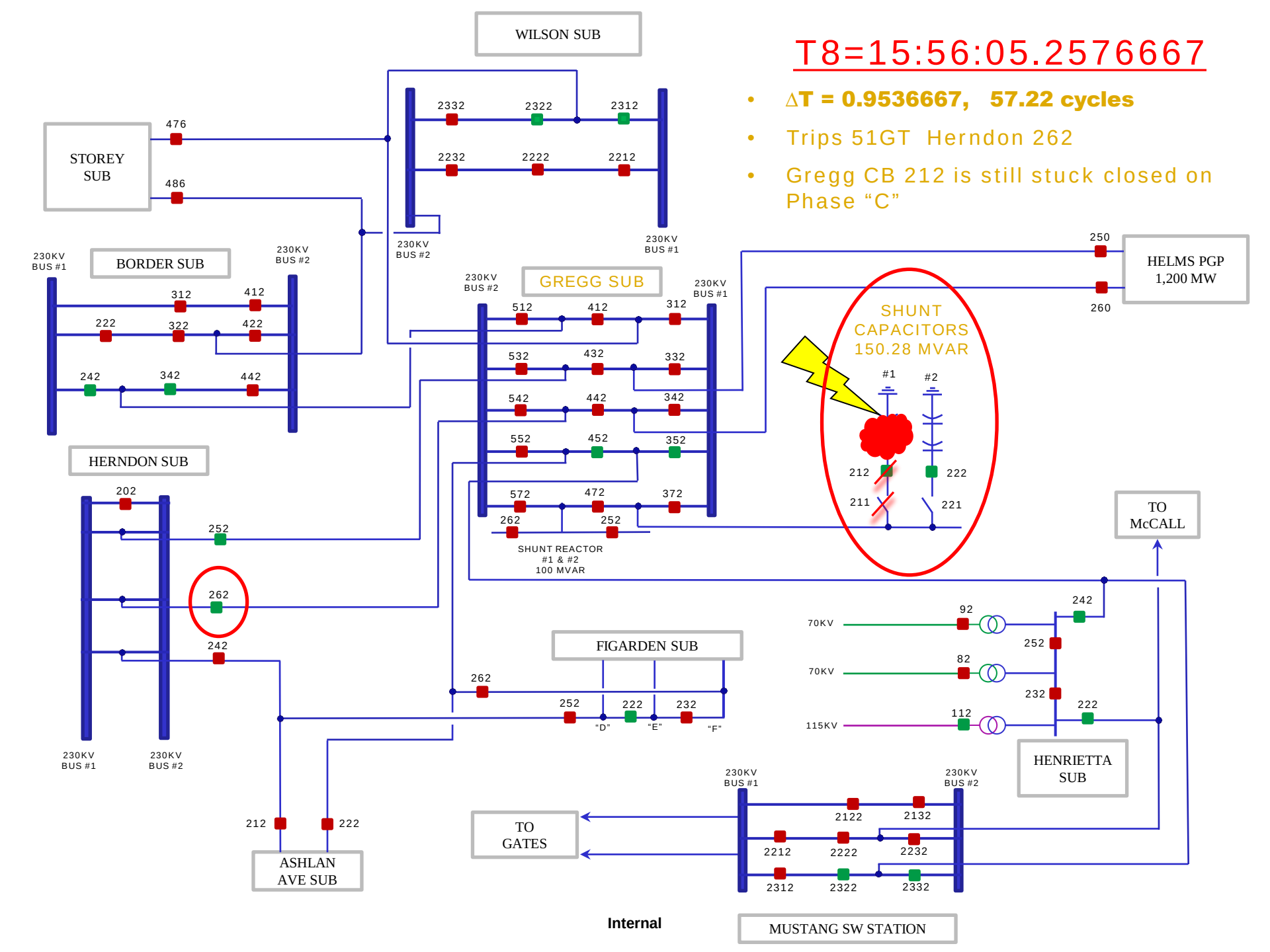

T3=15:56:04.6873
• ΔT = 0.38333, 23 cycles
• Trips Z2GT Wilson 2312 / 2322
• Gregg CB 212 is still stuck closed
WILSON SUB
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
STOREY SUB
476
486
230KV BUS #1
BORDER SUB
230KV BUS #2
312
412
222
322
422
242
342
442
GREGG SUB
230KV BUS #2
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
250
260
HELMS PGP 1,200 MW
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
FIGARDEN SUB
262
252
222
232
"D"
"E"
"F"
TO McCALL
70KV
92
242
252
70KV
82
232
222
115KV
112
HENRIETTA SUB
212
222
ASHLAN AVE SUB
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Internal

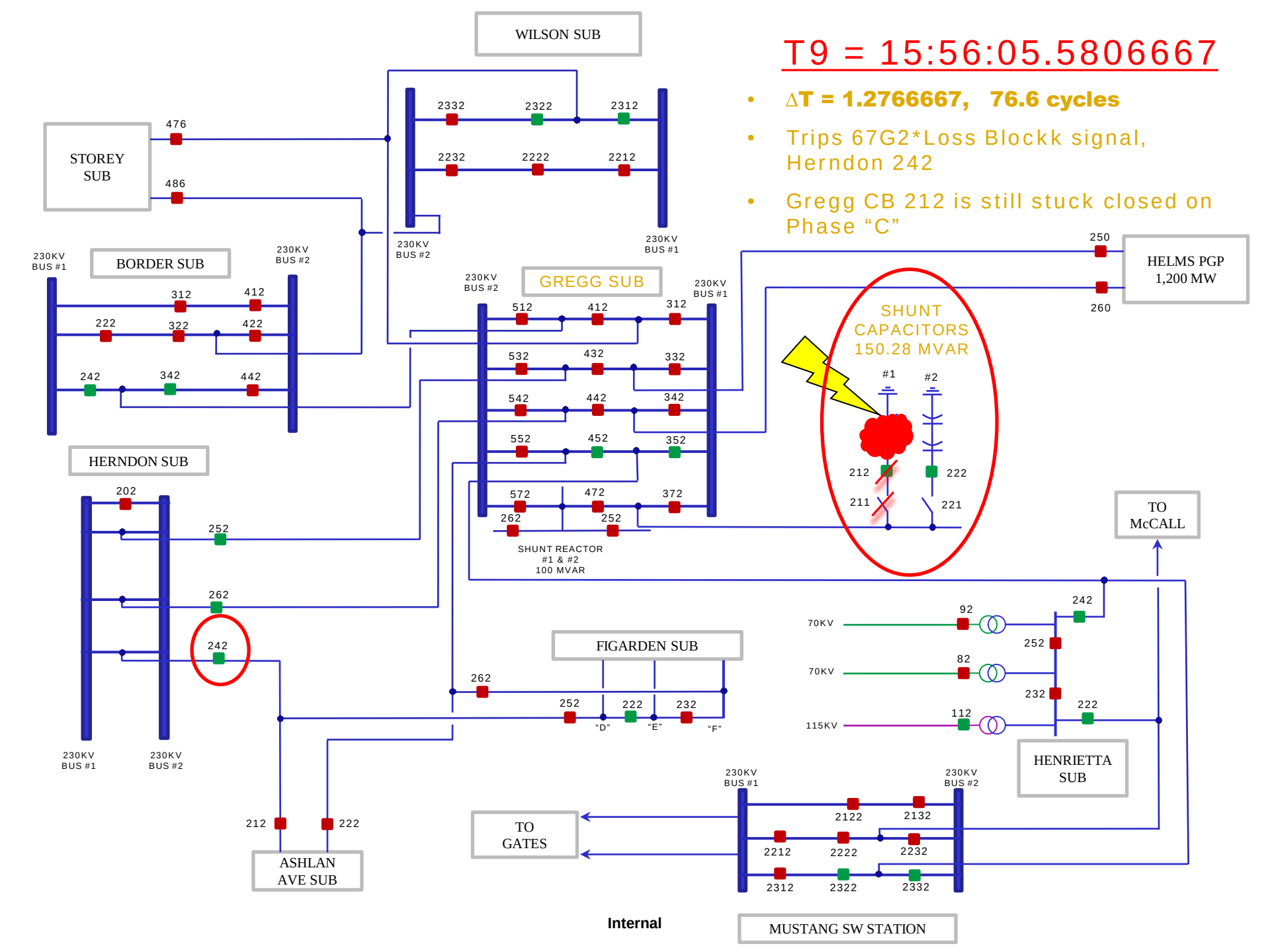

T4 = 15:56:05.07066
• ΔT = 0.76666, 46 cycles
• Trips 51GT Borden 242 / 342
• Gregg CB 212 is still stuck closed on Phase "C"
WILSON SUB
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
STOREY SUB
476
486
230KV BUS #1
BORDER SUB
230KV BUS #2
312
412
222
322
422
242
342
442
GREGG SUB
230KV BUS #2
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
250
260
HELMS PGP 1,200 MW
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
TO McCALL
FIGARDEN SUB
262
252
222
232
"D"
"E"
"F"
70KV
92
242
252
70KV
82
232
115KV
112
222
HENRIETTA SUB
212
222
ASHLAN AVE SUB
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Internal

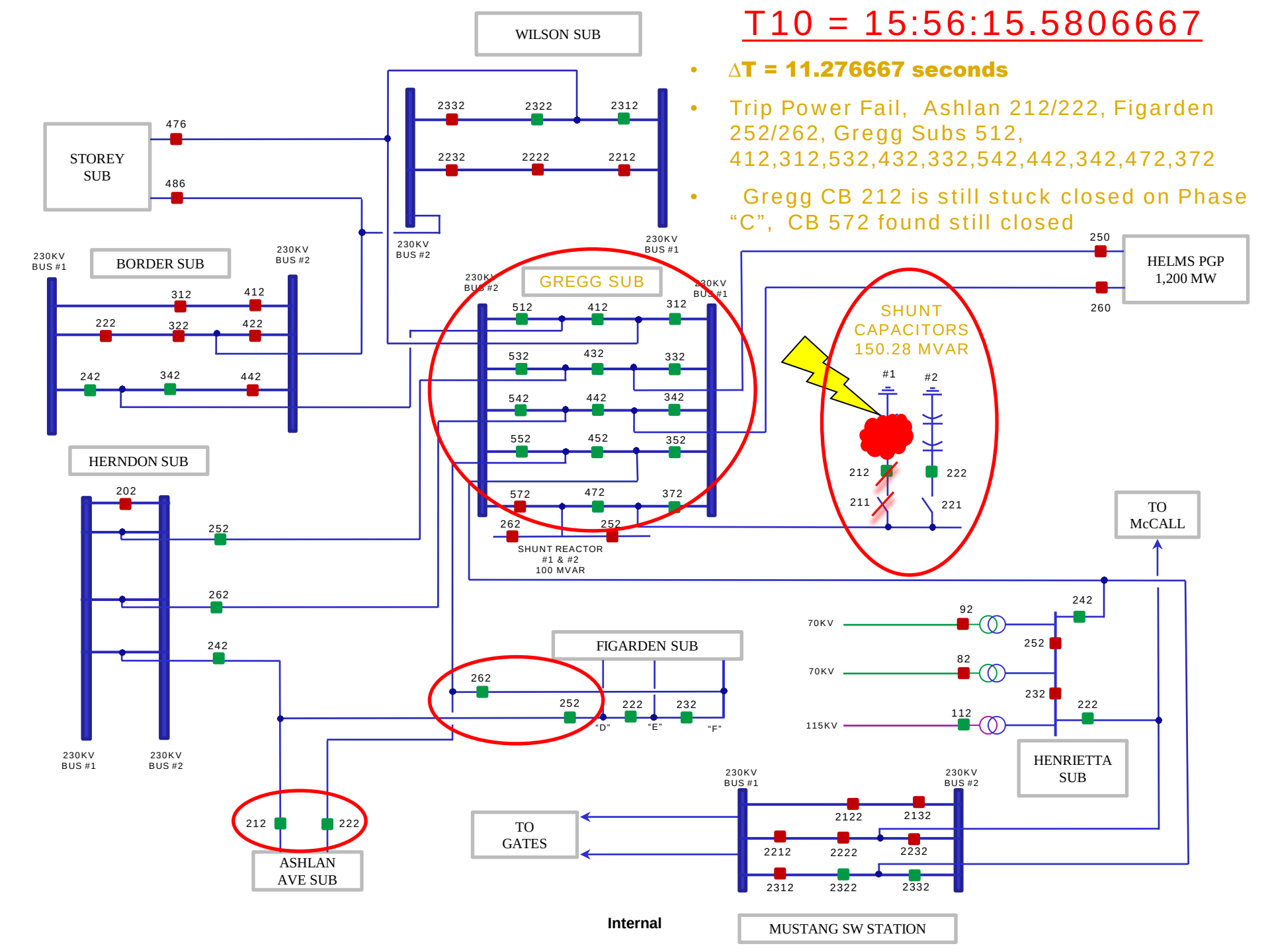

T5 = 15:56:05.0741667
ΔT = 0.77016667, 46.21 cycles
Trips 51GT Herndon 252
Gregg CB 212 is still stuck closed on Phase "C"
WILSON SUB
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
STOREY SUB
476
486
230KV BUS #1
BORDER SUB
230KV BUS #2
312
412
222
322
422
242
342
442
230KV BUS #2
GREGG SUB
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
250
260
HELMS PGP 1,200 MW
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
TO McCALL
FIGARDEN SUB
262
252
222
232
"D"
"E"
"F"
70KV
92
242
252
70KV
82
232
222
115KV
112
HENRIETTA SUB
212
222
ASHLAN AVE SUB
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Internal

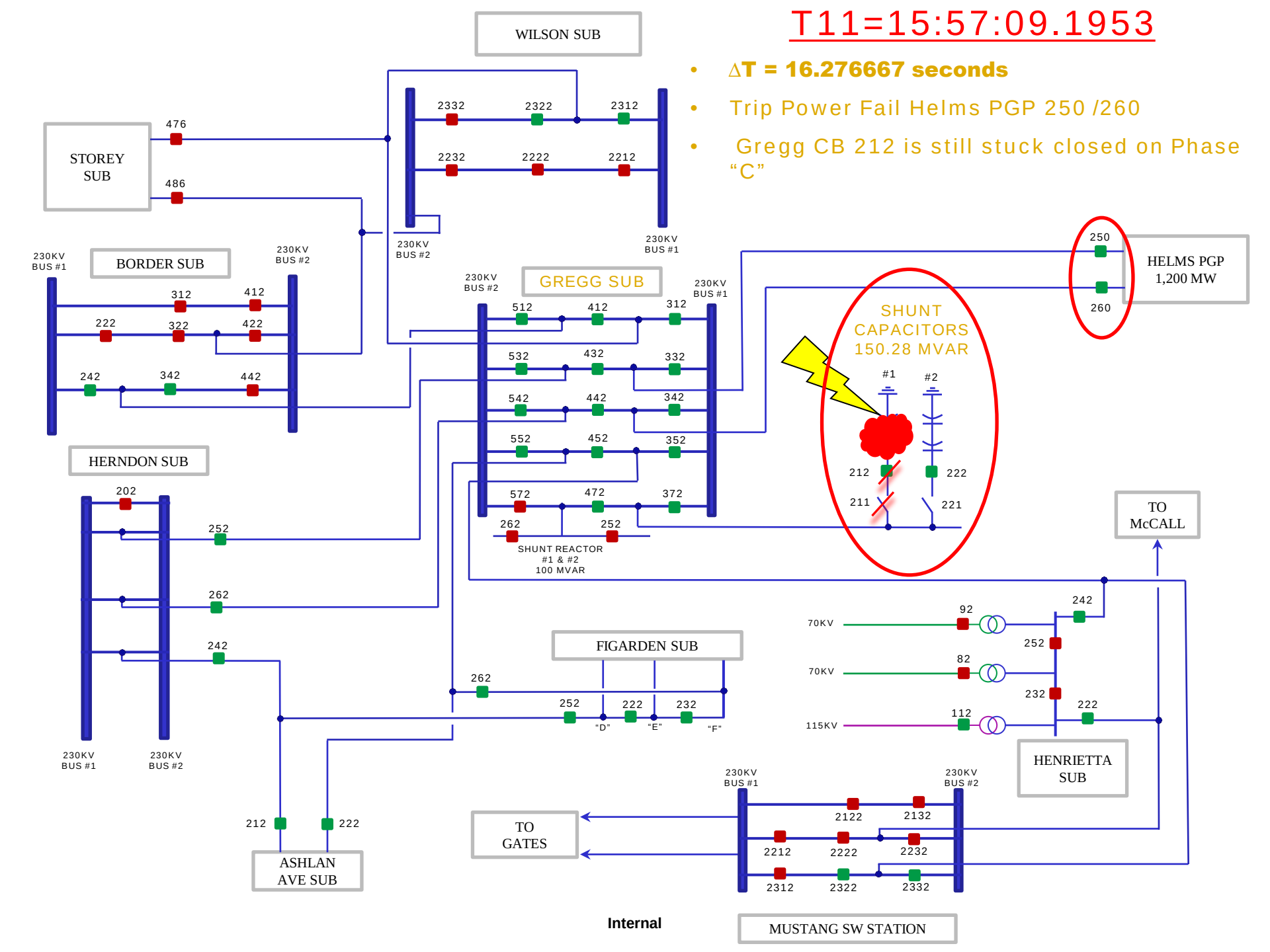

T6=15:56:05.157333
• ΔT = 0.8533333, 51.2 cycles
• Trips Z3GT Mustang 2322 / 2332.
• DTT Henrietta 242, Gregg 352 / 452
• Gregg CB 212 is still stuck closed on Phase "C"
WILSON SUB
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
STOREY SUB
476
486
230KV BUS #1
BORDER SUB
230KV BUS #2
312
412
222
322
422
242
342
442
GREGG SUB
230KV BUS #2
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
250
260
HELMS PGP 1,200 MW
TO McCALL
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
FIGARDEN SUB
262
252
222
232
"D"
"E"
"F"
70KV
92
242
252
70KV
82
232
222
115KV
112
HENRIETTA SUB
212
222
ASHLAN AVE SUB
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Internal


T7=15:56:05.157333
ΔT = 0.9033333, 54.2 cycles
SPS Trip Henrietta CB 112
Gregg CB 212 is still stuck closed on Phase "C"
WILSON SUB
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
STOREY SUB
476
486
230KV BUS #1
BORDER SUB
230KV BUS #2
312
412
222
322
422
242
342
442
GREGG SUB
230KV BUS #2
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
250
260
HELMS PGP 1,200 MW
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
TO McCALL
FIGARDEN SUB
262
252
222
232
"D"
"E"
"F"
70KV
92
242
252
70KV
82
232
115KV
112
222
HENRIETTA SUB
212
222
ASHLAN AVE SUB
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Internal


T8=15:56:05.2576667
ΔT = 0.9536667, 57.22 cycles
Trips 51GT Herndon 262
Gregg CB 212 is still stuck closed on Phase "C"
WILSON SUB
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
STOREY SUB
476
486
230KV BUS #1
BORDER SUB
230KV BUS #2
312
412
222
322
422
242
342
442
GREGG SUB
230KV BUS #2
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
250
260
HELMS PGP 1,200 MW
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
TO McCALL
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
FIGARDEN SUB
262
252
222
232
"D"
"E"
"F"
70KV
92
242
252
70KV
82
232
115KV
112
222
HENRIETTA SUB
212
222
ASHLAN AVE SUB
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Internal

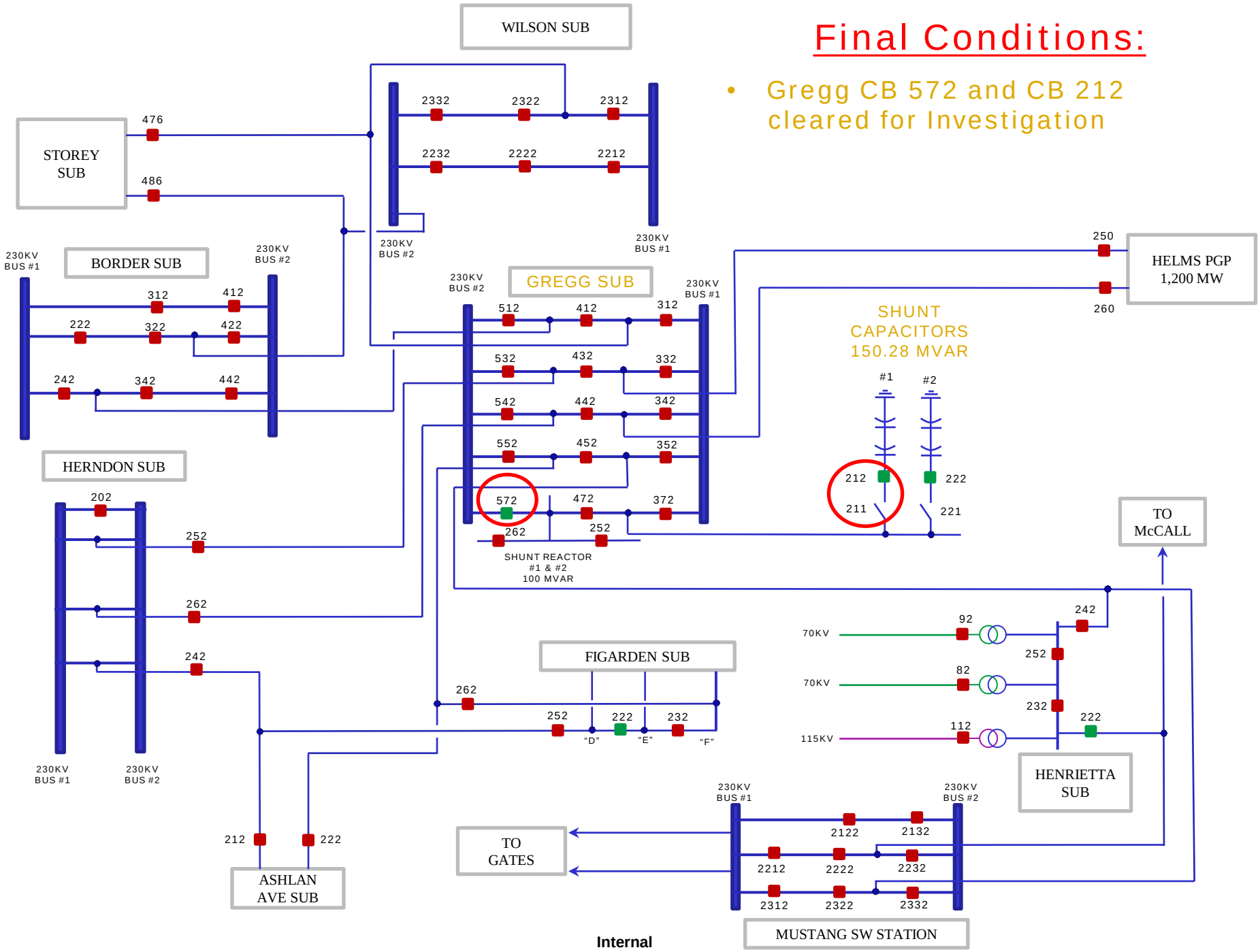

T9 = 15:56:05.5806667
ΔT = 1.2766667, 76.6 cycles
Trips 67G2*Loss Blockk signal, Herndon 242
Gregg CB 212 is still stuck closed on Phase "C"
WILSON SUB
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
STOREY SUB
476
486
230KV BUS #1
BORDER SUB
230KV BUS #2
312
412
222
322
422
242
342
442
GREGG SUB
230KV BUS #2
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
250
260
HELMS PGP 1,200 MW
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
TO McCALL
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
FIGARDEN SUB
262
252
222
232
"D"
"E"
"F"
70KV
92
242
252
70KV
82
232
222
115KV
112
HENRIETTA SUB
212
222
ASHLAN AVE SUB
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Internal


T10 = 15:56:15.5806667
ΔT = 11.276667 seconds
Trip Power Fail, Ashlan 212/222, Figarden 252/262, Gregg Subs 512, 412,312,532,432,332,542,442,342,472,372
Gregg CB 212 is still stuck closed on Phase "C", CB 572 found still closed
WILSON SUB
STOREY SUB
476
486
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
BORDER SUB
230KV BUS #1
230KV BUS #2
312
412
222
322
422
242
342
442
GREGG SUB
230KV BUS #2
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
250
260
HELMS PGP 1,200 MW
TO McCALL
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
FIGARDEN SUB
262
252
222
232
"D"
"E"
"F"
70KV
92
242
252
70KV
82
232
222
115KV
112
HENRIETTA SUB
ASHLAN AVE SUB
212
222
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Internal

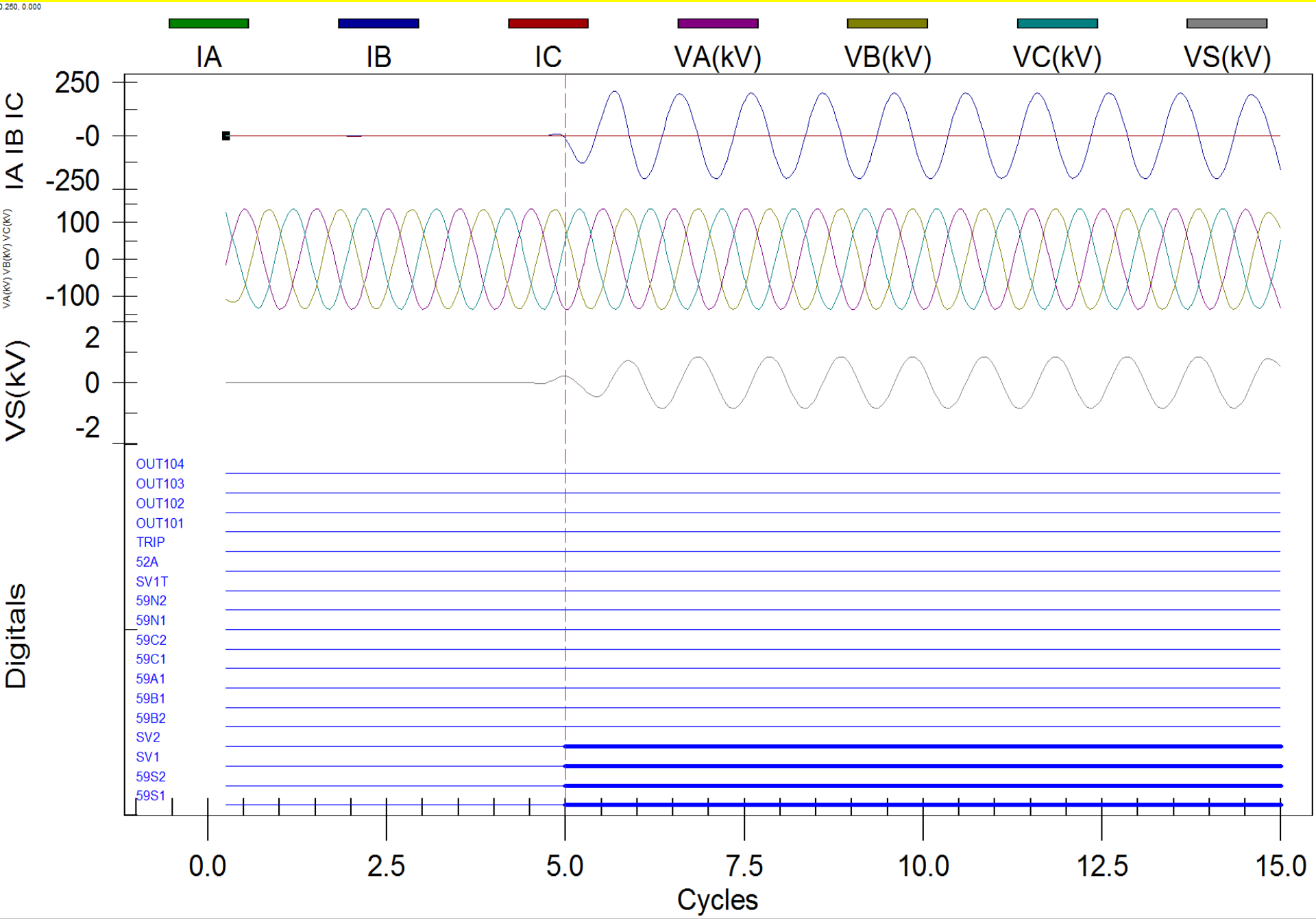

T11=15:57:09.1953
• ΔT = 16.276667 seconds
• Trip Power Fail Helms PGP 250 /260
• Gregg CB 212 is still stuck closed on Phase "C"
WILSON SUB
2332
2322
2312
2232
2222
2212
230KV BUS #2
230KV BUS #1
STOREY SUB
476
486
230KV BUS #1
BORDER SUB
230KV BUS #2
312
412
222
322
422
242
342
442
230KV BUS #2
GREGG SUB
230KV BUS #1
512
412
312
532
432
332
542
442
342
552
452
352
572
472
372
262
252
SHUNT REACTOR #1 & #2 100 MVAR
250
260
HELMS PGP 1,200 MW
SHUNT CAPACITORS 150.28 MVAR
#1
#2
212
222
211
221
HERNDON SUB
202
252
262
242
230KV BUS #1
230KV BUS #2
FIGARDEN SUB
262
252
222
232
"D"
"E"
"F"
TO McCALL
70KV
92
242
252
70KV
82
232
222
115KV
112
HENRIETTA SUB
212
222
ASHLAN AVE SUB
TO GATES
230KV BUS #1
230KV BUS #2
2122
2132
2212
2222
2232
2312
2322
2332
MUSTANG SW STATION
Internal

Final Conditions:

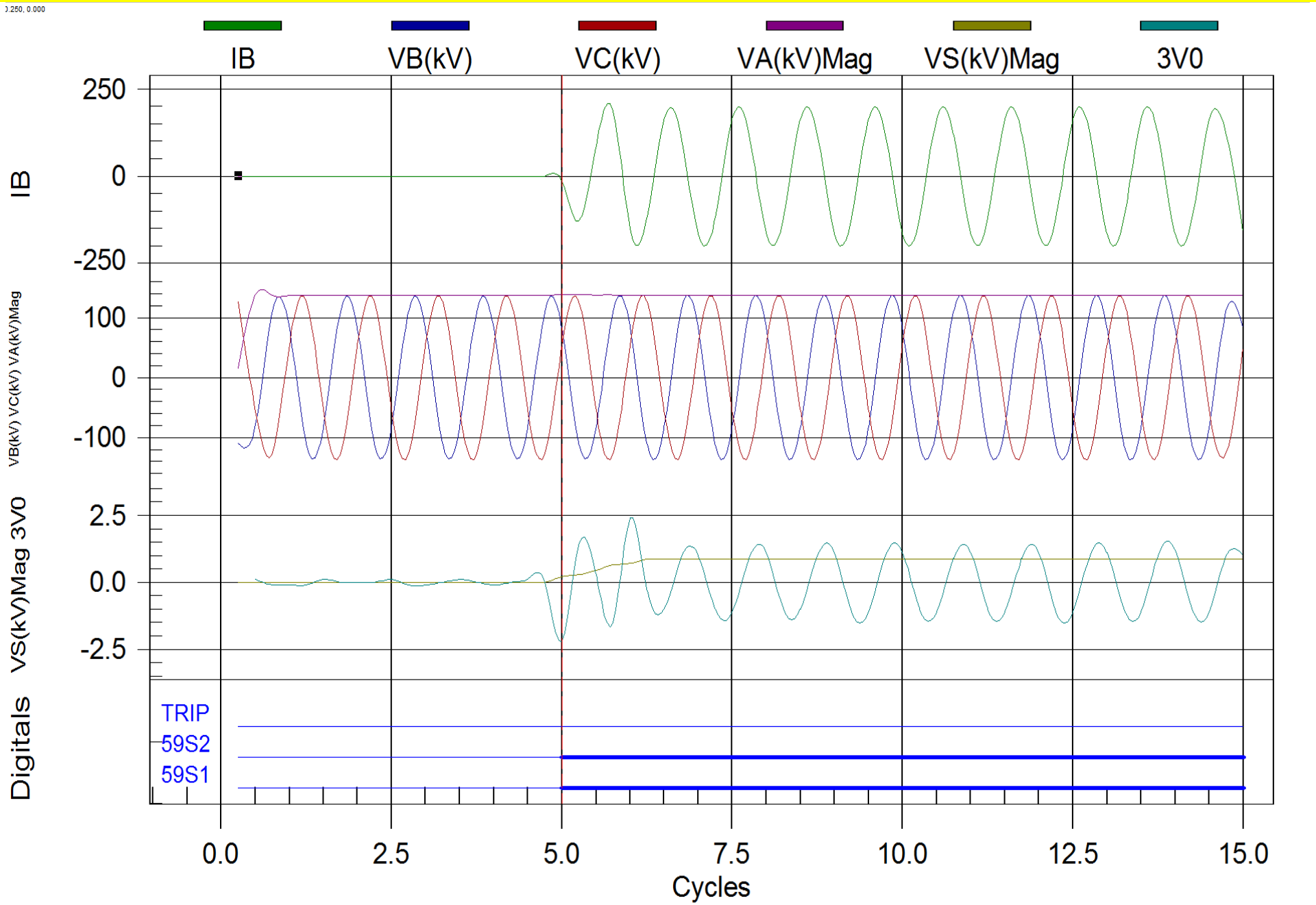
- Gregg CB 572 and CB 212 cleared for Investigation



CB 212 DEV 267-C1

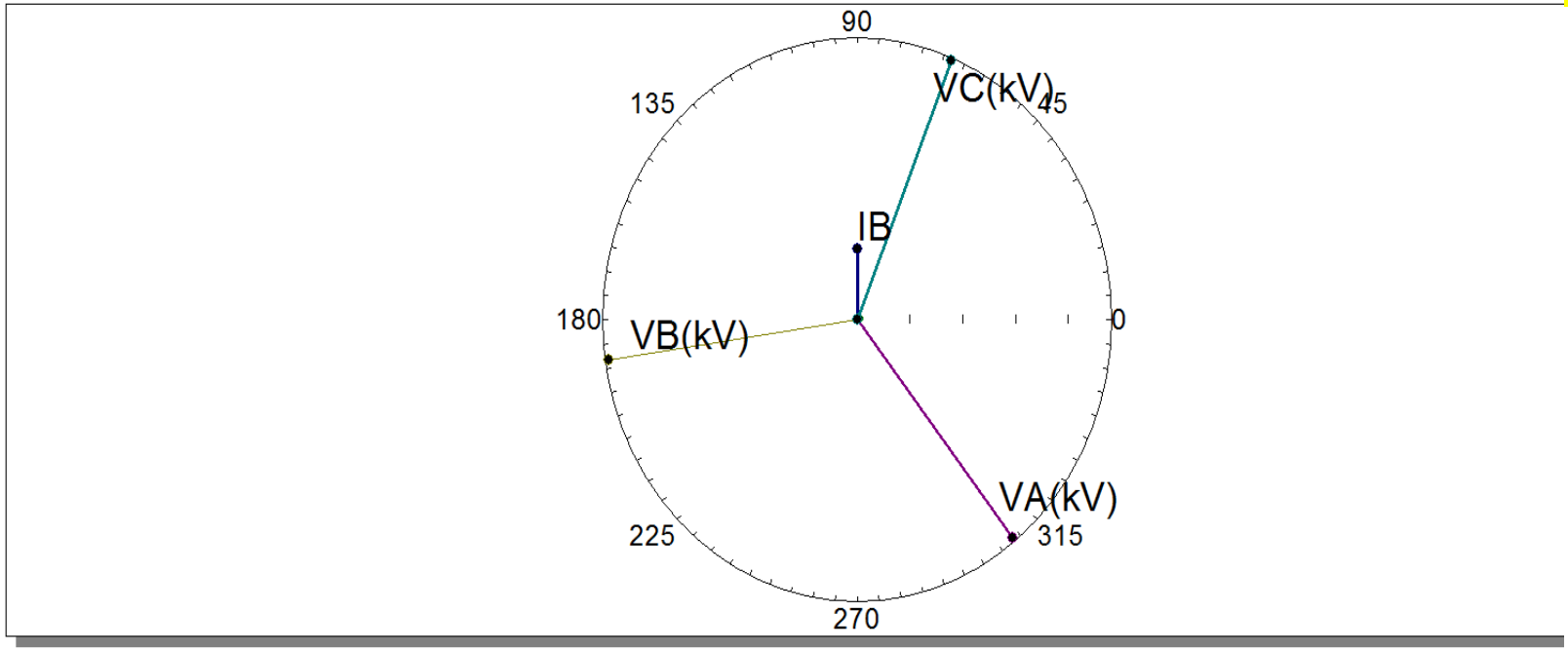


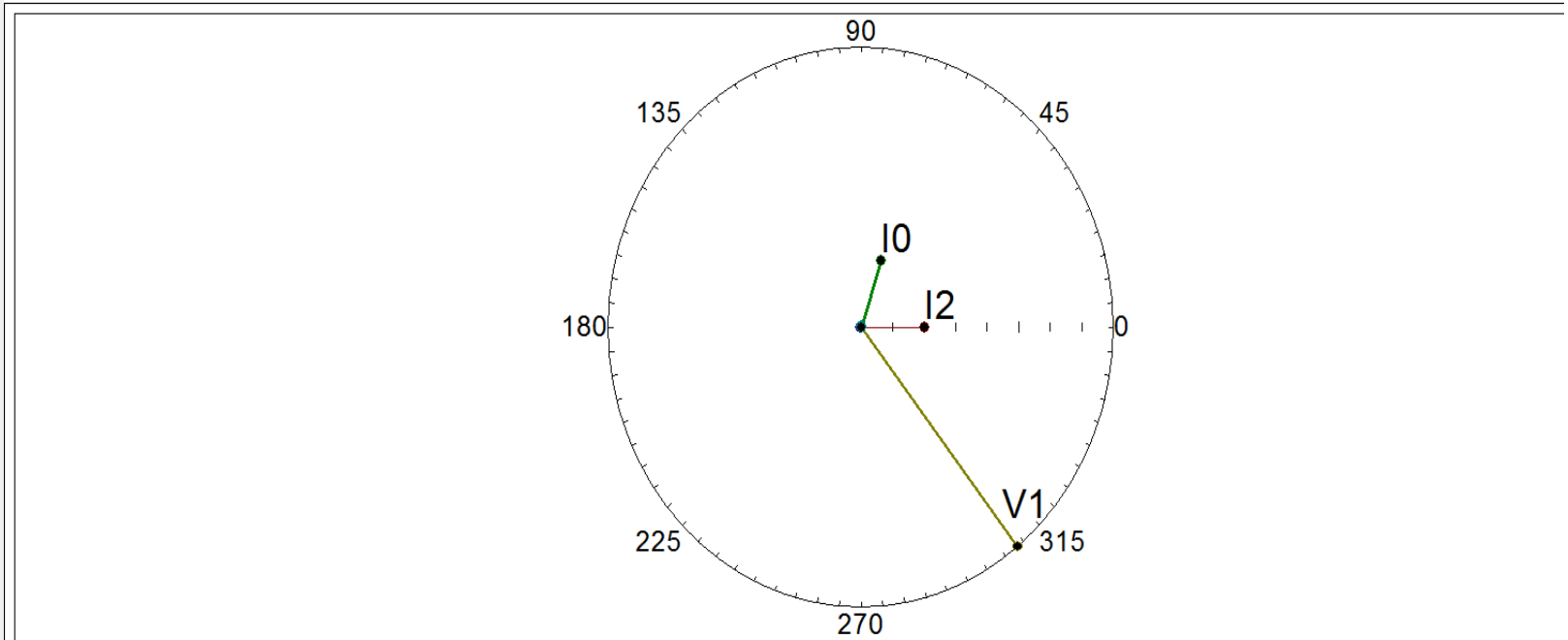
CB 212 DEV 267-C1



PRE-FAULT VOLTAGE , 3V0 =0 V , VS = 0 V, VB = 137.4 KV

Channel	Mag	Angle	Scale	Show	Ref
IA	1.0	45.0	1	1	0
IB	1.4	90.0	1	1	0
IC	0.0	225.0	1	1	0
IN	1.4	90.0	1	0	0
IG	2.2	71.6	1	0	0
VA(kV)	137.0	308.3	1	1	0
VB(kV)	137.4	188.4	1	1	0
VC(kV)	137.5	68.1	1	1	0
VS(kV)	0.0	225.0	1	0	0
VDC	132.0	N/A	1	0	0
FREQ	60.0	N/A	1	0	0
I0	0.7	71.6	1	1	0
I1	0.2	180.0	1	1	0
I2	0.6	0.0	1	1	0
V0	0.0	0.0	1	1	1
V1	137.3	308.3	1	1	0
V2	0.3	132.2	1	1	0





Data Selection

Auto Increment

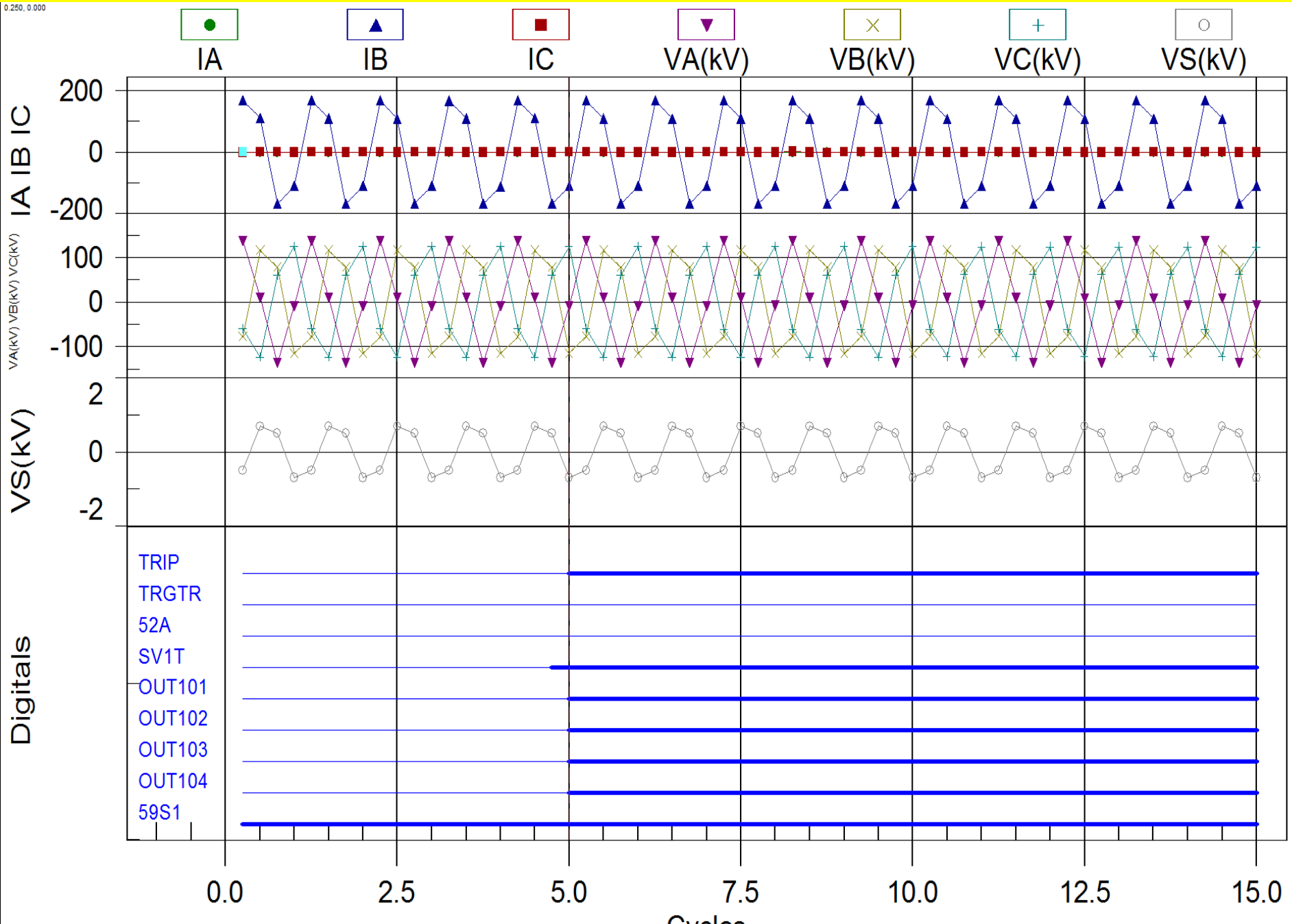
Start Delay (ms): 500

Cycles: 0.750

Show History

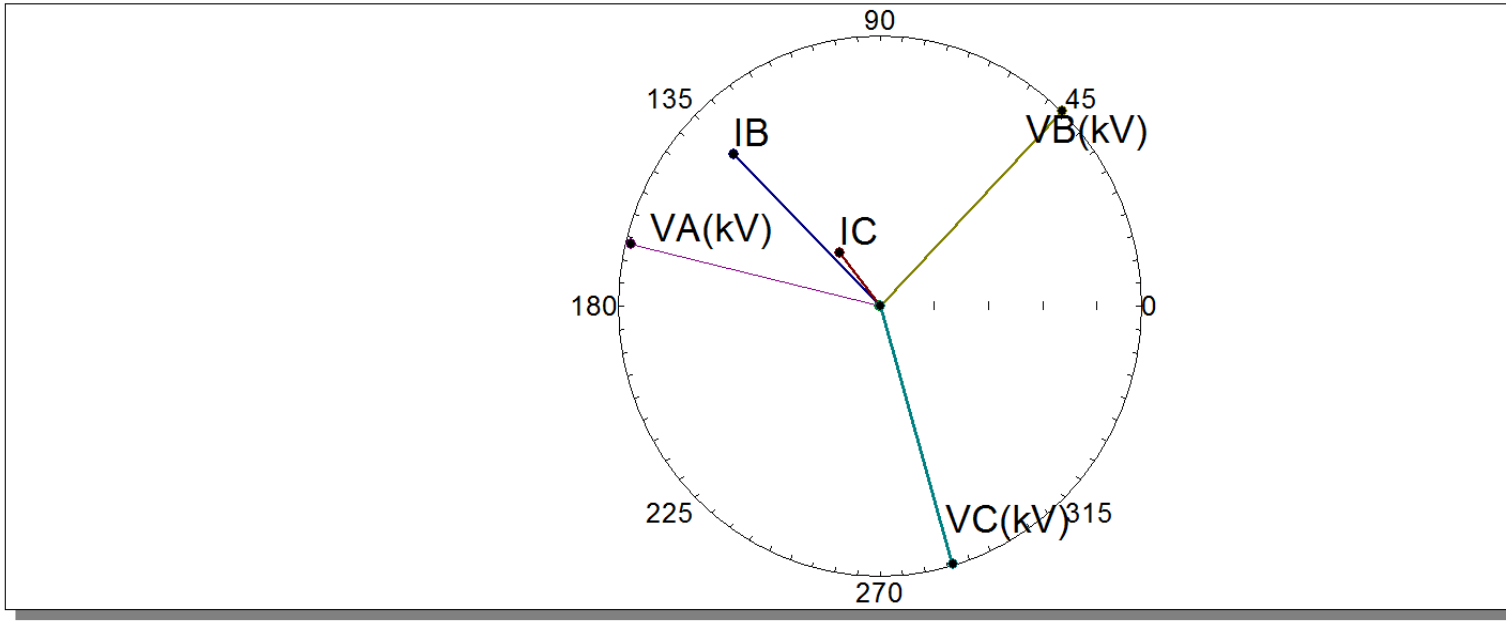
Print Close

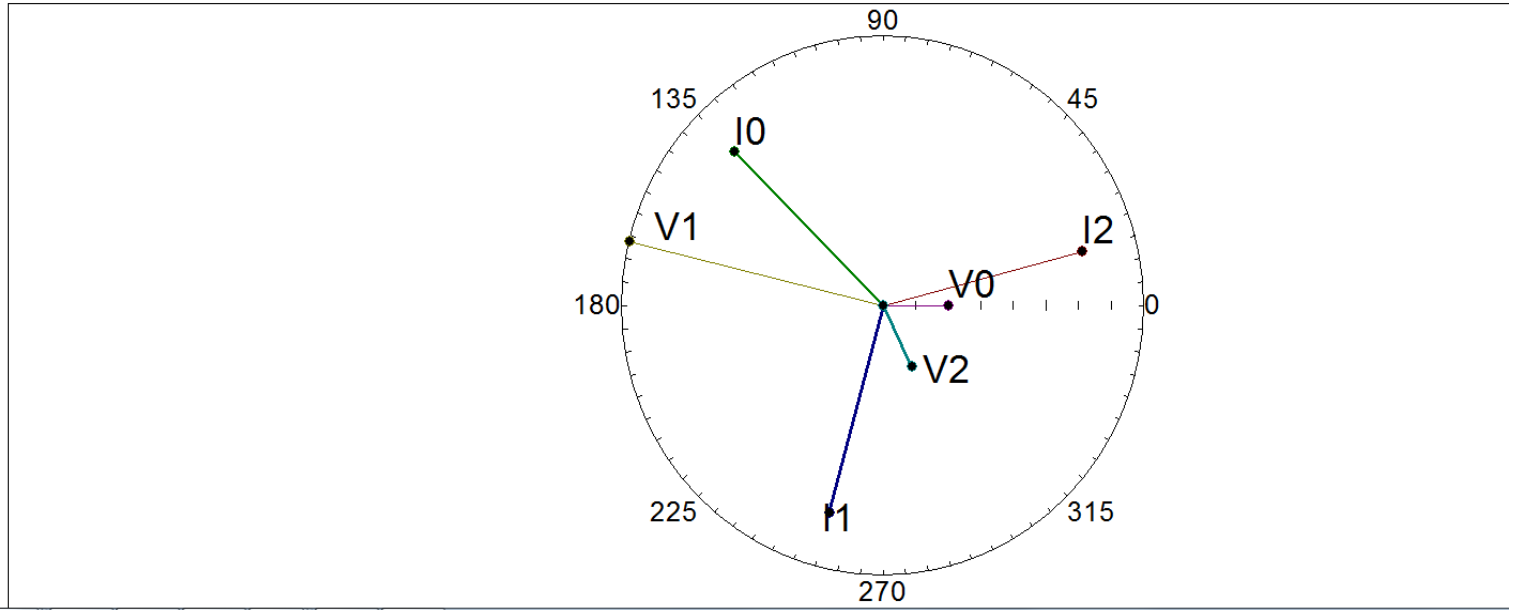
CB 212 DEV 267-C1



FAULT VOLTAGE CB 212 DEV 267-C1 , 3VO = 3X 800V = 2400 V, VS = 1100 VOLTS, VB = 139.4 KV , DIFF = 2000 VOLTS

Channel	Mag	Angle	Scale	Show	Ref
A	1.0	172.9	1	1	0
B	191.6	134.9	1	1	0
C	1.4	127.9	1	1	0
N	1.4	37.9	1	0	0
G	194.6	135.2	1	0	0
/A(kV)	136.7	166.4	1	1	0
/B(kV)	139.4	46.1	1	1	0
/C(kV)	137.9	286.2	1	1	0
/S(kV)	0.9	47.3	1	0	0
/DC	132.0	N/A	1	0	0
FREQ	60.0	N/A	1	0	0
0	64.6	135.0	1	1	0
1	63.7	255.0	1	1	0
2	63.3	14.6	1	1	0
/0	0.8	0.0	1	1	1
/1	138.0	166.3	1	1	0
/2	0.8	295.7	1	1	0





Data Selection

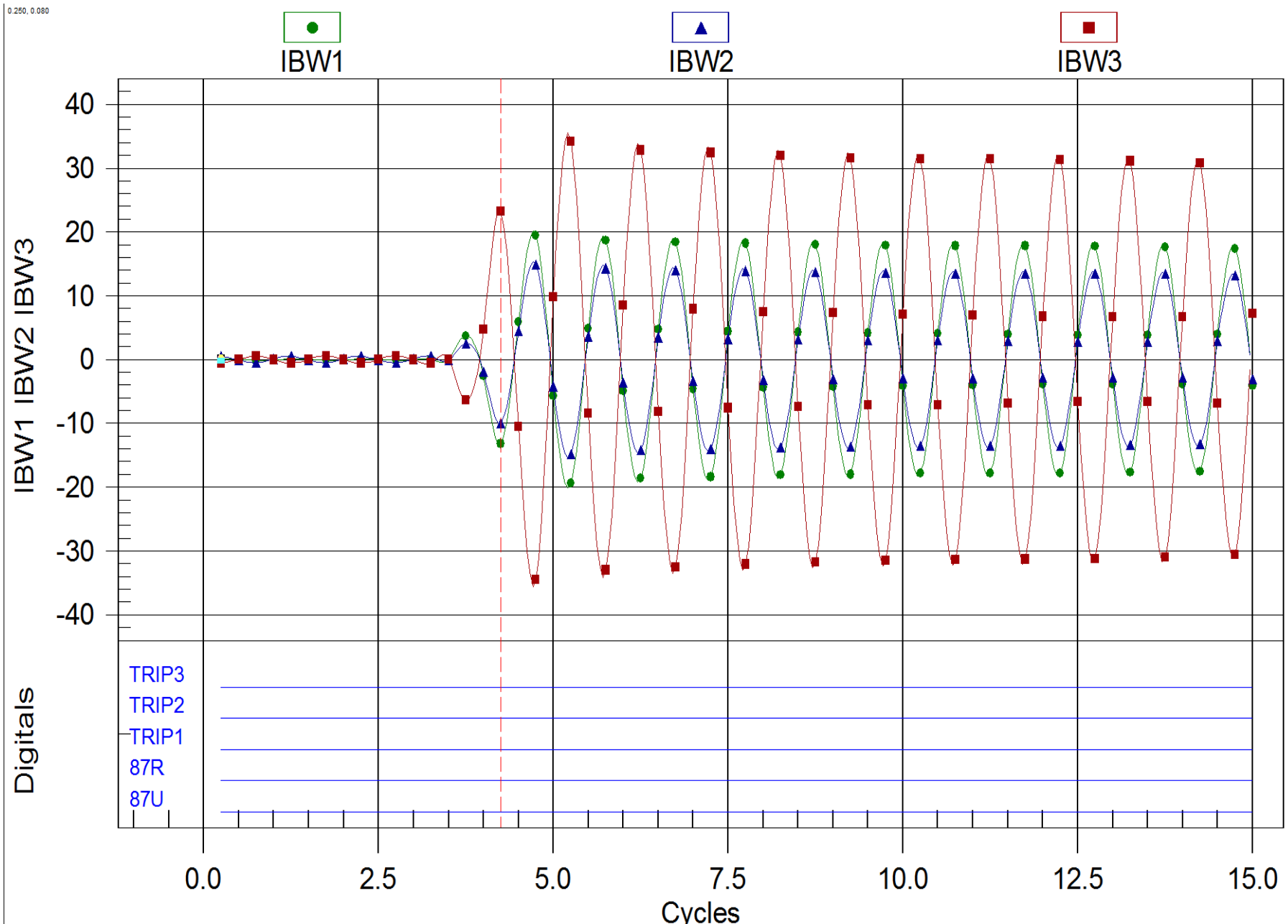
Auto Increment

Start | Delay (ms): 500 | Cycles: 6.250

Show History

Print | Close

287B RELAY, CB 212 IBW3 = 36.1 X 400 CTR = 14,440 A
FAULT CURRENTS TO CAPACITOR BANK 1



CB 212 IBW3 = 36.1 X 400 CTR = 14,440 AMPS FAULT CURRENTS TO CAPACITOR BANK 1

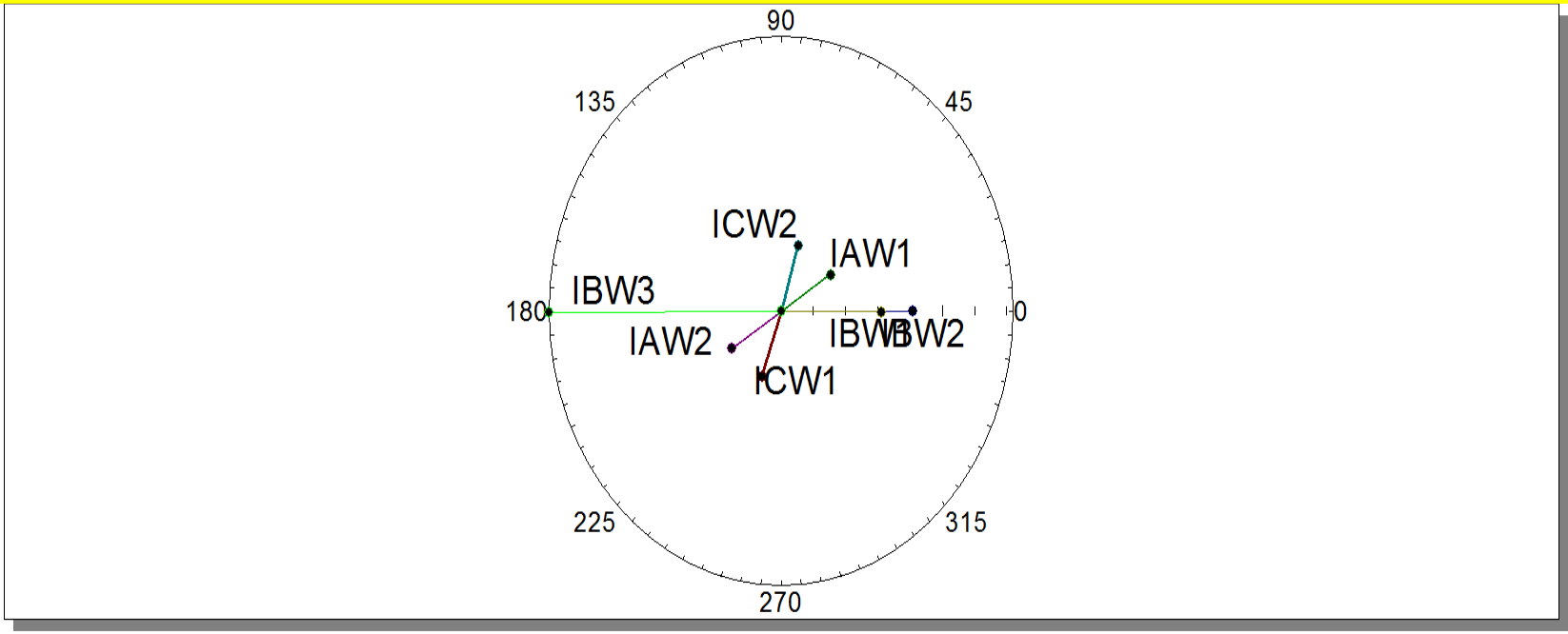
Channel	Mag	Angle	Scale	Show	Hel
IAW1	0.4	32.5	1	1	0
IBW1	20.4	0.0	1	1	0
ICW1	0.2	250.6	1	1	0
IAW2	0.4	212.5	1	1	0
IBW2	15.6	-0.1	1	1	0
ICW2	0.2	73.2	1	1	0
IAW3	0.0	343.2	1	1	0
IBW3	36.1	180.2	1	1	0
ICW3	0.0	343.2	1	1	0
IAW4	0.0	163.2	1	1	0
IBW4	0.0	163.2	1	1	0
ICW4	0.0	163.2	1	1	0
VDC	132.0	N/A	1	0	0
IW10	6.9	0.0	1	1	1
IW11	6.9	119.1	1	1	0
IW12	6.6	241.0	1	1	0
IW20	5.1	-0.1	1	1	0
IW21	5.1	121.1	1	1	0
IW22	5.3	238.7	1	1	0
IW30	12.0	180.2	1	1	0
IW31	12.0	300.2	1	1	0
IW32	12.0	60.2	1	1	0
IW40	0.0	163.2	1	1	0
IW41	0.0	343.2	1	1	0
IW42	0.0	343.2	1	1	0

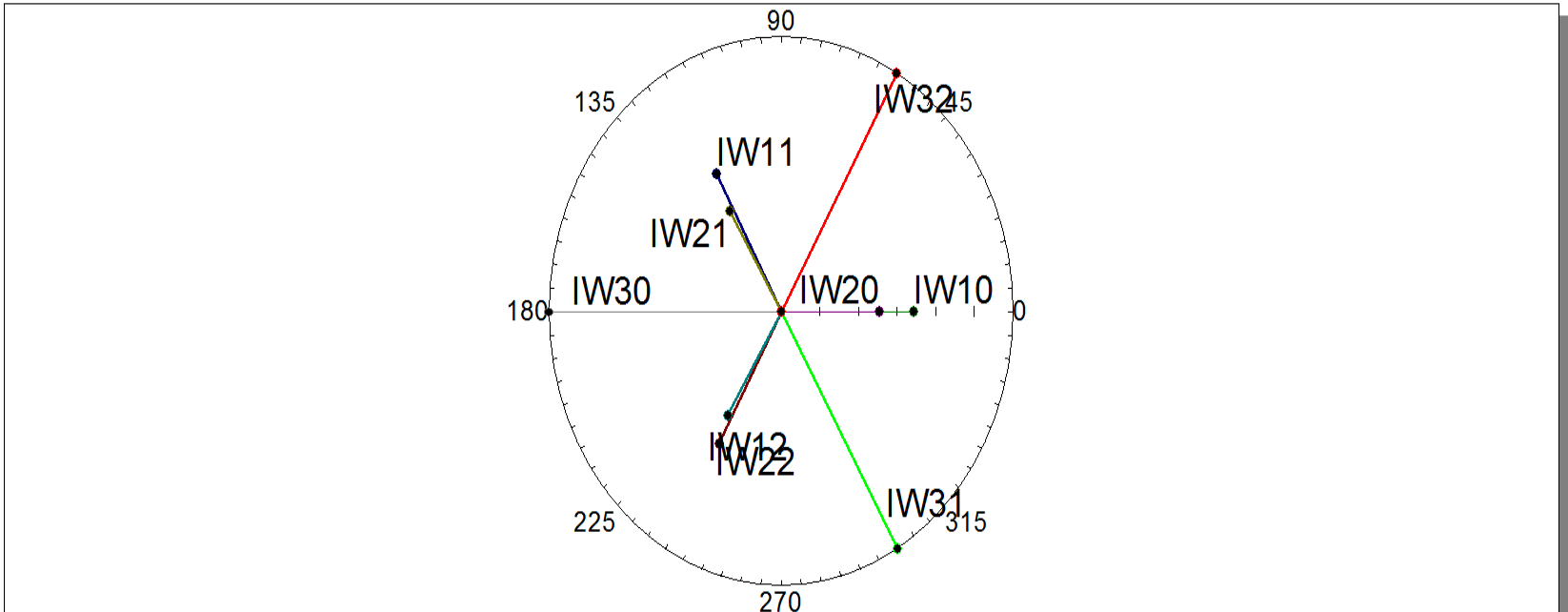
Data Selection

Auto Increment

Start | Delay (ms): 500 | Cycles: 4,750

Show History





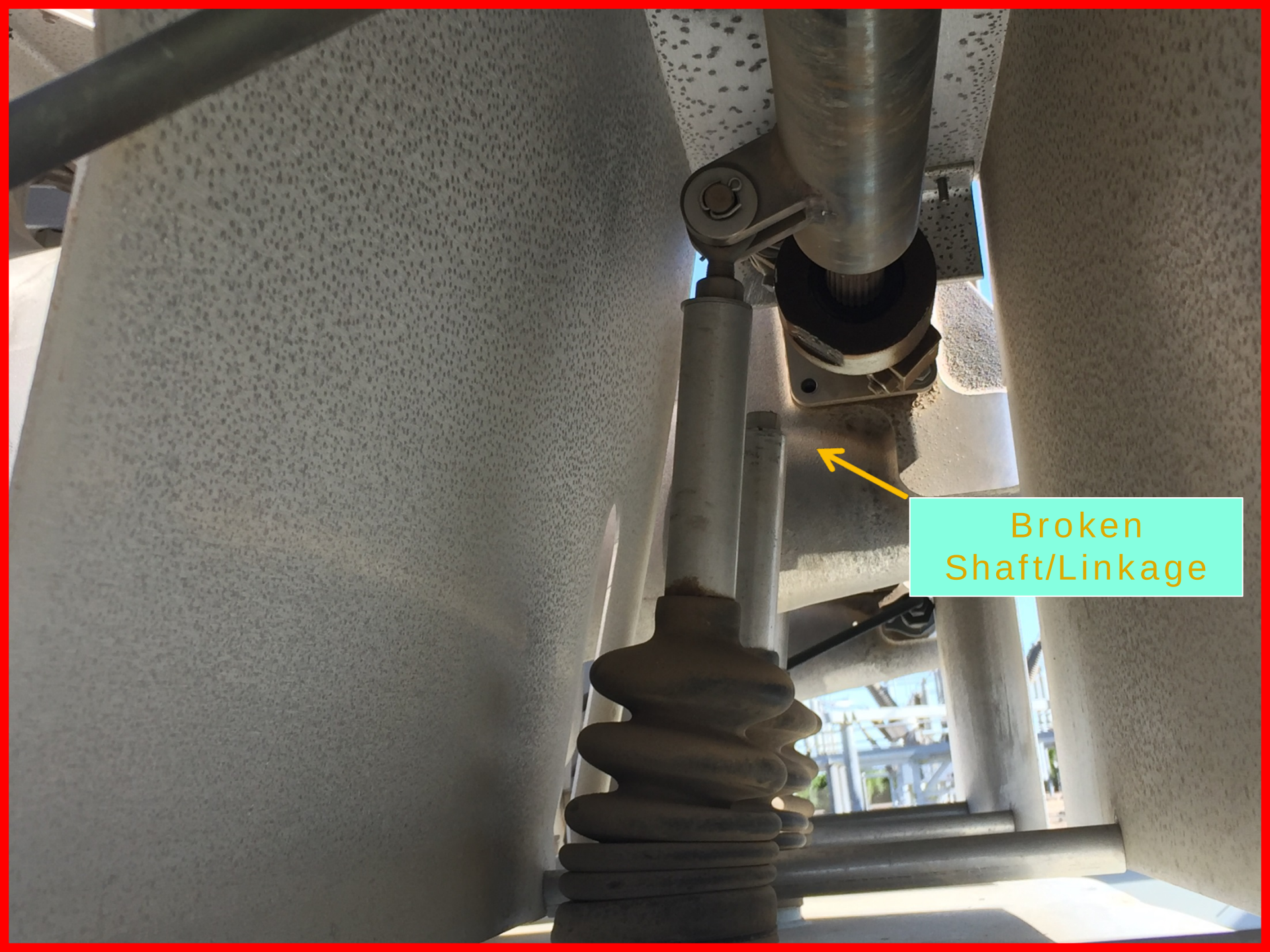

PHASE " C " STRINGS
OF CAPACITOR 'S
DAMAGED


LOW VOLTAGE CAPACITOR, 825 V,
NEUTRAL POINT TO GROUND, BLOWN

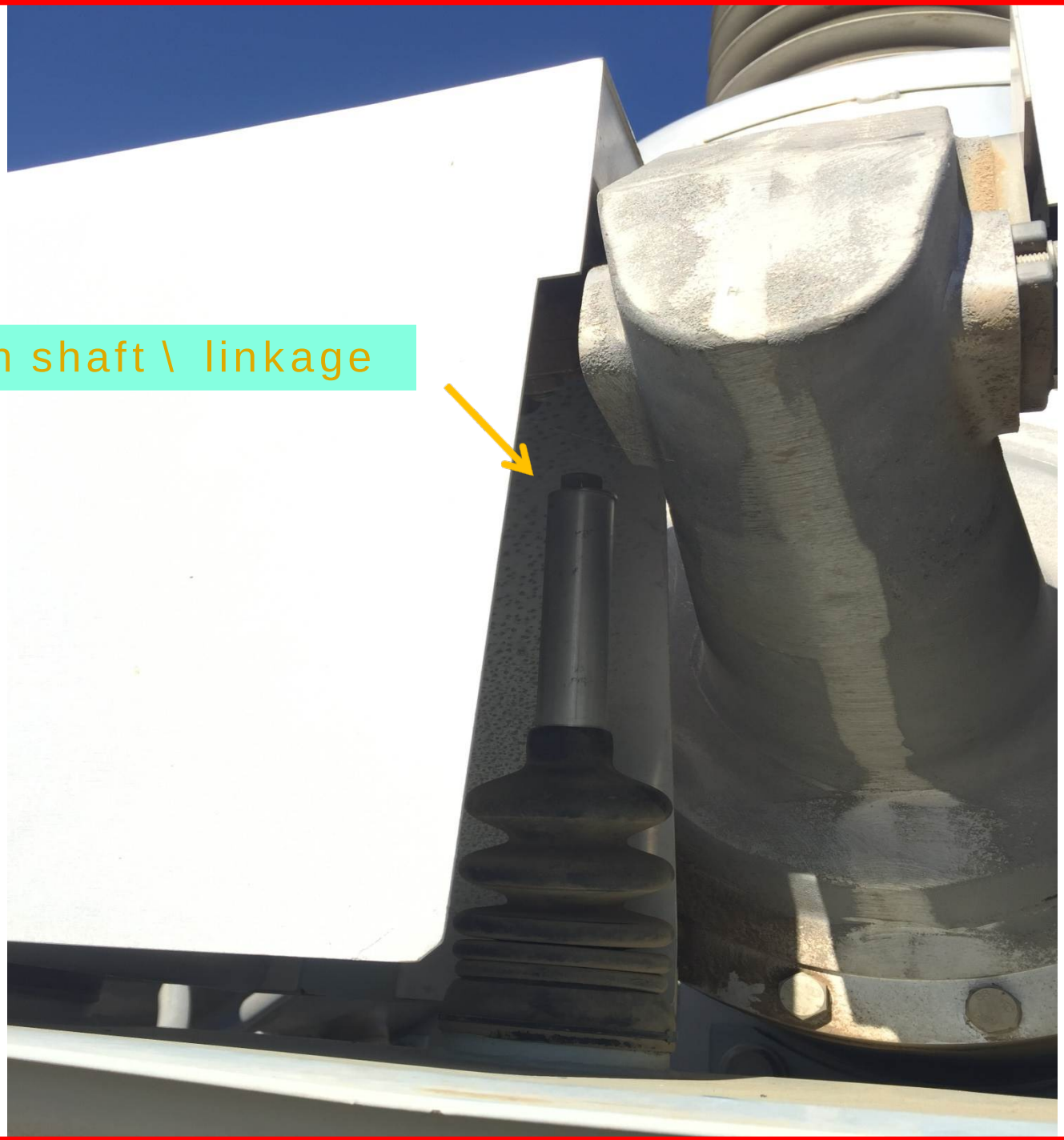

PHASE "CX" LOW VOLTAGE
CAPACITOR RUPTURED


PHASE " CY " LOW VOLTAGE
CAPACITOR BLOWN


PHASE “CY” STRINGS
CAPACITOR DAMAGED


Broken
Shaft/Linkage

Broken shaft \ linkage



Analysis & Findings

- Gregg CB 212 failed on miss-adjusted push rod per manufacturer. PG&E ATS concluded, component failure on ductile overload fracture or mal-adjusted eyelet bolt in service.
- Gregg CB 572 operating linkage lever, fractured in two places yet remained in closed position on power fail trip operation. Main circuit breaker contacts successfully open as designed.
- Gregg CB 212 breaker failure relay settings were found different from issued and desired relay settings of relay database. Errant settings were traced to have changed on July 2015 in the field for unknown reasons during maintenance.

Analysis & Findings

- Ashlan CB 212 radio power amplifier was burnt and failed in service during cascading events. Blocking signal was not received continuously at Herndon 242 causing carrier hole and over tripping. No High speed reclosing (HSR) initiate at Herndon 242 due to missed ground element at HSR output logic.

Corrective Action & Execution

- Telecommunication Techs to complete new replacement of Radio power amplifier on 06/28/2016. Carrier level checks performed and Pilot Line Blocking Scheme returned to service on 6/30/2016.

- Herndon CB 242 High Speed Reclosing relay settings updated, issued and completed on June 21, 2016.

- Evaluate Breaker Failure Relay, Phase & ground fault pickup at Gregg CB-212. Updated BFR relay minimum value of 0.5 amp on 6-20-2016.

Recommendations

- Replace Gregg CB 212 with new breaker for Capacitor Bank application, Zero Voltage Crossing type. Completed and placed in service 4-28-2017.

- Replace Gregg CB 572 operating linkage lever from cast aluminum to aluminum bar stock.

- Replace Gregg CB 212 and CB 222 existing vintage breaker failure relay with new microprocessor breaker fail relay. Completed replacement and released new breaker fail relay for service on 4-28-2017.

Recommendations

- Replace new Phase “C” Capacitor Bank units and associated metering and relaying components. Placed on service on April 28, 2017.
- TBA
- TBA

Lessons Learned

- Testing after adjustments to CB 212 did not reveal mal-adjusted operating rod on Phase “C”. Circuit breaker design provides no external indication that internal linkage broke & main breaker contacts closed.

- Breaker Failure Relay on CB 212 could have contained outage to the 230 kV Capacitor Bus only by tripping upstream breakers, CB 372 and CB 472 BAAH Bay 2. Errant settings left in the relay from previous maintenance activity was the root cause.

- Test Technicians & Protection Engineers reinforced not to change relay setting without out following proper procedures & documenting changes.

Neutral Capacitor Banks on Fire Video

20160616_155608.mp4

Thank you

Questions?