Widows Creek Disturbance
June 22, 2002 @1115

Problems and Near-Misses

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Abstract

On June 22, 2002 at 11:15 A.M. system time, motor-operated disconnect (MOD) 922 flashed over at the Widows Creek Fossil Plant while it was being opened in an attempt to deenergize Common Station Service Transformer E. The primary protection for this zone had been disabled, and this led to a temporary island of four Widows Creek generators with the tap loads of 13 substations. The final result was 12 Customer Connection Point Interruptions (CCPI), 4 generator interruptions, and 0.16 MWh of Load-Not-Served (LNS).

This paper discusses the results of the internal TVA investigation of this event, addressing the following items:

1. The importance of primary protection during primary switching;
2. Details of six relay misoperations which occurred during the event (for follow-up investigation and resolution);
3. The lack of abnormal frequency protection on TVA fossil-powered generators;
4. Reclosing issues: Blind reclosing into unsynchronized islands (why it occurred, how to prevent it); slow reclosing; reclosing failures.

Introduction

The Tennessee Valley Authority (TVA) is the largest public power producer in the United States. TVA has over 30,000 megawatts of generation, providing electrical power to the Tennessee Valley service area spanning portions of seven states. TVA owns over 17,000 miles of transmission lines covering over 80,000 square miles. All generation, interchange of power, and system dispatching are coordinated and controlled from Chattanooga, TN. The operation and maintenance of TVA's transmission system are divided into 15 geographical offices.

Generating plant switchyards are operated and maintained by the internal Transmission/Power Supply (TPS) organization. The ownership and maintenance boundary between TPS and the generating plants is at the high-side bushing of the generator step-up transformers (GSU). Switching procedures for clearance of all power equipment in the transmission system and up to the GSUs is issued by TPS transmission operators (formerly known as dispatchers).

Widows Creek Fossil Plant is located in northeast Alabama, with the following transmission and generation connections:

- Six 125MVA and two 500MVA fossil-fueled steam turbine-generators, with common station service and unit transformers;
- One 1200MVA 500/161/13kV intertie transformer bank;
- Four 500kV transmission lines terminated on two bus sections in a zig-zag arrangement;
- Eleven 161kV transmission lines and one 230kV (with series 230/161kV autotransformer) transmission line terminated on two bus sections in a zig-zag arrangement.
- The 161kV switchyard is divided into two sections, known as the North bus and the South bus. These buses are normally operated split. The South bus has eight 161kV lines, four 125MVA generators, and one 500MVA unit. The North

bus has three 161kV lines, the 230/161kV autotransformer and 230kV line, two 125MVA generators, one 500MVA unit, and the 500/161kV intertie transformer bank.

This paper is concerned with an event which occurred in the South bus, shown in Figure 1:

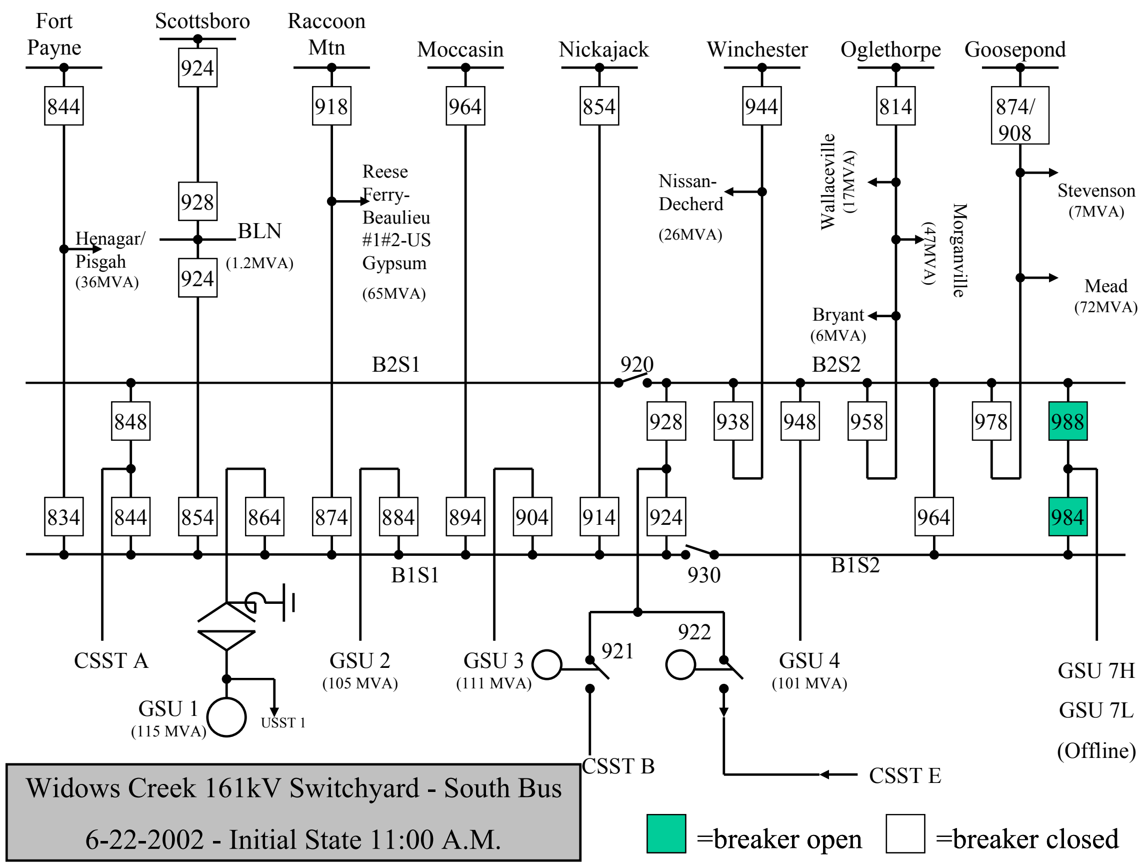


Figure 1: Widows Creek 161kV Switchyard - South Bus

Sequence of Events

On the morning of June 22, 2002, a clearance had been requested on common station service transformer (CSST) “E”, which provides power to the unit 7 scrubber through an 1800-ft section of underground oil-filled cable. While this should have been a routine procedure to adjust transformer taps, the decisions regarding protection of the transformer feeder and the subsequent switch flashover resulted in a near catastrophic event and a local blackout.

A timeline of events is provided in Appendix A. This can be used with the slides attached at the end of the paper to review each event as it occurred. Rather than detailing these events with text, each salient item regarding system protection (primary protection, relay misoperations, abnormal frequency protection of machines, and reclosing issues) will be reviewed in the following paragraphs.

Item 1: The importance of primary protection during primary switching

As shown in Figure 1, PCBs 924/928 feed Common Station Service Transformers B (Units 4,5,6 start boards) and E (Unit 7 Scrubber). This feeder is protected by differential overcurrent relays (figure 2). This protection was removed from service while 922 was being operated, supposedly to avoid a misoperation of the protection during switching, which would have resulted in a loss of CSST B. This indicates a misunderstanding of differential protection and its importance during primary switching.

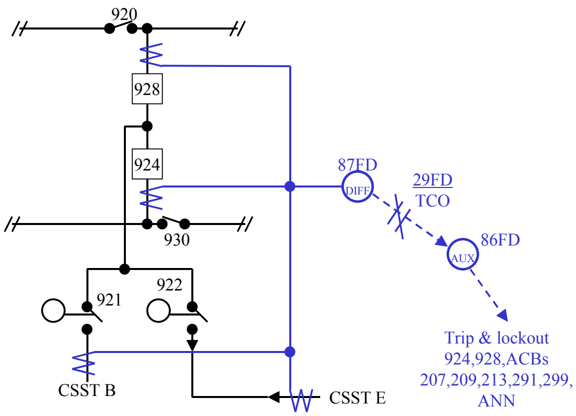


Figure 2: CSST B/E Feeder Differential Protection

The reason for disabling the protection is related to a disturbance which occurred on December 17, 2001, during which MOD 921 was operated to clear CSST B and flashed over because the low side 4kV ACBs were not opened to unload the transformer. The resulting fault was cleared in 4 cycles by the primary feeder differential protection.

On June 22, 2002, those involved in preparing the switching, including plant personnel and ESO system operators, made a conscious decision to remove the feeder differential protection from service by opening 29FD, thus disabling local primary protection for MOD 922. To be fair, it should be noted that at least a contributing factor in this decision is the fact that both CSST B and CSST E are fed from the same switchyard bay. If breakers 924 and 928 were used to deenergize CSST E, CSST B would be deenergized (and vice versa). Due to known problems in the transferring (both automatic and manual) of the common boards, this has caused the loss of control air and other significant loads (e.g., Raw Water Board #2, ignition systems) and has even resulted in unit trips. This is a known issue and is being worked on by site engineers.

In any event, the resulting disturbance lasted over 150 cycles (almost three seconds), taking 83.5 cycles to clear 16kA (initial) phase-to-ground bus fault. Backup protection at all eight remote terminals, plus backup protection on all four 125MVA generators, necessarily had to operate to clear this fault.

Disabling the feeder differential protection was the major cause of the extended duration of the disturbance and the resulting threats to TVA generators (described below). It is crucial that plant personnel and system operators recognize the importance of primary protection and be extremely careful in evaluating its removal from service, giving careful thought to the consequences should a fault occur in the primary zone of protection. As a guideline, primary protection should remain in service at all times except during secondary switching (e.g., switching bank differential CTs) or for relay testing. If there are any questions regarding the principles behind a relaying scheme, ESO/System Protection & Analysis should be contacted.

ESO/Transmission Operations dispatchers have issued new guidelines for Fossil Plant Switching (see attached).

A side issue in this case is the problem of deenergizing the predominantly capacitive current drawn by the oil-filled cable with an air-break MOD. Calculations indicated the cable would draw about 5.6A of capacitive current. This combines with the magnetizing current of the unloaded CSST of about 2.5A, for a net capacitive current of about 3A. According to the manufacturer, the air-break switch can break 3A, but not capacitive current. Typical switches of this type can break only about 2.2A capacitive current. While plant operators insisted this same procedure had been followed in the past with no trouble, this factor almost surely contributed to the flashover.

Item 2: Details of six relay misoperations

Referencing the timeline of events (included as an attachment), it can be seen that there were three line terminals that misoperated twice by carrier relay:

- t=4.1 cycles: At Scottsboro on the Bellefonte line (CLPG) (repeated at t=27 cycles) The set failed the carrier test a couple of weeks earlier, and a bad indicating milliammeter was found and repaired by fixing a cold solder joint. This same circuit picks up the carrier auxiliary relay that blocks tripping, so this is most likely what caused the carrier misop at Scottsboro. (However, this terminal again misoperated on 9/10/2002.)

- t=4.9 cycles: At Fort Payne on the Widows Creek line (MDAR) (repeated at t=37 cycles). Carrier level at Fort Payne was found to be too low. Sensitivity was adjusted at Fort Payne. Also a jumper in the MDAR was found to be in the wrong position so that the relay was not sensing the carrier set blocking output.

- t=5.3 cycles: At Winchester on the Widows Creek line (DEF) (repeated at t=25.8 cycles). The signal receive level at Winchester was found to be very high, which drove the receiver into overload, shutting it down.

While the Fort Payne and Winchester terminals had to trip anyway to clear the fault, these are still carrier relay misoperations.

In addition, there were two misoperations of KD zone 1 distance relays (Westinghouse KD-10 style #719B195A12):

- t=43.8 cycles: At Widows Creek on the Fort Payne line
- t=87.2 cycles: At Widows Creek on the Bellefonte line

Both relays misoperated with no fault in the forward direction. The relay misoperation on the Fort Payne line resulted in an extended outage to the Henagar and Pisgah tap stations. It was suspected this was a problem with memory voltage elapsing during the fault, possibly in connection with the simultaneous fault which occurred on the Nickajack terminal at the Widows Creek bus at t=37.1 cycles. Investigation revealed a problem in the control spring adjustment, which was corrected.

The final relay “misoperation” occurred at t=62.3 when unit 1 PCB 864 opened. Plant operators indicated that there were no targets, and only the high-side breaker 864 opened (no turbine trip, no field breaker trip, etc). This is unusual in that the other three units (2,3,4) which tripped all had A-phase 51V (IJCV voltage-restrained overcurrent relay) targets, which is the relay which should have operated for this fault.

The original design for 51V on smaller units (less than 500MW) tripped only the high-side breaker. Since 51V provides backup protection for transmission system phase faults, the early designers evidently believed that the units could have been ready to resynchronize in a short period of time once the system fault had been cleared. However, it was noted that tripping only the generator breaker could lead to an overspeed condition if the governor does not immediately operate to limit steam flow. Additionally, since the plant was built, local breaker failure has been installed for the 161kV line breakers. This made 51V a backup for the overall unit differential, and for faults in that zone, the entire unit should be shutdown (per IEEE 502-1995 paragraph 10.3).

It was thus decided that the 51V relay should be rewired on Widows Creek units 1-6 to shutdown the unit. This was to be done on unit 1 during the fall 1996 outage, but evidently was not. This has been corrected.

While these first two items are cause for concern, the last two items involve events which arose over the course of the disturbance that could have resulted in catastrophic damage to the Widows Creek generators (shaft twisting due to out-of-phase closing and/or turbine blade failure due to operation at or near mechanical resonant frequency)

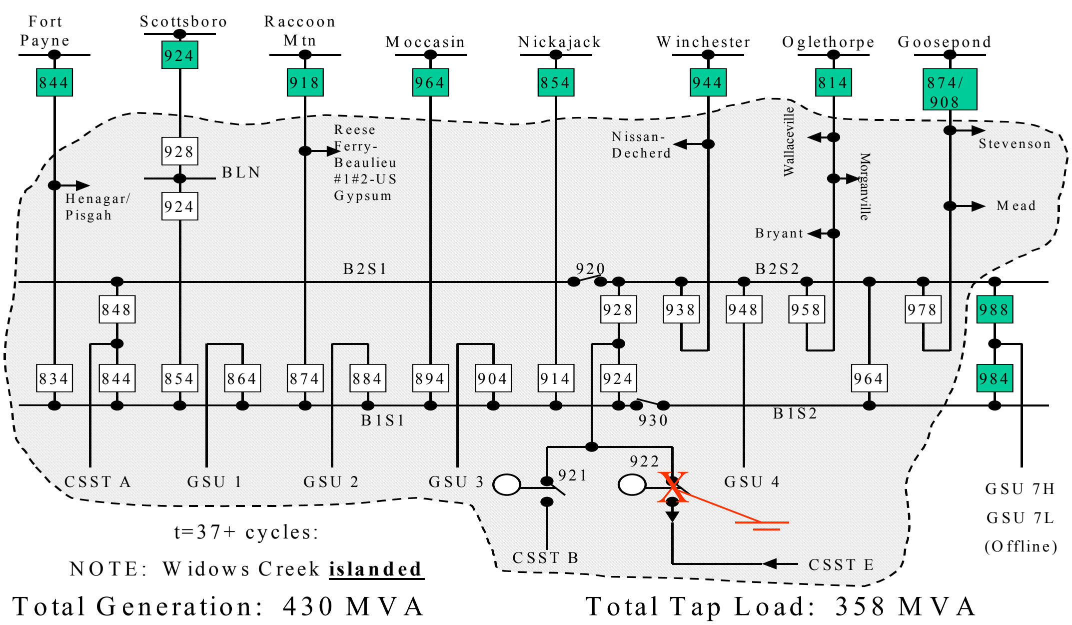


Figure 3: Widows Creek South Bus - Islanded

Item 3: Lack of abnormal frequency protection on fossil generators

Regarding abnormal frequency protection of fossil-power generators, the timeline shows that after the last remote terminal cleared (Fort Payne 844 at t=37 cycles), an island was formed (figure 3), with the Widows Creek generators 1, 2, 3, and 4 along with loads tapped off the eight 161kV lines and the Widows Creek station service loads. Total available generation was 4*125 MVA=500 MVA, matched against total prefault three-phase load of 358 MVA. As expected, then, the frequency of the island increased to about 60.73 Hz in about 16 cycles (267 msec) (figure 4).

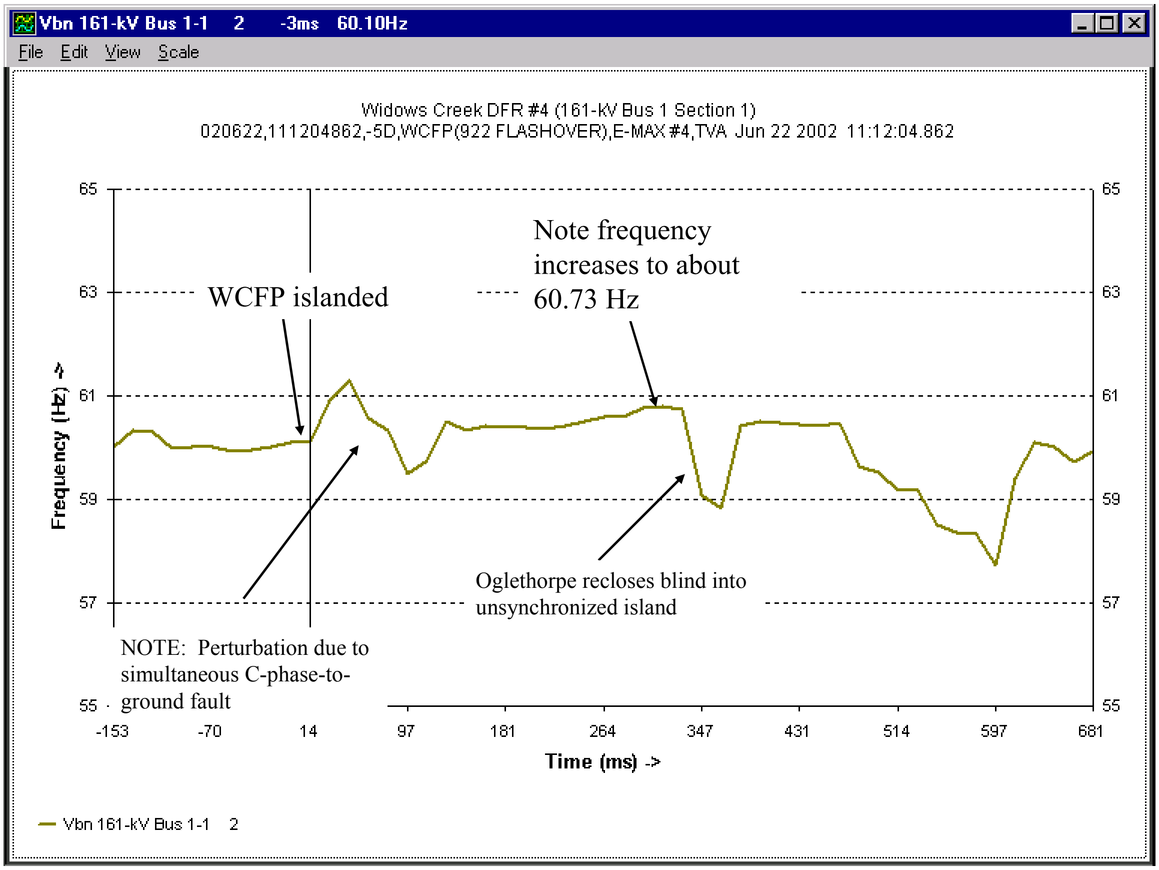


Figure 4: Widows Creek South Bus - Frequency

It should be noted that this event occurred on a Saturday at 11:00 A.M. Had the event occurred on a weekday during an extreme summer peak, the load of the island would have approached 487 MVA. If only three Widows Creek units had been online (a reasonable system configuration), the available generation would have been about 375 MVA, and the frequency of the island would have decreased. Underfrequency load shedding is installed at three of the tap stations, but it was in service at only two, so that the total load shed would have been only about 55 MVA, leaving 432 MVA of load against 375 MVA of generation. Under this scenario, the frequency of the island most likely would have dropped to the point that damage would have occurred to the Widows Creek steam turbines. This is because TVA steam turbine/generator units do not currently have underfrequency protection as prescribed by IEEE standards. A proposal is currently under development to upgrade TVA's generator protection on larger units to include underfrequency protection.

The importance of TVA's underfrequency load shedding program is also evident.

This is the second time in the past year that TVA has islanded local generation against local loads. In neither case did the underfrequency load shedding protection provide adequate load relief for the steam turbines. In both cases, the islands were formed as a result of a combination of operating errors and relay misoperations. Unlike some other utilities, TVA does not pre-determine desired islanding configurations. Rather, shedding net system load is considered adequate. As such TVA's present load shedding philosophy cannot provide adequate protection during island events as this one. (That is why the IEEE standards require generators to have underfrequency protection as the ultimate backup to system load shedding.)

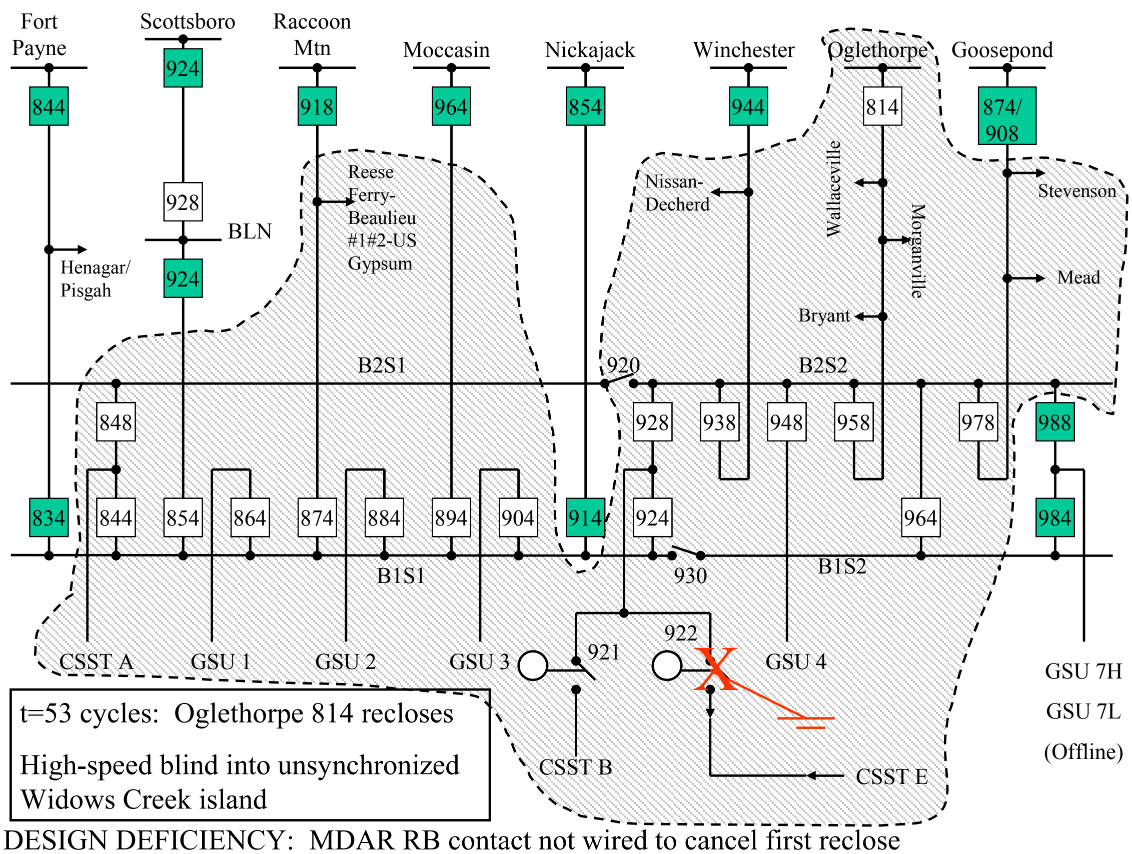


Figure 5: Widows Creek South Bus - Oglethorpe 814 reclosing into island

Item 4: Reclosing issues - blind reclosing into unsynchronized islands, etc

With regard to blind reclosing into an island which has changed frequency relative to the remainder of the power system: According to the attached timeline, at t=53 cycles, Oglethorpe PCB 814 reclosed high-speed "blind" (unsupervised) into the island (figure 5), due to a problem with the reclosing circuits at Oglethorpe. Calculations show that the island was approximately 30 degrees out of phase with the TVA system (figure 6), but, as noted above, the island was operating at about 60.73 Hz, with the TVA system still operating at 60 Hz. Had the reclose occurred with the two systems 180 degrees out of phase, it likely would have resulted in some degree of damage or at best loss-of-life to the shafts of all four Widows Creek generators (the effects of such events were studied in the 60's and 70's, resulting in the decision to eliminate high speed reclosing on the 500kV transmission system).

TVA reclosing standard design calls for the first reclose shot to be canceled for a time delayed trip on 161kV lines with carrier. This was not the case on this breaker and has been rectified by modifying the circuit per the present TVA standard[1]. (NOTE: Bellefonte PCB 924 is wired per the standard, but it failed to operate, which resulted in a

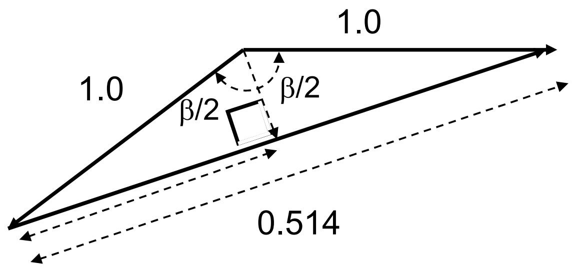
[1] It is recommended that the RB-1 contact of both MDAR relays (8121/67G-A and -B) at Oglethorpe be connected to operate the 79H/O coil (in parallel with 79RCT contact 6/8), canceling the first reclose on any time delay trip.

blind reclose after a ground time overcurrent trip at t=55 cycles. This will be investigated.)

Four other reclosing issues are being investigated: 1) Fort Payne 844 took 26.5 cycles to reclose high-speed (it should have taken 12-20 cycles), 2) Widows Creek 914 failed to reclose high-speed after successfully interrupting the C-phase-to-ground fault on the Nickajack line, 3) and 4) Widows Creek 834 and 854 both failed to reclose high-speed after the zone 1 KD misoperations.

$$I = \frac{dV}{X} = \frac{|1\angle 0 - 1\angle\beta|}{X_S + X_L + X''_D} = \frac{|1\angle 0 - 1\angle\beta|}{0.0172 + 0.0922 + 0.0447} = \frac{|1\angle 0 - 1\angle\beta|}{0.1541} = 3.33$$

$$|1\angle 0 - 1\angle\beta| = 0.514$$



Solve for β:

sin (β/2) = 0.514/2

$\therefore \beta = 2*\sin^{-1}(1.89/2) = 30^\circ$

Figure 6: Approximate calculation of angle across open Oglethorpe 814 just before blind reclose

Conclusions

The final result of this disturbance could have been much worse. This was a major transmission system disturbance that offers valuable lessons that should be heeded. The following steps were thus recommended:

1. Results of this analysis to presented to transmission operators, discussing importance of primary protection especially during primary switching;
2. Troubleshooting and design changes necessary on some reclosing circuits, keeping the standard in mind (cancel high-speed blind reclosing on time-delay trip on pilot lines).
3. Results of this analysis presented to fossil power management, emphasizing need/justification for underfrequency protection on TVA fossil turbine-generators (something TPS has been recommending since 1994).

Biographical Sketch

Gary Kobet is a Project Specialist, System Protection & Analysis for the Tennessee Valley Authority (TVA) in Chattanooga, Tennessee. His responsibilities include scoping relaying schemes for transmission and generation projects, as well as relay setpoint calculations. He has performed transient studies using EMTP for breaker TRV studies and switching surge overvoltages. Previously he worked as a field engineer and as power quality specialist. Mr. Kobet earned the B.S.E. (electrical) from the University of Alabama in Huntsville in 1989 and the M.S.E.E. from Mississippi State University in 1996. He is a member of the IEEE Power Engineering Society, CIGRE', Eta Kappa Nu, Tau Beta Pi, and is a registered professional engineer in the state of Alabama. Presently he is serving on the NERC System Protection & Control Task Force.

Appendix A
Timeline of Events for WCFP 922 Flashover 6-22-2002@1115

time (cycles)	Event	Targets	Findings
0	Operator opens WCF MOD 922		
4.1	Scottsboro 924 trips	9264 carrier ground	Carrier relay **misoperation**
4.9	Fort Payne 844 trips	PLTG	Carrier relay **misoperation**
5.3	Winchester 944 trip	DEF carrier ground	Carrier relay **misoperation**
20.5	Winchester 944 recloses	High-speed blind	
21	Scottsboro 924 recloses	High-speed blind	
23	Nickajack 854 trips	DEF ground TOC	Backup ground relay operation
25.8	Winchester 944 trips	DEF carrier ground	Carrier relay **misoperation**
26	Moccasin 964 trips	9664 ground TOC	Backup ground relay operation
27	Scottsboro 924 trips	9264 carrier ground	Carrier relay **misoperation**
30.6	Oglethorpe 814 trips	GB	Backup ground relay operation
31.3	Fort Payne 844 recloses	High-speed blind	
32.5	Goosepond 874/904 trip	DEF ground TOC	Backup ground relay operation
36.1	Raccoon Mountain 918 trips	9K67G JBCG time	Backup ground relay operation
37	Fort Payne 844 trips	PLTG carrier ground	Carrier relay **misoperation** (WCFP Units 1-4 **islanded** with tap and CSST load)
37.1	C-phase-to-ground fault develops at Widows Creek in Nickajack bay (adjacent to 922 A-phase arcing)		
38.3	Bellefonte 924 trips	9264 ground TOC	Backup ground relay operation
39	Widows Creek 914 trips	DEF carrier ground	Carrier relay operation (**didn't reclose auto**)
43.8	Widows Creek 834 trips	8321Z1	KD relay **misoperation** (**didn't reclose auto**)
53	Oglethorpe 814 recloses	High-speed blind	**Blind reclose into unsynchronized island** (MDAR RB contact not wired to cancel first reclose)
55	Bellefonte 924 recloses	High-speed blind	**Erroneous** (ground backup trip should have cancelled high-speed)
60.5	Widows Creek 904 trips	A-phase IJCV	
61.2	Bellefonte 924 trips	9264 ground TOC	Suspect notching and no instantaneous reset (only took 6.2 cycles to retrip)
62.3	Widows Creek 864 trips	Unknown	Plant reports no IJCV target, 87C did not trip, only 864 tripped. Suspect A-phase IJCV tripped 864 only and did not drop target. In early 1997 units 1-6 were to be rewired to shutdown unit instead of just 864. Probably unit 1 was missed.
65	Widows Creek 884 trips	A-phase IJCV	
68	Widows Creek 948 trips	A-phase IJCV	
83.5	Oglethorpe 814 trips	GB	Backup ground relay operation
83.5	Widows Creek Buses 1-1, 1-2,2-1,2-2 deenergized		All tap loads deenergized
87.2	Widows Creek 854 trips	8521Z1	KD relay **misoperation (didn't reclose auto)**
150	Winchester 944 recloses, reenergizing Widows Creek, Buses 1-1,1-2,2-1,2-2	Standard-speed dead-line	Island restored
150+	Nickajack 854 recloses dead-line, Raccoon Mtn 918, Goosepond 874/908, Moccasin 964, Oglethorpe 814, Widows Creek 914 reclose sync-check		
150++	Manually closed: Scottsboro 924 (SCADA), Bellefonte 924 (local), Fort Payne (SCADA), Widows Creek 834, 854 (local)		

Appendix B
FOSSIL PLANT SWITCHING

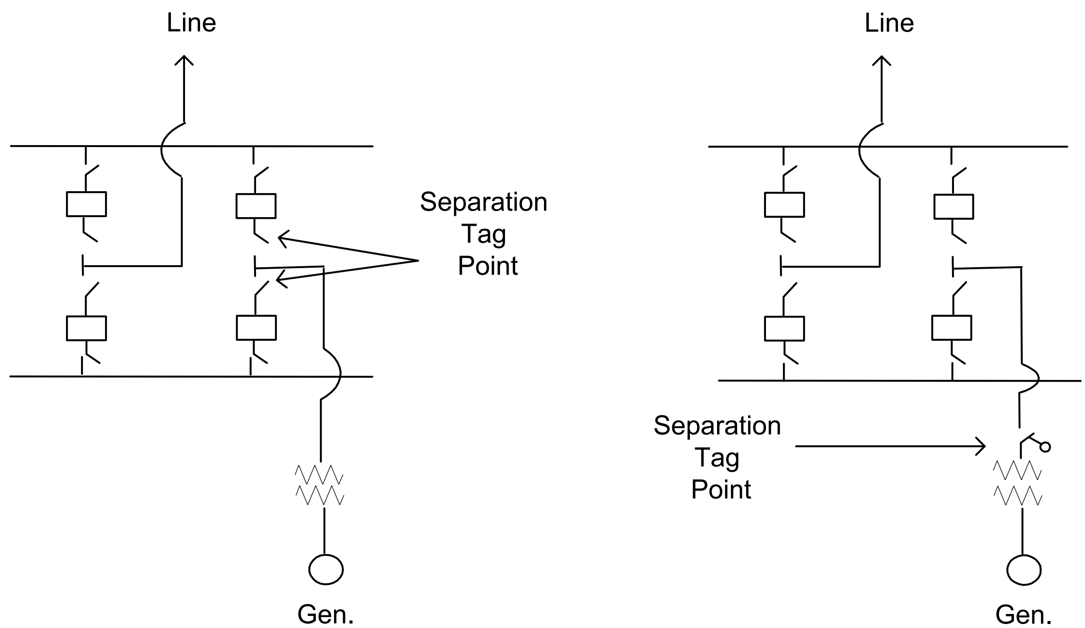
- No relays will be removed from service while switching any equipment with the exception of normal PK switching.
- Dispatching will not issue switching to de-energize plant transformers with a disconnect.
- Never issue a "separation clearance" to anyone to do work, only to someone to establish a complete working clearance. Dispatching only issues a "separation clearance."

Safety grounds procedure for working clearance at fossil plant will be done according to operation Letter No. 13.

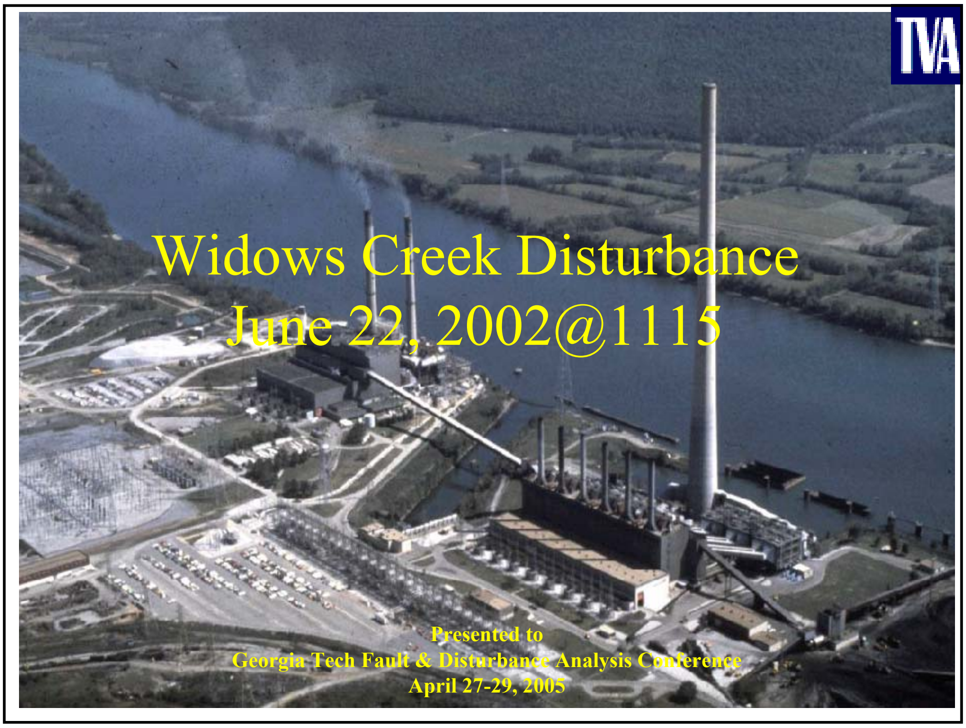
Who switches what?

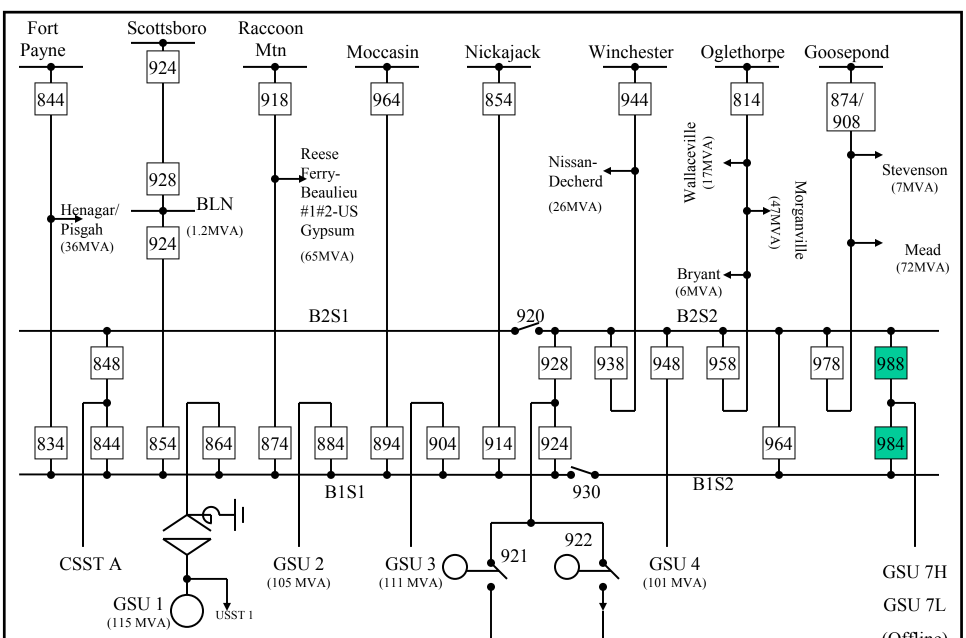
- All breakers solely dedicated to plant equipment would be switched by plant personnel (Fossil or Combustion Turbine personnel).
- All breakers dedicated to transmission equipment would be switched by Transmission Operations and Maintenance (TOM) personnel.
- All breakers dedicated to plant/transmission equipment would be switched by the organization requesting the clearance.

Note: All switching (from generator to system) at fossil plant must be coordinated through Electric System Operations (ESO) dispatching organization.



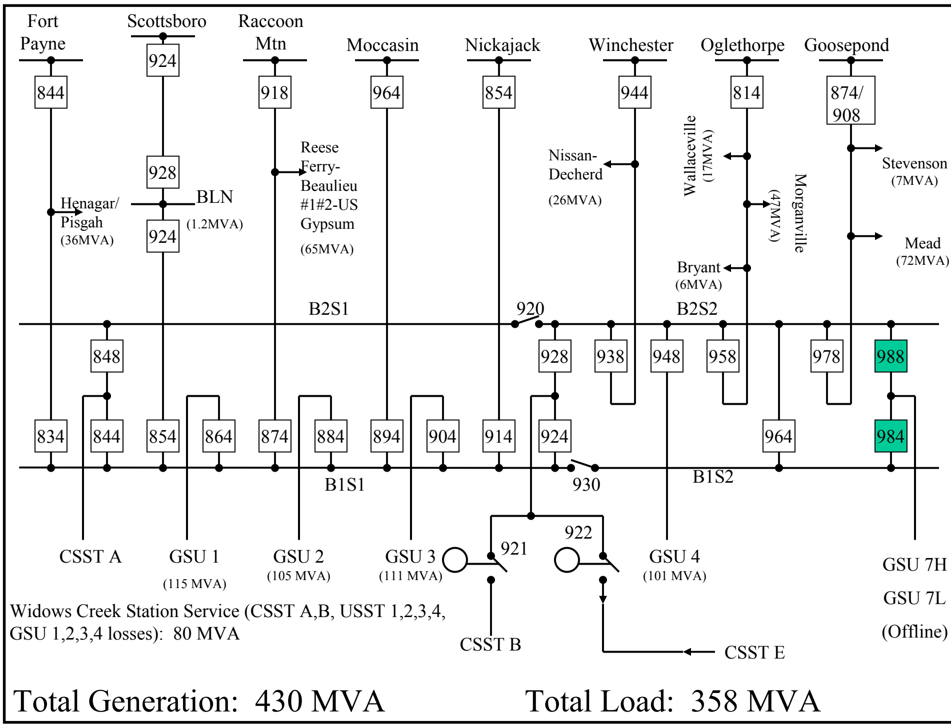
Plants will assume the responsibility of tagging their GSU transformers and generators, including station service breakers for their work.



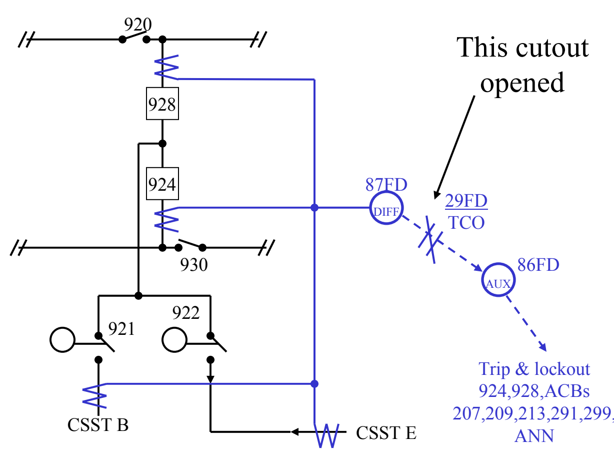


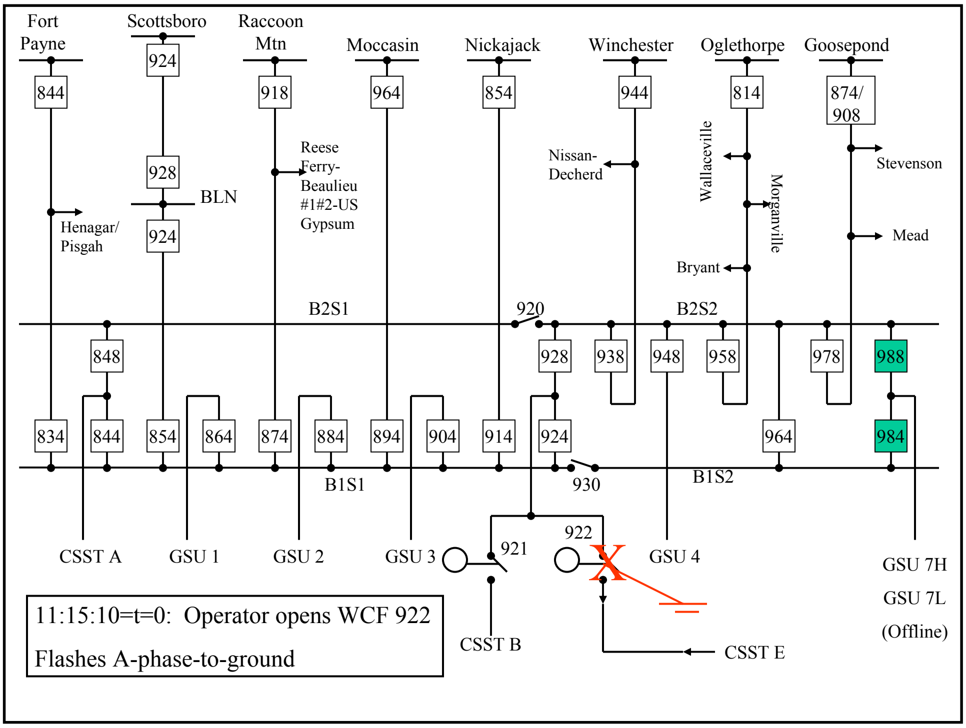
Widows Creek 161kV Switchyard - South Bus

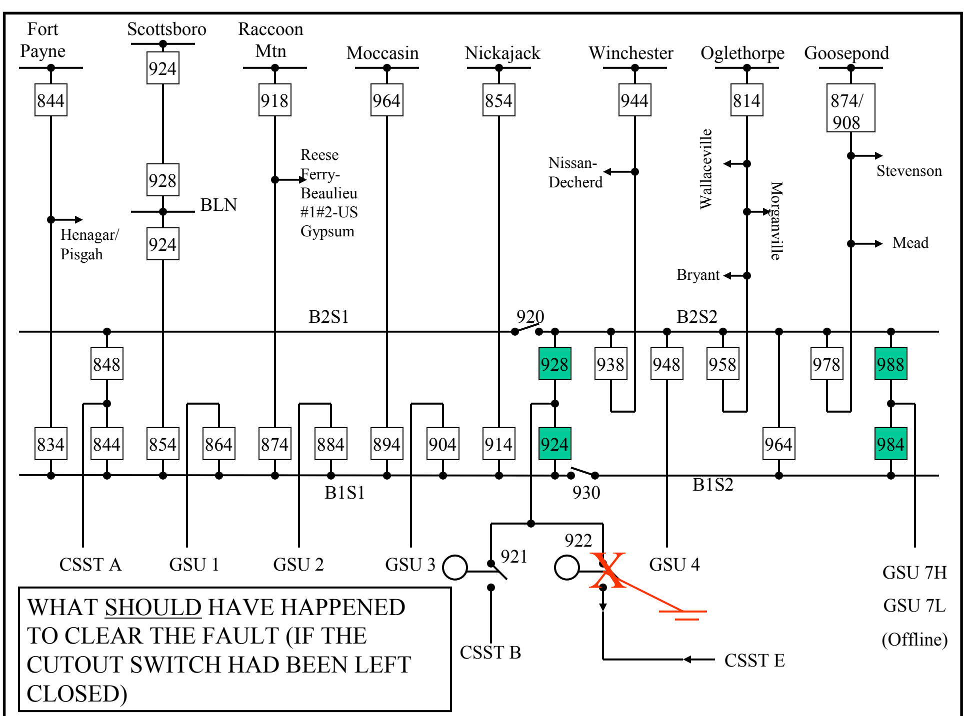
6-22-2002 - Initial State 11:00 A.M.



Widows Creek CSST B/E Feeder Differential Protection




Fort Payne
Scottsboro
Raccoon Mtn
Moccasin
Nickajack
Winchester
Oglethorpe
Goosepond
924
844
918
964
854
944
814
874/ 908
928
BLN
924
Reese Ferry-Beaulieu #1#2-US Gypsum
Nissan-Decherd
Wallaceville
Morganville
Stevenson
Mead
Henagar/ Pisgah
Bryant
B2S1
920
B2S2
848
928
938
948
958
978
988
834
844
854
864
874
884
894
904
914
924
964
984
B1S1
930
B1S2
CSST A
GSU 1
GSU 2
GSU 3
921
922
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
11:15:10=t=0: Operator opens WCF 922
Flashes A-phase-to-ground


Fort Payne
Scottsboro
Raccoon Mtn
Moccasin
Nickajack
Winchester
Oglethorpe
Goosepond
924
844
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854
944
814
874/ 908
928
BLN
924
Reese Ferry-Beaulieu #1#2-US Gypsum
Nissan-Decherd
Wallaceville
Morganville
Stevenson
Mead
Henagar/ Pisgah
Bryant
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848
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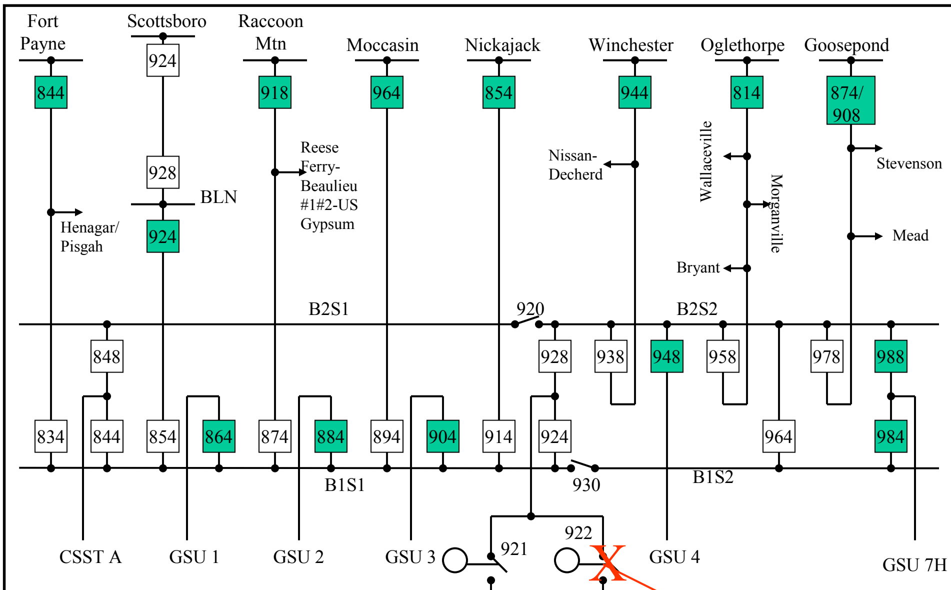
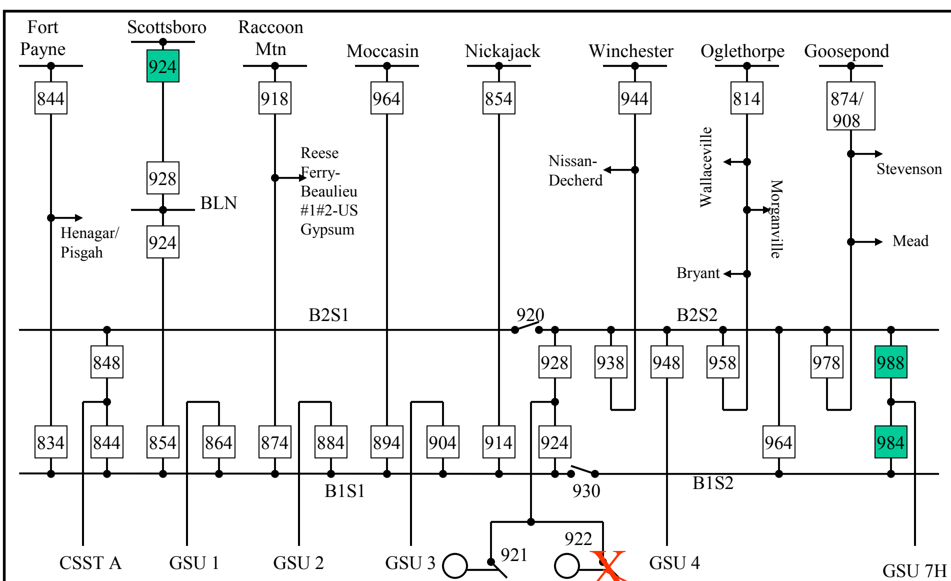
988
834
844
854
864
874
884
894
904
914
924
964
984
B1S1
930
B1S2
CSST A
GSU 1
GSU 2
GSU 3
921
922
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
WHAT SHOULD HAVE HAPPENED TO CLEAR THE FAULT (IF THE CUTOUT SWITCH HAD BEEN LEFT CLOSED)



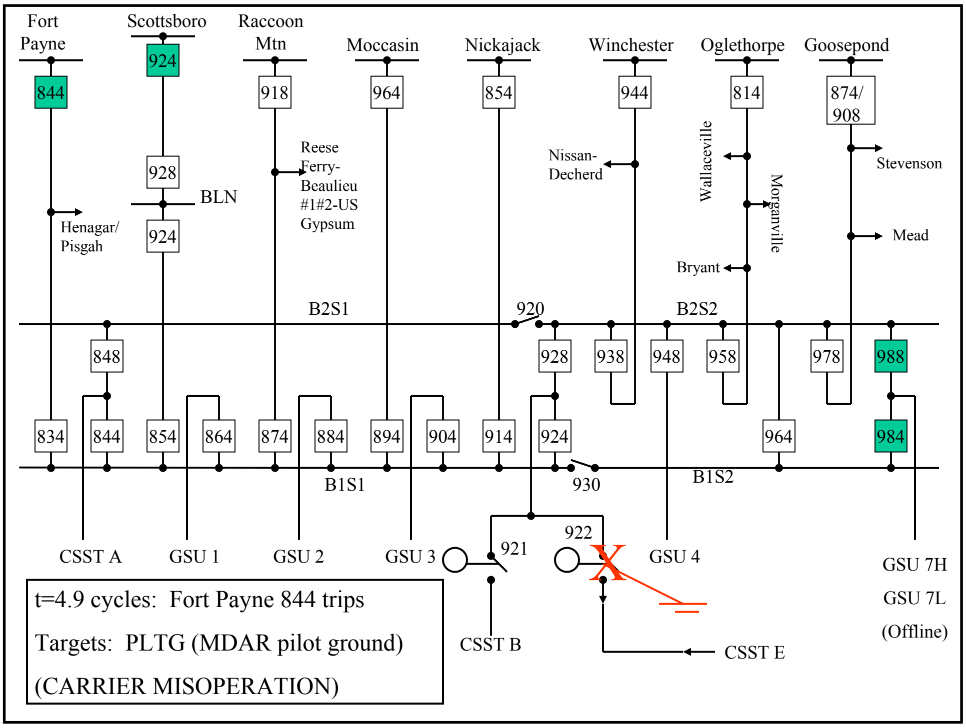
WHAT MUST HAPPEN TO CLEAR THE FAULT WITH THE CUTOUT OPEN



WHAT ACTUALLY HAPPENED

t=4.1 cycles: Scottsboro 924 trips

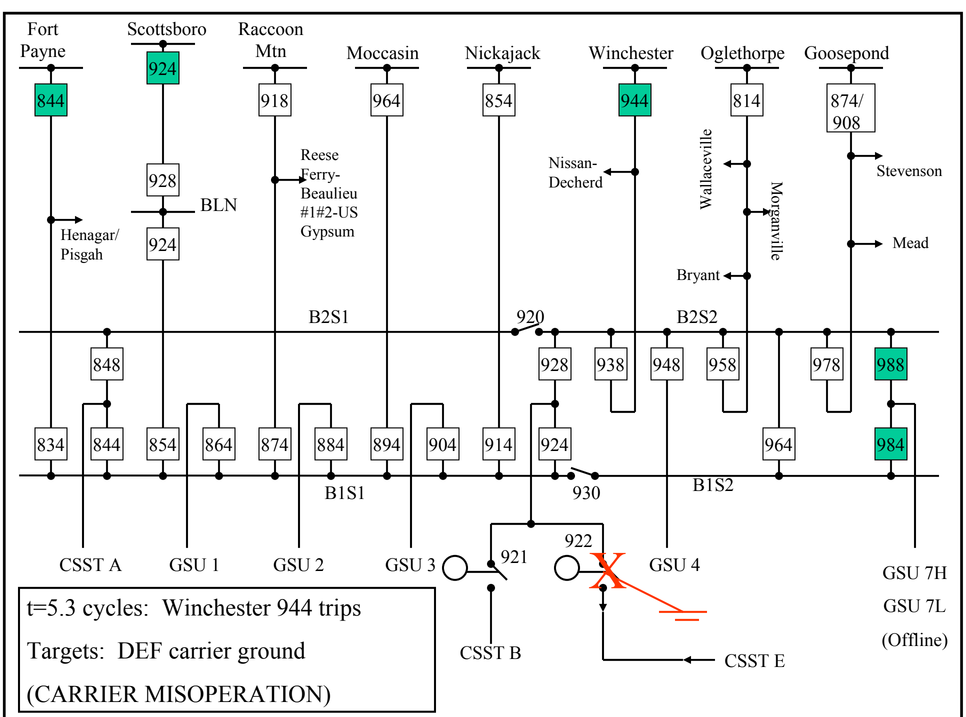
Targets: 9264H carrier ground (CARRIER MISOPERATION)



t=4.9 cycles: Fort Payne 844 trips

Targets: PLTG (MDAR pilot ground)

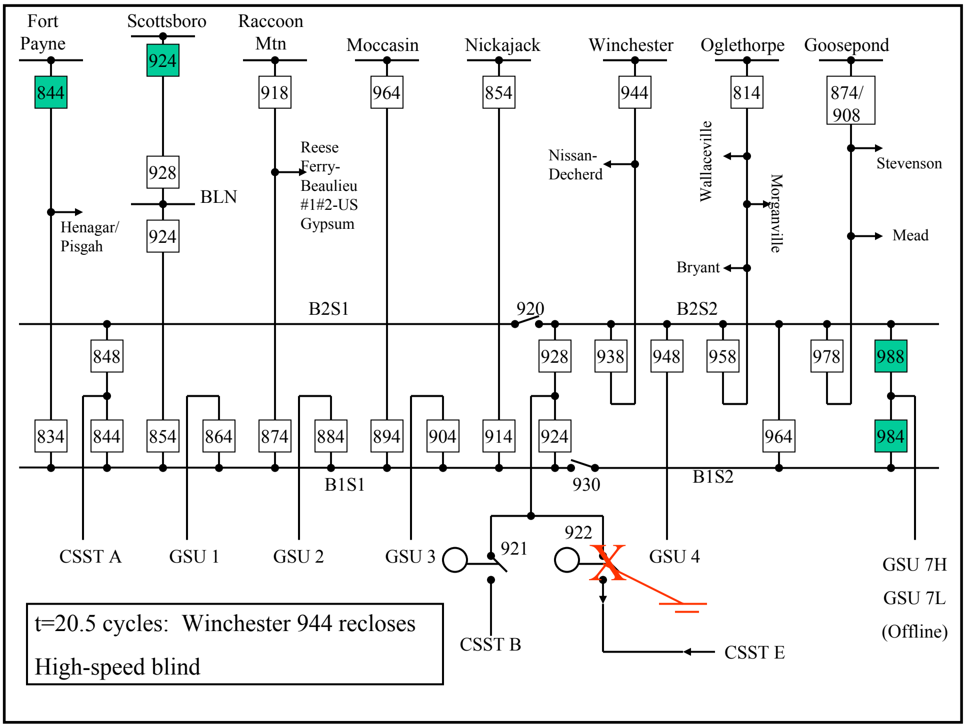
(CARRIER MISOPERATION)



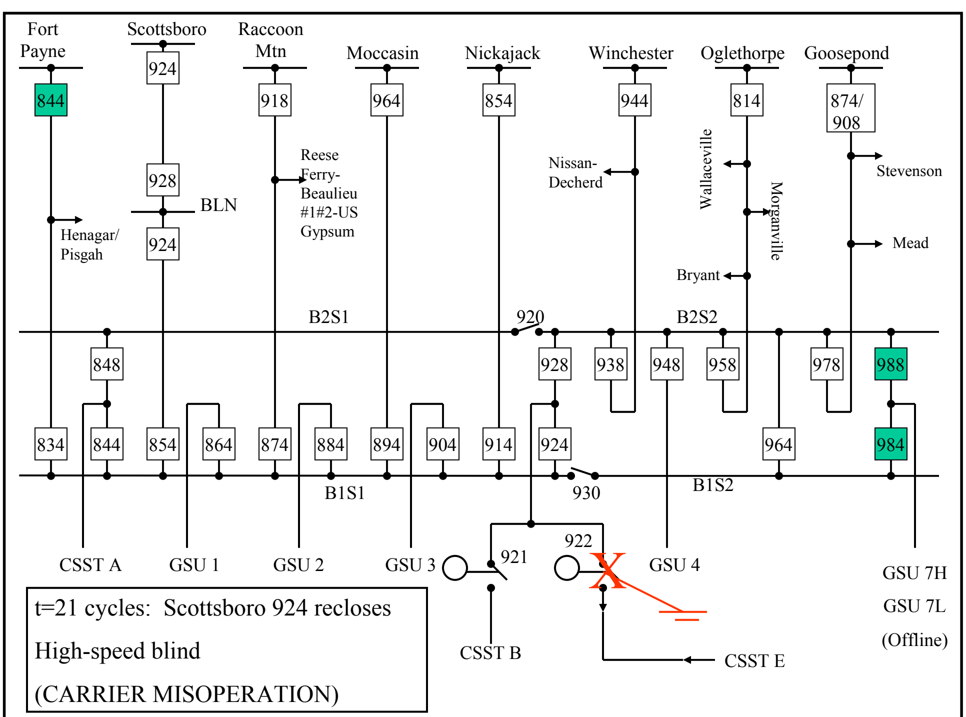
t=5.3 cycles: Winchester 944 trips

Targets: DEF carrier ground

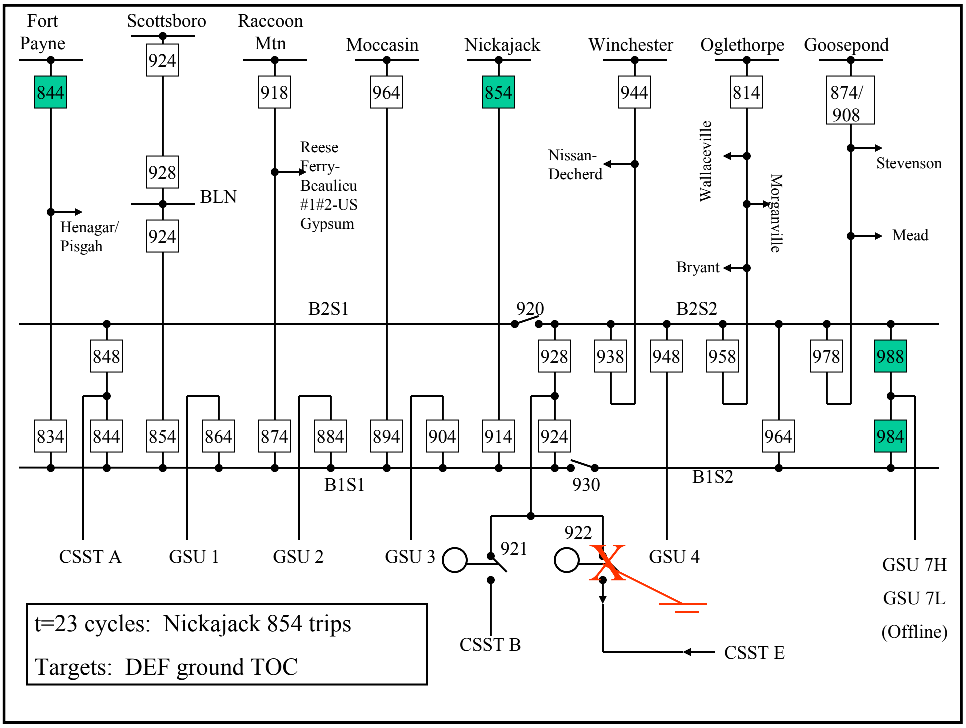
(CARRIER MISOPERATION)



t=20.5 cycles: Winchester 944 recloses
High-speed blind



t=21 cycles: Scottsboro 924 recloses
High-speed blind
(CARRIER MISOPERATION)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Reese Ferry-Beaulieu #1#2-US Gypsum
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Wallaceville
Morganville
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CSST A
GSU 1
GSU 2
GSU 3
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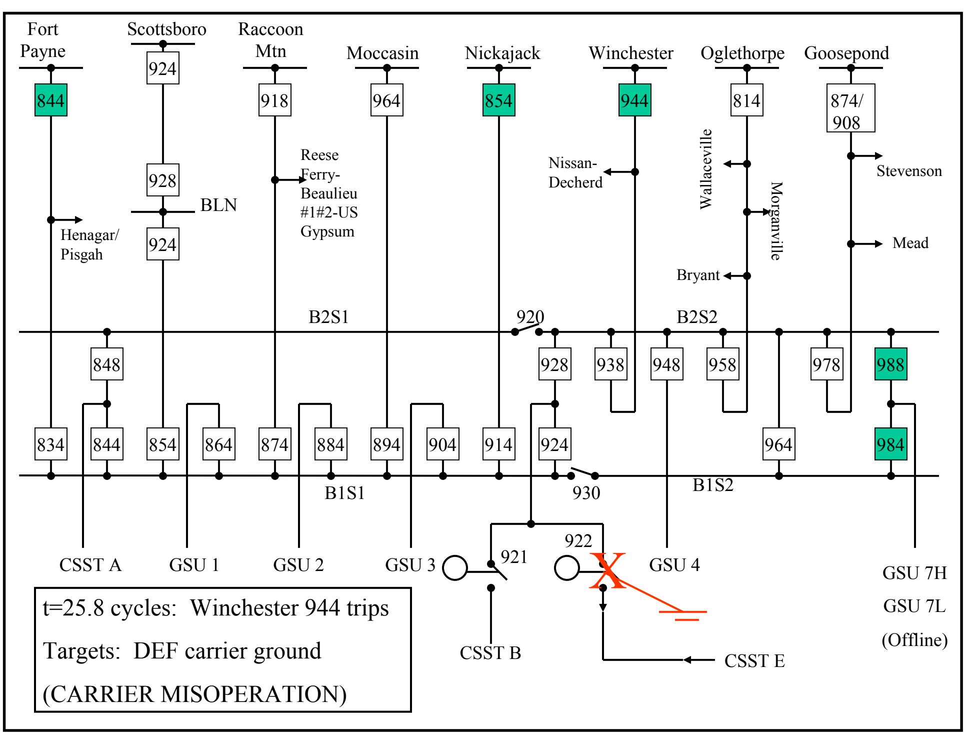
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=23 cycles: Nickajack 854 trips
Targets: DEF ground TOC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CSST A
GSU 1
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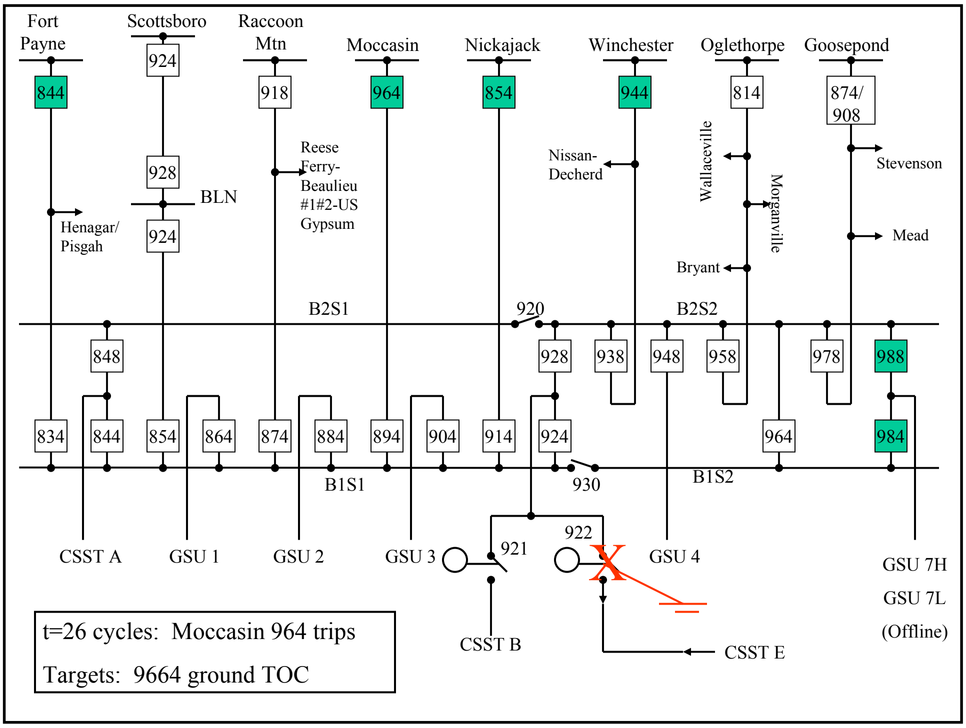
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=25.8 cycles: Winchester 944 trips
Targets: DEF carrier ground
(CARRIER MISOPERATION)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B1S2
CSST A
GSU 1
GSU 2
GSU 3
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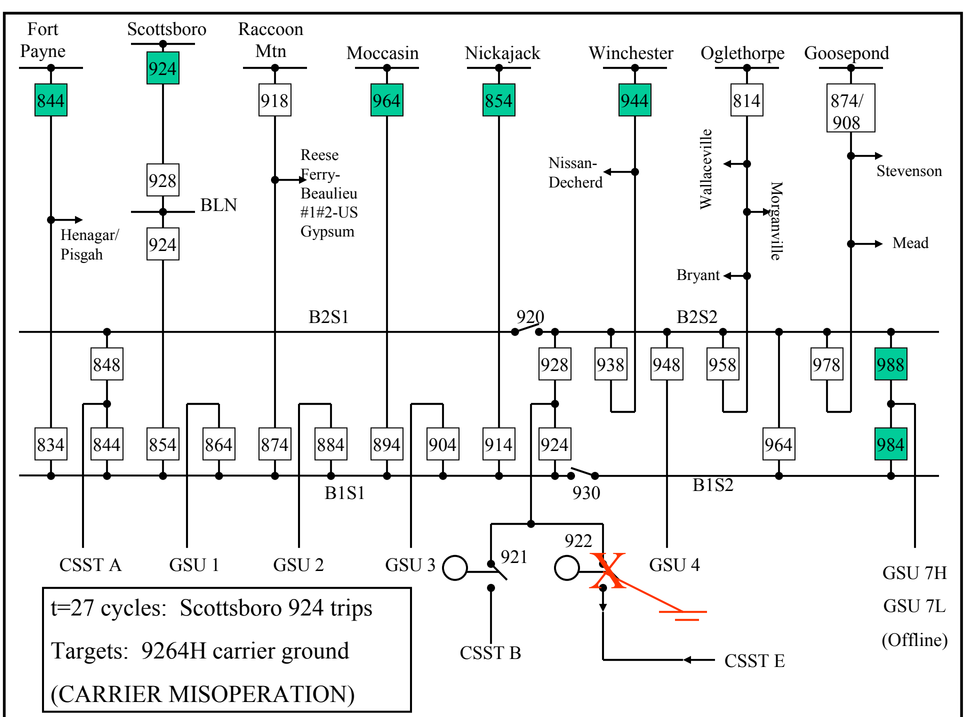
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
X
t=26 cycles: Moccasin 964 trips
Targets: 9664 ground TOC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CSST A
GSU 1
GSU 2
GSU 3
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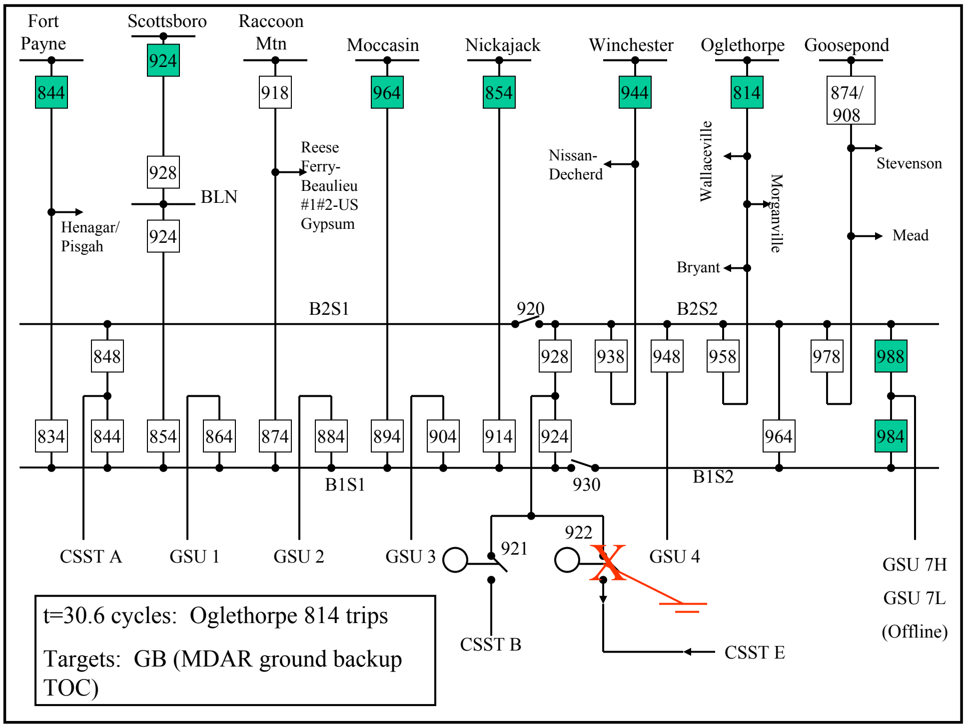
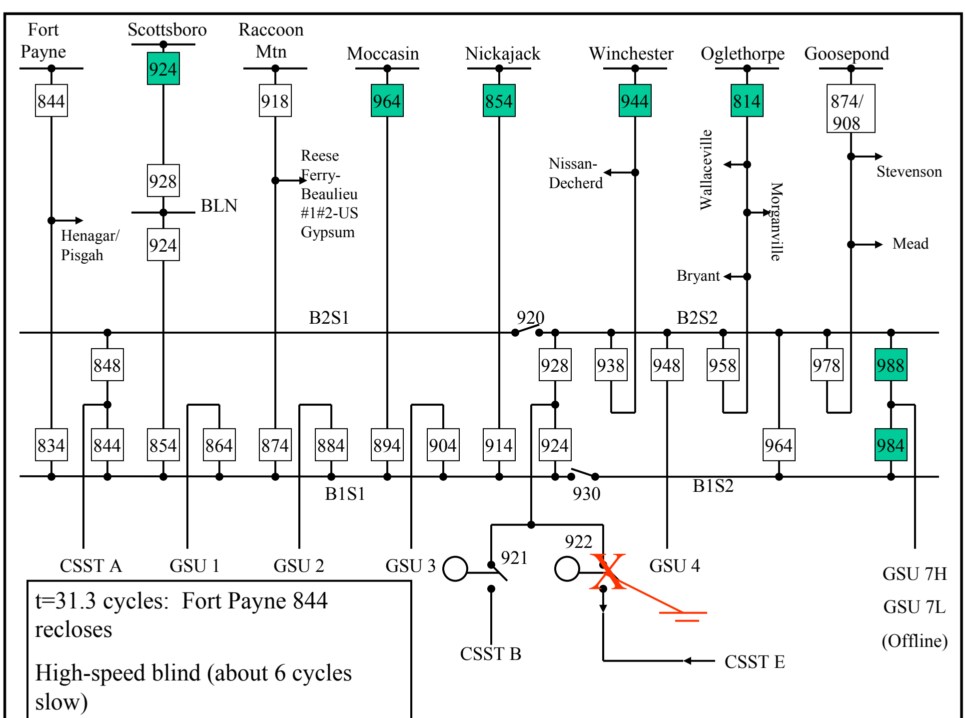
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
X
t=27 cycles: Scottsboro 924 trips
Targets: 9264H carrier ground
(CARRIER MISOPERATION)



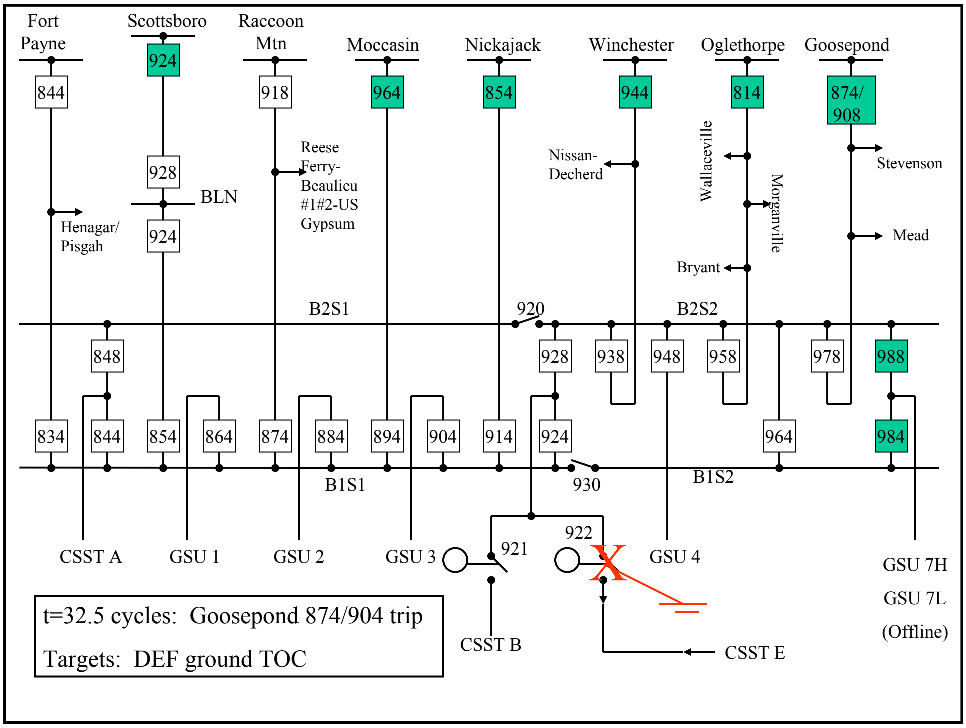
t=30.6 cycles: Oglethorpe 814 trips

Targets: GB (MDAR ground backup TOC)



t=31.3 cycles: Fort Payne 844 recloses

High-speed blind (about 6 cycles slow)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CSST A
GSU 1
GSU 2
GSU 3
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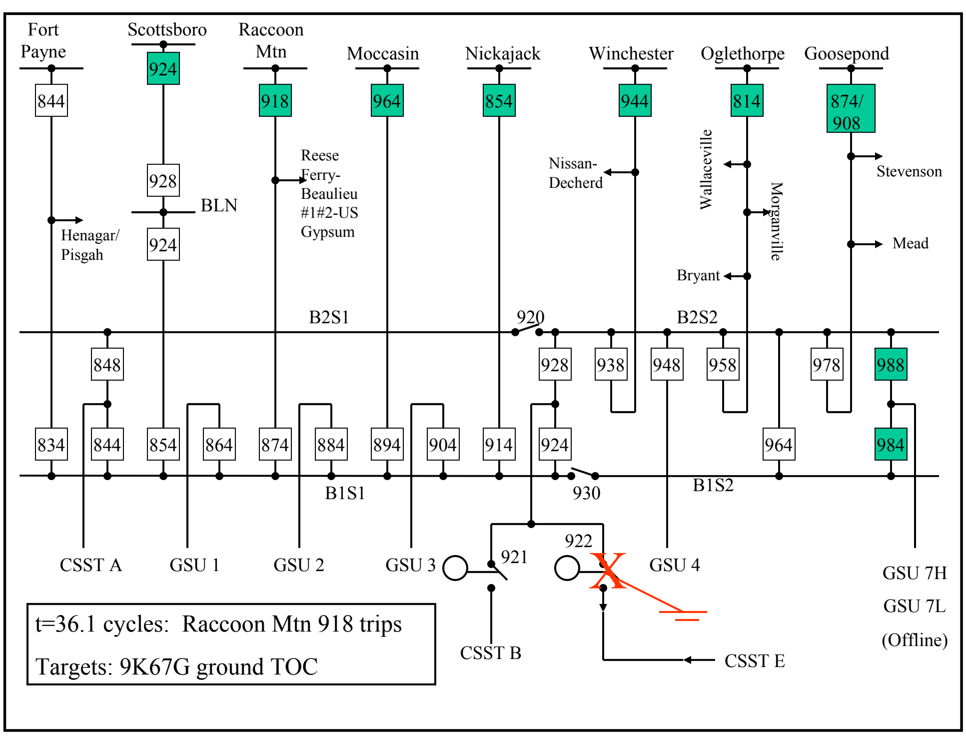
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=32.5 cycles: Goosepond 874/904 trip
Targets: DEF ground TOC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Reese Ferry-Beaulieu #1#2-US Gypsum
Henagar/ Pisgah
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CSST A
GSU 1
GSU 2
GSU 3
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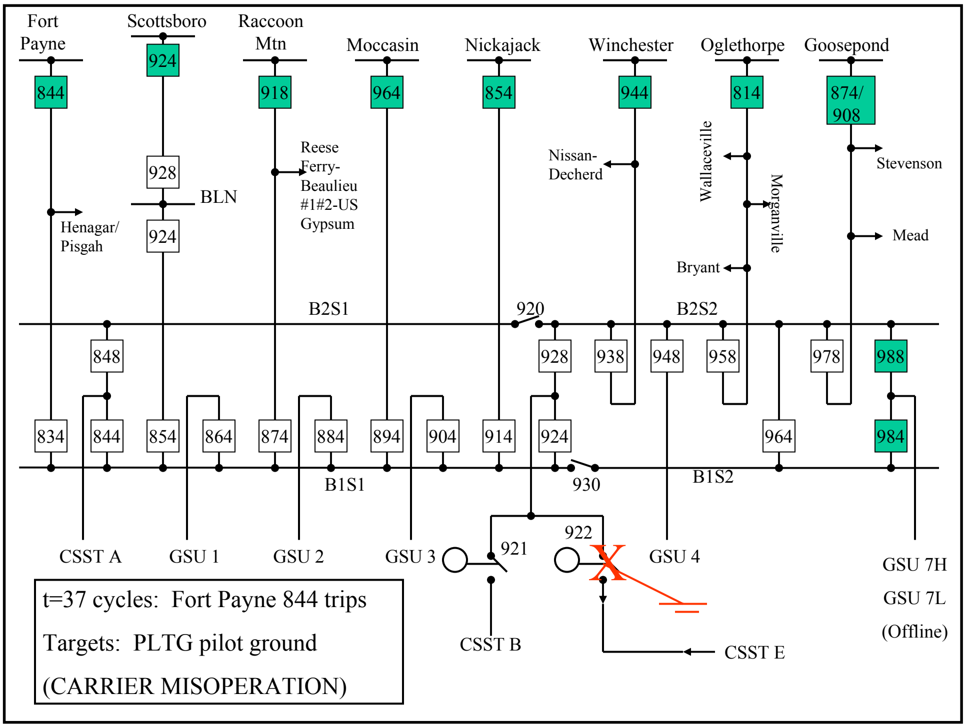
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=36.1 cycles: Raccoon Mtn 918 trips
Targets: 9K67G ground TOC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CSST A
GSU 1
GSU 2
GSU 3
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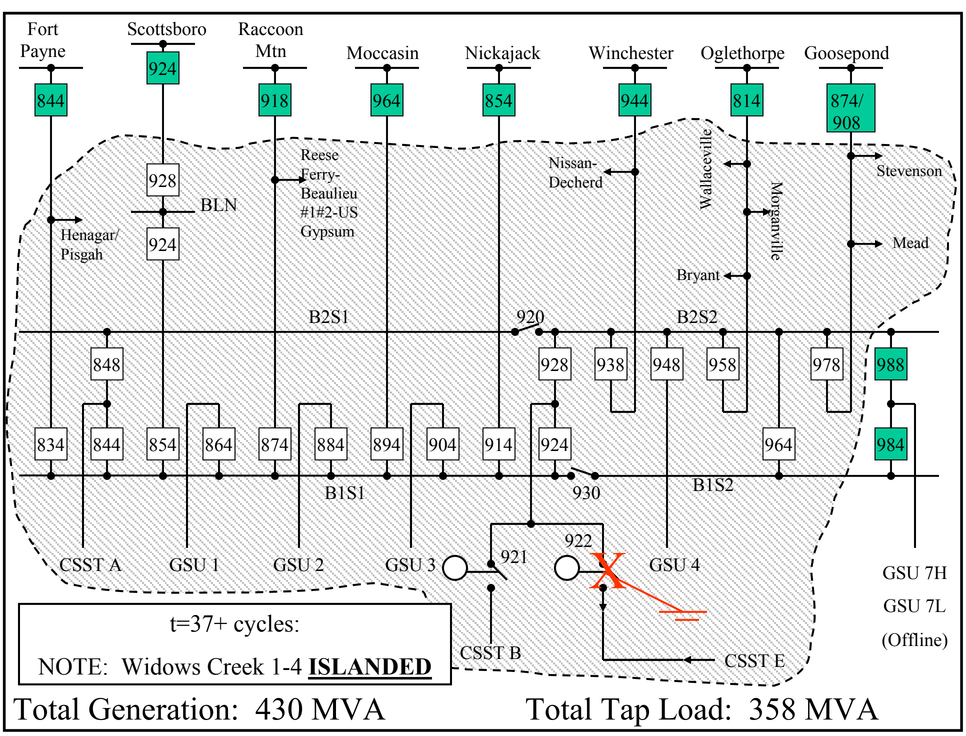
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=37 cycles: Fort Payne 844 trips
Targets: PLTG pilot ground
(CARRIER MISOPERATION)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CSST A
GSU 1
GSU 2
GSU 3
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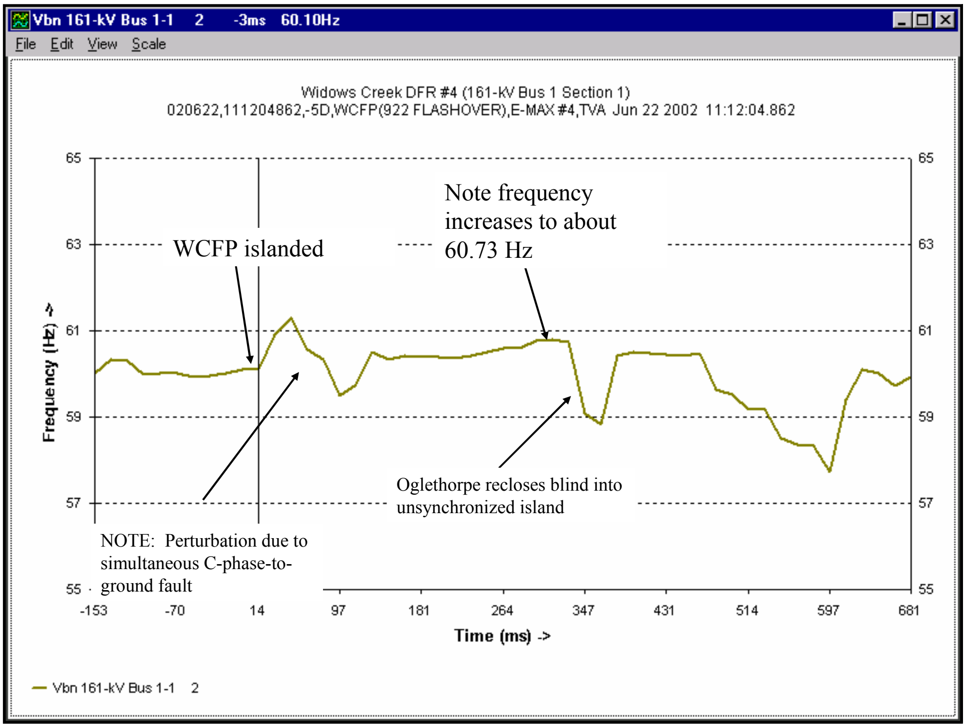
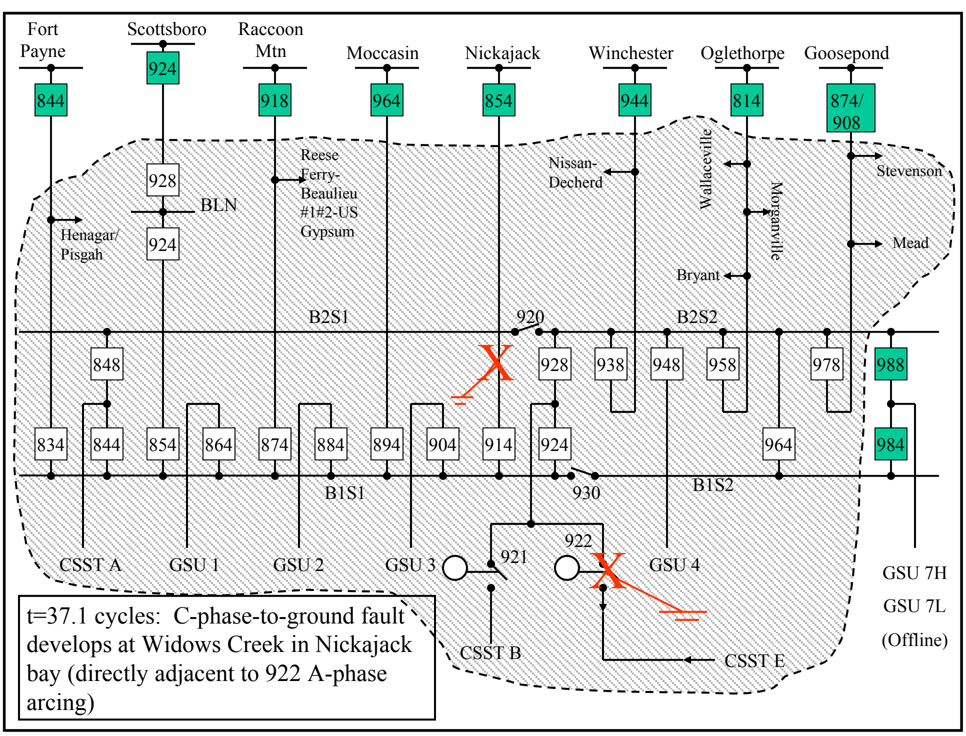
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=37+ cycles:
NOTE: Widows Creek 1-4 **ISLANDED**
Total Generation: 430 MVA
Total Tap Load: 358 MVA


Vbn 161-kV Bus 1-1 2 -3ms 60.10Hz
File Edit View Scale
Widows Creek DFR #4 (161-kV Bus 1 Section 1)
020622,111204862,-5D,WCFP(922 FLASHOVER),E-MAX #4,TVA Jun 22 2002 11:12:04.862
WCFP islanded
Note frequency increases to about 60.73 Hz
Oglethorpe recloses blind into unsynchronized island
NOTE: Perturbation due to simultaneous C-phase-to-ground fault
Frequency (Hz) ->
Time (ms) ->
65
63
61
59
57
55
-153
-70
14
97
181
264
347
431
514
597
681
Vbn 161-kV Bus 1-1 2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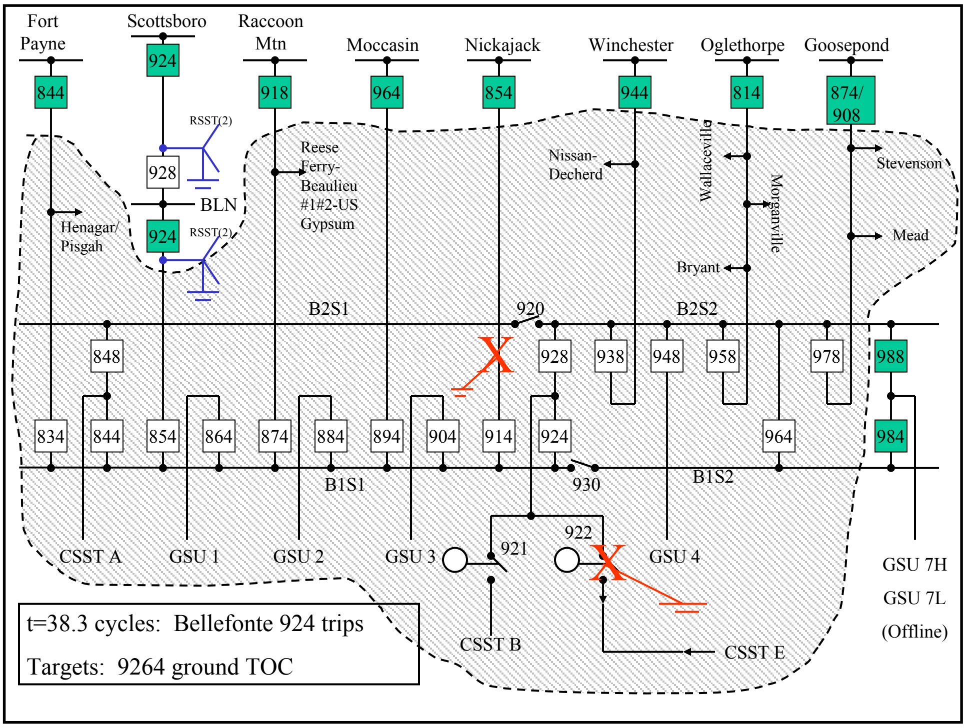
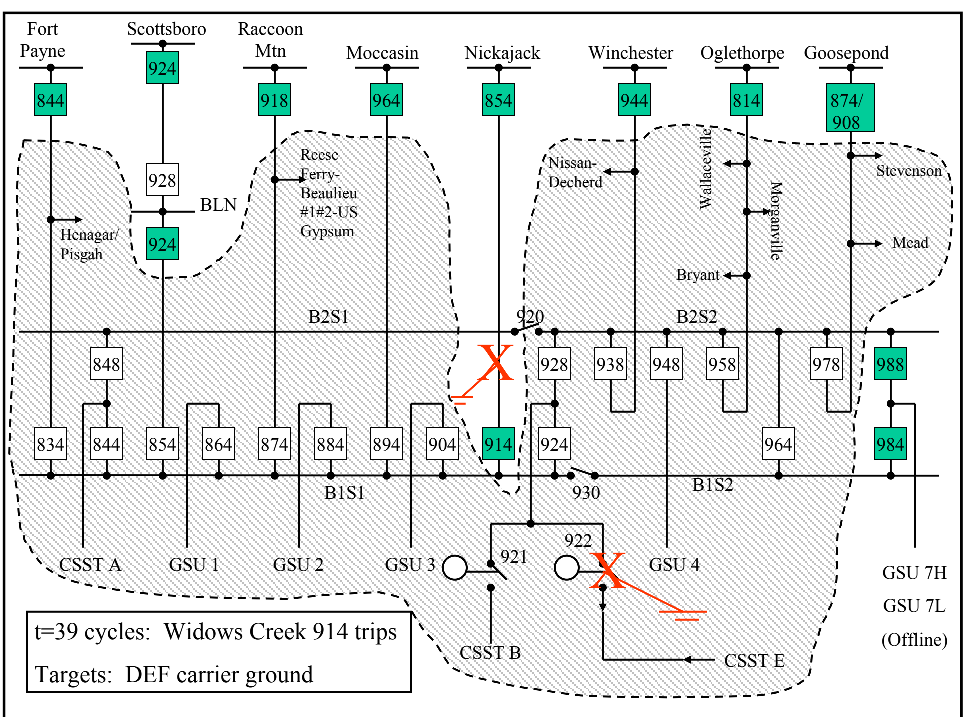
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=37.1 cycles: C-phase-to-ground fault develops at Widows Creek in Nickajack bay (directly adjacent to 922 A-phase arcing)



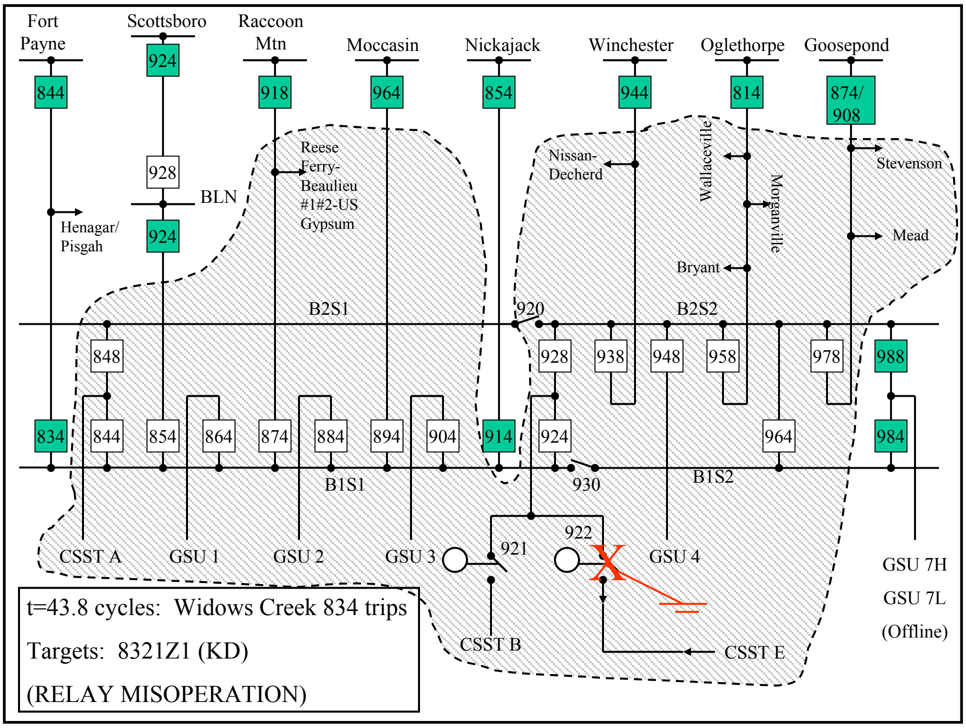
t=38.3 cycles: Bellefonte 924 trips

Targets: 9264 ground TOC



t=39 cycles: Widows Creek 914 trips

Targets: DEF carrier ground


Fort Payne
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B1S2
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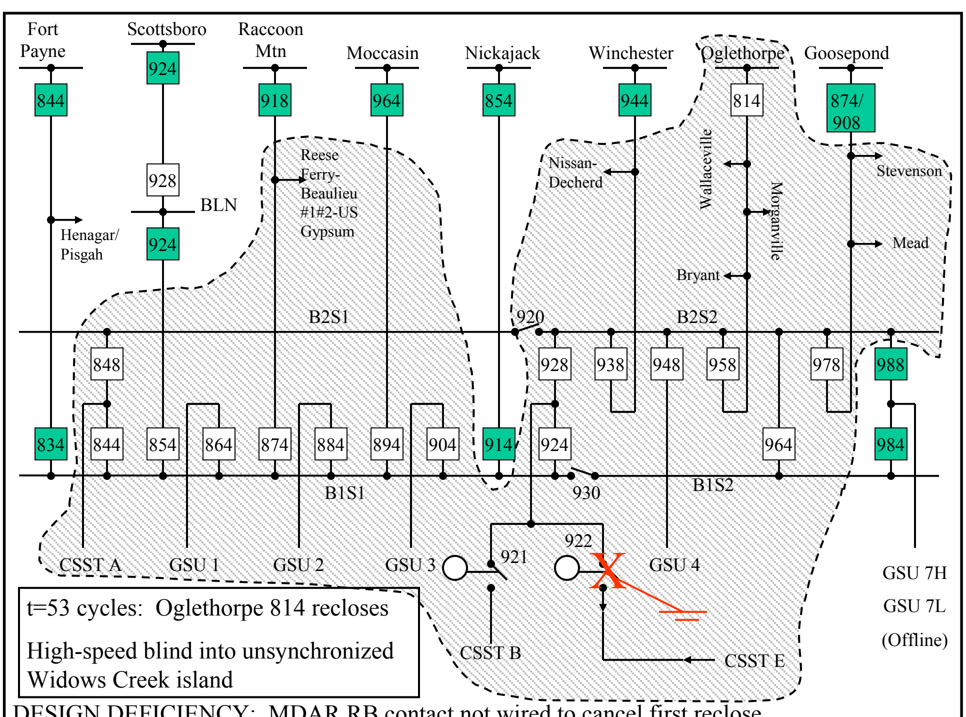
CSST A
GSU 1
GSU 2
GSU 3
GSU 4
CSST B
CSST E
GSU 7H
GSU 7L
(Offline)
t=43.8 cycles: Widows Creek 834 trips
Targets: 8321Z1 (KD)
(RELAY MISOPERATION)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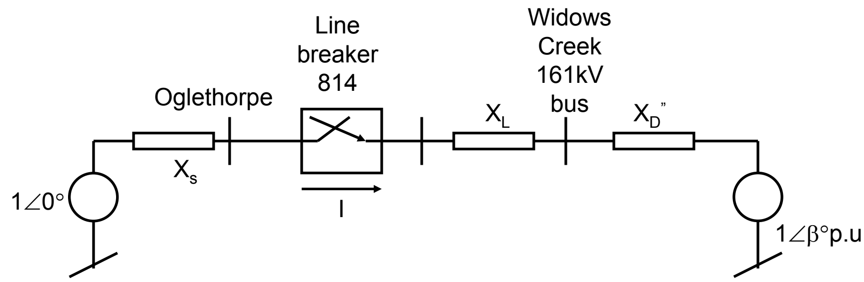
CSST A
GSU 1
GSU 2
GSU 3
GSU 4
CSST B
CSST E
GSU 7H
GSU 7L
(Offline)
t=53 cycles: Oglethorpe 814 recloses
High-speed blind into unsynchronized Widows Creek island
DESIGN DEFICIENCY: MDAR RB contact not wired to cancel first reclose



X_s=system equivalent impedance at Oglethorpe=1.72 ∠84° % on 100 MVA

X_L=Widows Creek-Oglethorpe #1 line impedance=9.22∠81° % on 100 MVA

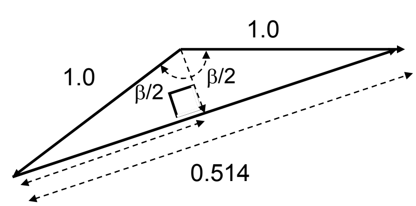
X_D''=system equivalent impedance at Widows Creek with units 1-4 online (using generator subtransient (saturated) impedance, includes GSUs)=4.47∠89° % on 476 MVA=5.46% on 100 MVA

β=angle of the generator relative to the system

I=current that flows at the instant of breaker closing (measured through Widows Creek 858)=1195 A primary=3.33 pu

$$I=\frac{dV}{X}=\frac{|1\angle 0-1\angle\beta|}{X_S+X_L+X_D''}=\frac{|1\angle 0-1\angle\beta|}{0.0172+0.0922+0.0447}=\frac{|1\angle 0-1\angle\beta|}{0.1541}=3.33$$

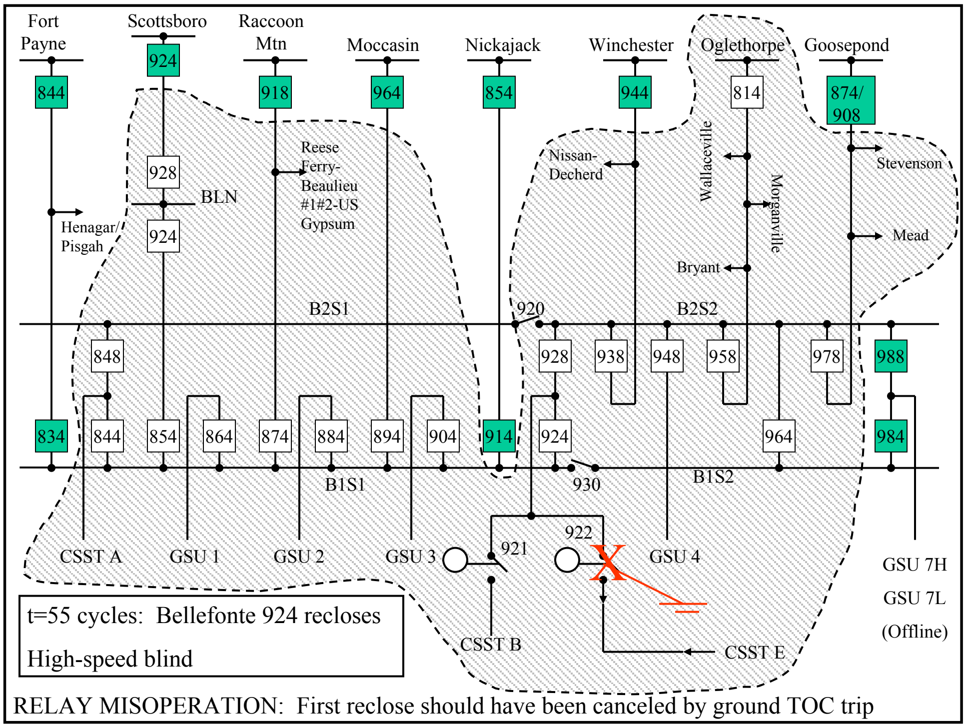
$$|1\angle 0\text{-}1\angle\beta|=0.514$$



Solve for β:

sin (β/2) = 0.514/2

∴ β = 2*sin^{-1}(1.89/2)=30°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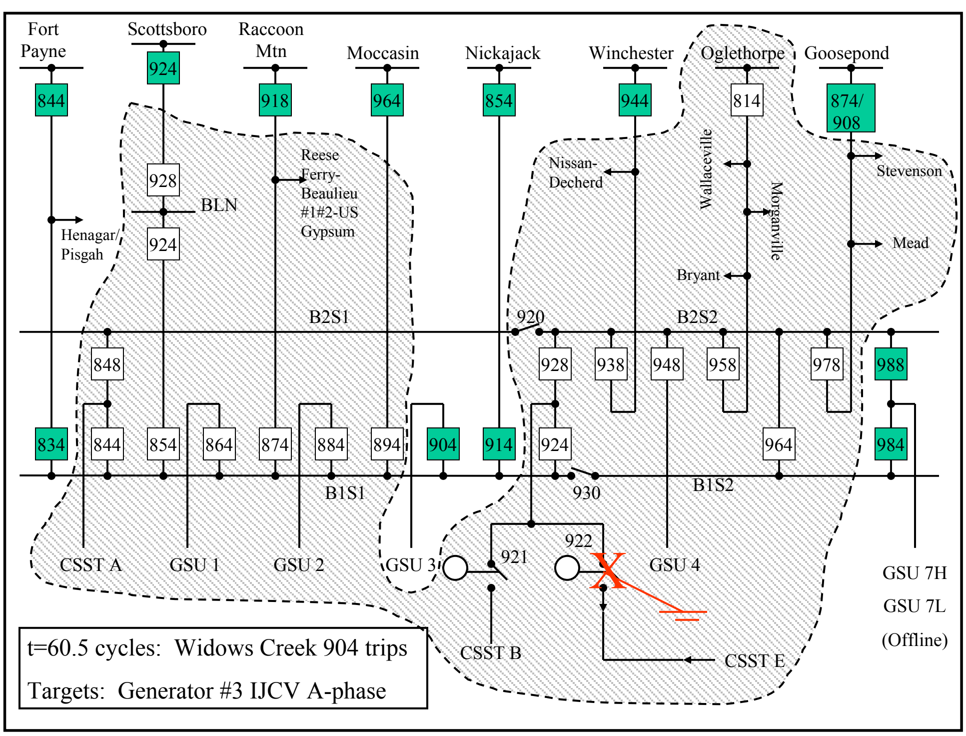
CSST A
GSU 1
GSU 2
GSU 3
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=55 cycles: Bellefonte 924 recloses
High-speed blind
RELAY MISOPERATION: First reclose should have been canceled by ground TOC trip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CSST A
GSU 1
GSU 2
GSU 3
GSU 4
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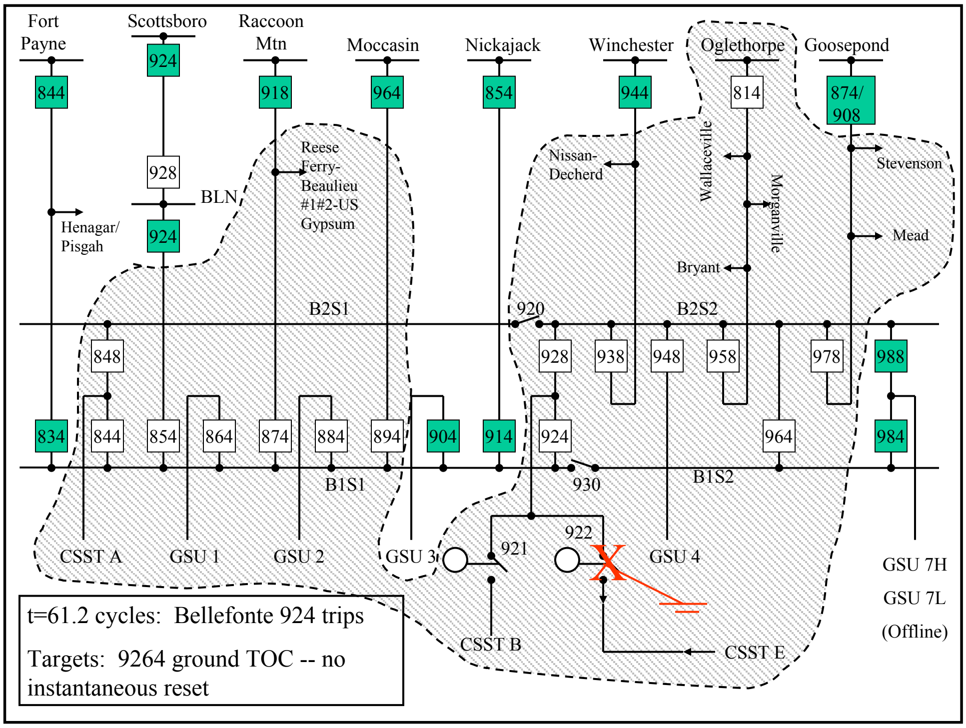
GSU 7L
(Offline)
CSST B
CSST E
t=60.5 cycles: Widows Creek 904 trips
Targets: Generator #3 IJCV A-phase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Reese Ferry-Beaulieu #1#2-US Gypsum
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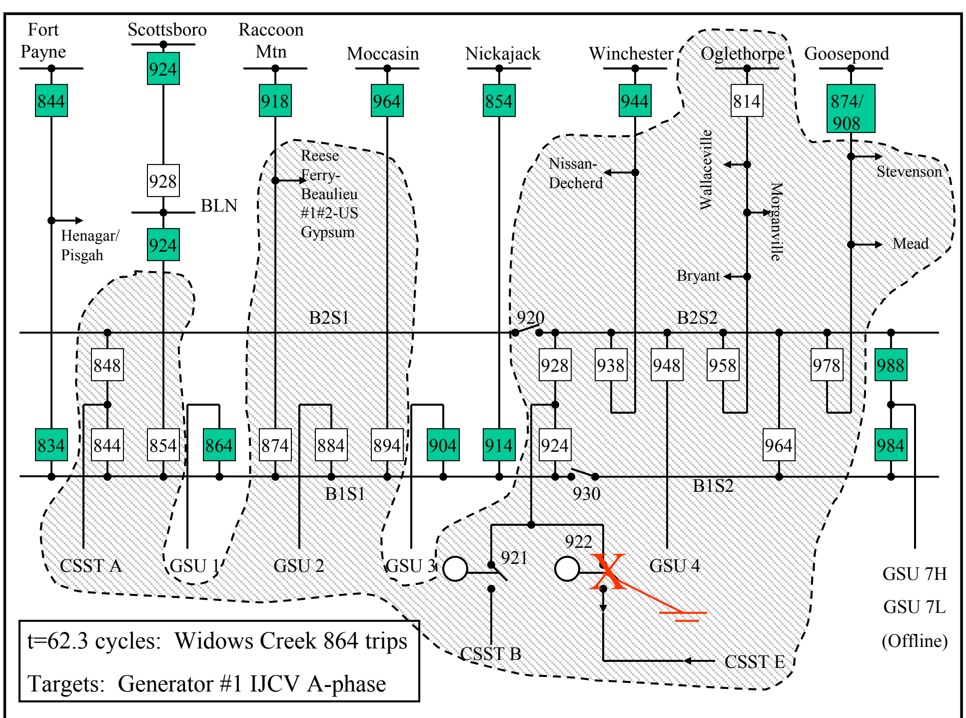
CSST A
GSU 1
GSU 2
GSU 3
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=61.2 cycles: Bellefonte 924 trips
Targets: 9264 ground TOC -- no instantaneous reset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CSST A
GSU 1
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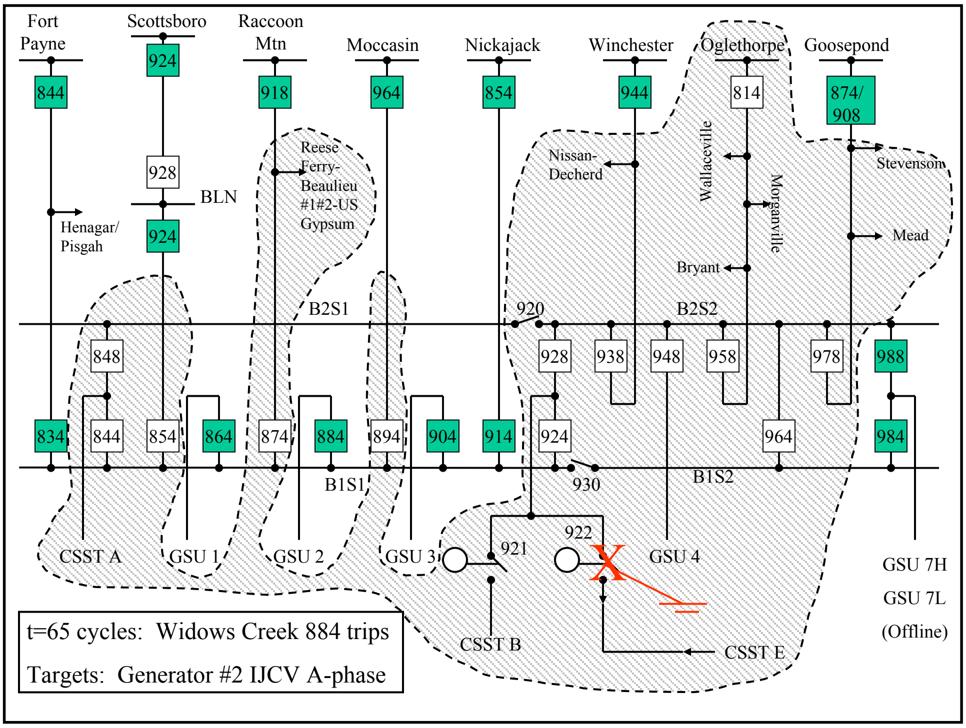
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=62.3 cycles: Widows Creek 864 trips
Targets: Generator #1 IJCV A-phase


Fort Payne
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Reese Ferry-Beaulieu #1#2-US Gypsum
Nissan-Decherd
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Morganville
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B1S2
CSST A
GSU 1
GSU 2
GSU 3
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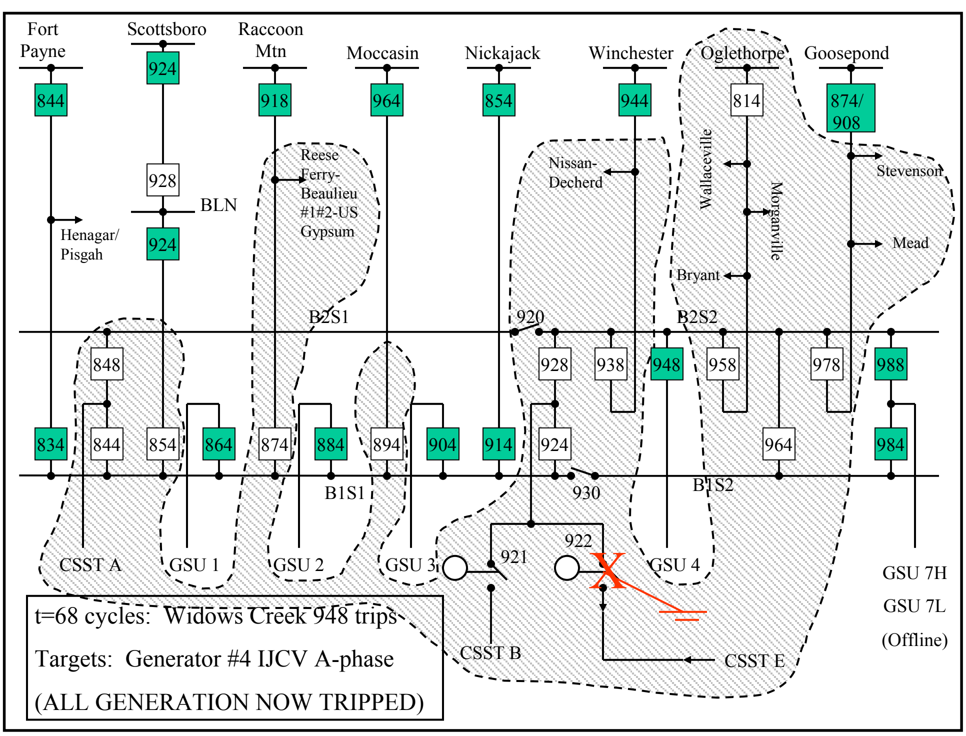
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=65 cycles: Widows Creek 884 trips
Targets: Generator #2 IJCV A-phase


Fort Payne
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B1S2
CSST A
GSU 1
GSU 2
GSU 3
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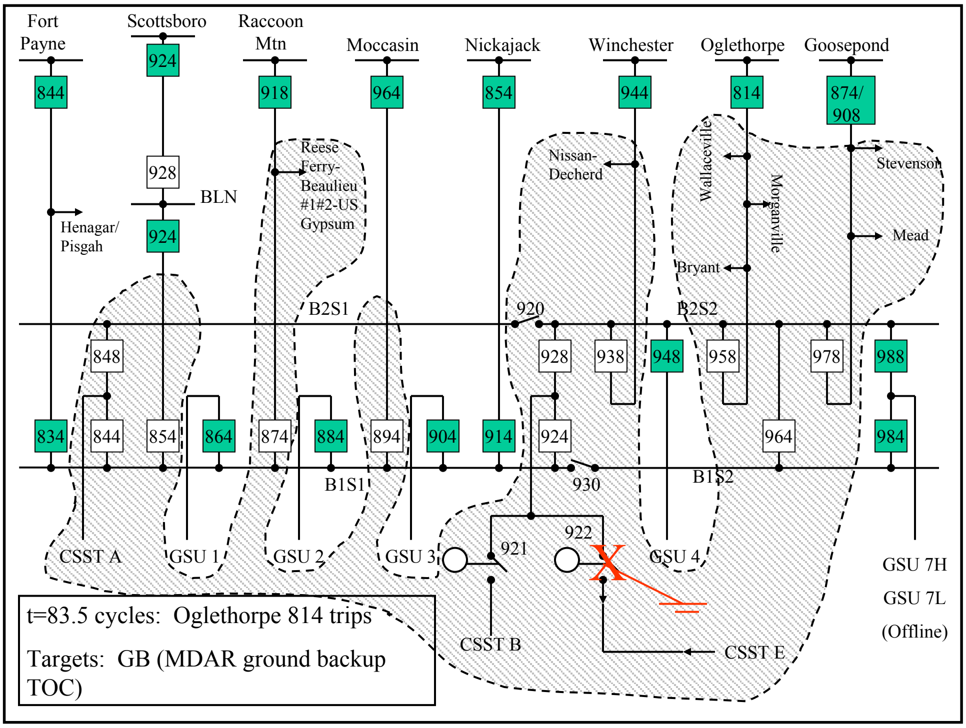
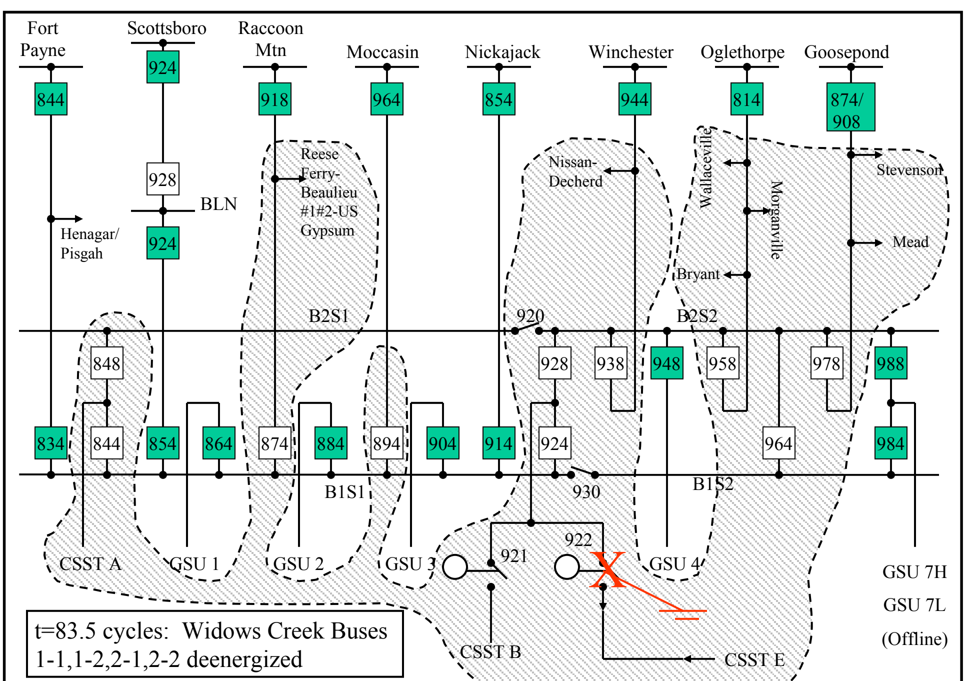
922
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=68 cycles: Widows Creek 948 trips
Targets: Generator #4 IJCV A-phase
(ALL GENERATION NOW TRIPPED)



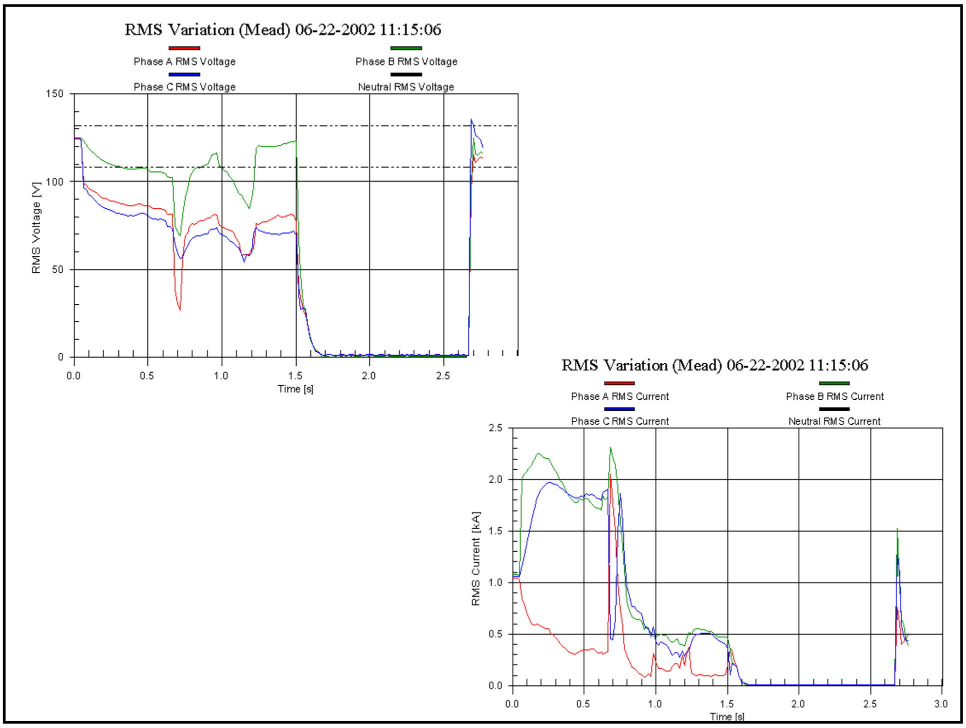
t=83.5 cycles: Oglethorpe 814 trips

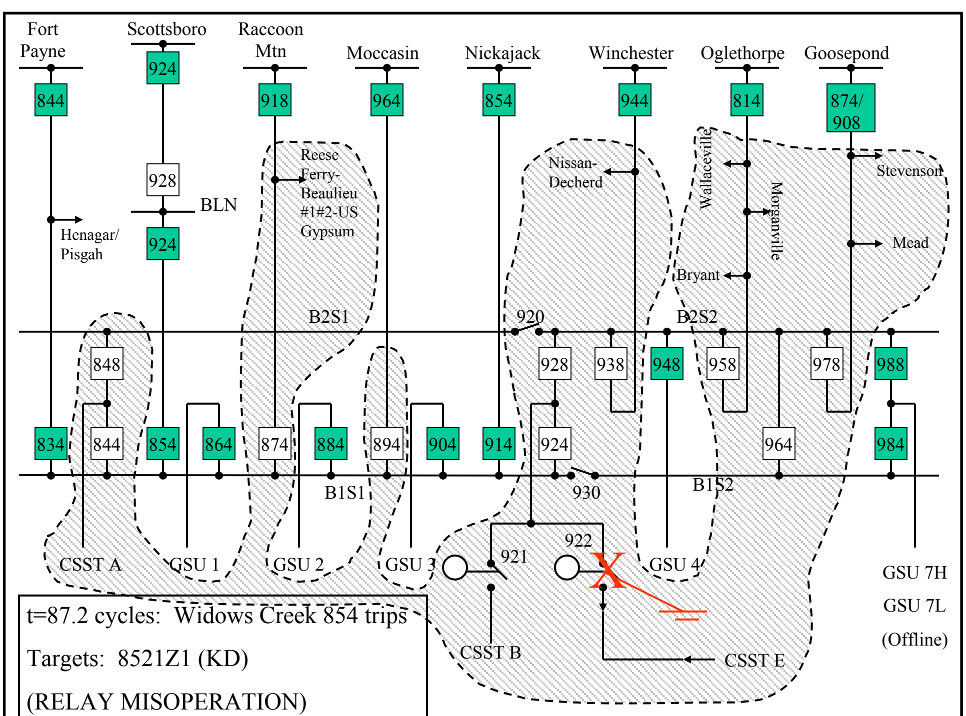
Targets: GB (MDAR ground backup TOC)



t=83.5 cycles: Widows Creek Buses 1-1,1-2,2-1,2-2 deenergized

12 CCPI, 4 generators interrupted, 0.16 MWh LNS


RMS Variation (Mead) 06-22-2002 11:15:06
Phase A RMS Voltage
Phase B RMS Voltage
Phase C RMS Voltage
Neutral RMS Voltage
RMS Voltage [V]
Time [s]
RMS Variation (Mead) 06-22-2002 11:15:06
Phase A RMS Current
Phase B RMS Current
Phase C RMS Current
Neutral RMS Current
RMS Current [kA]
Time [s]


Fort Payne
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Nickajack
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Henagar/ Pisgah
Reese Ferry-Beaulieu #1#2-US Gypsum
Nissan-Decherd
Wallaceville
Morganville
Stevenson
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B1S1
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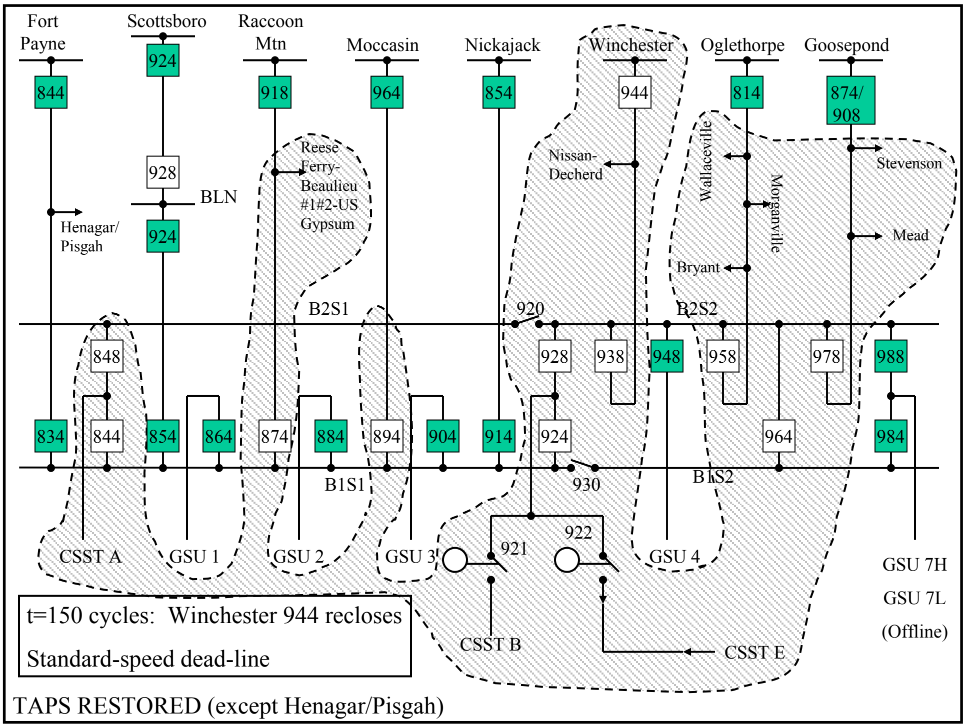
B1S2
922
921
CSST A
GSU 1
GSU 2
GSU 3
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=87.2 cycles: Widows Creek 854 trips
Targets: 8521Z1 (KD)
(RELAY MISOPERATION)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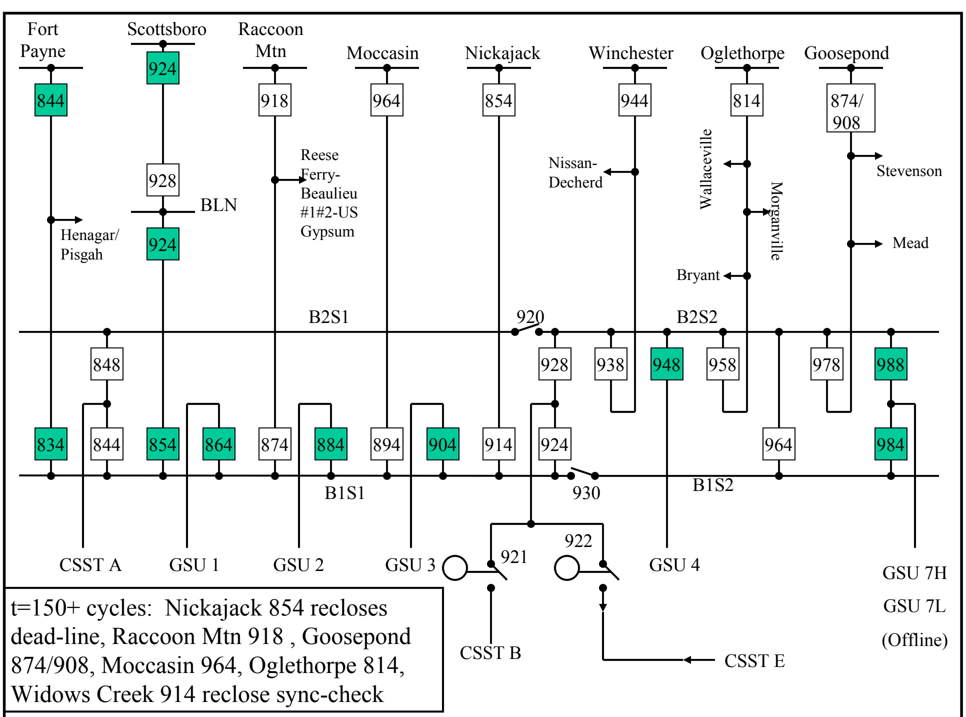
CSST A
GSU 1
GSU 2
GSU 3
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=150 cycles: Winchester 944 recloses
Standard-speed dead-line
TAPS RESTORED (except Henagar/Pisgah)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B1S1
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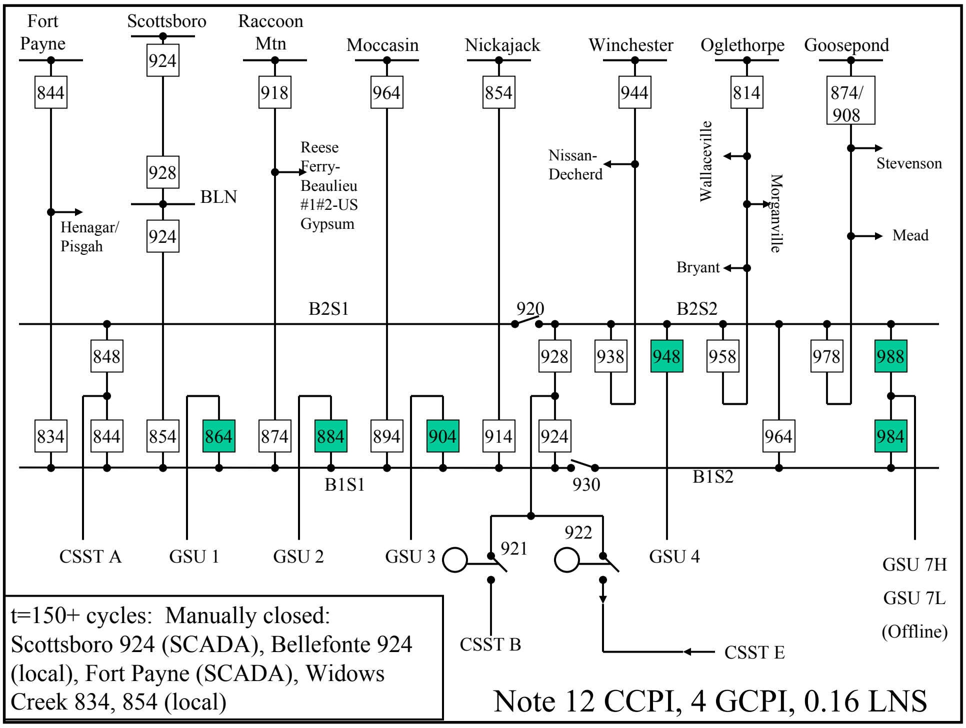
B1S2
922
921
CSST A
GSU 1
GSU 2
GSU 3
GSU 4
GSU 7H
GSU 7L
(Offline)
CSST B
CSST E
t=150+ cycles: Nickajack 854 recloses dead-line, Raccoon Mtn 918 , Goosepond 874/908, Moccasin 964, Oglethorpe 814, Widows Creek 914 reclose sync-check



Lessons Learned

- Use this event to educate **ESO/Transmission Operations** and **Fossil Power Group**, discussing importance of primary protection especially during primary switching
- TPS recommends **Fossil Power Group** consider installing underfrequency protection on TVA fossil turbine-generators.
- ESO/Transmission Dispatching has issued new guidelines for switching at Fossil Plants

Lessons Learned

•No relays will be removed from service while switching any equipment with the exception of normal PK switching.

•Dispatching will not issue switching to de-energize plant transformers with a disconnect.

•Never issue a “separation clearance” to anyone to do work, only to someone to establish a complete working clearance. Dispatching only issues a “separation clearance.”

•Safety grounds procedure for working clearance at fossil plant will be done according to operation Letter No. 13.

Lessons Learned

Who switches what?

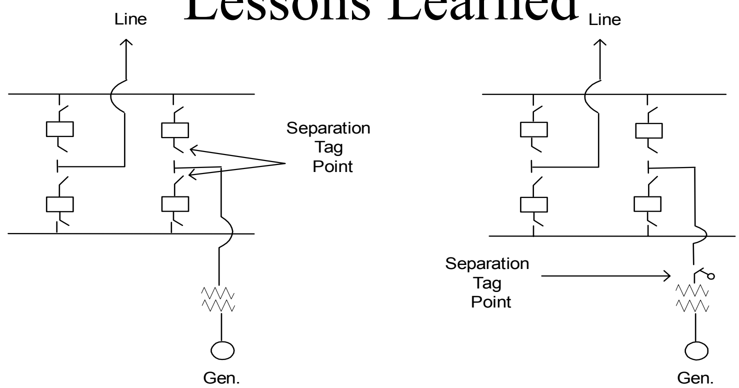
•All breakers solely dedicated to plant equipment would be switched by plant personnel (Fossil or Combustion Turbine personnel).

•All breakers dedicated to transmission equipment would be switched by Transmission Operations and Maintenance (TOM) personnel.

•All breakers dedicated to plant/transmission equipment would be switched by the organization requesting the clearance.

Note: All switching (from generator to system) at fossil plant must be coordinated through Electric System Operations (ESO) dispatching organization.

Lessons Learned



Plants will assume the responsibility of tagging their GSU transformers and generators, including station service breakers for their work.