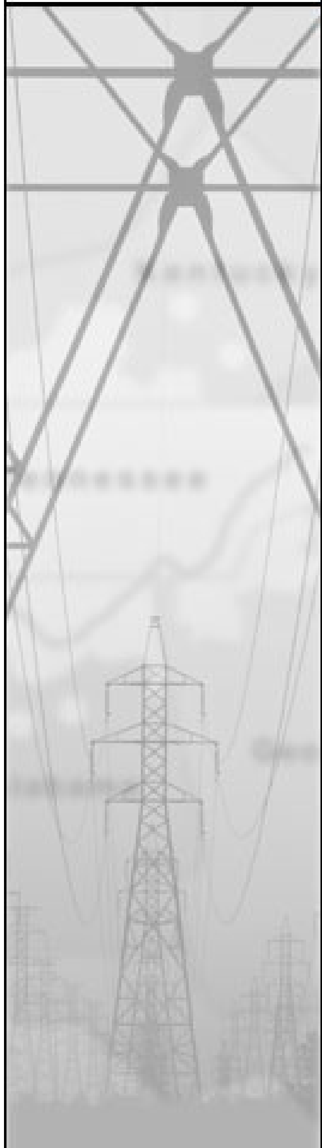
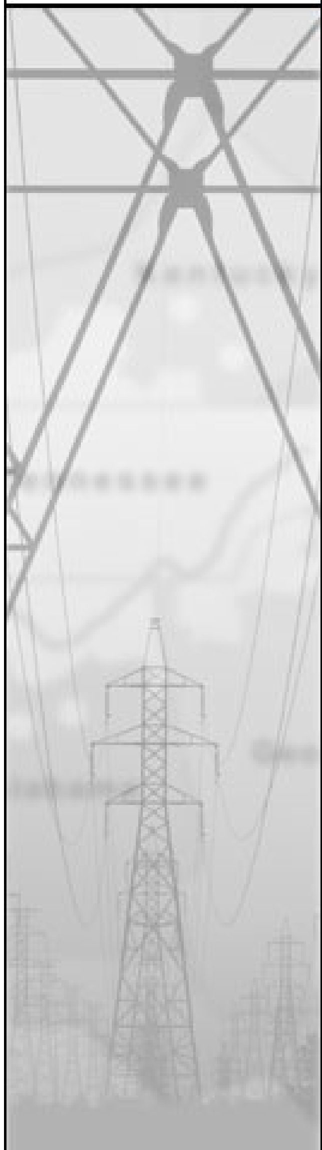
Class 1E Protection - Unbalanced Voltage

Class 1E Unbalanced Voltage Protective Function



Protect the functionality of Class 1E equipment from unbalanced voltage, including the presence of an open phase of consequence.

Open Phase vs. Unbalanced Voltage



Open Phase

- Event which causes voltage irregularities
- Detection of an open phase does not determine the ability of equipment to function.

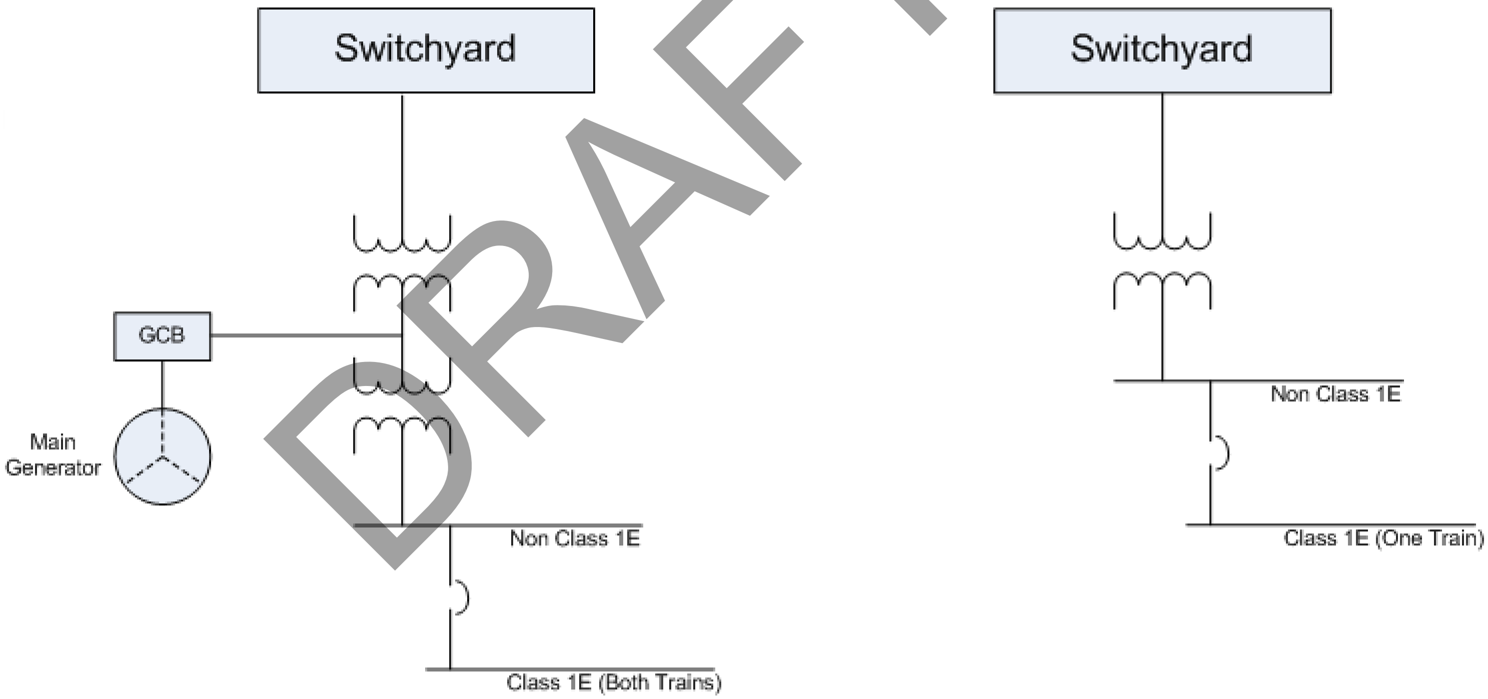
Unbalanced Voltage

- Caused by various events including open phases, breaker failures, grid unbalance, auxiliary system unbalance, etc.
- Direct measurable parameter (voltage) which can determine the ability of equipment to function.

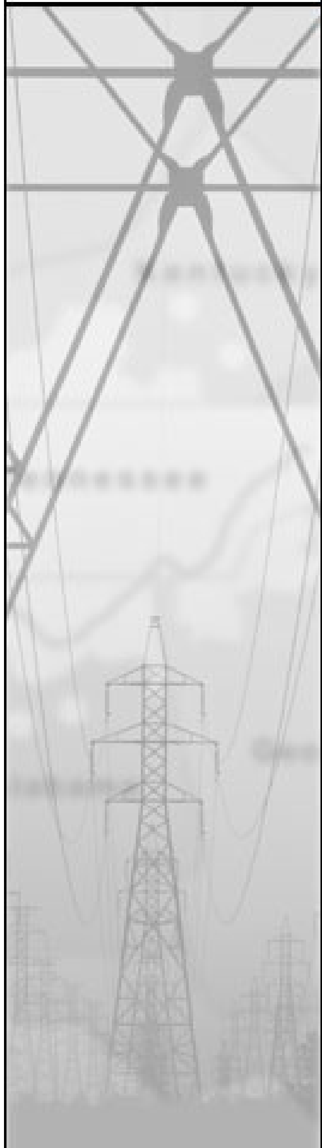
Offsite Power Connections
Sequoyah Nuclear Plant (SQN)

Simplified Offsite Power (OSP) Connections

Offsite Power Circuit #1 | Offsite Power Circuit #2



Offsite Power Connection Description



The Class 1E system is immediately connected to one GDC 17 offsite power source (i.e., no transfer required) during all modes of operation.

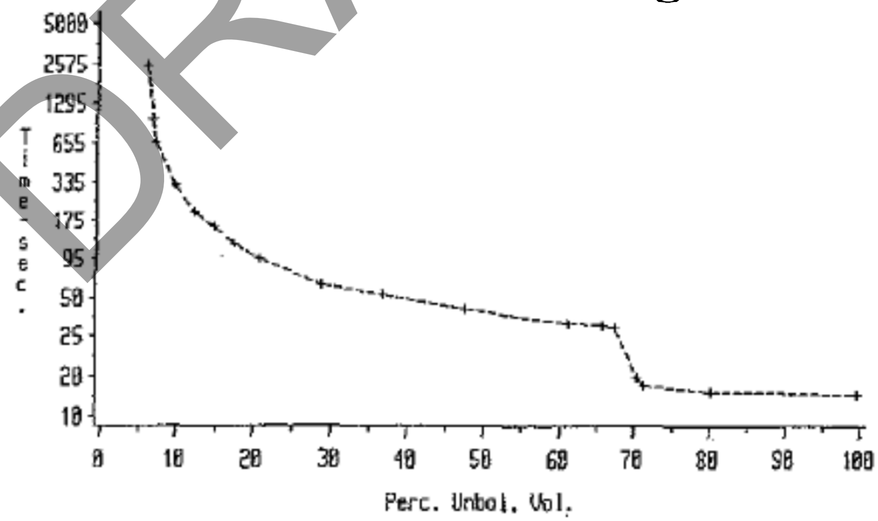
Including:

- Normal Operation
- Unit Trip/Full Load Rejection
- Design Basis Accident
- Unit Start Up
- Unit Shutdown/Refuel

TVA Unbalance Voltage Relay Design Basis

TVA Unbalance Voltage Relay Design Basis

- Voltage unbalance can cause serious motor overheating damage due to negative sequence current (I_2).
- NEMA MG-1:
  - Motors can withstand 1% voltage unbalance, should not be operated with >5% voltage unbalance
  - Above 1% voltage, the motor must be de-rated due to **excess heating**
- Well known inverse-time relationship between voltage unbalance and motor thermal damage[1]

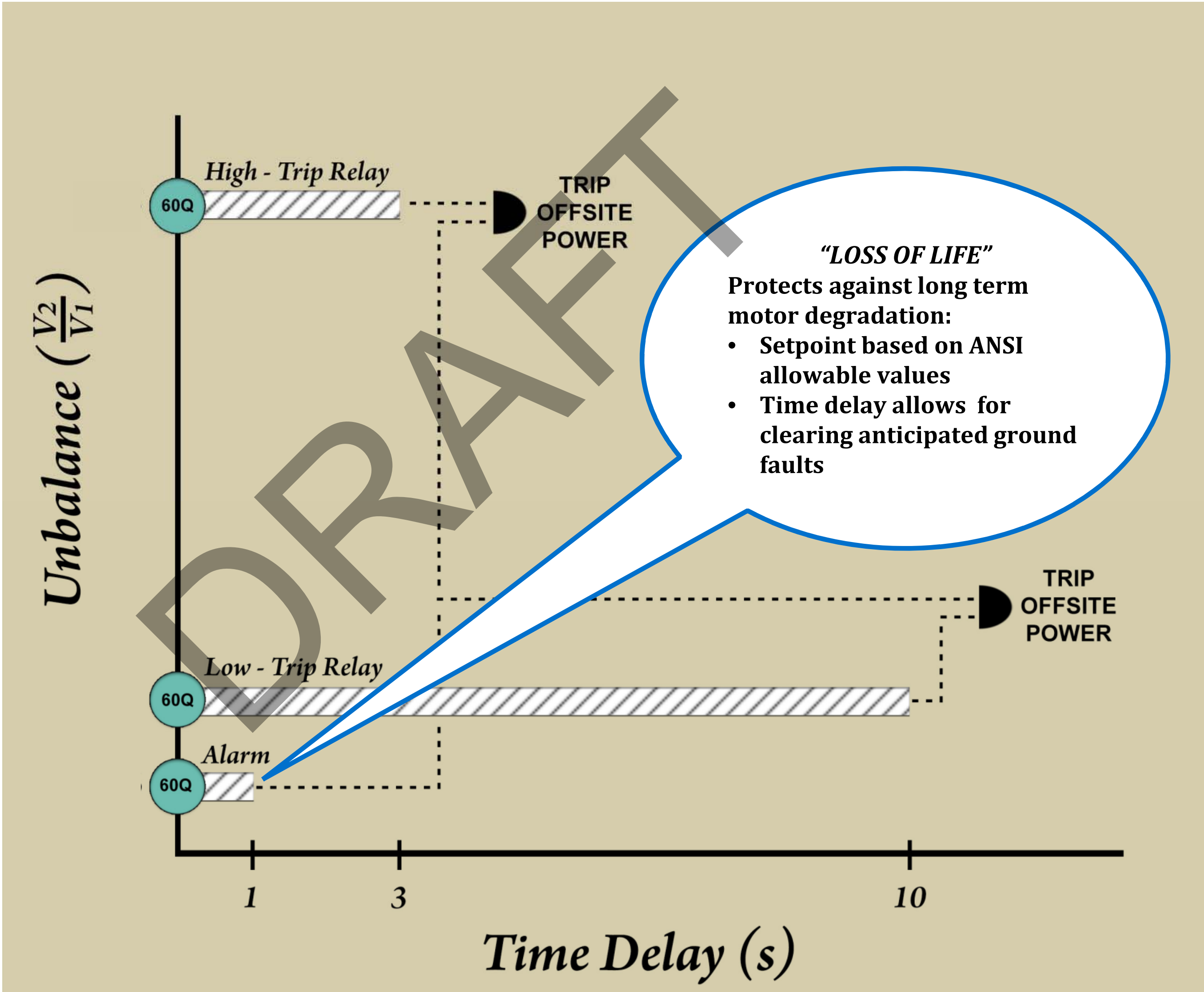


1. Motor Temperature Estimation Incorporating Dynamic Rotor Impedance, IEEE Transactions on Energy Conversion, Vol. 6, No. 1, March 1991

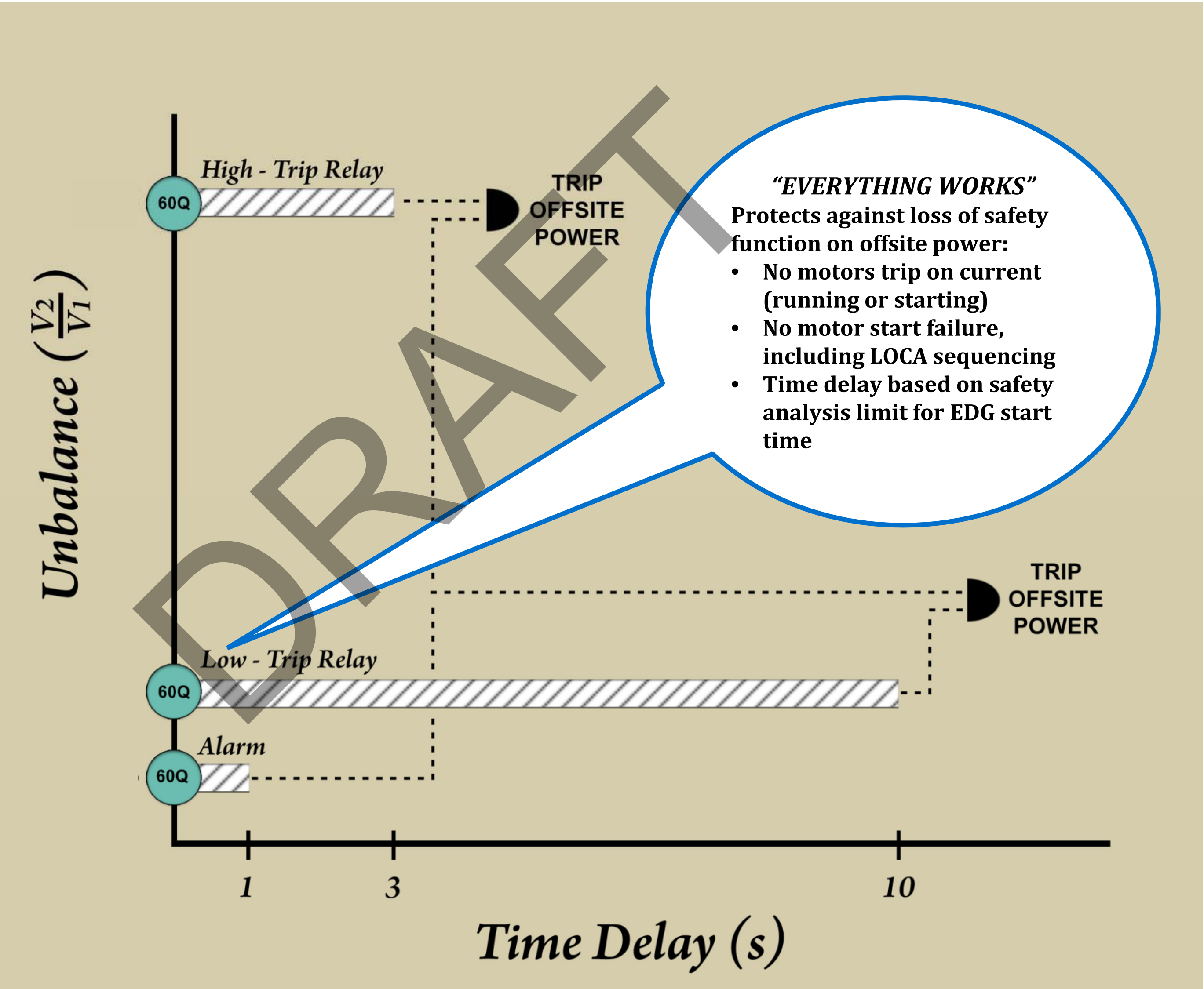
TVA Unbalance Voltage Relay Design Basis

- Provide 100% protection against loss of safety function due to unbalanced voltages at the safety-buses, including upstream open phase events
  - Including both in-plant and transformer open phase events
- Utilize existing undervoltage protection circuits
  - Existing sensing circuits (Bus PTs)
  - Existing logic circuits (trip offsite power)
  - Huge savings for modification costs
- Utilize relays qualified for Class 1E use
  - TVA choosing ABB Type 60Q Phase Unbalance Relay (negative sequence overvoltage) due to experience with similar relays

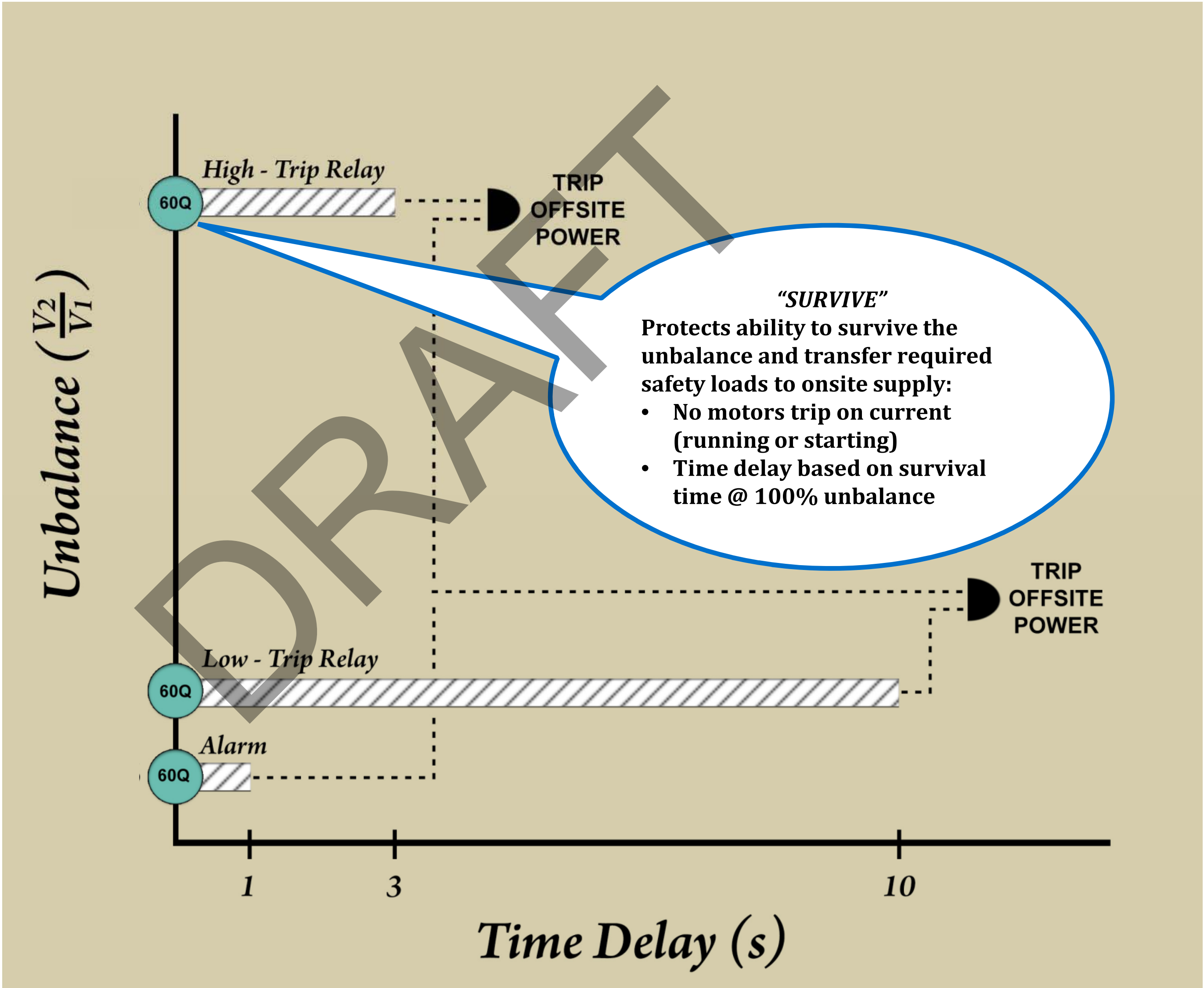
Unbalance Voltage Relay Setpoint Methodology



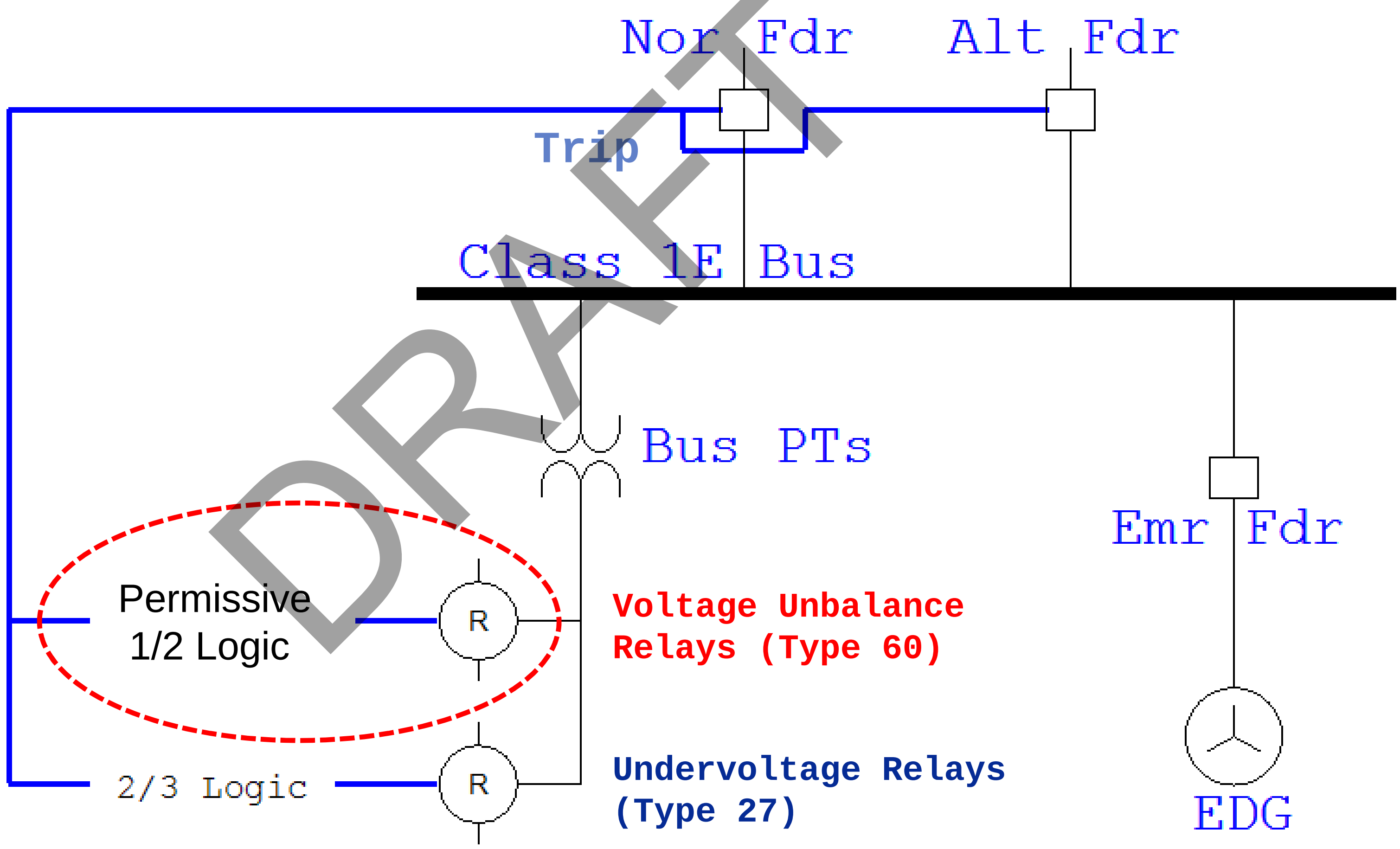
Unbalance Voltage Relay Setpoint Methodology



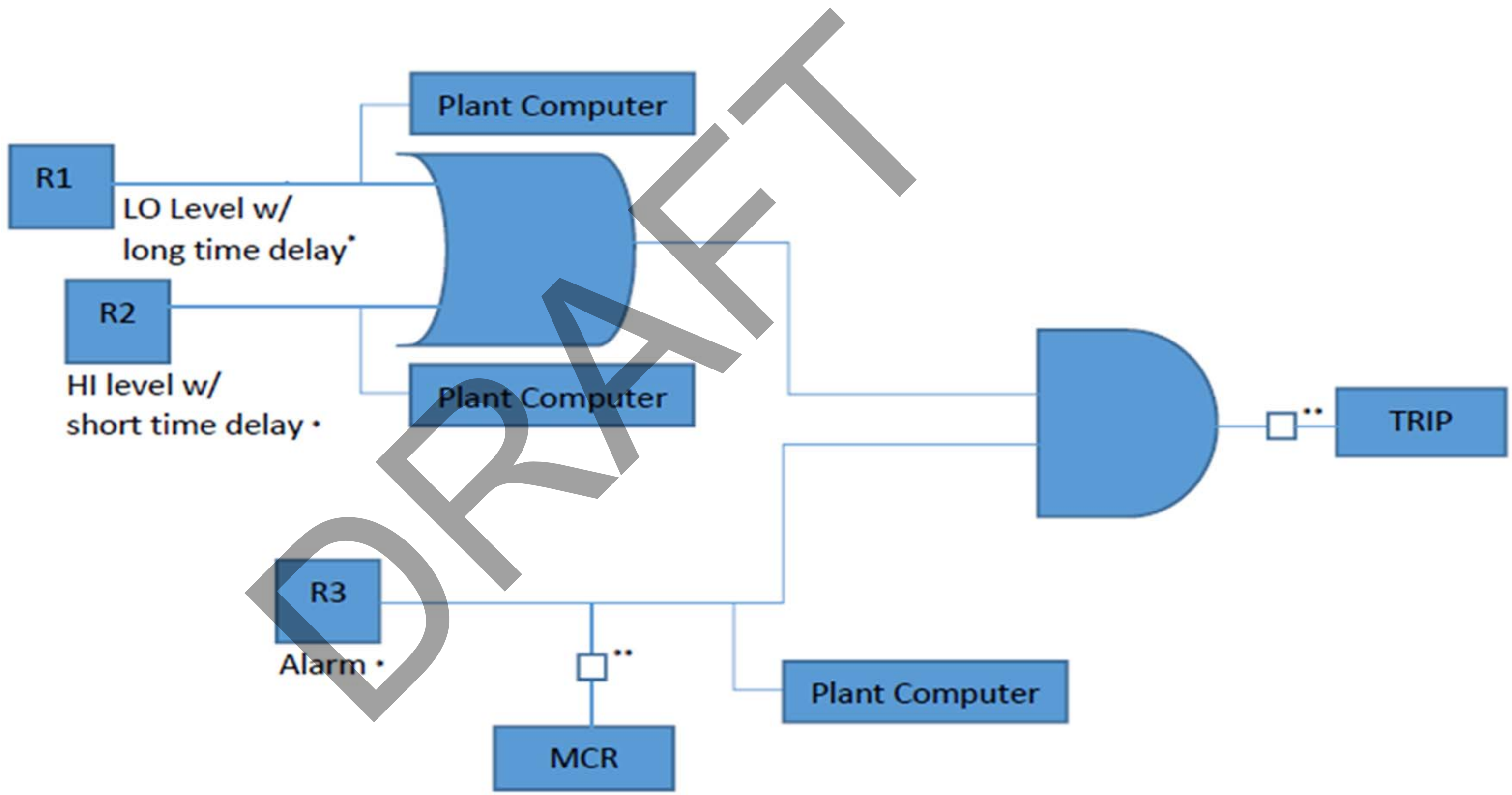
Unbalance Voltage Relay Setpoint Methodology



Unbalance Voltage Relays Added to Existing Undervoltage Circuits



Unbalanced Voltage Relay Scheme



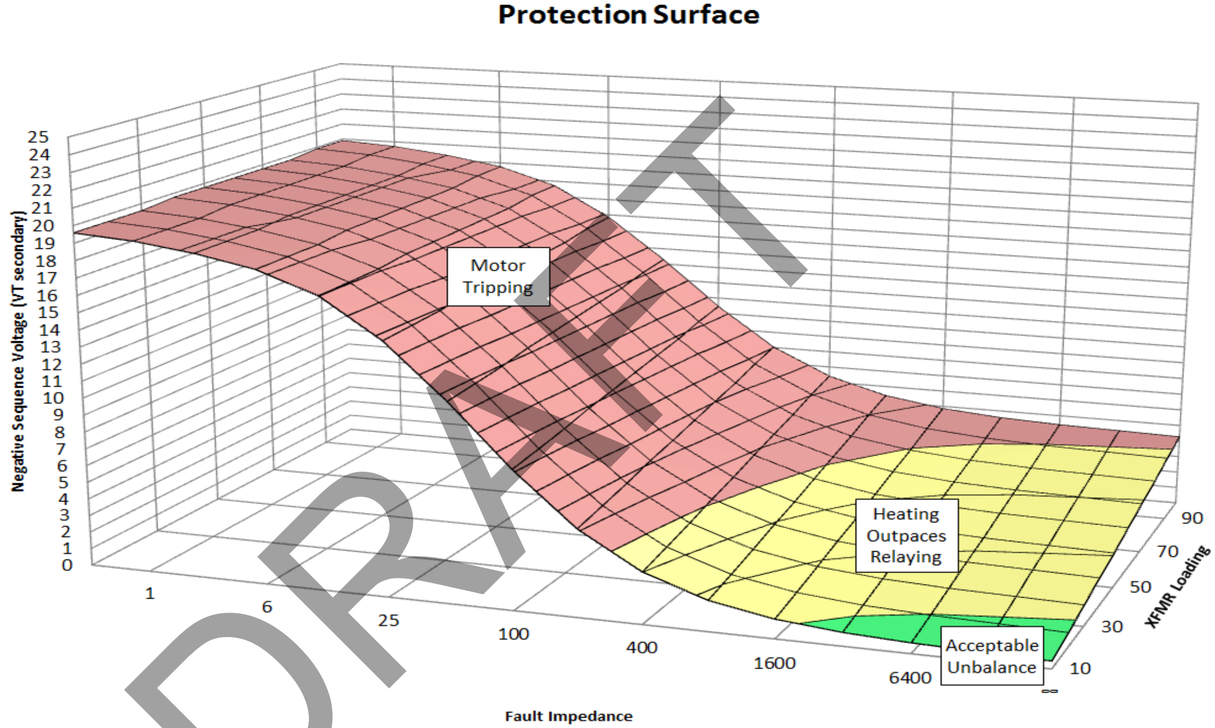
* Setpoints are Tech Spec values

** Activation of MCR indication and trip function require LAR approval

Unbalance Voltage Relays (ABB 60Q): Already Qualified for Class 1E Use

TVA's Unbalance Voltage Relay Setpoints

Unbalance Voltage Relay Setpoint Methodology



	Affect on Function	Response Required
Red	Limited allowable time since loss of function is imminent due to protective device actuation.	Automatic Response (< allowable manual action time)
Yellow	Limited allowable time since heating may outpace protective relays. This will result in loss of equipment life.	Controlled Response (loss of life is gradual and equipment is functional)
Green	Unlimited allowable time. No affect on equipment function.	No response required (full capacity and capability)

SQN Analytical Limits

Relay	Voltage (Volts Line-Neutral Secondary)		Time Delay (Seconds)	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Alarm	0.9	*1.5	0.3	*3.0
Low Trip	1.5	*3.3	4.0	*10
High Trip	3.3	*20.0	3.0	*4.0

**designated analytical limits*

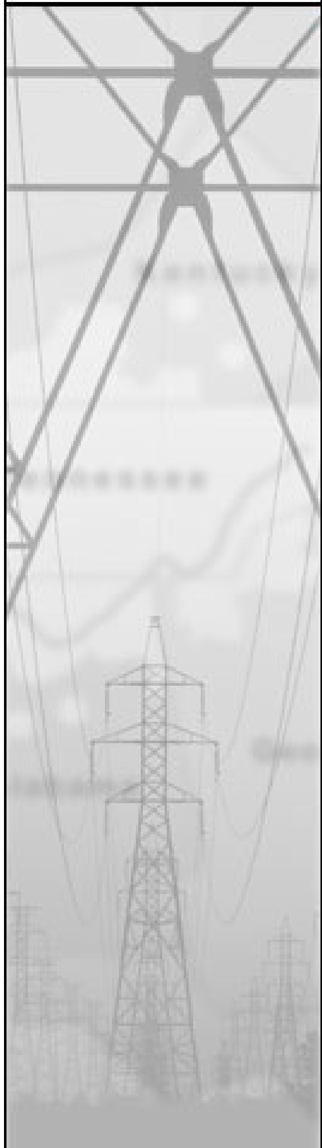
- To avoid nuisance actuations, the three relays' nominal pick-up settings should be as close as possible to the upper limits, accounting for associated errors and tolerances.
- The time delay setpoints for the Low Trip and the High Trip relays must not overlap with the Alarm relay time delay setpoint, accounting for associated errors and tolerances

Class 1E Compliance with NRC's 4 Functional Requirements

Functional Requirement 1 – Single Failure

- Class 1E qualified protective relays (ABB 60Q) on each train/division
- Permissive 1 out of 2 logic scheme to provide reliability
- Any failure of a component is the Class 1E failure and the second train will remain available, per single failure criteria.

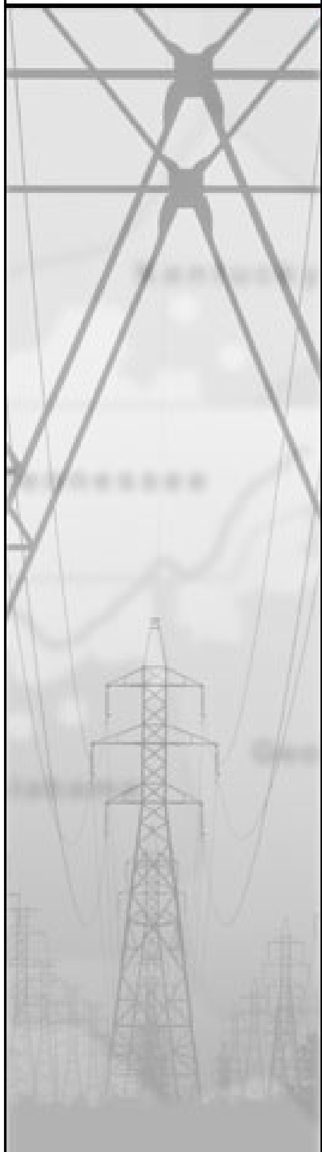
Functional Requirement 2 – Detection on Immediately Connected Source



- Automatic detection and MCR alarm of an abnormal voltage unbalance which affects the Class 1E equipment is provided by the alarm relay under all operating configurations and loading conditions
- Consistent with existing degraded voltage/loss of voltage protection schemes

Automatic detection and disconnection from degraded source is required to maintain functionality of Class 1E equipment and meet requirements of GDC 17.

Functional Requirement 2 – Detection on Second Available Source



Detection in this case is confined to an open phase event which may affect availability of an unconnected source (i.e. operability):

- Since protection cannot be predictive, automatic detection of a future or unconnected degraded source cannot occur prior to the degradation or connection to the source.
- Visual inspections can occur within allowable LCO time and still meet the intent of the Tech Specs.
- Automatic OPC detection could provide operators quicker notification but actions would still be within the Tech Spec LCO timeframe (i.e., utilize existing procedures for a single unqualified offsite power source)

*Automatic detection and disconnection from degraded source is **not** required to maintain functionality of Class 1E equipment and meet requirements of GDC 17 as determined by presence of a timeframe to remain in such condition in the Tech Specs.*

Functional Requirement 2 – Detection Summary

- Detection requires connection to the equipment or source being monitored.
- <u>Automatic</u> notification and MCR alarm of events that could affect the functionality of Class 1E equipment is not currently required or available for <u>all conditions</u>.
- Unbalanced voltage protection is consistent with existing degraded voltage/loss of voltage protection schemes.

Functional Requirement 3 – Time Delay

Consistent with degraded/loss of voltage protection

- Setpoints ensure Class 1E equipment will be able to provide their safety function under all anticipated operational occurrences, including a concurrent design basis event.
- Time delays ensure the power source is automatically transferred to the onsite power system within the time assumed in the accident analysis.

Functional Requirement 4 – Tech Specs

TS Surveillance Requirement and Limiting Condition of Operation should be consistent with the operability requirements specified in the existing plant TSs

- *Unbalanced Voltage TS Surveillance Requirements and LCO will be consistent with existing undervoltage (i.e., DVR)*

TS Change Summary

- Loss of Power Diesel Generator Start Instrumentation (TS 3.3.5) is being modified
- New function provided by the unbalanced voltage relays for initiation of the diesel generators

4 Functional Requirements Summary

The Class 1E Unbalanced Voltage Protection scheme meets the 4 function requirements and closes the gap to GDC 17.

Monitoring Summary

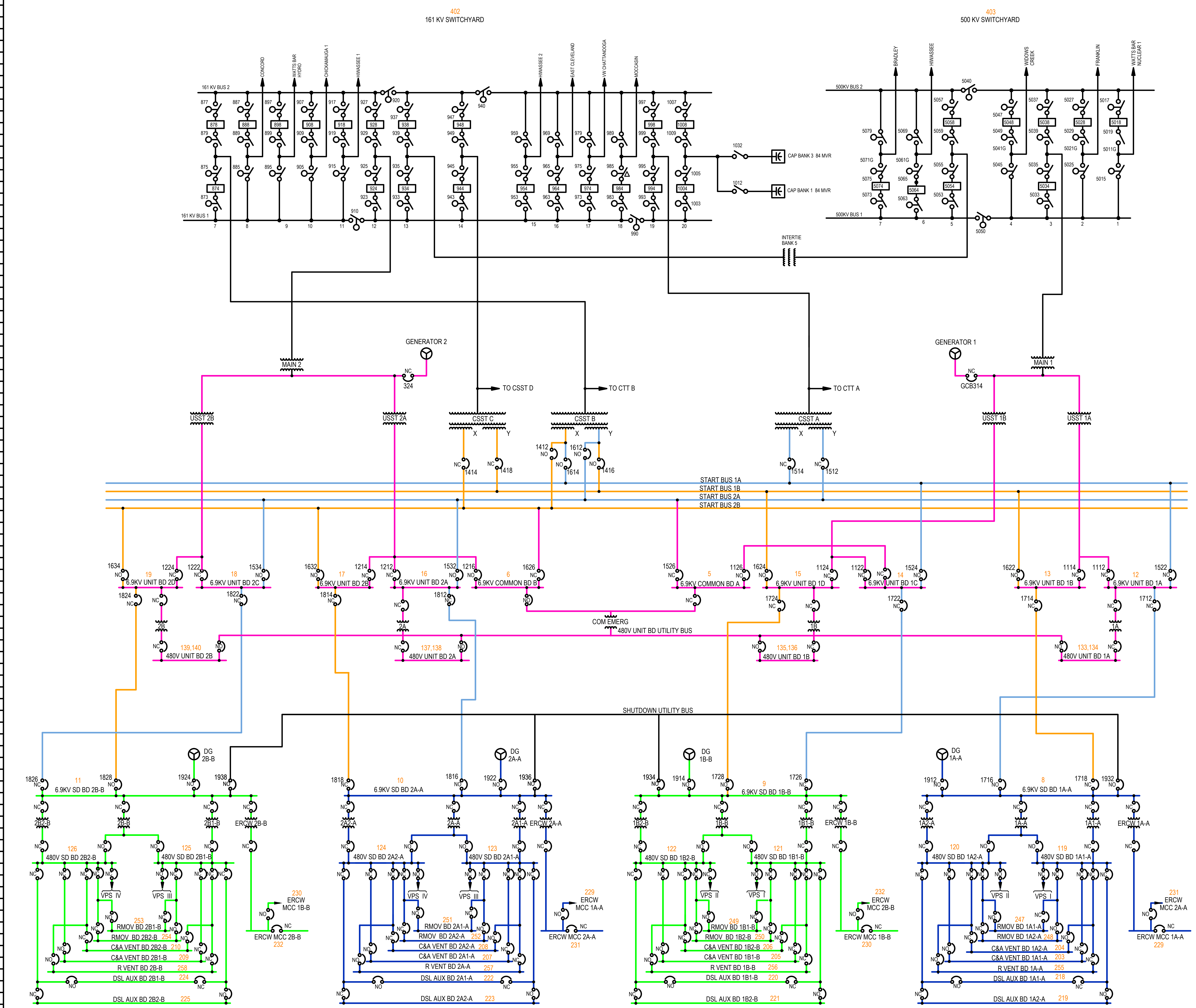
Monitoring Summary

- Monitoring setpoint are set significantly lower and in such a manner to provide granularity for monitoring purposes.
- Since the start of the monitoring phase for the fleet no event has occurred that would challenge the final setpoints (i.e., result in a trip)

Monitoring Summary

- Have seen multiple events without erroneous actuation:
  - Multiple main generator power changes (start-up, shutdown, entrance/exit of refuel outages)
  - Hot functional test for WBN U2
  - Spurious SI
  - Upstream fast bus transfers
  - Lightning strikes in area
- Actuates appropriately for unbalanced voltage conditions caused by
  - Relay testing
  - Grid Disturbances (grid unbalance)

Questions



LEGEND

- HIGH VOLTAGE
- OFFSITE POWER CKT 1
- OFFSITE POWER CKT 2
- NON-SAFETY B.O.P.
- SAFETY RELATED - TRAIN A
- SAFETY RELATED - TRAIN B
- XXX ETAP NODE NUMBERS

Reference Drawings

1-15E500-1	45N502
1-15E500-1-29	45N504
1-15E500-2	45N505
1-15E500-2-35	
1-75W500	
1-75W500-16	

Sequoyah Nuclear Plant Electrical Distribution System 480V-500KV

INFORMATION ONLY

Engineer: Mark D. Bowman | CAD MAINTAINED DRAWING

8-7-2015 | SQN Electrical Distribution System | 4

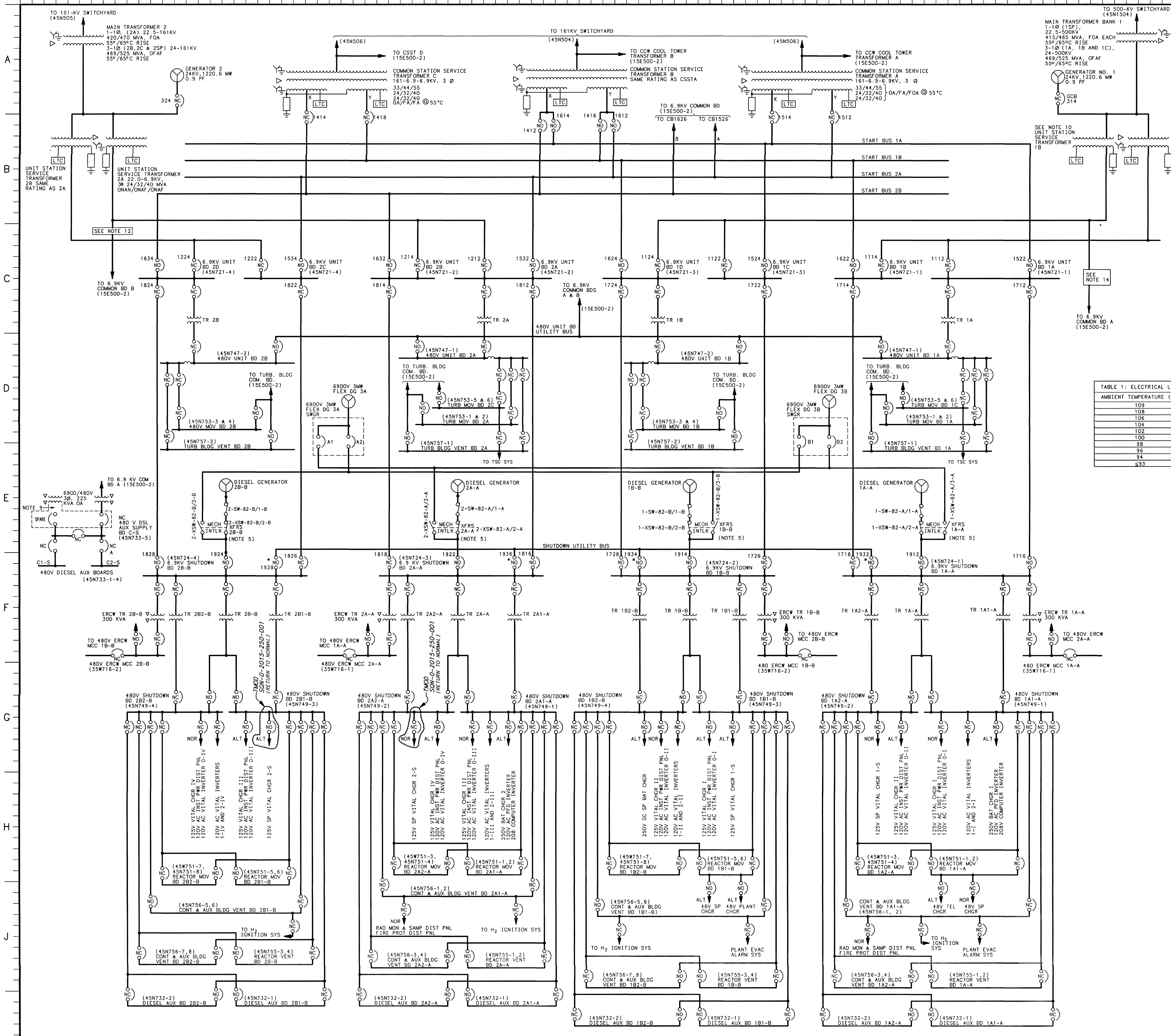


TABLE 1: ELECTRICAL LOAD SUPPORTED (kWe)		
AMBIENT TEMPERATURE (°F)	DG 3A	DG 3B
109	2375	2470
108	2400	2495
106	2445	2545
104	2495	2600
102	2545	2650
100	2590	2700
98	2635	2750
96	2685	2750
94	2730	2750
≤93	2750	2750

NOTES:

1. ALL 6900-480V TRANSFORMERS ARE 1500/1725 KVA OA/FA AND ARE DELTA (▷) PRIMARY AND SECONDARY UNLESS OTHERWISE MARKED.(SEE NOTE 15).
2. * INDICATES BREAKER IS NOT NORMALLY RACKED TO THE CONNECT POSITION. IF BREAKER IS INSTALLED, "DISCONNECT" IS THE PREFERRED POSITION. THE PURPOSE OF THE SHUTDOWN UTILITY BUS IS TO INCREASE THE FLEXIBILITY OF THE SYSTEM UNDER LEVELS OF DEGRADATION BEYOND CONSIDERATION OF THE SINGLE FAILURE CRITERIA AND SHOULD BE USED ONLY UNDER SUCH CONDITIONS.
3. THE 6900V 3MW FLEX DIESEL GENERATORS POWER SYSTEM SHALL BE NORMALLY ISOLATED FROM THE CLASS 1E 6900V SHUTDOWN BOARD(S) TO PRECLUDE MISALIGNMENT.
4.
5. THIS TRANSFER SWITCH IS ADMINISTRATIVELY CONTROLLED TO PRECLUDE INADVERTENT MISALIGNMENT REGARDING APPENDIX R AND LICENSING BASIS LEVEL EVENTS.
6.
7.
8. THE 3MW FLEX DG ARE DE-RATED TO AN OUTPUT VALUE IN ACCORDANCE WITH TABLE 1 DUE TO ADGB AMBIENT TEMPERATURE CONDITIONS *REFERENCE SQN-DC-V-48.0. THE GENERATOR JACKET WATER TEMPERATURE* SHOULD BE MAINTAINED BELOW THE ALARM VALUE OF 215.6°F.
9. CABLE LEADS FROM BREAKER 52DSB TO TRANSFORMER C1-S HAVE BEEN DISCONNECTED AND ARE NOT TO BE RECONNECTED WITHOUT N.E. APPROVAL.
10. WHEN THE USST'S ARE OUT OF SERVICE, THEY ARE NOT IMMEDIATELY AVAILABLE ALTERNATE SOURCES TO THE 6.9 KV COMMON BOARD A AND UNIT BOARDS 1A, 1B, 1C, 1D. HOWEVER, THE 6.9 KV LOADS TO THESE BOARDS CAN BE TRANSFERRED UNDER THE TABLE 3 ALTERNATE FEED RESTRICTION ON 1,2-15E500-3. WHILE USST 1A AND 1B ARE DISCONNECTED, ASSOCIATED CURRENT TRANSFORMER QUANTITIES AND RATINGS ARE SHOWN FOR INFORMATION ONLY.
11. NOT USED
12. A SECTION OF BUS AND BUS DUCT IS DISCONNECTED BETWEEN USST 2A AND COMMON BOARD B PER DCN 22617.
13. NOT USED
14. A SECTION OF BUS AND BUS DUCT IS DISCONNECTED BETWEEN USST 1B AND COMMON BOARD A PER DCN 22616.
15. UNIT BOARD TRANSFORMERS: 1500/2000 KVA AA/FA. TURBINE BUILDING COMMON BOARD TRANSFORMERS A & B: 1500/2000 KVA AA/FA. SERVICE BUILDING MAIN BOARD TRANSFORMER A: 1000/1333 KVA AA/FA. SERVICE BUILDING MAIN BOARD TRANSFORMER B: 1000/1333 KVA AA/FA.

REV	CHANGE REF	PREPARER	CHECKER	APPROVED	DATE
53	TMOD SQN-2015-250-001	BLR	[signature]	[signature]	1-9-2016
INC: T-MOD SQN-0-2015-250-001-002 AND RETURN TO NORMAL					

SCALE: NONE EXCEPT AS NOTED

GENERAL CATEGORY 1

KEY DIAGRAM STATION AUX POWER SYSTEM

SEQUOYAH NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY

DESIGN		INITIAL ISSUE	ENGINEERING APPROVAL
DRAFTER: PBD	CHECKER: C.A.BADGETT	RO ISSUE PER: CCD RECONCILIATION SHEET NO.CCD-8128. DRAWING MADE A CCD FROM AC-H & AD-R5 .	1 CHARLES BADGETT
DESIGNER: N/A	REVIEWER: K.R.SPINO		2 MARIO A AGUIRRE
			3 M.R.SEDLACIK/LWA

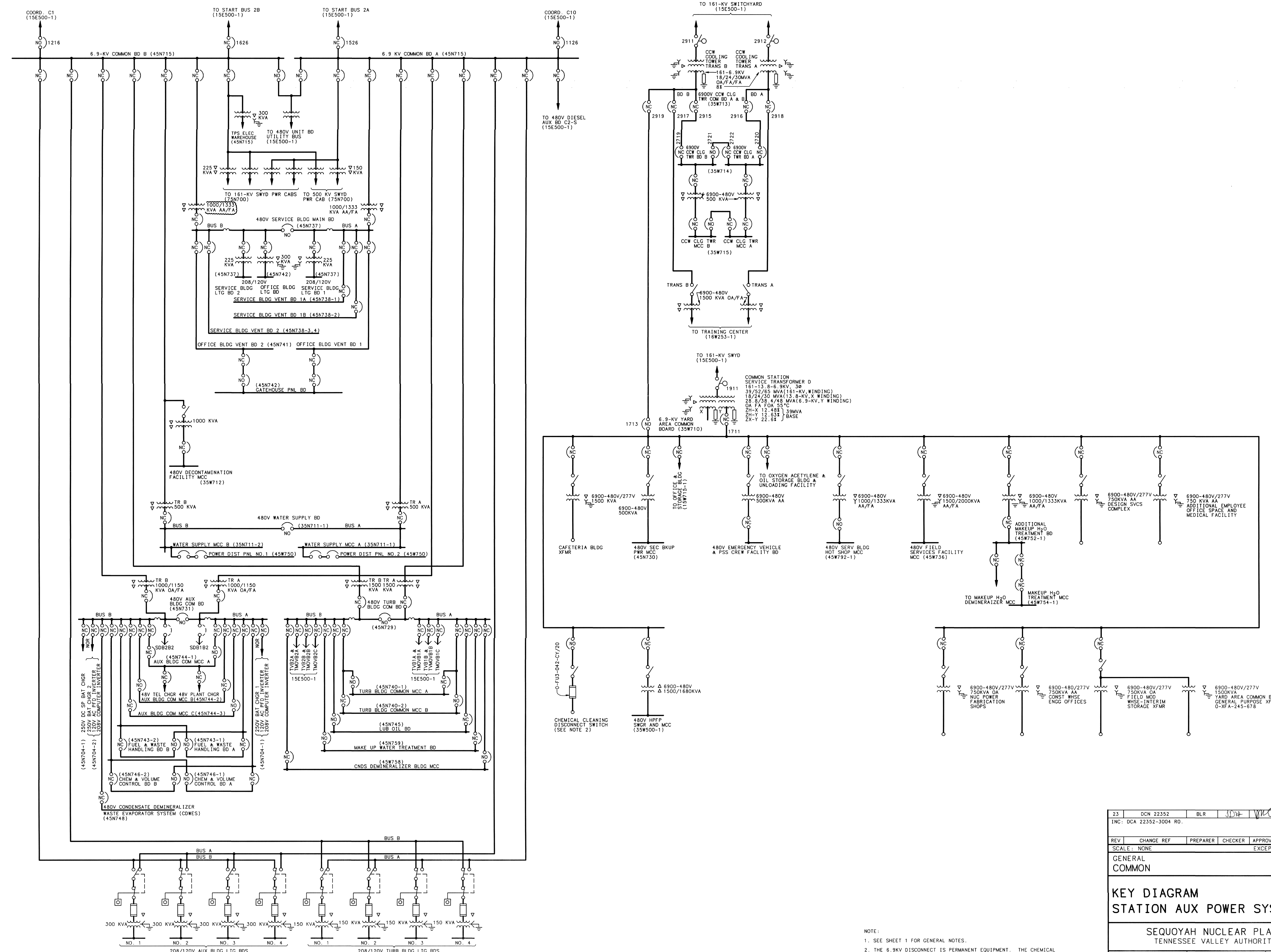
DATE 4-25-90 | 45 | E | CCD NO: 1,2-15E500-1 R53

THIS DRAWING AND COMPANION DRAWING 15E500-2 SUPERSEDE DRAWING 15N500 PER ECN L5377.

ISSUED BY: P.G.TRUDEL

CAD MAINTAINED DRAWING

CONTROL ROOM DWG



NOTE:

1. SEE SHEET 1 FOR GENERAL NOTES.

2. THE 6.9KV DISCONNECT IS PERMANENT EQUIPMENT. THE CHEMICAL CLEANING SKID IS A TEMPORARY TRANSFORMER/DISTRIBUTION PANEL ARRANGEMENT USED DURING OUTAGES. THE CHEMICAL CLEANING SKID IS A FACTORY ASSEMBLY CONSISTING OF A 1000KVA TRANSFORMER WITH A 6.9KV PRIMARY AND A 480V SECONDARY WITH A 480V DISTRIBUTION PANEL MOUNTED AT THE FACTORY. THE CHEMICAL CLEANING SKID MAY BE TRANSFERRED BETWEEN SITES AS NEEDED.

REV	CHANGE REF	PREPARER	CHECKER	APPROVED	DATE
23	DCN 22352 INC: DCA 22352-3004 RO.	BLR	JDH	[signature]	9-2-15

SCALE: NONE EXCEPT AS NOTED

GENERAL
COMMON CATEGORY 1

KEY DIAGRAM
STATION AUX POWER SYSTEM

SEQUOYAH NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY

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DESIGNER: N/A	REVIEWER: H.L. SUTTON		2 M.R. SEDLACIK
			3 MARIO A. AGUIRRE

DATE 01-11-90 | 45 | E | CCD NO: 1,2-15E500-2 R23

ISSUED BY: P.G. TRUDEL

CAD MAINTAINED DRAWING

CONTROL ROOM DWG

1,2-15E500-3 | E | 45

TABLE 1 - ELECTRIC POWER DISTRIBUTION TRANSFORMERS - VOLTAGE TAP SETTINGS

TRANSFORMER	SPECIFIED TAP		REMARKS
	PERCENT	TAP POSITION	
MAIN 1	SEE TABLE 6	SEE TABLE 6	SEE NOTES 11 & 12
MAIN 2	SEE TABLE 6	SEE TABLE 6	SEE NOTES 11 & 12
USST 1A	-2.5%	4	SEE NOTE 7
USST 1B	-2.5%	4	SEE NOTE 7
USST 2A	0%	3	SEE NOTE 7
USST 2B	0%	3	SEE NOTE 7
TR1A-A	-2.5%	4	SEE NOTE 8
TR1A1-A	-2.5%	4	SEE NOTE 8
TR1A2-A	-2.5%	4	SEE NOTE 8
TR1B-B	-2.5%	4	SEE NOTE 8
TR1B1-B	-2.5%	4	SEE NOTE 8
TR1B2-B	-2.5%	4	SEE NOTE 8
TR2A-A	-2.5%	4	SEE NOTE 8
TR2A1-A	-2.5%	4	SEE NOTE 8
TR2A2-A	-2.5%	4	SEE NOTE 8
TR2B-B	-2.5%	4	SEE NOTE 8
TR2B1-B	-2.5%	4	SEE NOTE 8
TR2B2-B	-2.5%	4	SEE NOTE 8
ERCW TR1A-A	NOMINAL	3-4	SEE NOTE 6
ERCW TR1B-B	NOMINAL	3-4	SEE NOTE 6
ERCW TR2A-A	NOMINAL	3-4	SEE NOTE 6
ERCW TR2B-B	NOMINAL	3-4	SEE NOTE 6

TABLE 2 - VOLTAGE LIMITS

EQUIPMENT	MINIMUM VOLTAGE	MAXIMUM VOLTAGE	REMARKS
UNIT GENERATOR	22,800	24,800	SEE NOTE 5
6.9KV UNIT BDS	6,560	7,260	SEE NOTE 4
6.9KV SHUTDOWN BDS	6,560	7,260	SEE NOTE 4
480V SHUTDOWN BDS	440	508	SEE NOTE 4
161KV GRID	165KV	170KV	SEE NOTE 9
500KV GRID	510KV	530KV	SEE NOTE 10

TABLE 3 - ALIGNMENT RESTRICTIONS AND LIMITATIONS

ALIGNMENT	RESTRICTIONS AND LIMITATIONS
NORMAL ALIGNMENT	ALL 6.9KV AND 480V BOARDS RECEIVING POWER FROM THEIR NORMAL SUPPLY AS SHOWN ON SHEETS 1 AND 2, • ADHERE TO NOTES 9, 10, 11, 12 • BOTH TRANSFORMER YARD DISTRIBUTION CABINETS 3 AND 4 IN SERVICE • BOTH 6.9KV COMMON BOARDS AND THEIR DOWNSTREAM LOADS NORMALLY SUPPLIED AS SHOWN ON SHEET 1,2-15E500-2. • NO MORE THAN ONE 6.9KV SHUTDOWN BOARD PER CSST WINDING. • LTC'S FOR CSST'S ALIGNED TO A START BUS MUST BE IN AUTO.
6.9KV SHUTDOWN BOARD	TWO 6.9KV SHUTDOWN BOARDS RECEIVING POWER FROM ANY ONE CSST WINDING. • ADHERE TO NOTES 1, 2, 9, 10, 11 • NO MORE THAN THREE SHUTDOWN BOARDS PER CSST. • ALL NON-1E BOARDS NORMALLY ALIGNED. • LTC'S FOR CSST'S ALIGNED TO A START BUS MUST BE IN AUTO. • BOTH TRANSFORMER YARD DISTRIBUTION CABINETS 3 AND 4 IN SERVICE.
6.9KV COMMON BOARD LOADS	ANY OR ALL BOARD(S) NORMALLY ALIGNED TO RECEIVE POWER DIRECTLY OR INDIRECTLY FROM EITHER 6.9KV COMMON BOARD ALIGNED TO ITS ALTERNATE SUPPLY. (REF SHEET 2) I.E. ALL B BOARDS ALTERNATELY ALIGNED. • ADHERE TO NOTES 1, 5, 7, 8, 9, 10 • ONLY ONE 6.9KV SHUTDOWN BOARD PER CSST WINDING. • LTC'S FOR CSST'S ALIGNED TO A START BUS MUST BE IN AUTO. • ALL OTHER NON-1E BOARDS NORMALLY ALIGNED.
CSST WINDING IN MANUAL	ONE OR MORE CSST LTC'S ALIGNED TO A START BUS NOT IN AUTO. • ADHERE TO NOTES 1, 3, 4, 6, 9, 10 • ONLY ONE WINDING PER OPERATING UNIT IN MANUAL AT A TIME. EXCEPT DURING MANUAL TRANSFER, SEE BELOW. • NO ADDITIONAL LOAD ON THE WINDING IN MANUAL; I.E. ONLY LOADS WHICH ARE NORMALLY ALIGNED ON THAT WINDING. • TAP CHANGER SET AT POSITION 2R. MANUAL UNIT 1 START BUS TRANSFERS (ONLY THE RESTRICTIONS LISTED ON TABLE 5 ON THIS DRAWING ARE APPLICABLE TO UNIT 2 TRANSFERS) • ADHERE TO NOTES 1, 6, 9, 10 • NO ADDITIONAL LOAD ON THE WINDING IN MANUAL; I.E. ONLY LOADS WHICH ARE NORMALLY ALIGNED ON THAT WINDING. • BOTH THE NORMAL AND ALTERNATE SUPPLY FOR THE START BUS BEING TRANSFERRED HAVE THEIR LTC IN MANUAL AND AT 2R. • NO LTC FOR THAT UNIT'S OPPOSITE START BUS IN MANUAL. • THE 161 BUS SEGMENTS FEEDING THE CSST TRANSFORMERS INVOLVED IN THE TRANSFER TIED TOGETHER. • THE MAXIMUM AMOUNT OF TIME FOR PARALLELED OPERATION SHOULD BE 5 MINUTES OR LESS.
480V UNIT BOARDS AND FEEDS	ANY OF THE FOLLOWING ON AN ALTERNATE SUPPLY: A SINGLE 480V UNIT BOARD, ONE OR MORE UNIT 1 TB MOV BOARDS AND/OR TB VENT BOARDS, OR ONE OR MORE UNIT 2 TB MOV BOARDS AND/OR TB VENT BOARDS. • ADHERE TO NOTES 1, 9, 10 • ONLY ONE 6.9KV SHUTDOWN BOARD PER CSST WINDING. • LTC'S FOR CSST'S ALIGNED TO A START BUS MUST BE IN AUTO. • ALL OTHER NON-1E BOARDS NORMALLY ALIGNED.

NOTES:

1. THE TRANSMISSION OPERATOR AT THE SOUTH EAST AREA DISPATCH CONTROL CENTER (TOSEADCC) MUST BE NOTIFIED OF ALTERNATE ALIGNMENTS PRIOR TO ENTRY AND IMMEDIATELY AFTER EXIT. THE TOSEADCC USES DIFFERENT NAMES FOR THE ALTERNATE ALIGNMENTS AS FOLLOWS...
   - 6.9KV SHUTDOWN BOARD → MV SHUTDOWN BOARD ALTERNATE ALIGNMENT
   - 6.9KV COMMON BOARD LOADS → "OTHER" ALTERNATE ALIGNMENT
   - CSST WINDING IN MANUAL → "OTHER" ALTERNATE ALIGNMENT
   - 480V UNIT BOARDS AND FEEDS → "OTHER" ALTERNATE ALIGNMENT
2. IN THE EVENT OF A LOCA AND SIMULTANEOUS LOSS OF OFFSITE POWER, IT WILL BE NECESSARY TO REALIGN THE 6.9KV SHUTDOWN BOARDS SUCH THAT EACH CSST WINDING FEEDS ONLY ONE BOARD BEFORE ALIGNING TO THE GRID FOR POWER.
3. WITH A CSST WINDING LOAD TAP CHANGER IN MANUAL AND SET TO THE 2R POSITION, IF A SPARE CSST WINDING WITH THE ASSOCIATE LOAD TAP CHANGER IN AUTO IS AVAILABLE, THEN A NOTIFICATION TO THE TOSEADCC OF AN ALTERNATE ALIGNMENT IS NOT NECESSARY. IF, UNDER THIS CONDITION, A SIMULTANEOUS LOSS OF OFFSITE POWER AND LOCA OCCUR, THEN THE LOAD MUST BE TRANSFERRED FROM THE WINDING WITH THE LOAD TAP CHANGER IN MANUAL TO THE SPARE CSST WINDING PRIOR TO RESTORATION OF OFFSITE POWER TO THE 6.9KV SHUTDOWN BOARDS.
4. IF BOTH UNITS ARE IN MODES 5 OR 6: FOR ANY LOW SIDE TAPS OPERATED IN MANUAL, THE 6.9KV SHUTDOWN BOARD VOLTAGE SHALL BE MANUALLY MAINTAINED BETWEEN 6900V AND 7100V.
5. THE FOLLOWING 6.9KV COMMON BOARDS LOADS DO NOT HAVE ALTERNATE FEED CAPABILITY FROM THE OPPOSITE 6.9KV COMMON BOARD:
   - 480V DECONTAMINATION FACILITY MCC
   - 6.9KV AUX BUILDING CHILLER
   - 480V 5TH DIESEL AUX BOARDS
6. CAUTION: IF THE GRID VOLTAGE EXCEEDS THE NORMAL OPERATING RANGE SPECIFIED BY THE GENERATING PLANT VOLTAGE SCHEDULE, OVER VOLTAGE CONDITIONS MAY EXIST RESULTING IN ANNUNCIATION AND POTENTIAL EQUIPMENT DEGRADATION/REDUCTION IN LIFE.
7. FOR THE 480V SERVICE BUILDING MAIN BOARDS A AND B: CONTINUOUS CURRENT (METER READING) SHALL NOT EXCEED 1425 AMPS FOR THE MAIN FEEDER BREAKER AND 540 AMPS FOR THE BUS TIE BREAKER AT CLOSURE. OPEN LOAD BREAKERS WHICH ARE NOT NECESSARY FOR THE TRANSFERRED PERIOD. TOTAL LOADING IS CONTROLLED BY ALTERNATE MAIN FEEDER BREAKER AMP METER NOT TO EXCEED 1425 AMPS. TIE BREAKER LOADS ARE CONTROLLED ADMINISTRATIVELY NOT TO EXCEED 540 AMPS.
8. FOR THE 480V AUXILIARY BUILDING COMMON BOARDS: CROSSTIE OF 480V AUXILIARY BUILDING COMMON BOARD BUS A AND B IS PROHIBITED WHEN OPERATION OF LOWER CONTAINMENT OUTAGE COOLING TEMPORARY PUMP SKID IS REQUIRED. THIS LOAD IS SUPPLIED FROM 480V AUX BLDG COMMON MCC A COMPARTMENT 9E. OPERATION WITH CROSSTIE IN SERVICE COULD RESULT IN OVERLOAD OF 480V AUX BLDG COMMON BD TRANSFORMER OR BUSES.
9. THE RESTRICTIONS LISTED IN THIS TABLE ENSURE THAT THE OFFSITE AND ONSITE POWER SYSTEM CAPABILITY AND CAPACITY ARE MAINTAINED. HOWEVER, TECHNICAL SPECIFICATION REQUIREMENTS REGARDING INDEPENDENT CIRCUITS MUST BE EVALUATED.
10. ANY DEVIATIONS FROM THESE RESTRICTIONS OR ALIGNMENTS NOT SPECIFICALLY ADDRESSED BY THIS TABLE SHOULD BE EVALUATED BY ELECTRICAL DESIGN ENGINEERING PRIOR TO IMPLEMENTATION. THE RESTRICTIONS AND LIMITATIONS ARE APPLICABLE ONLY TO THE BOARDS FED FROM CSST A, B, OR C AS SHOWN ON SHEETS 1 AND 2 AND ARE NOT APPLICABLE TO CSST D, CTT A, OR CTT B OR THE LOADS THEY SUPPLY.
11. REMOVING TRANSFORMER YARD DISTRIBUTION CABINET 3 OR 4 FROM SERVICE RESULTS IN THE LOSS OF 1 OFFSITE POWER SOURCE.
12. REMOVING EITHER TRANSFORMER YARD DISTRIBUTION CABINET 3 OR 4 FROM SERVICE WHILE IN THE NORMAL ALIGNMENT CAN BE DONE WHILE MAINTAINING TWO OFFSITE POWER SOURCES IF THE RESTRICTIONS AND LIMITATIONS FOR THE 6.9KV COMMON BOARD LOADS ALTERNATE ALIGNMENT ARE ADHERED TO.

TABLE 4 - SUMMARY OF RECOMMENDED TRANSFORMER TAP SETTINGS

	UNIT ON LINE	UNIT SHUTDOWN	BUS A	BUS B
480V UNIT BOARD 1A	C-G	E-G	-	-
480V UNIT BOARD 1B	C-G	E-G	-	-
480V UNIT BOARD 2A	C-G	E-G	-	-
480V UNIT BOARD 2B	C-G	E-G	-	-
480V COMMON EMERGENCY TRANSFORMER	3	3	-	-
480V TURBINE BUILDING COMMON BOARD	-	-	E-G	E-G
480V AUXILIARY BUILDING COMMON BOARD	-	-	4	4
480V WATER SUPPLY BOARD	-	-	3	3
480V SERVICE BUILDING MAIN BOARD	-	-	D-G	D-G

TABLE 5 - UNIT 2 START BUS MANUAL TRANSFER RESTRICTIONS

THE RESTRICTIONS BELOW SHALL BE OBSERVED WHILE THE UNIT 2 MAIN GENERATOR IS CONNECTED TO THE 161KV GRID.

- ALL 6.9KV AND 480V BOARDS ARE NORMALLY ALIGNED.
- THE 161KV BUS SEGMENTS FEEDING THE CSSTS INVOLVED IN THE START BUS TRANSFER SHALL BE TIED TOGETHER.
- NOTIFY TOSEADCC TO MAINTAIN 161KV GRID VOLTAGE AT 166KV MAXIMUM.
- NOTIFY TOSEADCC TO DISCONNECT 500KV TO 161KV INTERTIE TRANSFORMER FROM 161KV GRID.
- TWO SOURCES SHALL NOT BE CONNECTED TO A SINGLE START BUS FOR LONGER THAN FIVE MINUTES.
- LOAD TAP CHANGERS FOR CSSTS ALIGNED TO THE START BUS TO BE TRANSFERRED ARE NOT IN AUTO AND THE TAP CHANGERS ARE SET TO POSITION N.
- NO 6.9KV 1E MOTORS ARE RUNNING. (SEE NOTE 1)
- AUXILIARY BUILDING CHILLER MOTOR IS NOT RUNNING. (SEE NOTE 1)
- ADHERE TO NOTES 4 THROUGH 5 IN THIS TABLE.
- ADHERE TO NOTES 2 THROUGH 3 IN THIS TABLE ONLY WHEN THE START BUS IS CONNECTED TO LOAD.

THE RESTRICTIONS BELOW SHALL BE OBSERVED WHILE THE UNIT 2 MAIN GENERATOR IS DISCONNECTED FROM THE 161KV GRID.

- THE 161KV BUS SEGMENTS FEEDING THE CSSTS INVOLVED IN THE START BUS TRANSFER SHALL BE TIED TOGETHER.
- NOTIFY TOSEADCC TO MAINTAIN 161KV GRID VOLTAGE AT 168KV MAXIMUM.
- TWO SOURCES SHALL NOT BE CONNECTED TO A SINGLE START BUS FOR LONGER THAN FIVE MINUTES.
- LOAD TAP CHANGERS FOR CSSTS ALIGNED TO THE START BUS TO BE TRANSFERRED ARE NOT IN AUTO AND THE TAP CHANGERS ARE SET TO POSITION N.
- ONE REACTOR COOLANT PUMP MOTOR AND ONE CONDENSER CIRCULATING WATER PUMP MOTOR MAY BE RUNNING. ALL OTHER 6.9KV UNIT BOARD CONNECTED MOTORS ARE NOT RUNNING. (SEE NOTE 1)
- ADHERE TO NOTES 4 THROUGH 5 IN THIS TABLE.
- ADHERE TO NOTES 2 THROUGH 3 IN THIS TABLE ONLY WHEN THE START BUS IS CONNECTED TO LOAD.

NOTES:

1. LOAD RESTRICTIONS APPLY ONLY TO THE BOARDS OR MOTORS WHICH ARE SUPPLIED BY THE START BUS TO BE TRANSFERRED. RESTRICTED 1E MOTORS MAY BE AUTO STARTED; RESTRICTED NON-1E MOTOR AUTO START SHALL BE BLOCKED.
2. DURING THE START BUS TRANSFER, NO MODIFICATION, MAINTENANCE OR HEAVY LIFTING IS TO BE PERFORMED WHICH COULD IMPACT THE FEEDER CABLES FOR THE UNIT 2 RCP'S OR UNIT 2 6.9KV SHUTDOWN BOARDS INSIDE THE FOLLOWING FIRE AREAS:
   - FAR-002; REACTOR BUILDING ANNULUS UNIT 2
   - FAA-081; 6.9KV SHUTDOWN BD RM B
   - FAA-054; AUXILIARY BUILDING CORRIDOR (EL 714)
   - FAA-080; AUXILIARY BUILDING EMERGENCY GAS TREATMENT FILTER ROOM (EL 734)
   - FAA-081; AUXILIARY BUILDING PERSONNEL AND EQUIPMENT ACCESS ROOM (UNIT 2 MECHANICAL EQUIPMENT ROOM, EL 734)
   - FAA-102; AUXILIARY BUILDING UNIT 2 MECHANICAL EQUIPMENT ROOM (EL 749)
3. PRIOR TO INITIATING A START BUS TRANSFER, VERIFY THERE IS NO INDICATION OF A FIRE IN FIRE ZONES 142-145, 162-163, 174-175, 186-187, 239-240, 332-333, 374-375.
4. THE PARALLELED CONDITION SHALL BE EXITED EXPEDITIOUSLY SHOULD ANY OF THE RESTRICTIONS BE VIOLATED WHILE A TRANSFER IS IN PROGRESS.
5. ADHERE TO NOTES 6, 9 AND 10 OF TABLE 3 (THIS SHEET).

TABLE 6 - MAIN BANK TRANSFORMER RATINGS, TAP SETTINGS AND IMPEDANCE.

TRANSFORMER DESCRIPTION	TRANSFORMER RATING	TAP SETTING	IMPEDANCE	CALCULATED IMPEDANCE
UNIT 1				
MAIN BANK TRANSFORMER 1S	415/465 MVA (1Ø), 500-22.5KV 500KV +1/-3 EACH TAP 2.5%	500.0 KV (TAP 4) DE-ENERGIZED TAP CHANGER	15.5% 487KV-22.5KV 14.7% 500KV-22.5KV 13.1% 537KV-22.5KV FOR 415 MVA	14.7% (ACTUAL VALUE ON NAME PLATE AND NOT CALCULATED)
MAIN BANK TRANSFORMER 1A	469/525 MVA (1Ø), 500-24KV 537KV +3/-1 EACH TAP 2.5%	537.5 KV (TAP 2) DE-ENERGIZED TAP CHANGER	16.0% 500KV-24KV 15.8% 550KV-24KV FOR 525 MVA	15.9%
MAIN BANK TRANSFORMER 1B	469/525 MVA (1Ø), 500-24KV 537KV +3/-1 EACH TAP 2.5%	537.5 KV (TAP 2) DE-ENERGIZED TAP CHANGER	16.0% 500KV-24KV 15.8% 550KV-24KV FOR 525 MVA	15.9%
MAIN BANK TRANSFORMER 1C	469/525 MVA (1Ø), 500-24KV 537KV +3/-1 EACH TAP 2.5%	537.5 KV (TAP 2) DE-ENERGIZED TAP CHANGER	15.9% 500KV-24KV 15.7% 550KV-24KV FOR 525 MVA	15.8%
UNIT 2				
MAIN BANK TRANSFORMER 2A	420/470 MVA (1Ø), 161-22.5KV 161KV +1/-3 EACH TAP 2.5%	161.000KV (TAP 4) DE-ENERGIZED TAP CHANGER	11.9% 157KV-22.5KV 12.5% 161KV-22.5KV 13.5% 173KV-22.5KV FOR 420 MVA	12.5% (ACTUAL VALUE ON NAME PLATE AND NOT CALCULATED)
MAIN BANK TRANSFORMER 2B	469/525 MVA (1Ø), 161-24KV 173KV +3/-1 EACH TAP 2.5%	173.075KV (TAP 2) DE-ENERGIZED TAP CHANGER	13.5% 166KV-24KV 13.1% 177.1KV-24KV FOR 525 MVA	13.3%
MAIN BANK TRANSFORMER 2C	469/525 MVA (1Ø), 161-24KV 173KV +3/-1 EACH TAP 2.5%	173.075KV (TAP 2) DE-ENERGIZED TAP CHANGER	13.7% 166KV-24KV 13.4% 177.1KV-24KV FOR 525 MVA	13.5%
MAIN BANK TRANSFORMER 2S	469/525 MVA (1Ø), 161-24KV 173KV +3/-1 EACH TAP 2.5%	173.075KV (TAP 2) DE-ENERGIZED TAP CHANGER	13.4% 166KV-24KV 13.1% 177.1KV-24KV FOR 525 MVA	13.2%

NOTES:

1. FOR GENERAL NOTES AND REFERENCE DRAWINGS, SEE 15E500-1.
2.
3. BUS VOLTAGES SHOULD BE MAINTAINED WITHIN THE VOLTAGE LIMITS IN TABLE 2 FOR MAXIMUM EQUIPMENT LIFE.
4. VOLTAGE BASED ON ANSI STANDARD C84.1-1982, RANGE B.
5. VOLTAGE BASED ON DNE CALCULATION OE2-EEBCAL001(B43870921902).
6. TAP SETTINGS BASED ON CALCULATION OE2-EEBCAL001(B43870921902).
7. HIGH VOLTAGE TAP SETTINGS BASED ON CALCULATION SQNETAPAC.
8. TAP SETTINGS BASED ON CALCULATION SQN-EEB-MS-TI06-0002.
9. THE 161KV SCHEDULE GRID VOLTAGES ARE SPECIFIED AND CONTROLLED BY PSO.
10. THE 500KV SCHEDULE GRID VOLTAGES ARE SPECIFIED AND CONTROLLED BY PSO.
11. TAP SETTINGS BASED ON TRANSMISSION SYSTEM STUDIES COUPLED WITH THE SEQUOYAH GRID VOLTAGE SCHEDULES AND OPERATING INSTRUCTIONS (REFERENCE E31 961212 200 AND E31 961031 200) EXCEPT FOR 1A, 1B, 1C, 2B, 2C AND 2SP.
12. FOR MPT 1, PHASES A, B, C AND MPT 2, PHASES B, C AND SP TAP SETTINGS BASED ON CALCULATION NUMBER SQN-APS-062.

REV	CHANGE REF	PREPARER	CHECKER	APPROVED	DATE
39	ADMIN CHANGE	BLR	JDH	[signature]	4-5-16
	INC: ADMIN CHANGE PER RIMS: B85 160405 005 THIS RESOLVES CR 1127436				

SCALE: NONE EXCEPT AS NOTED

GENERAL
COMMON CATEGORY 1

TRANSFORMER TAPS & VOLTAGE LIMITS - AUX POWER SYSTEM

SEQUOYAH NUCLEAR PLANT
TENNESSEE VALLEY AUTHORITY

DESIGN		INITIAL ISSUE	ENGINEERING APPROVAL
DRAFTER: [signature]	CHECKER: E.M.WILLIAMS	RO ISSUE PER: CCD RECONCILIATION SHEET NO.CCD-8128. DRAWING MADE A CCD FROM AC-B & AD-R1.	1 J.E.FLOYD 2 M.A.AGUIRRE
DESIGNER: N/A	REVIEWER: J.A.DUCK		3 M.R.SEDLACIK

DATE 4-6-90 | 45 | E | CCD NO: 1,2-15E500-3 R39

ISSUED BY: P.G.TRUDEL

CAD MAINTAINED DRAWING

CONTROL ROOM DWG

1. PURPOSE

The purpose of this calculation is to establish limits for the setpoint and time delay settings for the Class 1E unbalanced voltage relays on the 6.9kV Shutdown Boards at Sequoyah Nuclear Plant (SQN). These relays are intended to protect the onsite Class 1E distribution system and connected loads from abnormal voltage unbalances, especially those caused by an upstream open phase fault. The limits established in this calculation can be used to establish the final setpoints and time delays, accounting for all associated errors and tolerances, in accordance with TVA Technical Instruction TI-28.

2. REFERENCES

2.1. ABB Descriptive Bulletin 41-238S September 1995 for Type 60Q Phase Unbalance Relay (Attachment 1)
2.2. ABB Instructions IB 7.4.1.7-3 Issue C for Phase Unbalance Relay Type 60Q (Attachment 2)
2.3. P. Pillay and M. Manyange, "Loss of Life in Induction Machines Operating With Unbalanced Supplies", IEEE Transactions on Energy Conversions, Vol. 21, No. 4, December, 2006
2.4. R. Harley, E. Makram, and E. Duran, "Starting Transients of Induction Motors Connected to Unbalanced Networks, Electric Power Systems Research, 17 (1989) 189- 197.
2.5. NPG Common Technical Procedure, NETP-107, “Medium Voltage Motor Testing and Maintenance Program”
2.6. Generic Specification, SS-E9.2.01, “Alternating - Current Induction Motors (Squirrel - Cage Type)”
2.7. NEMA MG-1, Motors and Generators, Revision 1 - March and July 1988, January 1989
2.8. IEEE Standard 242-2001, “IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book)”
2.9. U.S. Nuclear Regulatory Commission BTP 8-9, “Design Vulnerability in Electric Power System,” Bulletin 2012-01, dated July 27, 2012, ADAMS Accession No. ML12074A115
2.10. Branch Technical Instruction EEB-TI-28 R8, "Setpoint Calculations” (B43 110818 002)
2.11. Electrical Design Guide DG-E2.4.6 “Equipment Typical Data”
2.12. Relay Setting Sheets for Transmission Yard and Transformer Tap Changers

2744	822889	771798	058206	004613	768788	2750
2745	260483	771898	058306	542596	456577	2751
473396	007404	783473	029512	431695	717479	2587
473596	007504	6735	058006	867501	865801	2590
783373	025514	672372	058106	483177	865901	569396
911291	030414	672572	431895	260683	431995	569496
025314	034114	2600	431795	7863	2753	
025414	79092	050106	050406	007604	0793	
030214	776188	050206	004713	769488	2754	
030314	078492	822989	005013	769288	2755	

2.13. M. Bowman et al. “Open-Phase Fault Analysis” presented at 2014 ETAP Nuclear Utility User Group (NUUG) Conference and Symposium. ETAP Learning Center. Irvine, CA, June 18 -20, 2013
2.14. Calculation SQN-APS-003, “480VAC APS Class 1E Load Coordination Study,” Revision 88
2.15. P. Cooper, T. Fallesen, T. Womack, and M. Bowman, “Analysis of Open Phase Fault Events Using ETAP Unbalanced Load Flow Module”, 2016 IEEE Power & Energy Society General Meeting, July 17-21, 2016, Boston MA, USA.
2.16. SQN FSAR Amendment 26

2.17. U.S. Nuclear Regulatory Commission, "Industry Initiative on Open Phase Condition - Functioning of Important-to-Safety Structures, Systems and Components," ADAMS Accession No. ML13333A142

2.18. U.S. Nuclear Regulatory Commission, NRC letter dated November 25, 2014, from William Dean, Office of Nuclear Reactor Regulation to Anthony Pietrangelo, Nuclear Energy Institute, ADAMS Accession No. ML14120A203

3. DESIGN INPUT

Unbalanced Voltage Relays
Per References 2.1 and 2.2
Manufacturer /Model: ABB Type 60Q

- Catalog Number: 412J5275
  - Voltage Tap Ranges: I, 2, 3, 5, 7, 10 volts
  - Time Delay Range: 0.32, 0.63, 1.25, 2.5, 5, 10 sec
- Catalog Number: 412J5375
  - Voltage Tap Ranges: 2, 4, 6, 10, 14, 20 volts
  - Time Delay Range: 0.32, 0.63, 1.25, 2.5, 5, 10 sec

4. ASSUMPTIONS

4.1. The voltage unbalance will not be greater on the downstream buses than that present on the 6.9kV safety buses.

Technical Justification:

Transformers located between 6.9kV and 480V buses will serve to reduce voltage unbalance on the downstream busses due to their winding construction. (Delta - Delta)

4.2. Over-frequency / under-frequency heating is not considered for this analysis.

Technical Justification:

The grid is maintained very close to 60 Hz and motors are rated for ± 5% of nominal frequency (Ref. 2.5 & 2.6).

5. SPECIAL REQUIREMENTS/LIMITING CONDITIONS

Operator action is required when the unbalanced voltage alarm actuated in the main control room. Either correction of the voltage unbalance or removal of the affected loads, must occur in a timely manner to prevent undue thermal aging of the motors.

6. COMPUTATIONS AND ANALYSIS

6.1. BACKGROUND

As a result of the Byron Open Phase Event in 2012, industry-wide concerns were raised about the adequacy of existing protection schemes to protect the Class 1E safety system from the effects of an open phase fault. In response to these concerns, an industry working group was formed by the Nuclear Energy Institute (NEI). This industry working group established criteria (NEI Open Phase Industry Initiative) (Ref. 2.17) and analytical guidelines (NEI Open Phase Analysis Guidance Document) to be used to determine proper open phase protection. In response to the industry guidance, the NRC provided guidance in BTP 8-9 (Ref. 2.9) in the form of 4 functional requirements (Ref. 2.18) to protect against open phase conditions (OPC) . The 4 functional requirements are:

i. The design should address single failure criteria as outlined in the 10CFR50 Appendix A GDCs or the principle design criteria specified in the undated final safety analysis report.
ii. The OPC should be automatically detected and alarmed in the main control room under all operating electrical systems configurations and loading conditions.
iii. If offsite power circuits are degraded due to OPC, the power source should be transferred automatically to the onsite power system within the time assumed in the accident analysis and without actuating any protective devices, given a concurrent design basis event.
iv. TS Surveillance Requirement and Limiting Condition of Operation for equipment used for mitigation of OPC should be consistent with the operability requirements specified in the existing plant TSs.

The main issue with open phase conditions degrading an offsite power circuit is that loss of a phase causes a voltage unbalance in the connected distribution system. This unbalance causes additional heating in the connected loads due to the “negative sequence” phase currents. At lower-level voltage unbalances, a resulting elevated temperature can cause a reduction in service life (leading to premature failure). If the voltage unbalance is high enough, the resulting current unbalance can cause protective devices (overcurrent relays, circuit breakers, thermal overload relays) to trip prematurely, leading to unanalyzed loss of safety loads. For a double open phase fault (two phases open-circuit), the connected loads lose rotational torque which causes them to quickly transition to locked-rotor current conditions and ultimately trip their protective devices, leading to unanalyzed loss of safety loads.

6.2. FUNCTIONAL DESCRIPTION OF CLASS 1E UNBALANCED VOLTAGE PROTECTION SYSTEM

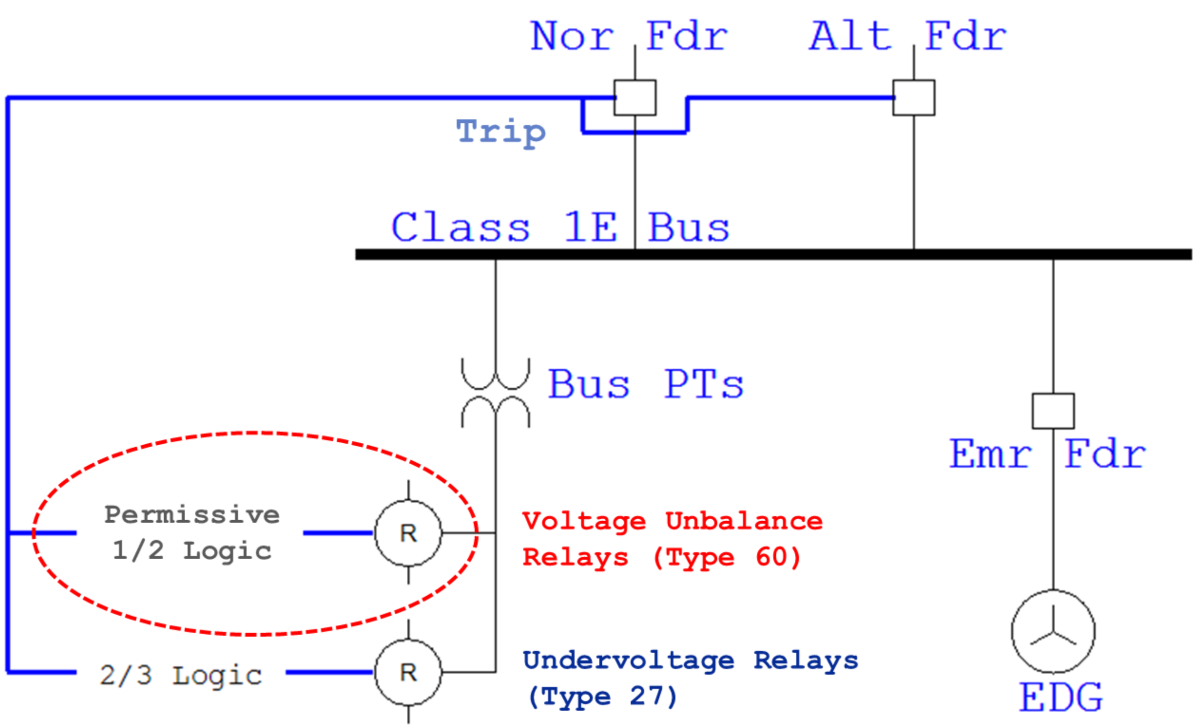
The SQN unbalanced voltage protection system was designed to not only follow the guidance of the NRC 4 functional requirements for an open phase condition, but also to protect against any other initiating event that could cause loss of safety function due to unbalanced voltages on the Class 1E distribution system. An open phase condition in a three phase power system (single or double), causes a negative sequence “over-voltage” condition in the individual phase voltages. Therefore, a phase unbalance relay (also known as a negative sequence overvoltage relay) essentially compares the voltages in all three phases and determines the amount of negative sequence voltage to determine if the voltage has become unbalanced. This is the case for the relays chosen for this unbalanced voltage protection system; negative sequence overvoltage relays were chosen to monitor the amount of negative sequence voltage at the Shutdown Board (bus) level, which correlates to the amount of voltage unbalance in the Class 1E distribution system. The relays include a built-in, adjustable time delay intended to allow the relay to ride through anticipated system disturbances and for those disturbances to be cleared by other protective devices (e.g. a ground fault causes voltage unbalance, but would typically be cleared by ground fault protection). Should a voltage unbalance occur with a negative sequence component larger than the setpoint value, a time delay would be initiated. If the negative sequence component exists longer than the time delay, a trip signal (contact closure) is generated.

Each 6.9kV Shutdown Board will have three separate unbalanced voltage relays:
1. Alarm Relay: Alerts the main control room of an abnormal voltage unbalance. Protects against “loss of life” or long-term motor degradation for the connected Class 1E loads.
2. Low Trip Relay (long time delay): Trips the offsite power supply when the voltage unbalance may cause a loss of safety function within the connected Class 1E distribution system.

3. High Trip Relay (short time delay): Quickly trips the offsite power supply when the voltage unbalance may cause a loss of safety function within the connected Class 1E distribution system.

The voltage input to the unbalanced voltage relays are from the existing bus level potential transformers (PT) on the 6.9kV Shutdown Board. There are the existing 7200V / 120V PTs that are used for the second-level (degraded) under-voltage protection. The relays are arranged in a permissive one-out-of-two actuation logic; the Alarm Relay is used to supervise either the Low Trip Relay or High Trip Relay (Figure 1). This provides both redundancy as well as reliability (prevent nuisance tripping). For a given voltage unbalance, if the Alarm Relay and either the Low Trip Relay or High Trip Relay times out, the resulting trip signal is sent to trip the incoming offsite power circuit breakers on the 6.9kV Shutdown Board. This disconnects the onsite Class 1E distribution system from the voltage unbalance. Existing under-voltage protective relays will then transfer the affected Class 1E board to the onsite power supply (EDG), in the same manner as a loss-of-offsite power.

Figure 1 Simplified Schematic of Unbalanced Voltage Protection Scheme



6.3. SETPOINT METHODOLOGY

In order to determine the analytical limits for the unbalanced voltage relays, supporting analysis is done in a "bottom-up" manner (based on load requirements, and independent of characteristics of the incoming power source). The underlying bases behind these allowable limits for voltage unbalance and associated time delays are accepted industry standards, design requirements of the connected Class 1E loads, and the analysis time allowed for connection of the onsite power supply.

For each of the following setpoints, this calculation will only establish the applicable analytical limits and boundaries. These limits should then be used to establish the setpoints, accounting for all associated errors and tolerances, in accordance with TVA Technical Instruction TI-28 (Ref. 2.10).

6.3.1. Alarm Relay Setpoint

The Alarm Relay must alert the main control room of an abnormal voltage unbalance and must protect against unacceptable "loss of life" or long-term motor degradation for the connected Class 1E loads.

a. A lower operating limit for the setting should be established that is greater than the acceptable "normal" range for voltage unbalance from industry standards.
b. The upper analytical limit of the setting should prevent an unacceptable reduction of service life from the additional heating caused by a voltage unbalance. This can be accomplished by ensuring the additional heating does not outpace that accounted for in traditional overload protection settings. <u>Note</u>: To avoid nuisance alarms, the relay nominal setting should be as close as possible to this upper limit, accounting for associated errors and tolerances.
c. The lower operating limit of the time delay must be set to avoid nuisance alarms in the main control room during anticipated electrical distribution system faults; greater than the clearing time of switchyard ground fault protection devices.
d. The upper operating limit of the time delay should be less than transformer tap changer setpoints.

6.3.2. Low Trip Relay Setpoint

The Low Trip Relay must protect against loss of safety function for the connected Class 1E loads during a voltage unbalance. In short, the analytical limit protects the point where all required safety loads perform their safety function during a voltage unbalance, for all anticipated transients, operational occurrences, and design basis events.

a. The lower operating limit of the setting should be greater than the Alarm Relay setting.
b. The upper analytical limit of the setting must be less than the recommended maximum limit of voltage unbalance for motors to tolerate from industry standards. <u>Note</u>: To avoid nuisance tripping (unnecessary loss of offsite power), the relay nominal setting should be as close as possible to this upper limit, accounting for associated errors and tolerances.
c. The lower operating limit of the time delay should be greater than the Alarm Relay time delay setting.
d. The upper analytical limit of the time delay must be less than the safety analysis time allowed for the emergency diesel generators to come up to rated speed and voltage and be ready to accept load; should be equivalent to the upper analytical limit of the degraded voltage relay time delay.

6.3.3. High Trip Relay Setpoint

The High Trip Relay must protect against loss of safety function for the connected Class 1E loads during a voltage unbalance. This relay provides a faster tripping time for high-level unbalances, where catastrophic load failure may occur within a few seconds.

a. The lower operating limit of the setting should be greater than the Alarm Relay setting.
b. The upper analytical limit of the setting must be less than the smaller of:
   1. The maximum relay setting (relay should be capable of at least 25% voltage unbalance), or

2. The maximum limit of voltage unbalance to prevent motor stalling, based on industry standards

Note: To avoid nuisance tripping (unnecessary loss of offsite power), the relay nominal setting should be as close as possible to this upper limit, accounting for associated errors and tolerances.

c. The lower operating limit of the time delay should be greater than the Alarm Relay time delay setting.

d. The upper analytical limit of the time delay should be less than minimum design time allowed for motor starting, adjusted for additional current created by unbalanced voltages; less than the tripping time of overcurrent protective devices during unbalance voltage conditions.

6.4. SETPOINT COMPUTATIONS:

6.4.1. Alarm Relay:

a. Pick-up Lower Limit

NEMA MG-1 (Ref 2.7) states motors do not need to be de-rated for unbalances less than one percent. A one percent unbalance at a nominal voltage of 6900V is 69V. The potential transformer for the relays is 7200V - 120V or a ratio of 60:1. So the secondary voltage is $69/60$ or 1.15V. This is a line to line value and the ABB 60Q relays operate on a line to neutral value. Thus the 1.15V must be divided by $\sqrt{3}$, yielding 0.7V. For added conservatism, and to avoid nuisance tripping, a **lower operating limit of 0.9V will be used.**[1]

b. Pick-up Upper Limit

The NEI Task force on open phase published a report and the results were presented to the ETAP Nuclear Utility User's Group meeting (Ref 2.13) that states an equation for calculating an equivalent current for an unbalanced system.

$$I_{eq} = \sqrt{I_1^2 + 175\left(\frac{I_2}{LR_{pu}}\right)^2}$$

A worst case phase current would occur where the positive sequence and negative sequence values are 60 degrees out of phase.

$$I_{WC} = |I_1 + I_2\angle 60°|$$

Setting these two equations equal to each other, and substituting voltage for current where

$$I_1 = \frac{1}{V_1}$$

$$I_2 = V_2 * LR$$

Yields

$$V_2 = \frac{LR}{175 - LR^2}$$

Typical motors from TVA Design Guide DG-E2.4.6 (Ref. 2.11) range of 5 to 7 times locked rotor currents. For conservatism, a motor with locked rotor equal to 3.75 times nominal, the maximum V_2 is 2.3%. Multiplying this percentage by the nominal of, reflecting it across the potential transformers, and converting to line to neutral values will give the upper limit.

[1] 0.9V is greater than the normal voltage unbalance for SQN Shutdown Boards, as seen on the secondary of the bus potential transformers. This is based on actual readings taken November 5, 2015 as part of WO 115834948.

$$\left(\frac{0.023 * 6900}{60\sqrt{3}}\right) = 1.5$$

This yields an **upper analytical limit of 1.5V.**

c. Time Delay Lower Limit
Review of relay setting sheets in reference 2.12 shows that a ground fault in the transmission system will be cleared by at most 0.3 seconds. This yields a **lower operating limit of 0.3 seconds.**

d. Time Delay Upper Limit
Review of the relay setting sheets in reference 2.12 shows that the transformer tap changers will complete one tap movement is 3 seconds. This yields an **upper operating limit of 3 seconds.**

6.4.2. Low Trip Relay

a. Pick-up Lower Limit
The lower operating limit of the setting should be greater than the Alarm Relay setting. For conservatism, the upper limit of the alarm relay setting can be used as the **lower operating limit (1.5V).**

b. Pick-up Upper Limit
NEMA MG-1 (Ref. 2.7) states motors should not be operated at unbalances greater than five percent. A five percent unbalance at a nominal voltage of 6900V is 345V. The potential transformer for the relays is 7200V - 120V or a ratio of 60:1. So the secondary voltage is $345/60$ or 5.75V. This is a line to line value and the ABB 60Q relays operate on a line to neutral value. Thus the 5.75V must be divided by $\sqrt{3}$. This yields an **upper analytical limit of 3.3V.**

c. Time Delay Lower Limit
The lower operating limit of the time delay should be greater than the Alarm Relay and High Set Relay time delay. For conservatism, the upper limit of the High Trip Relay setting can be used as the **lower operating limit (4 seconds).**

d. Time Delay Upper Limit
Review of the FSAR (Ref. 2.16) shows that the maximum time delay for under-voltage relaying is 10 seconds. This value shall be used as the **upper analytical limit (10 seconds).**

6.4.3. High Trip Relay

a. Pick-up Lower Limit
The lower operating limit of the setting should be greater than the Alarm Relay setting. For conservatism, the upper limit of the Low Trip Relay setting can be used as the **lower operating limit (3.3V).**

b. Pick-up Upper Limit
ABB 60Q relay manual (Ref. 2.2) shows that the highest voltage setting is 20V. Changing this line to neutral voltage to line to line, and reflecting it across the potential transformers $(20 * \sqrt{3} * 60)$ yields 2078V or 30.1% of nominal 6900V. This would reduce motor torque less than 20% due to the locked rotor power factor typically less than 62% $(0.291 * 0.62 = 0.18)$. (Ref. 2.11) Typical motors have a breakdown torque of two times full load torque. Since motors would have appropriate torque to operate at the relay maximum setting, it shall be used as the **upper analytical limit (20V).**

c. Time Delay Lower Limit
The lower operating limit of the time delay should be greater than the Alarm Relay time delay. For conservatism, the upper limit of the Alarm Relay setting can be used as the **lower operating limit (3 seconds).**

d. Time Delay Upper Limit
Analytical basis included in calculation SQN-APS-003 (Ref. 2.14) states that motors shall be allowed an acceleration time of at least 8 seconds by their protective devices. Limiting the maximum phase to ground voltage to the pre-fault line to line voltage yields the following:

$$\left(V_1 = \frac{-V_2 \pm \sqrt{4-3V_2^2}}{2}\right)$$

Using this equation, varying V_2 from 0% to 100%, the maximum $V_1 + V_2$ is 1.15 per unit. Thus, the maximum locked rotor current a motor can pull at any unbalance that starts from nominal voltage is 115%. Since motor heating is an I^2t value, a ratio of current squared to starting time, the following equation yields a 6 seconds tolerance for 115% locked rotor.

$$\left(\frac{1^2}{1.154^2} = \frac{X}{8}\right)$$

Due to the tap changers in the system and variations of thermal overload device selection, it is recommended to have a two second margin for the time yielding a **upper analytical limit of 4 seconds.**

7. SUMMARY OF RESULTS

The phase unbalanced voltage relays are to be set using the following boundaries and analytical limits.

Relay	Voltage (Volts Line-Neutral Secondary)		Time Delay (Seconds)	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Alarm	0.9	*1.5	0.3	3.0
Low Trip	1.5	*3.3	4	*10
High Trip	3.3	*20.0	3.0	*4

** designate analytical limits*

- To avoid nuisance actuations, the three relays' nominal pick-up settings should be as close as possible to the upper limits, accounting for associated errors and tolerances.
- To avoid nuisance actuations the time delay for the Alarm, Low Trip and High Trip relays should be as close as possible to the upper limits, accounting of associated errors and tolerances.
- The time delays setpoints for the Low Trip and the High Trip relays must not overlap with the Alarm relay time delay setpoint accounting for associated errors and tolerances.

8. CONCLUSIONS

Setting the phase unbalanced voltage relays in this manner complies with the 4 functional requirements and industry initiative.

9. ATTACHMENTS

Attachment 1	ABB Descriptive Bulletin 4 l-238S (Ref. 2.1)	3 Pages
Attachment 2	ABB Instructions IB 7.4.1.7-3 (Ref. 2.2)	11 Pages

1.0 Purpose

The purpose of this calculation is to determine the accuracy of the 60Q unbalanced voltage relays for the 6.9kV Shutdown Boards. The relays provide a level of protection to the onsite Class 1E distribution system and connected loads from abnormal unbalances, especially those caused by an upstream open phase fault. This calculation establishes the final voltage and time delay setpoints for each installed relay, accounting for any associated errors and tolerances.

2.0 Assumptions

_x_ This calculation contains no assumptions.

___ The following assumptions were used in the performance of this calculation. These assumptions require further analysis. This calculation may require revision if the assumptions below are shown to be invalid.

3.0 Source of Design Input Information (References)

1	-	DCN 23398 – SQN Installation of Unbalanced Voltage Relays
2	1	“TVA Testing of the ABB 60Q Voltage Unbalance Relay-Determining the Accuracy Characteristics
3		SQN-VTD-AB06-0250 - ABB Instructions for Phase Unbalance Relay Type 60Q, IB 7.4.1.7-3 Issue C
4	-	NOT USED
5	-	SQN Calculation EDQ0002022016000331 – “Determination of Unbalance Voltage Relay Analytical Limits”
6	-	BTI-EEB-TI-28, R0011 – “Setpoint Calculations”
7	-	NPG-SPP-06.7, R0003 – “Instrumentation Setpoint, Scaling and Calibration Program”
8	-	SQN Design Criteria SQN-DC-V-21.0, R26 – “Environmental Design”
9	2	ABB Certification Report – 60Q Phase Unbalance Relay

4.0 Design Input Data

4.1 Definitions and Abbreviations

Abbreviation	**Definition**
A_a	Accident accuracy
A_{as}	Combined accident and seismic accuracy
A_b	Acceptance band
A_{dbe}	Design Basis Event Accuracy
AL	Analytical limit
A_n	Normal accuracy
A_{nf}	Normal Measurable Accuracy
A_s	Post-seismic accuracy
A_v	Allowable value
CAL_e	Calibration error
CS	Calibrated span
D_e	Drift inaccuracy

Abbreviation	Definition
HELB	High energy line break
IAD	Integrated accident dose
ICR_e	Input test instrument reading inaccuracy
ICT_e	Input test instrument calibration in accuracy
$INDR_e$	Indicator reading error
IR_e	Insulation Resistance Error
LA_a	Loop Accident Accuracy
L_{an}	Loop Normal Accuracy
L_{as}	Loop Post Seismic Accuracy
LAL	Lower Analytical Limit
LOCA	Loss of coolant accident or LOCA
M	Margin
M_e	Measurement Error
M&TE	Maintenance and Test Equipment
N/A	Not applicable
N/R	Not Required
OCR_e	Output test instrument reading inaccuracy
OCT_e	Output test instrument calibration inaccuracy
PAM	Post-accident monitoring
$PRCS_e$	Process uncertainty
PSE_e	Power Supply Effect
PV	Process value (actual)
RAD_e	Accident Radiation Effect
R_e	Reference accuracy
RH	RHR line break
RH_e	Relative Humidity Effect
RND_e	Normal Radiation Effect
S_e	Seismic Effect
SEC_u	Span error correction uncertainty
SL	Safety Limit
SP	Set Point
SPE_e	Zero error due to effects of operating pressure
SSD	Setpoint and Scaling Document
TA_e	Temperature effect at accident conditions
TID	Total 40 years integrated dose
TN_e	Temperature effect in the maximum/minimum abnormal temperature ranges
TPR_e	Test point resistor error
UAL	Upper Analytical limit
WL_e	Waterleg Uncertainty
WL_{HP}	Waterleg High Point
WL_{LP}	Waterleg Low Point

4.2 Loop component List

UNID	Description/Function	Model #
1-RLY-202-60PI1	Voltage Unbalance Relay (LO)	412J5275
1-RLY-202-60PI2	Voltage Unbalance Relay (HI)	412J5375
1-RLY-202-60PI3	Voltage Unbalance Relay (ALARM)	412J5275
1-RLY-202-60PI4	Voltage Unbalance Relay (LO)	412J5275
1-RLY-202-60PI5	Voltage Unbalance Relay (HI)	412J5375
1-RLY-202-60PI6	Voltage Unbalance Relay (ALARM)	412J5275
2-RLY-202-60PI1	Voltage Unbalance Relay (LO)	412J5275
2-RLY-202-60PI2	Voltage Unbalance Relay (HI)	412J5375
2-RLY-202-60PI3	Voltage Unbalance Relay (ALARM)	412J5275
2-RLY-202-60PI4	Voltage Unbalance Relay (LO)	412J5275
2-RLY-202-60PI5	Voltage Unbalance Relay (HI)	412J5375
2-RLY-202-60PI6	Voltage Unbalance Relay (ALARM)	412J5275

4.3 Loop Function

Three (3) 60Q voltage unbalance relays (alarm, low and high) are installed in the 6.9kV shutdown boards 1A-A, 1B-B, 2A-A, 2B-B to detect and mitigate a voltage unbalance condition. An unbalanced voltage condition can prevent the actuation or unavailability of safety related systems. These 60Q relays will provide a new function for transferring the power source to the respective diesel generator for each shutdown board.

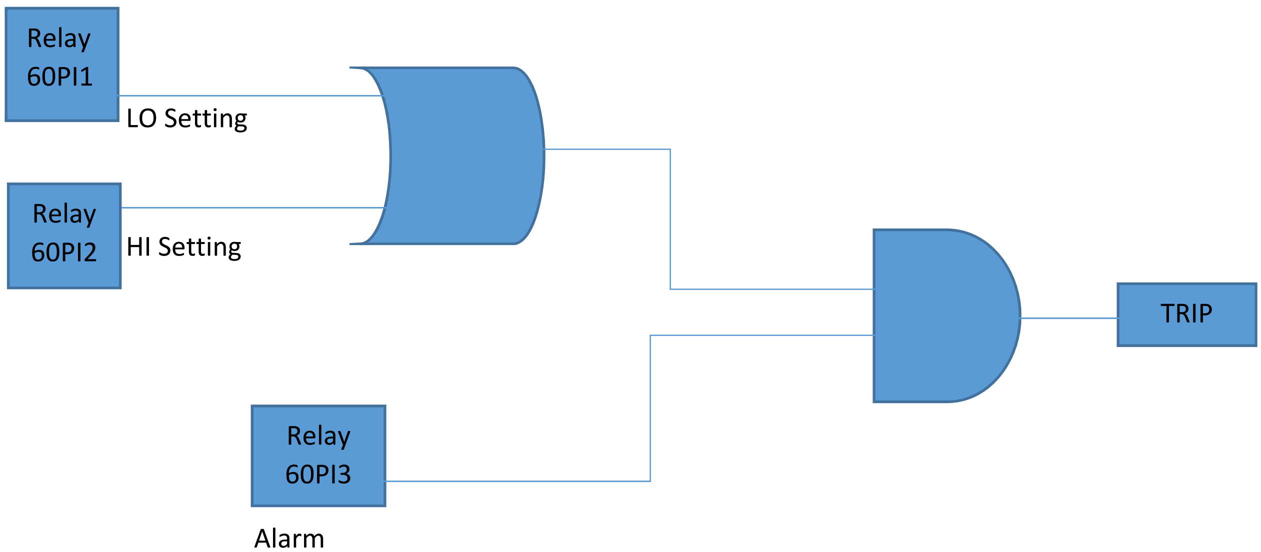


Figure 1. 6.9kV Voltage Unbalance Logic Diagram

(Typical for Each Shutdown Board)

The loop is designed with a 1 out of 2 logic scheme (see Figure 1) that, in combination with the alarm relay, will transfer the board load to the diesel generators.

4.3.1 Setpoint Limits

Reference 5 sets analytical limits for relays as outline below.

Relay	Voltage Limits	Time Delay Limits
Alarm	0.9V – 1.5V	0.3s – 3s
Lo Trip Relay	1.5V – 3.3V	4s – 10s
Hi Trip Relay	3.3V – 20V	3s – 4s

Reference 5 also states that to avoid nuisance actuations the time delay for the Alarm, Lo and HI trip relays should be as close as possible to the upper limits, accounting of associated errors and tolerances. Also, the time delay setpoints for the LO and HI trip relays must not overlap with the Alarm relay time delay setpoint accounting for associated errors and tolerances.

4.4 Component Data

Valid For Devices Identified in Section 4.2

Component: Unbalanced Voltage Relay Contract # See Maximo Reference # 1

		Note #	Reference #
Maufacturer/Model	ABB/Type 60Q	-	3
Input Range & Units	1-10 V 0.32-10 sec (412J5275) 2-20 V 0.32-10 sec (412J5375)	-	3
Output Range & Units	Contact Closure	-	3
Overrange Limit	160V, 60Hz	-	3
Room #/Panel#	6.9kV Shutdown Board Rm A/B	-	8
Elevation/Coordinate	EL 734 A2 (Rm A) A24 (Rm B)	-	8
Min/Max/Abnormal Temp	60 / 104 deg F	-	8
Accident Temperature	104 deg F	-	8
Radiation TID (RAD)	1.8E +3	-	8
Radiation IAD (RAD)	5.00E +2	-	8

Instrument Tap Information Reference #: N/A

WH_{LP} Tap Elevation: N/A WL_{HP} Condensing Pot Elevation: N/A

WL_{LP} Tap Elevation: N/A WL_{LP} Condensing Pot Elevation: N/A

Event/Category/Operating Time: N/A / N/A / N/A Note#: Reference#: N/A

4.5 60Q Relay Voltage Uncertainty Parameters

PARAMETER	VALUE/UNITS	NOTE#	REFERENCE#
R_e	$\pm$ 0.01 V	1	2
D_e	$\pm$ 0.05 V	1	-
TN_e	$\pm$ 2.37% of setpoint	1	2
SPE_e	N/A	-	-
SEC_u	N/A	-	-
PSE_e	$\pm$ 10% of setpoint V	2	3
RND_e	N/A	-	-
TPR_e	N/A	-	-
ICT_e	$\pm$ 0.1 V	4	7
ICR_e	N/A	5	2
OCT_e	N/A	5	2
OCR_e	N/A	5	2
A_b	$\pm$ 0.1 V	1	2
S_e	0	-	2, 9
RAD_e	N/A	3	-
TA_e	$\pm$ 2.37% of setpoint	1	2
WL_e	N/A	-	-
$PRCS_e$	N/A	-	-
$INDR_e$	N/A	-	-
IR_e	N/A	-	-

Notes:

#	NOTE
1	TVA testing of the 60Q relays noted in its conclusion values for repeatability, acceptance band, temperature effects and drift are used in lieu of vendor provided data.
2	Vendor documentation notes an operating voltage tolerance of +/- 10%.
3	The subject devices are located in mild environments. Therefore, the radiation effects need not be considered.
4	In accordance with reference 7, the M&TE accuracies should be at least equal to the instrument acceptance band (A_b).
5	Per reference 2, a highly accurate data-acquisition system is used. Therefore, ICR_e, OCR_e, OCT_e is negligible.
6	The output is a contact closure, so there is no error associated.
7	
8	
9	
10	
11	
12	

_x_ No process uncertainty exists for this calculation because:

_x_ The measured parameter is the parameter of concern; therefore, process variations are accounted for in the determination of safety and/or operational limits.

___ Other: See discussion below.

_N/A_ Process uncertainty does exist and is detailed in the following discussion/calculation.

4.6 60Q Relay Time Delay Tolerance

In accordance with Reference 3, the operating time should be within $\pm 10\%$ or ± 2 cycles, whichever is greater. As these 60Q relays are 60 Hz relays, 2 cycles would be equal to 0.033 seconds of tolerance. Although not explicitly measured for in testing, TVA concludes in reference 2 that drift, time related deviation, will be determined using the installed devices and that antidotal evidence suggests that the drift will be very small. A preliminary 0.05 V drift was given for voltage. This calculation uses a similar approach for time delay tolerance and uses a value of 0.05 sec. This establishes a preliminary value that is within the band of values suggested by the vendor and supported by testing performed by TVA.

5.0 Methodology

5.1 Waterleg Calculations Uncertainty Discussion/Calculation

___ Applicable to all of the following loops:
___ Applicable only to loops:

_x_ Waterleg uncertainty is not considered for this calculation because:
- _x_ No Waterleg exists for this calculation
- ___ The effects of waterleg changes are insignificant. See discussion/calculation below.
- ___ Other: See discussion/calculation below.

___ Waterleg uncertainty does not exist for this loop. See discussion/calculation below.
___ See Sensing Line Diagram, Section 7.2 of this calculation

5.2 Accuracy Discussion - Voltage

_x_ The accuracy of this instrument for normal, post seismic and accident conditions will be determined by considering the parameters tabulated in the design input section of this calculation.
The accuracy calculation for seismic (A_s) is bounding for all seismic events.

_x_ The square roots of the sum of the squares method shall be used in this calculation for calculating accuracy since the factors affecting accuracy are independent variables.

_x_ Bi-directional errors and uni-directional errors will be combined in a manner such that the sum of the positive uni-directional errors will be added to the positive portion of the bi-directional error (obtained from the square root of the sum of the squares method), and the sum of the negative uni-directional errors will be added to the negative portion of the bi-directional error.
This method is conservative. Therefore, it will be used in this calculation.

Example: ($\pm$)10 = bi-directional error
+5 = first uni-directional error
-2 = second uni-directional error
Total Error = (+10+5) to (-10-2) = 15 to -12

___ Other:

5.3 Accuracy Discussion – Time Delay

___ The accuracy of this instrument for normal, post seismic and accident conditions will be determined by considering the parameters tabulated in the design input section of this calculation.
The accuracy calculation for seismic (A_s) is bounding for all seismic events.

___ The square roots of the sum of the squares method shall be used in this calculation for calculating accuracy since the factors affecting accuracy are independent variables.

___ Bi-directional errors and uni-directional errors will be combined in a manner such that the sum of the positive uni-directional errors will be added to the positive portion of the bi-directional error (obtained from the square root of the sum of the squares method), and the sum of the negative uni-directional errors will be added to the negative portion of the bi-directional error.
This method is conservative. Therefore, it will be used in this calculation.

Example: ($\pm$)10 = bi-directional error
+5 = first uni-directional error
-2 = second uni-directional error
Total Error = (+10+5) to (-10-2) = 15 to -12

_x_ Other: A total tolerance of ± 0.05 sec is used for the overall accuracy of the time delay characteristic. See Section 4.6 for more details.

6.0 Computations/Analysis

6.1 Relay voltage Accuracy Equations

6.1.1 Uncertainty Parameter Common Base Conversion

In accordance with TI-28 (Reference 6), the Square Root Sum of Squares (SRSS) method is applied to determine a total accuracy value for the 60Q relays. As some values are expressed as a percent value of a setpoint, the uncertainty values must be converted to a common base to allow the calculation to be performed.

For the purpose of these calculations, Setpoint = x V.

$TN_E/T_{ae} = \pm 2.37\%$ of setpoint

$= \pm 0.0237x\ V$

$PSE_e = \pm 10.00\%$ of setpoint

$= \pm 0.10x\ V$

6.1.2 Normal Measurable Accuracy (A_{nf} or As-Found Tolerance)

In accordance with Reference 6, A_{nf} is calculated as follows:

$$A_{nf} = \pm\sqrt{R_e^2 + ICT_e^2 + OCT_e^2 + ICR_e^2 + OCR_e^2 + D_e^2 + Ab^2 + TN_e^2 + PSE_e^2 + RND_e^2}$$

$$= \pm\sqrt{0.01^2 + 0.1^2 + 0^2 + 0^2 + 0^2 + 0.05^2 + 0.1^2 + (0.0237x)^2 + (0.10x)^2 + 0^2}$$

$$= \pm\sqrt{0.0226 + 0.010562x^2}$$

Normal Accuracy, $A_n = A_{nf} = \quad = \pm\sqrt{0.0226 + 0.010562x^2}$

Accident Accuracy $A_a = \pm\sqrt{R_e^2 + ICT_e^2 + OCT_e^2 + ICR_e^2 + OCR_e^2 + D_e^2 + Ab^2 + TN_e^2 + PSE_e^2 + RAD_e^2}$

$$= \pm\sqrt{0.01^2 + 0.1^2 + 0^2 + 0^2 + 0^2 + 0.05^2 + 0.1^2 + (0.0237x)^2 + (0.10x)^2 + 0^2}$$

$$= \pm\sqrt{0.0226 + 0.010562x^2}$$

Post Seismic Accuracy $A_s = \pm\sqrt{A_n^2 + S_e^2} = \pm\sqrt{0.0226 + 0.010562x^2 + 0}$

Design Basis Even Accuracy A_{dbe} is the greater of A_a or A_s

$$A_{dbe} = A_s = A_s = \pm\sqrt{0.0226 + 0.010562x^2}$$

6.2 Voltage Setpoint and Accuracy Calculations

In accordance with Reference 5, the pick-up settings for all three relays should be as close as possible to the upper limits, accounting for associated errors and tolerances. As such, setpoint are calculated as follows.

Alarm – Voltage Setpoint

$$A_{nf} = \pm\sqrt{0.0226 + 0.010562x^2}$$

As the Alarm upper limit for the voltage setpoint is 1.5 V, the following equation is used to determine the setpoint.

$$1.5\ V = x \pm \sqrt{0.0226 + 0.010562x^2}$$

$$1.5V - x = \pm\sqrt{0.0226 + 0.010562x^2}$$

$$(1.5V - x)^2 = \left(\pm\sqrt{0.0226 + 0.010562x^2}\right)^2$$

$$2.25V - 3.0x + x^2 = 0.0226 + 0.01056x^2$$

$$0.9894x^2 - 3.0x + 2.2274 = 0$$

To solve, use the Quadratic Equation:

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Where:

$a = 0.9894,\qquad b = -3,\qquad c = 2.2274$

Which results in:

$$x = \frac{-(-3) \pm \sqrt{(-3)^2 - 4(0.9894)(2.2274)}}{2(0.9894)}$$

$$x = \frac{3 \pm \sqrt{9 - 8.8152}}{1.9788}$$

$$x = \frac{3 \pm \sqrt{0.1848}}{1.9788}$$

$$x = \frac{3 \pm 0.4299}{1.9788}$$

$$x = 1.5161 \pm 0.2173$$

Solving for x results in a setpoint of

$$x = 1.73\ V, 1.30\ V$$

This results in a setpoint of 1.30 V. With the established setpoint of 1.30 V, the accuracy is calculated to be $\pm 0.20\ V$.

LO – Voltage Setpoint

$$A_{nf} = \pm\sqrt{0.0226 + 0.010562x^2}$$

As the Alarm upper limit for the voltage setpoint is 3.3 V, the following equation is used to determine the setpoint.

$$3.3\ V = x + \pm\sqrt{0.0226 + 0.010562x^2}$$

Solving for X as demonstrated above results in a setpoint of

$$x = 3.71\ V, 2.96\ V$$

This results in a setpoint of 2.96 V. With the established setpoint of 2.96 V, the accuracy is calculated to be $\pm\ 0.34\ V$.

HI – Voltage Setpoint

$$A_{nf} = \pm\sqrt{0.0226 + 0.010562x^2}$$

As the Alarm upper limit for the voltage setpoint is 20.00 V, the following equation is used to determine the setpoint.

$$20\ V = x + \pm\sqrt{0.0226 + 0.010562x^2}$$

Solving for X as demonstrated above results in a setpoint of

$$x = 22.30\ V, 18.13\ V$$

This results in a setpoint of 18.13 V. With the established setpoint of 18.13 V, the accuracy is calculated to be $\pm\ 1.87\ V$.

6.3 Time Delay Accuracy Equations

Per Sections 4.6 and 5.3, a $\pm 0.05s$ tolerance is used as the overall accuracy. Therefore;

$$A_{nf} = A_n = A_a = A_s = A_{dbe} = \pm 0.05s$$

Reference 5 states that to avoid nuisance actuations the time delay for the Alarm, Lo and HI trip relays should be as close as possible to the upper limits, accounting of associated errors and tolerances. Also, the time delay setpoints for the LO and HI trip relays must not overlap with the Alarm relay time delay setpoint accounting for associated errors and tolerances.

Allowable values as determined in reference 5 are used with determined accuracy to determine time delay setpoints as calculated below.

Alarm – Time Delay Setpoint

Setpoint = upper limit – A_{nf}

= 3s – 0.05s

= 2.95s

LO – Time Delay Setpoint

Setpoint = upper limit – A_{nf}

= 10s – 0.05s

= 9.95s

HI – Time Delay Setpoint

Setpoint = upper limit – A_{nf}

= 3s – 0.05s

= 3.95s

7.0 Summary of Results

7.1 Evaluation of Voltage Setpoints

Alarm – Voltage Setpoint

$$A_n = A_{nf} = A_s = A_a = \pm 0.20\,V$$

$$A_v = 0.9\,V - 1.5\,V$$

$$A_b = \pm 0.1\,V$$

Upper AL	**1.50 V**
$SP + A_{as}$	1.50 V
$SP + A_a$	1.50 V
$SP + A_n$	1.50V
SP	**1.30 V**
$SP - A_n$	1.10 V
$SP - A_a$	1.10 V
$SP - A_{as}$	1.10 V
Lower AL	**0.90 V**

LO – Voltage Setpoint

$$A_n = A_{nf} = A_s = A_a = \pm 0.34\,V$$

$$A_v = 1.5\,V - 3.3\,V$$

$$A_b = \pm 0.1\,V$$

Upper AL	**3.30 V**
$SP + A_{as}$	3.30 V
$SP + A_a$	3.30 V
$SP + A_n$	3.30 V
SP	**2.96 V**
$SP - A_n$	2.62 V
$SP - A_a$	2.62 V
$SP - A_{as}$	2.62V
Lower AL	**1.50 V**

HI – Voltage Setpoint

$A_n = A_{nf} = A_s = A_a = \pm 1.87\, V$

$A_v = 3.3\, V - 20\, V$

$A_b = \pm 0.1\, V$

Upper AL	**20.00 V**
$SP + A_{as}$	20.00 V
$SP + A_a$	20.00 V
$SP + A_n$	20.00 V
SP	**18.13 V**
$SP - A_n$	16.26 V
$SP - A_a$	16.26 V
$SP - A_{as}$	16.26 V
Lower AL	**3.30 V**

7.2 Evaluation of Time Delay Setpoints

Alarm – Time Delay Setpoint

$A_n = A_{nf} = A_s = A_a = \pm 0.05\ s$

$A_v = 0.3\ s - 3s$

$A_b = \pm 0.05\ s$

Upper AL	**3.0 s**
$SP + A_{as}$	3.00 s
$SP + A_a$	3.00 s
$SP + A_n$	3.00 s
SP	**2.95 s**
$SP - A_n$	2.90 s
$SP - A_a$	2.90 s
$SP - A_{as}$	2.90 s
Lower AL	**0.30 s**

LO – Time Delay Setpoint

$A_n = A_{nf} = A_s = A_a = \pm 0.05\ s$

$A_v = 4\ s - 10\ s$

$A_b = \pm 0.05\ s$

Upper AL	**10.00 s**
$SP + A_{as}$	10.00 s
$SP + A_a$	10.00 s
$SP + A_n$	10.00 s
SP	**9.95 s**
$SP - A_n$	9.90 s
$SP - A_a$	9.90 s
$SP - A_{as}$	9.90 s
Lower AL	**4.00 s**

HI – Time Delay Setpoint

$A_n = A_{nf} = A_s = A_a = \pm 0.05\ s$

$A_v = 3\ s - 4\ s$

$A_b = \pm 0.05\ V$

Upper AL	**4.00 s**
$SP + A_{as}$	4.00 s
$SP + A_a$	4.00 s
$SP + A_n$	4.00 s
SP	**3.95 s**
$SP - A_n$	3.90 s
$SP - A_a$	3.90 s
$SP - A_{as}$	3.90 s
Lower AL	**3.00 s**

	Voltage Setpoint	Time Delay Setpoint
“alarm”	1.30 V	2.95s
“low”	2.96 V	9.95s
“high”	18.13 V	3.95s

7.3 As-Found/As-Left Values

Alarm Relay

As-Found:

$Upper = SP + A_{nf}$

Upper = 1.30 V + 0.20 V

Upper = 1.50 V

$Lower = SP - A_{nf}$

Lower = 1.30 V - 0.20 V

Lower = 0.90 V

As-Left:

$Upper = SP + A_b$

Upper = 1.30 V + 0.10 V

Upper = 1.40 V

$Lower = SP - A_b$

Lower = 1.30 V - 0.10 V

Lower = 1.20 V

LO Relay

As-Found:

$Upper = SP + A_{nf}$

Upper = 2.96 V + 0.30 V

Upper = 3.26 V

$Lower = SP - A_{nf}$

Lower = 2.96 V - 0.30 V

Lower = 2.66 V

As-Left:

$Upper = SP + A_b$

Upper = 2.96 V + 0.10 V

Upper = 3.06 V

$Lower = SP - A_b$

Lower = 2.96 V - 0.10 V

Lower = 2.86 V

HI Relay

As-Found:

$Upper = SP + A_{nf}$

Upper = 18.13 V + 1.87 V

Upper = 20.00 V

$Lower = SP - A_{nf}$

Lower = 18.13 V – 1.87 V

Lower = 16.26 V

As-Left:

$Upper = SP + A_b$

Upper = 18.13 V + 0.1 V

Upper = 18.23 V

$Lower = SP - A_b$

Lower = 18.13 V – 0.1 V

Lower = 18.03 V

Time Delay – Alarm Relay

As-Found:

$Upper = SP + A_{nf}$

Upper = 2.95 s + 0.05 s

Upper = 3.00 s

$Lower = SP - A_{nf}$

Lower = 2.95 s – 0.05 s

Lower = 2.90 s

As-Left:

$Upper = SP + A_b$

Upper = 2.95 s + 0.05 s

Upper = 3.00 s

$Lower = SP - A_b$

Lower = 2.95 s – 0.05 s

Lower = 2.90 s

Time Delay – Lo Relay

As-Found:

$Upper = SP + A_{nf}$

Upper = 9.95 s + 0.05 s

Upper = 10.00 s

$Lower = SP - A_{nf}$

Lower = 9.95 s – 0.05 s

Lower = 9.90 s

As-Left:

$Upper = SP + A_{b}$

Upper = 9.95 s + 0.05 s

Upper = 10.00 s

$Lower = SP - A_{b}$

Lower = 9.95 s – 0.05 s

Lower = 9.90 s

Time Delay – HI Relay

As-Found:

$Upper = SP + A_{nf}$

Upper = 3.95 s + 0.05 s

Upper = 4.0 s

$Lower = SP - A_{nf}$

Lower = 3.95 s – 0.05 s

Lower = 3.90 s

As-Left:

$Upper = SP + A_{b}$

Upper = 3.95 s + 0.05 s

Upper = 4.00 s

$Lower = SP - A_{b}$

Lower = 3.95 s – 0.05 s

Lower = 3.90 s

8.0 Conclusions

The established setpoints from Section 6.0 and 7.0 and expected relay inaccuracies have been evaluated in this calculation. As the analytical limits for all three “alarm”, “low”, and “high” 60Q relays are not exceeded, the established setpoints are deemed acceptable for the safety-related use of voltage unbalance detection.