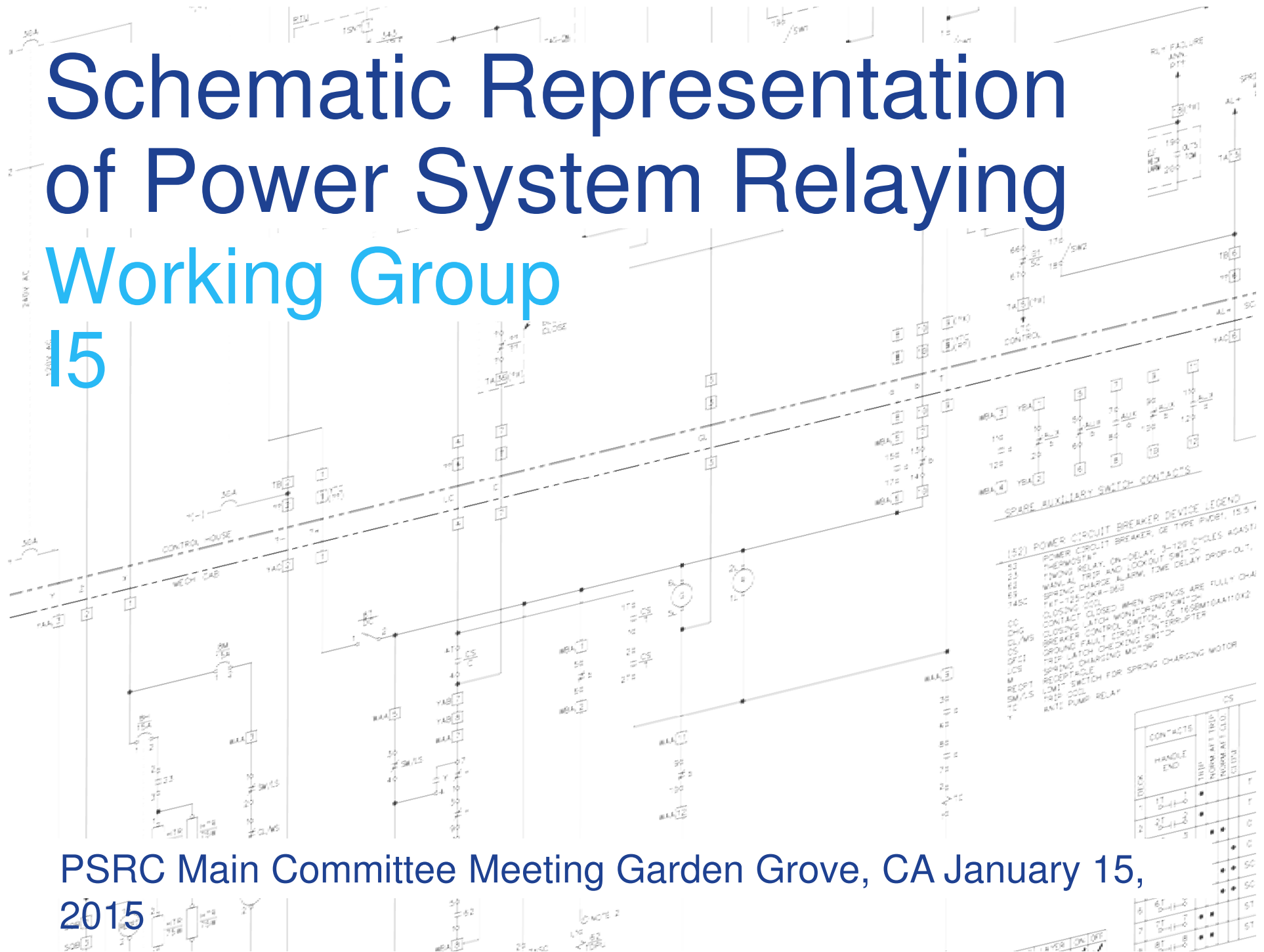


Schematic Representation of Power System Relaying

Working Group

15



PSRC Main Committee Meeting Garden Grove, CA January 15, 2015

PHILOSOPHY

Charles Sanders Peirce

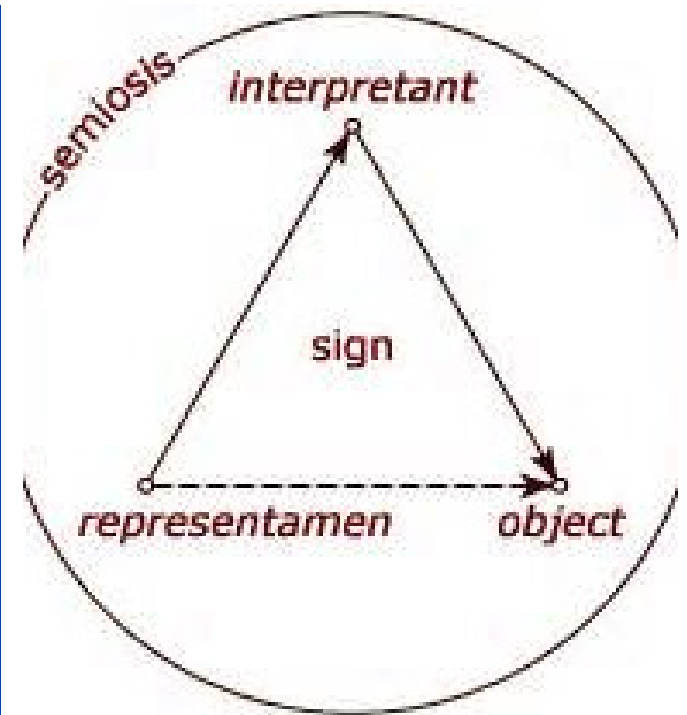
Triadic

Representamen-interpretant-object

Sign vehicle-sense-referent

Symbol-thought-object

Office-drawing-field



Semiotics
Ferdinand de
Saussure
dyadic



Working Group I5 Members

**Kevin Donahoe –
chair**

**Rich Young -
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John Appleyard

Hasnain Ashrafi

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Dac-Phuoc Bui

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Fuentes**

Larry Henriksen

Jack Jester

Jeff Long

Bruce Mackie

Dean Miller

Adi Mulawarman

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Jim Niemira

Craig Preuss

Tony Seegers

John Tengdin

Joe Uchiyama

Andre Uribe

Dolly Villasmil

Don Ware

Roger Whittaker

Karl Zimmerman



Why Write the Paper?

Things are changing at the source of schematics

Transformative technologies will redefine long-standing practices

Considerable investment in updating technologies, transmission assets and energy resources

What are Schematics?

A schematic is a diagram that represents the elements of a system using abstract, graphic symbols rather than realistic pictures.

Schematics communicate function.

Schematics omit details not relevant to the info it is intended to convey...

And may add unrealistic elements that aid comprehension.

What are the “Results” of Schematics?

Installation

Commissioning

Troubleshooting

Equipment Maintenance

Power System Operation

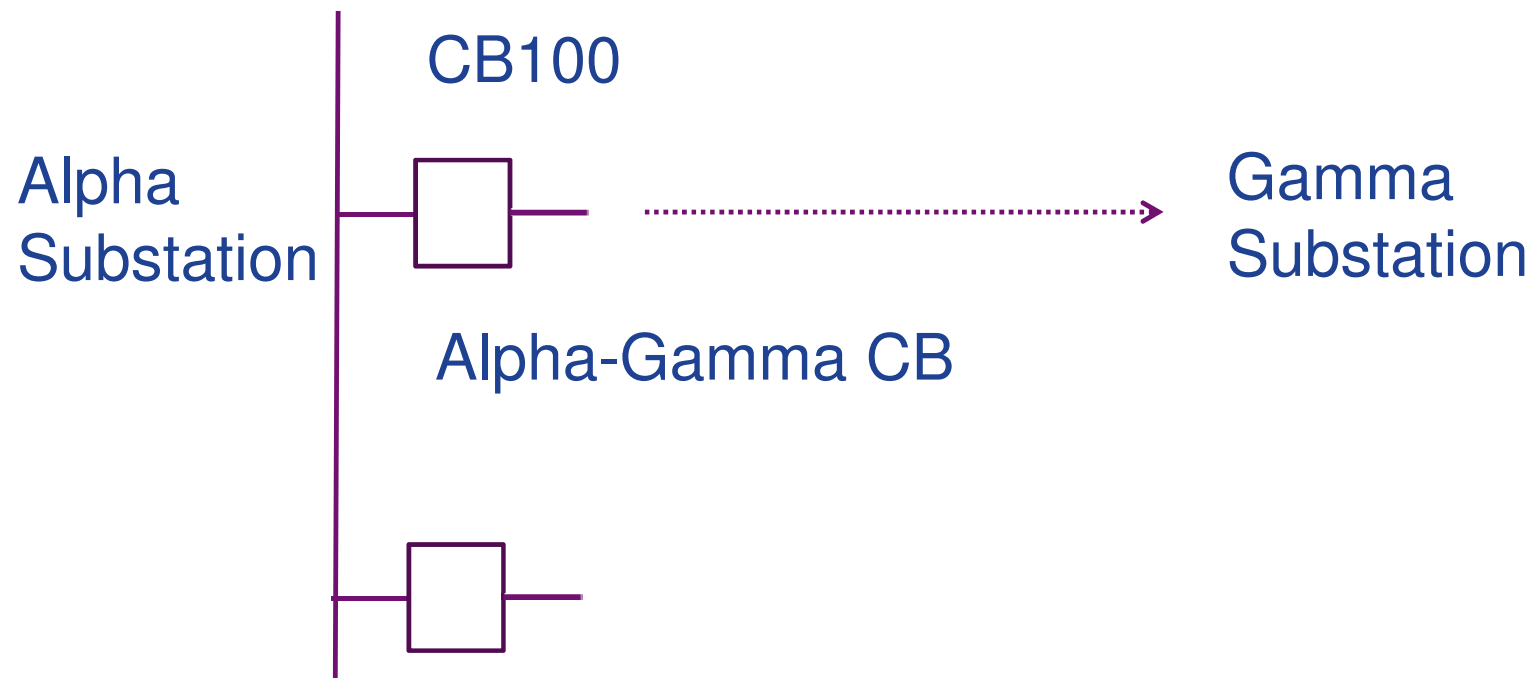
Legal Records

Estimating



Example of how a Schematic Addresses Different Functions

Operating and Maintenance



Hierarchy of Drawings

Hierarchy of detail between drawings

Single line diagram is the least detailed, uses basic symbols

AC & DC schematics at the next level of detail, necessary connection and function details

Remaining drawings greatest level of detail. Maintain the connection details from schematics & add physical details. Indicates precise location & connections.

Types of Schematics

Protection Zone Diagram

Single-Line Diagram

AC Schematics

DC Schematics

Logic Diagram

Other Forms of Documentation

Wiring Diagram

Panel Layout Diagram

Communication Diagrams

Design Philosophy Documents

Commissioning Documentation

Protection Zone Diagram

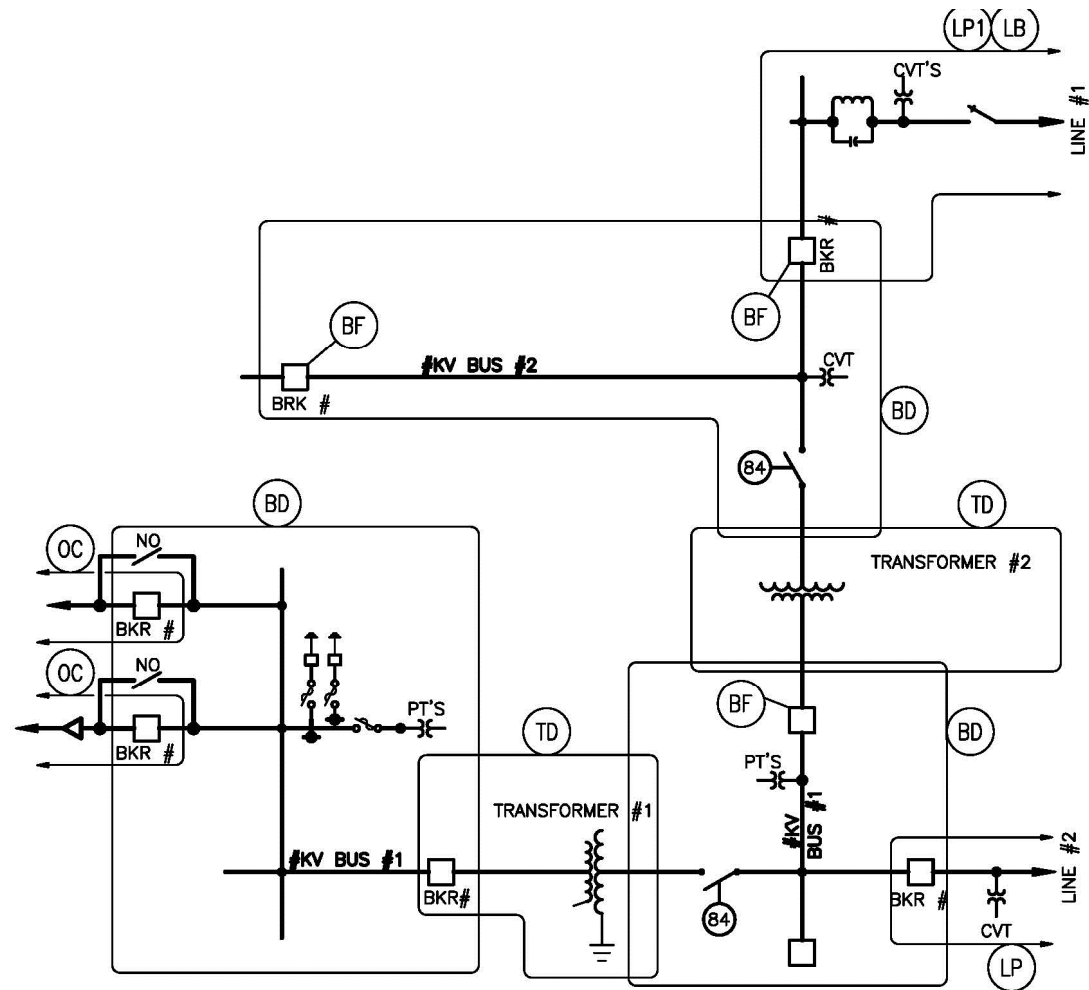
Labeled zones indicate type and area of protection

Easily identify functional protection scheme

Any fault or “X” should land inside a protected area

Protected areas should always overlap to provide full coverage

Protection Zone Diagram



Single Line Diagram

The three phase equipment and connections are shown with a single line

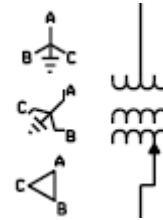
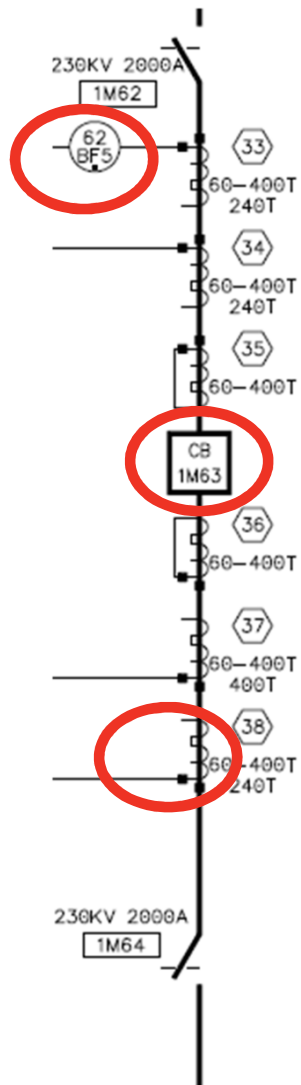
Highest level view of electrical and physical design of substation

Details primarily communicate function (i.e. polarity of CTs, transformer Wye or Delta winding, etc.)

Shows primary substation equipment as well as current & voltage transformers & their secondaries

Dashed lines with arrows indicate action commands which can be sent to equipment

Single Line Diagram Details



Single Line Diagrams & Process Bus

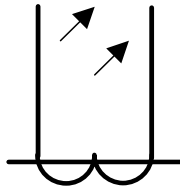
Process bus uses merging units (MU)

MU collects voltage, current and digital inputs and converts to IEC61850 protocol

The fiber connection alone between the MU and IEDs does not indicate what data is being used

The protective function the IED is performing will be less obvious since it isn't clear what input it is getting from the MU

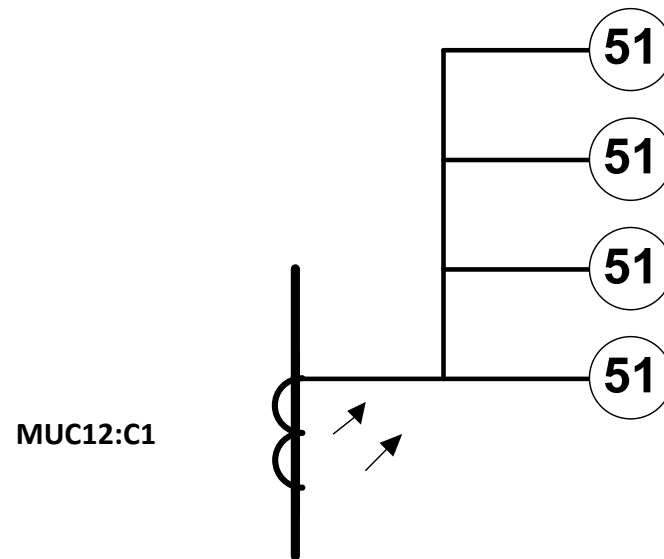
Theoretical Example



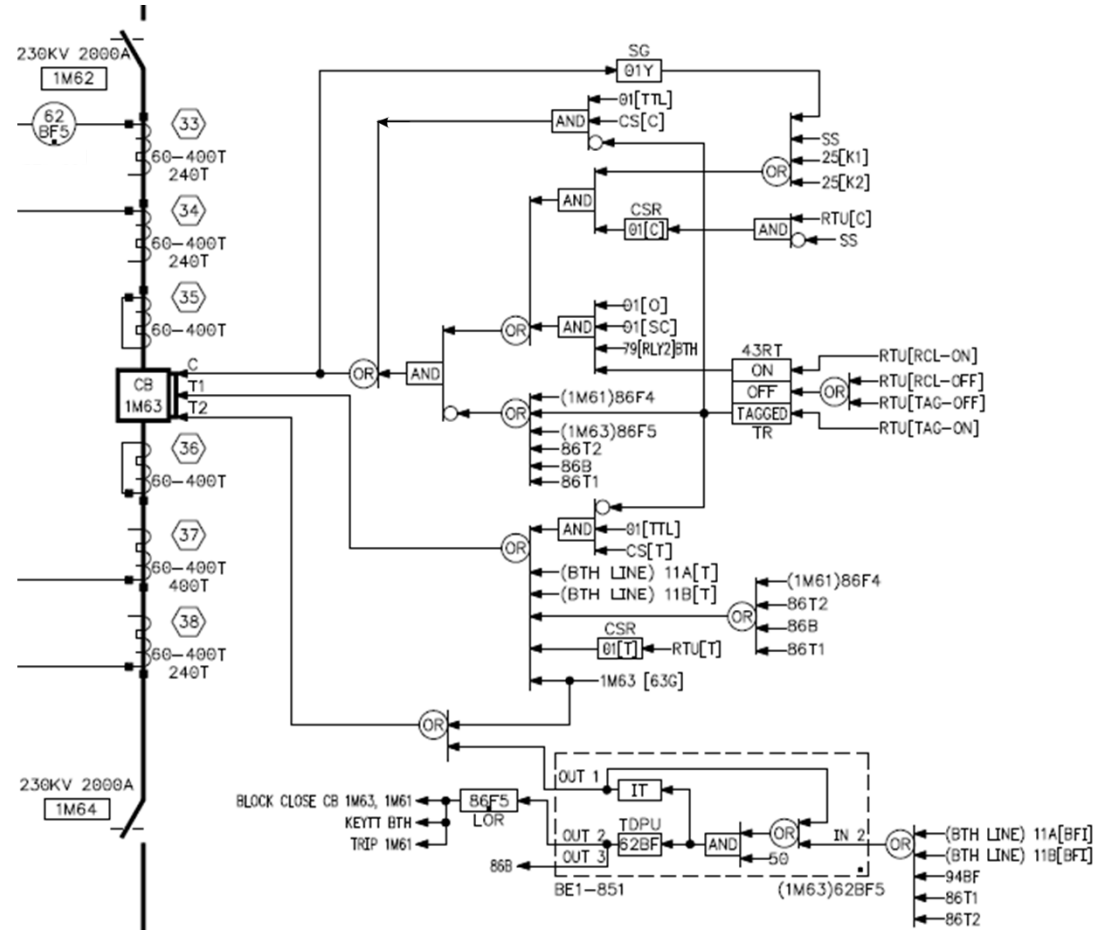
Current data from merging unit.



Voltage data from merging unit.



SLD with explicit logic



AC Schematics (Three-Line Diagrams)

Shows all three phases of primary system

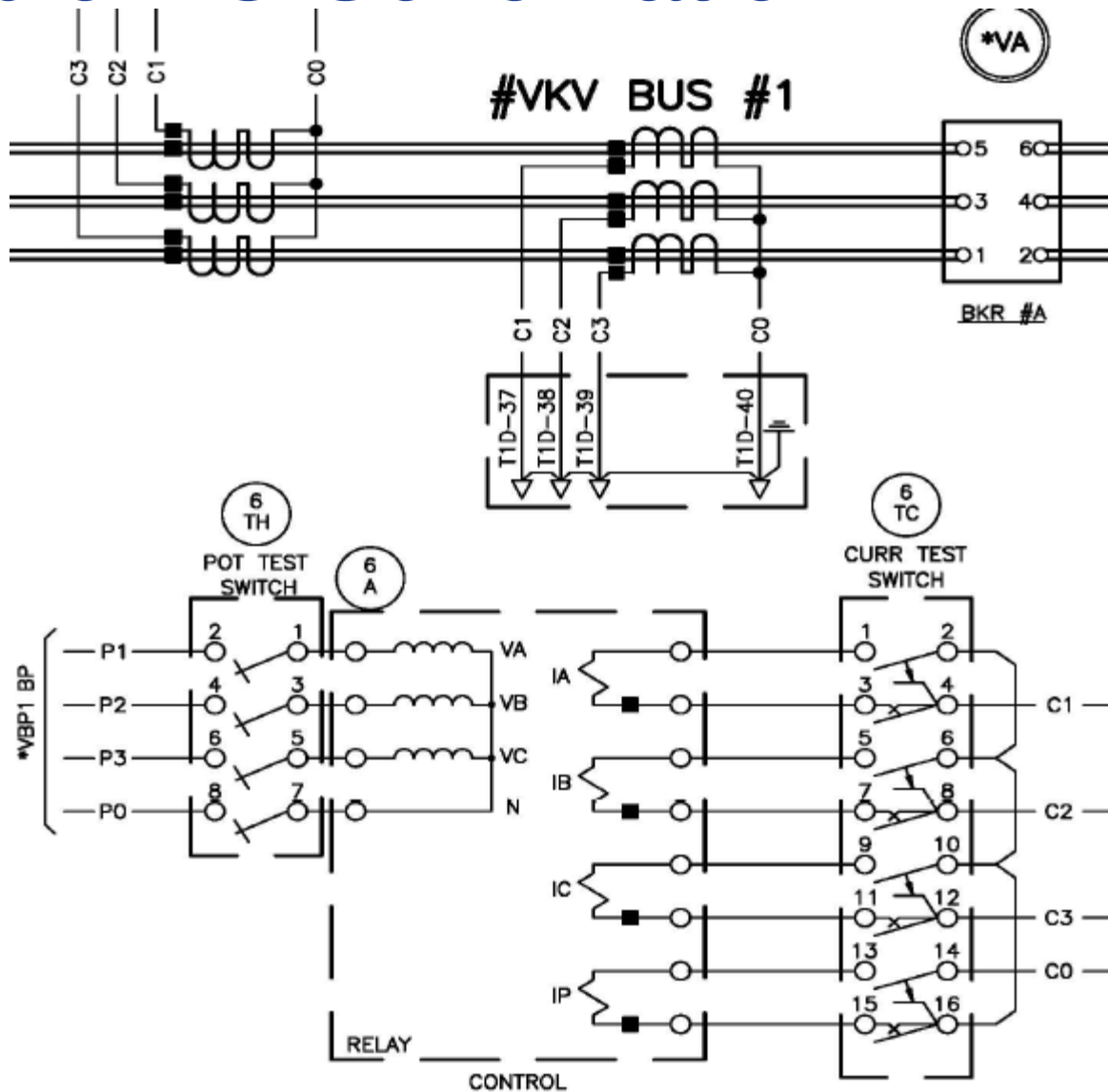
All significant equipment shown

Includes equipment thermal ratings, circuit breakers in amperes, and transformers in MVA

Also include VTs, PTs, and CTs, as well as protective relays and meters with their respective wiring

Test switch details

Example AC Schematic



DC Schematics

DC typically depict the protection and control functions of substation equipment

Sometimes those control functions are supplied by AC

Typically, DC source shown on left with initiating contacts located above operating elements

Many utilities have developed their own standards regarding symbology

Nuances DC Schematic

- Example: Difference between black triangles representing transitions verses triangles representing diodes

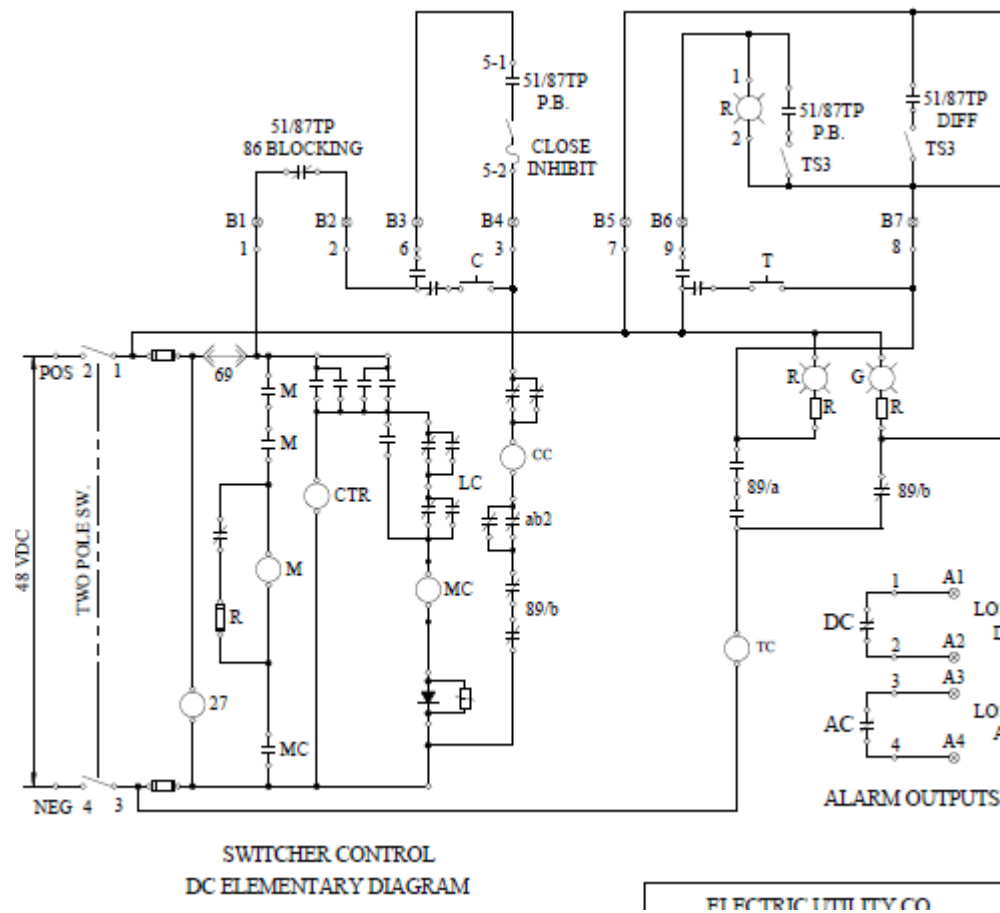
With widespread use of IEDs, it is advantageous to use DC schematics to show what functions are being used and which are available on each microprocessor relay

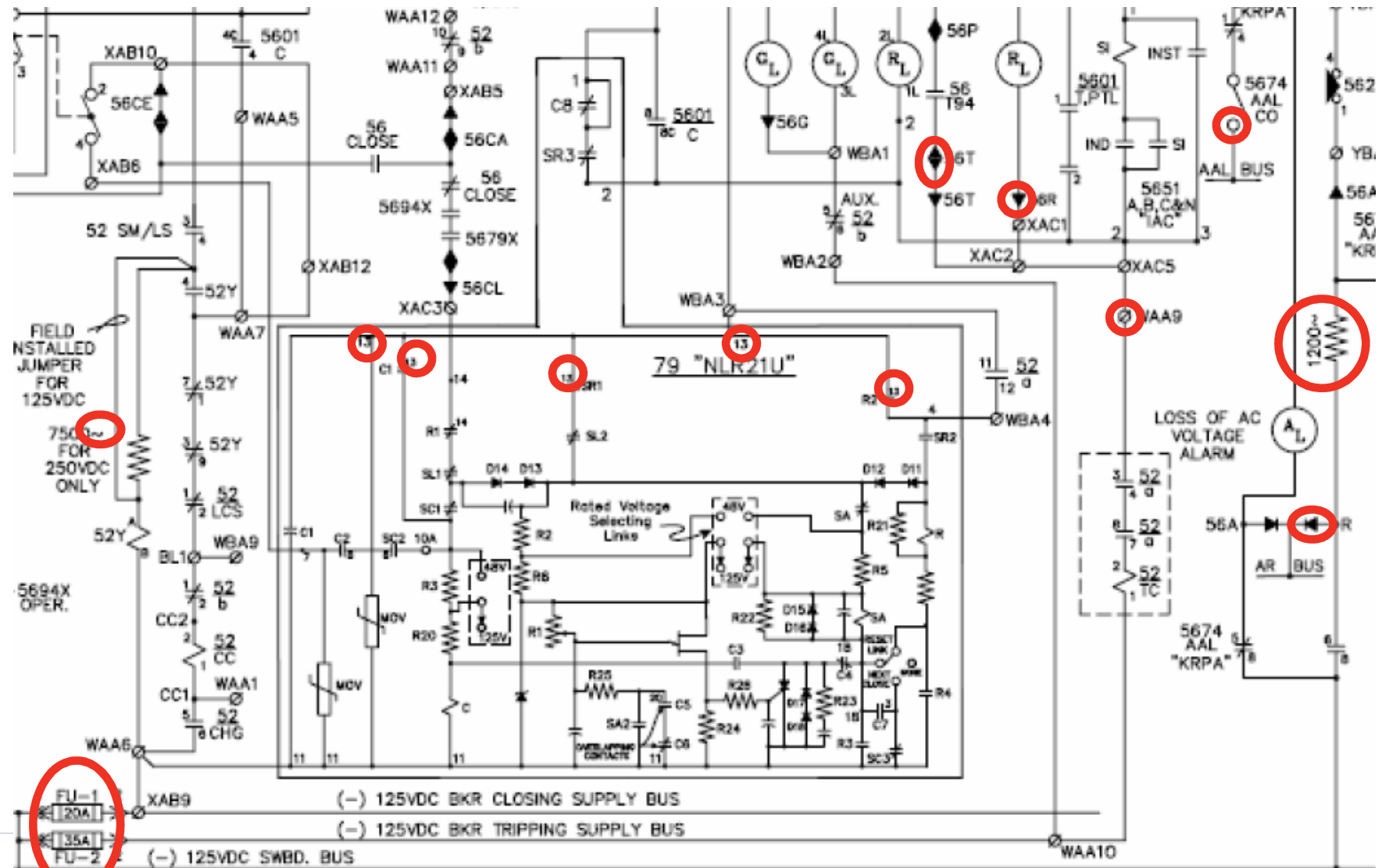
Nuances DC Schematic

- Example: Difference between black triangles representing transitions verses triangles representing diodes

With widespread use of IEDs, it is advantageous to use DC schematics to show what functions are being used and which are available on each microprocessor relay

DC Schematic Detail

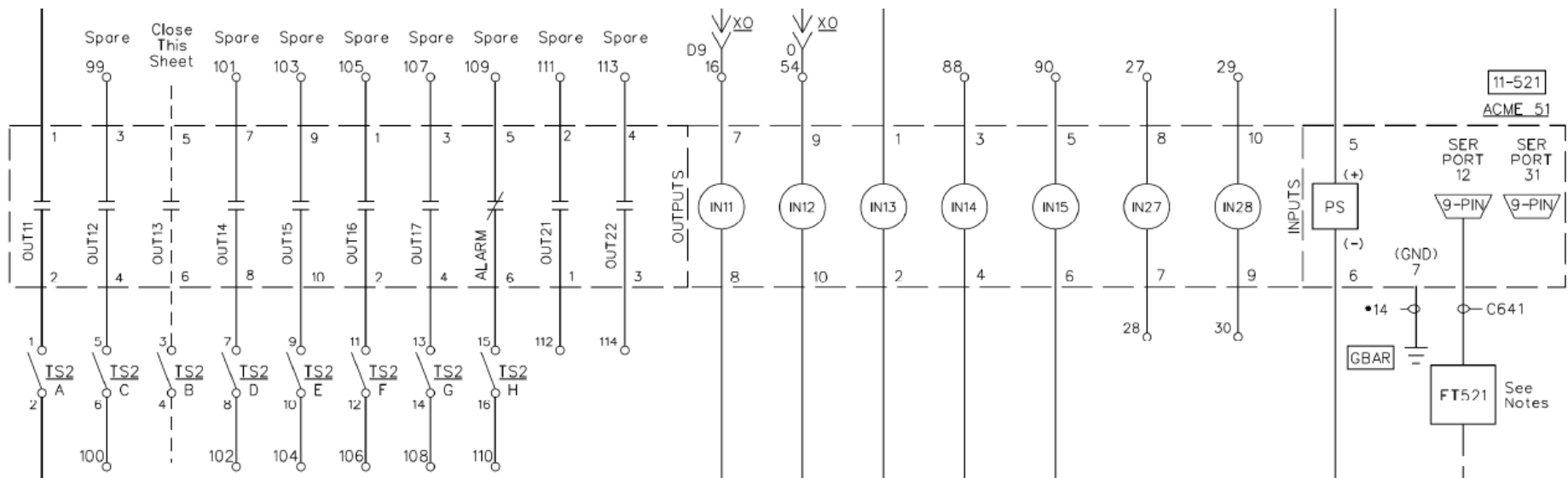




Alternatives to Show Available Microprocessor Relay Resources

11T3
ACME 51

Connections	Name	Function
70—□—08	IN11	SW 23 Close Position
80—□—010	IN12	SW 23 Open Position
10—□—02	IN13	SW 23 Trip Call Monitor
30—□—04	IN14	Loss of Emergency Station Power
50—□—06	IN15	SW 23 Lockout, Urgent SFB Alarm
70—□—08	IN16	SW 23 Low SFB Pressure Alarm
50—□—06	IN21	
70—□—08	IN22	Transformer 3 Device Alarm
80—□—010	IN23	Transformer 3 Gas Alarm
10—□—02	IN24	Transformer 3 Moisture Alarm
30—□—04	IN25	
50—□—06	IN26	
70—□—08	IN27	
80—□—010	IN28	
10— —02	OUT11	Trip SW 123
30— —04	OUT12	Close SW 123
50— —06	OUT13	
70— —08	OUT14	
80— —010	OUT15	
10— —02	OUT16	
30— —04	OUT17	
50— —06	ALARM	



DC Schematics & Microprocessor Programming

Hardware only documentation

Software shown as part of the elementary diagram

Logic diagram on the elementary

DC Schematics & IEC61850 Station Bus

Eliminates most dedicated control wiring between relays

Typical DC schematic not enough

Point-to-point list or spreadsheet format

GOOSE MESSAGES OUT									
VERIFIED IN RECEIVING ARCH ONLY RELAY VERIFIED IN SOURCE RELAY QUICKSET									
INITIATING RELAY	dataset name	CCOUT##	ELEMENT	Test Switch	TEST SW	97 SWITCH	BKRMOD FUNCTION	COMMENTS	21P/ABC 50BFP- N / 79/9P999 V Relay-Type-A
									CI 21S/ABC N 50BFS/9P999 V Relay-Type-A
87T2P_Relay Type - C	GooseDSet2	A2.phsA.C	A AMPS					A AMPS ,	
87T2P_Relay Type - C	GooseDSet2	A2.phsB.C	B AMPS					B AMPS ,	
87T2P_Relay Type - C	GooseDSet2	A2.phsC.C	C AMPS					C AMPS ,	
87T2P_Relay Type - C	GooseDSet13	MsgQuality	Goose Message Quality					Goose Message Quality ,	CCIN111
87T2P_Relay Type - C	GooseDSet2	PhV.phsA.C	VOLTAGE					VOLTAGE ,	
87T2P_Relay Type - C	GooseDSet13	S1LT2	97T2P					S97T2P STATUS,	
87T2P_Relay Type - C	GooseDSet13	S3V1T	86T2	TS-A	S397T2F	BK	T	86T2P TRIP, BFI, RECL WAIT, BKR 5P	CCIN050

Logic Diagrams

Variety of types including

- Timing diagrams
- Boolean logic diagrams
- Karnaugh Map
- Structured Text
- Functional Description
- Flowcharts

Considerations for Logic Diagrams

How should logic be organized in drawing sets?

What reference system will be used connect logic with other drawings?

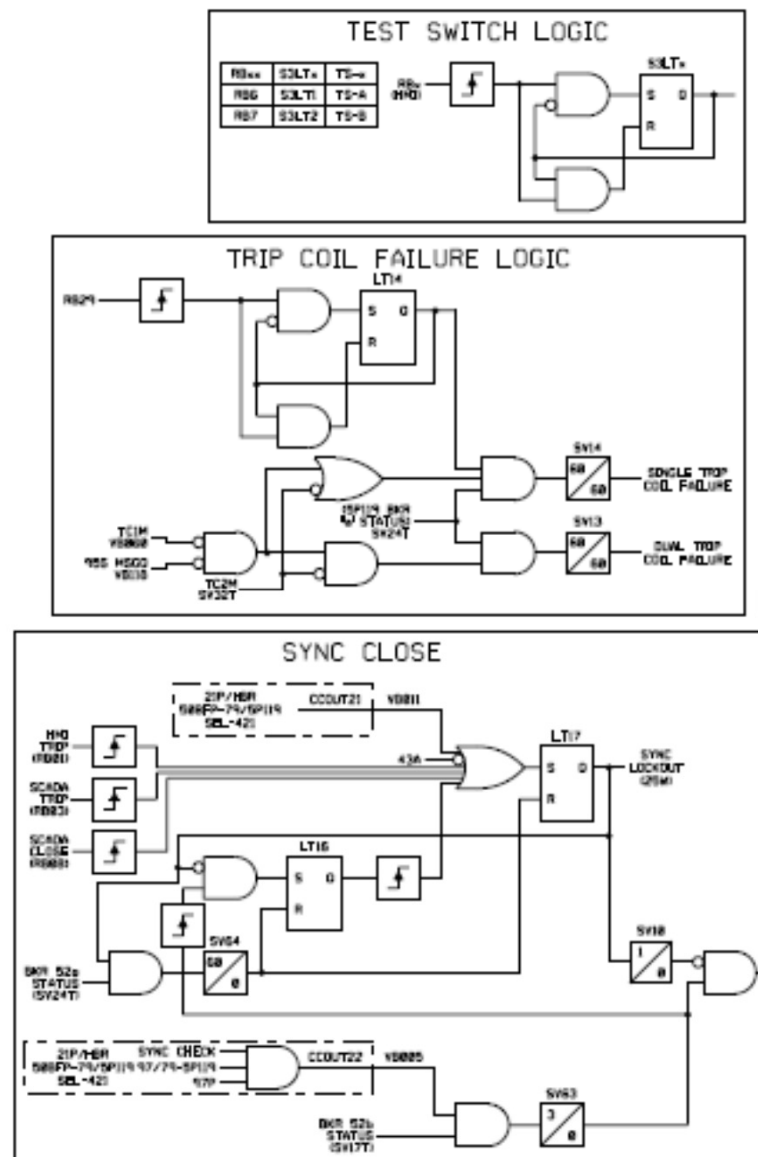
Will duplication of manufacturers' drawings create copyright issues?

How much of the included logic representations ought to be tested? How will it be verified?



What is the best way to create logic diagrams?

Example Logic Diagram



Other Forms of Documentation

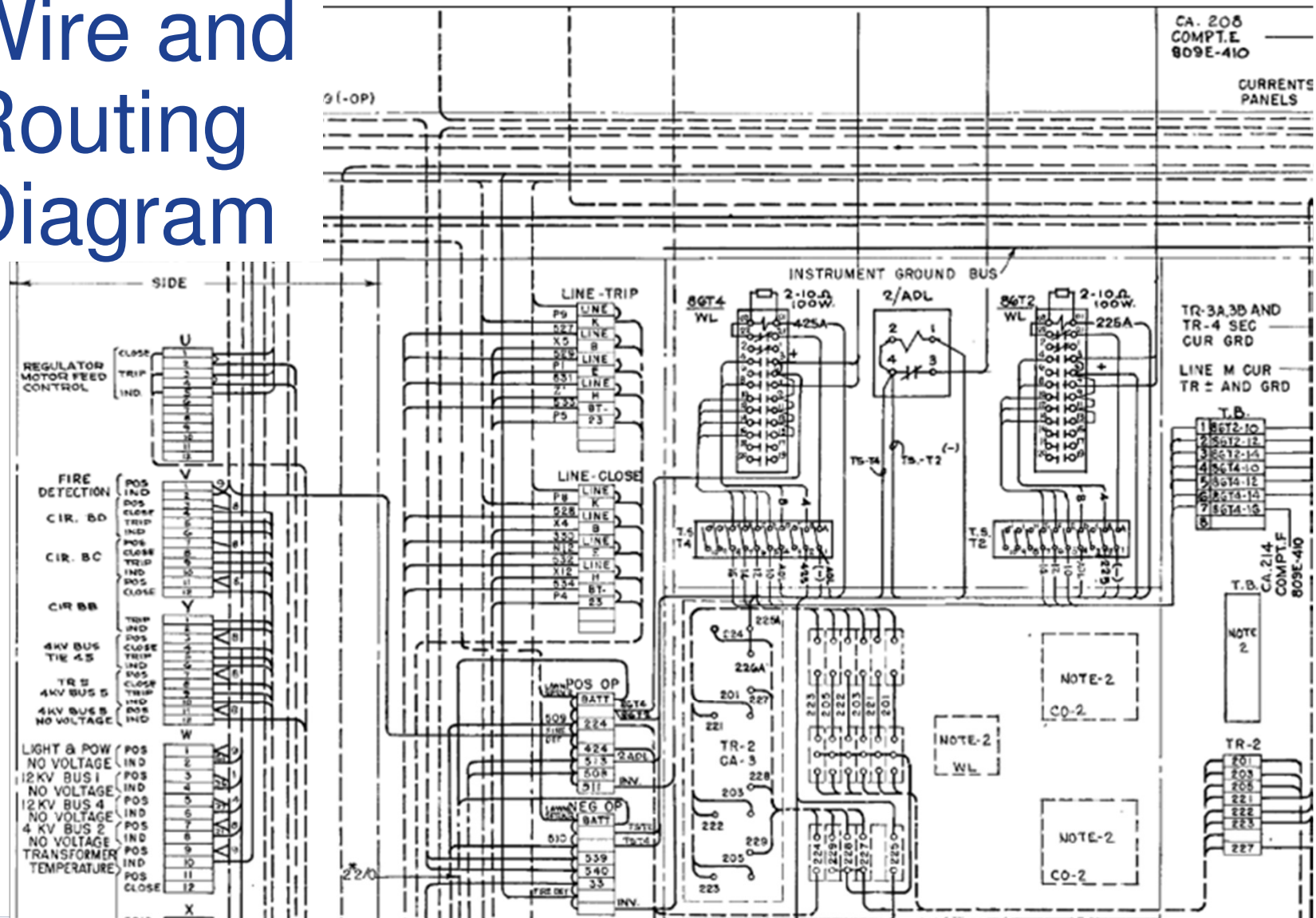
Wiring Diagrams and Rack Layout

Communication Diagrams

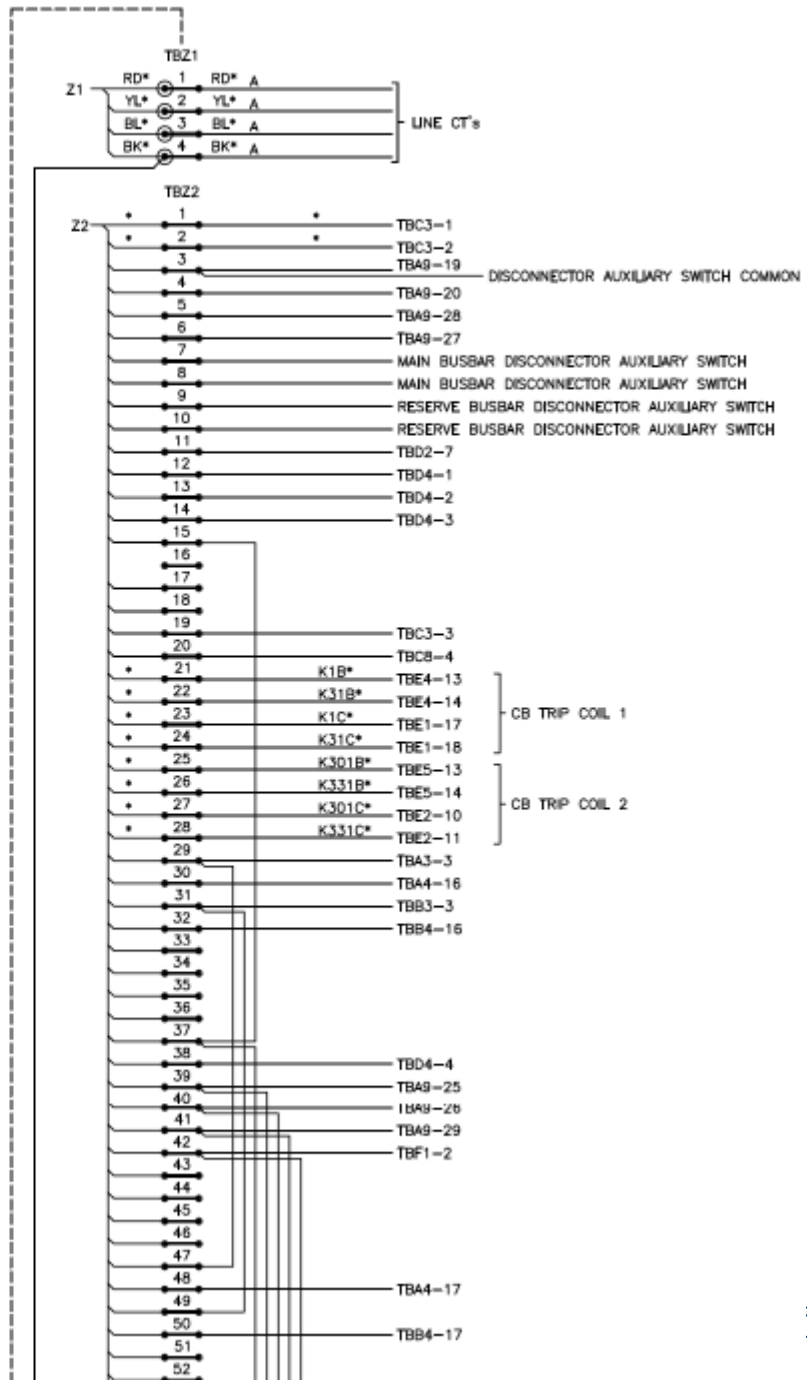
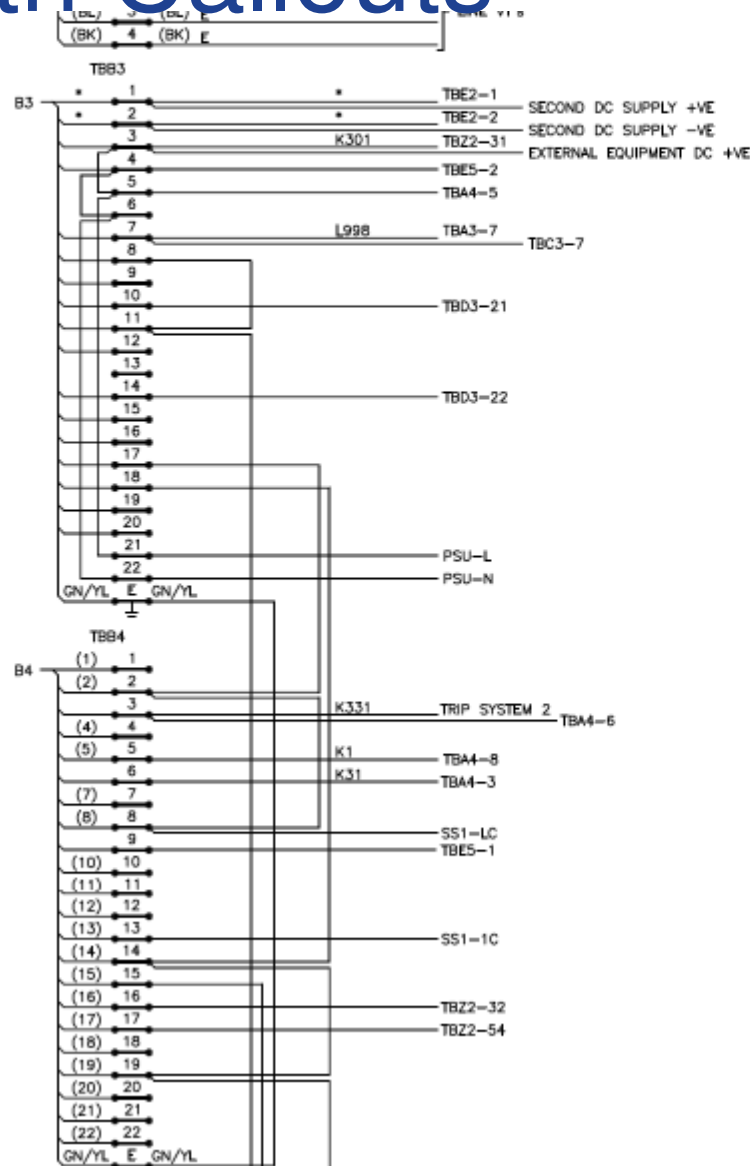
Design Philosophy

Commissioning Documentation

Wire and Routing Diagram



Wiring Diagram with Callouts



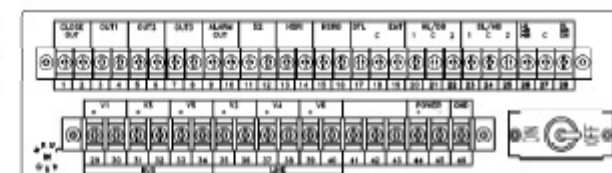
Wiring Diagram with Connection Tables

HYCB 332		A21
INTERNAL WIRING TABLE FOR 279-3		
TERMINAL	DESTINATION	WIRE LABEL
279-3-1	TS1-3-13	1/TS1-3-13
279-3-2	TS1-3-15	3/TS1-3-15
279-3-3	TS1-3-5	3/TS1-3-5
279-3-4	TS1-3-7	4/TS1-3-7
279-3-9	RM11	1/TS1-3-9
279-3-10	TS1-3-10	16/TS1-3-10
279-3-11	TS1-3-9	11/TS1-3-9
279-3-12	RE243MA-3-22	12/RE243MA-3-22
279-3-12	279-3-10	12/279-3-10

HYCB 332		A41
INTERNAL WIRING TABLE FOR 279-3		
TERMINAL	DESTINATION	WIRE LABEL
279-3-16	279-3-12	16/279-3-12
279-3-16	279-3-11	16/279-3-11
279-3-19	RC-11	1/RC-11
279-3-21	279-3-10	21/279-3-10
279-3-21	279-3-24	21/279-3-24
279-3-25	FC04-5-5	25/FC04-5-5
279-3-26	279-3-21	26/279-3-21
279-3-26	279-3-27	26/279-3-27
279-3-27	279-3-24	27/279-3-24

HYCB 332		A21
INTERNAL WIRING TABLE FOR 279-3		
TERMINAL	DESTINATION	WIRE LABEL
279-3-28	TS1-3-8	28/TS1-3-8
279-3-28	FC03-3-5	28/FC03-3-5
279-3-30	LG-2	30/GE-2
279-3-30	FC01-3-5	30/FC01-3-5
279-3-38	LE-12	38/LE-12
279-3-44	TS1-3-1	44/TS1-3-1
279-3-45	TS1-3-3	45/TS1-3-3
279-3-46	GN-5	46/GN-5

279-3



HYCB 332		A16
WIRING TABLE FOR TS1-3		
TERMINAL	DESTINATION	WIRE LABEL
TS1-3-1	279-3-44	1/279-3-44
TS1-3-2	TS2F-3-14	2/TS2F-3-14
TS1-3-2	FC243MA-3-11	2/FC243MA-3-11
TS1-3-3	279-3-45	3/279-3-45
TS1-3-4	RE243MA-3-24	4/RE243MA-3-24
TS1-3-5	279-3-3	5/279-3-3
TS1-3-5	FC03-3-3	5/FC03-3-3

HYCB 332		A18
WIRING TABLE FOR TS1-3		
TERMINAL	DESTINATION	WIRE LABEL
TS1-3-6	279-3-28	6/279-3-28
TS1-3-7	279-3-4	7/279-3-4
TS1-3-8	TS2F-3-10	8/TS2F-3-10
TS1-3-8	FC01-3-8	8/FC01-3-8
TS1-3-9	279-3-11	9/279-3-11
TS1-3-10	RF-2	10/RF-2
TS1-3-13	279-3-1	13/279-3-1

HYCB 332		A18
WIRING TABLE FOR TS1-3		
TERMINAL	DESTINATION	WIRE LABEL
TS1-3-14	RS-8	14/RS-8
TS1-3-15	279-3-2	15/279-3-2
TS1-3-16	FC01-3-3	16/FC01-3-3
TS1-3-19	279-3-10	19/279-3-10
TS1-3-20	RM-3	20/RM-3
TS1-3-20	TS2F-3-20	20/TS2F-3-20

TS1-3



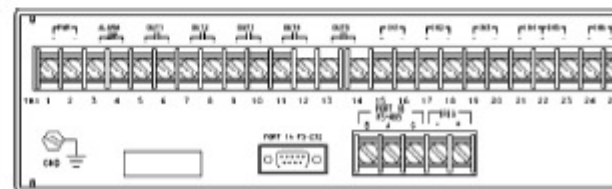
HYCB 332		A15
INTERNAL WIRING TABLE FOR 250/252BF-3		
TERMINAL	DESTINATION	WIRE LABEL
250/252BF-1-1	TS2F-3-1	1/TS2F-3-1
250/252BF-1-2	TS2F-3-5	2/TS2F-3-5
250/252BF-1-3	RM-12	3/ARM-12
250/252BF-1-4	TS2F-3-19	4/TS2F-3-19
250/252BF-1-5	TS2F-3-5	5/TS2F-3-5
250/252BF-1-6	TS2F-3-7	6/TS2F-3-7
250/252BF-1-11	TS2F-3-9	11/TS2F-3-9

HYCB 332		A15
INTERNAL WIRING TABLE FOR 250/252BF-3		
TERMINAL	DESTINATION	WIRE LABEL
250/252BF-1-12	TS2F-3-11	12/TS2F-3-11
250/252BF-1-13	TS1-3-13	13/TS1-3-13
250/252BF-1-14	TS2F-3-15	14/TS2F-3-15
250/252BF-1-15	RF-4	15/RF-4
250/252BF-1-16	TS2F-3-17	16/TS2F-3-17
250/252BF-1-17	TS2F-3-17	17/TS2F-3-17

HYCB 332		A15
INTERNAL WIRING TABLE FOR 250/252BF-3		
TERMINAL	DESTINATION	WIRE LABEL
250/252BF-1-18	RC-11	18/RC-11
250/252BF-1-19	250/252BF-1-15	19/250/252BF-1-15
250/252BF-1-20	TS2F-3-4	20/TS2F-3-4
250/252BF-2-1	TS1F-3-3	21/TS1F-3-3
250/252BF-2-2	TS1F-3-3	22/TS1F-3-3
250/252BF-2-3	TS1F-3-3	23/TS1F-3-3
250/252BF-2-4	TS1F-3-7	24/TS1F-3-7

HYCB 332		A15
INTERNAL WIRING TABLE FOR 250/252BF-3		
TERMINAL	DESTINATION	WIRE LABEL
250/252BF-2-5	TS1F-3-15	25/TS1F-3-15
250/252BF-2-6	TS1F-3-11	26/TS1F-3-11
250/252BF-2-7	TS1F-3-11	27/TS1F-3-11
250/252BF-2-8	TS1F-3-15	28/TS1F-3-15
250/252BF-2-9	UNDEF-9	29/UNDEF-9

250/252BF-3



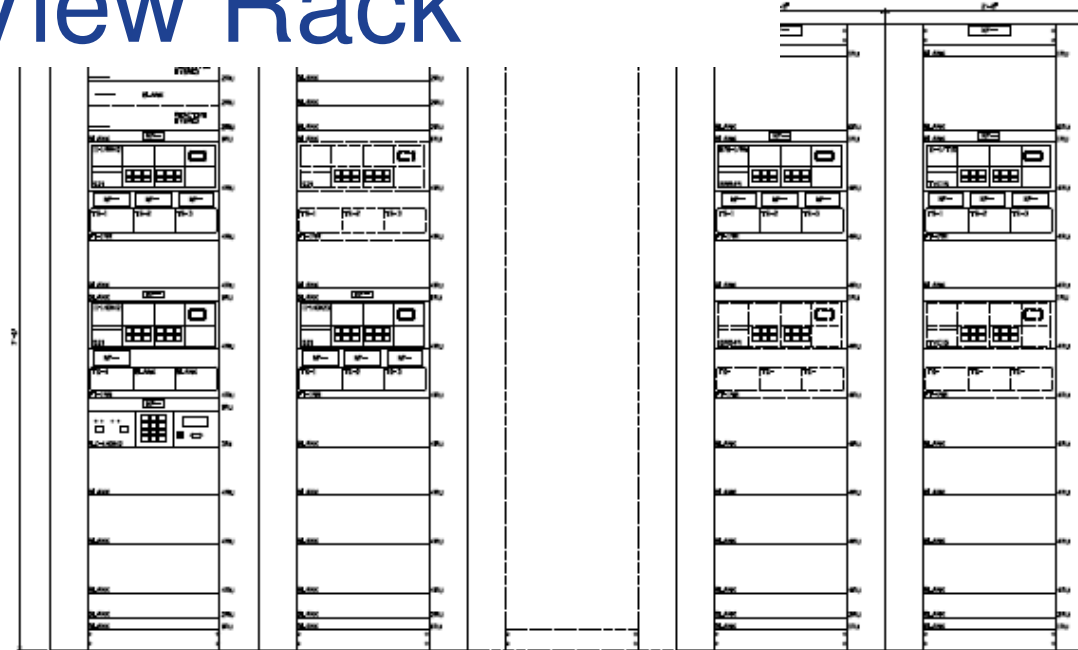
HYCB 332		A120
WIRING TABLE FOR TS2F-3		

HYCB 332		A120
WIRING TABLE FOR TS2F-3		

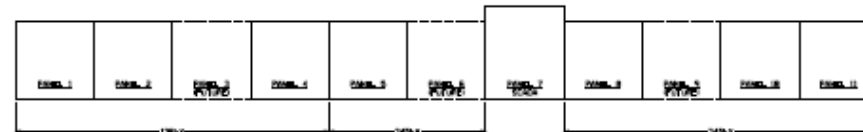
HYCB 332		A120
WIRING TABLE FOR TS1F-3		

HYCB 332		A120
WIRING TABLE FOR TS1F-3		

Front View Rack Layout



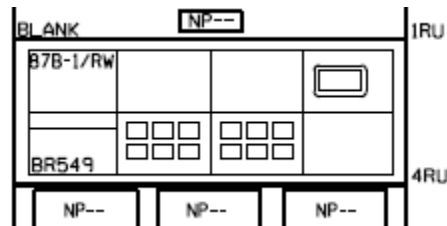
PANEL 1 BLACKBURN LOW VOLTAGE BUS
PANEL 2 LINC RING BUS
PANEL 3 FUTURE LINC RING & SHED
PANEL 4 FUTURE BUS
PANEL 5 345/138KV FID



345 & 138KV SYSTEM 1 PANEL LINEUP
N/A

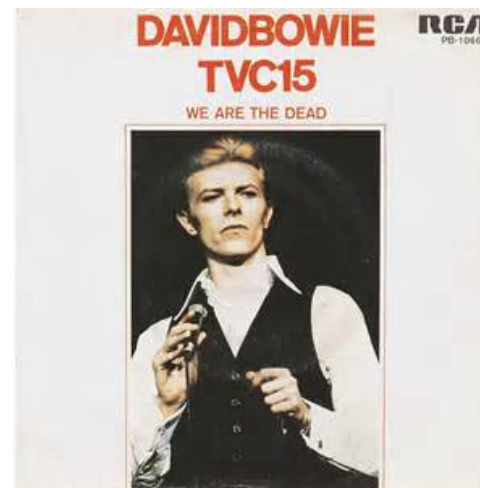
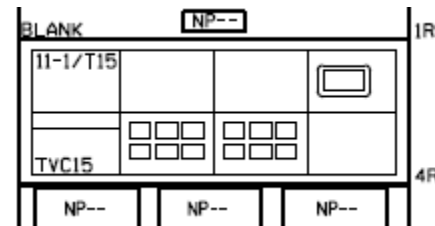
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Front View Rack Layout Easter Eggs



PANEL 1

BLACKBURN
LINE RM42



PANEL 2

LINE RM23 (FUTURE)
FORTESCUE

Front View Rack Layout Easter

DR. O.U. TRIPDIT	DATE 05/26/06	PSRC		345 & 138kV SYSTEM 1 RACKS 1, 2, 3, 4 & 5 FRONT VIEWS			
CK. PAUL DeTRIPS	05/26/06			ELMORE		SUBSTATION	
SECTION HEAD	/ /			SCALE	1 1/2"=1'-0"	DRAWING NO.	SHEET
DIVISION HEAD	/ /			JOB	WO 20120	NCC-1701	108
DEPARTMENT HEAD	/ /						

345 & 138kV SYSTEM 1 RACKS		
ELMORE		
SCALE		
JOB		
1 1/2"=1'-0"	SUBSTATION	
WO 20120	SHEET	REV.
	108	

DR. O.U. TRIPDIT	DATE 05/26/06
CK. PAUL DeTRIPS	05/26/06

Communication Diagrams

- Internal – system within substation which feeds into external communications
- SCADA – system used to communicate system properties and controls to remote location
- External – system used for inter-substation communication

Substation Internal Communication

IEEE Std C37.1-2007 discusses importance of block diagrams. Block diagrams should include:

Remote SCADA communications to one or more entities and/or utilities for operational data

Remote communications to one or more entities and/or utilities for non-operational data

Inter-substation protective relay communications via various transport methodologies

Local telco circuits for substation phone and/or data circuits

Revenue metering data circuits



Substation Internal Communication

The block diagram should detail the following connections for each IED:

Device designation

Device part number (optional)

RS-232 serial communication ports with connector type (terminal block, DB9 male/female) and port number with front or rear indicated as necessary

RS-485 serial communication ports with connector type (terminal block, DB9 male/female) and port number or terminal block number with front or rear indicated as necessary



Substation Internal Communication

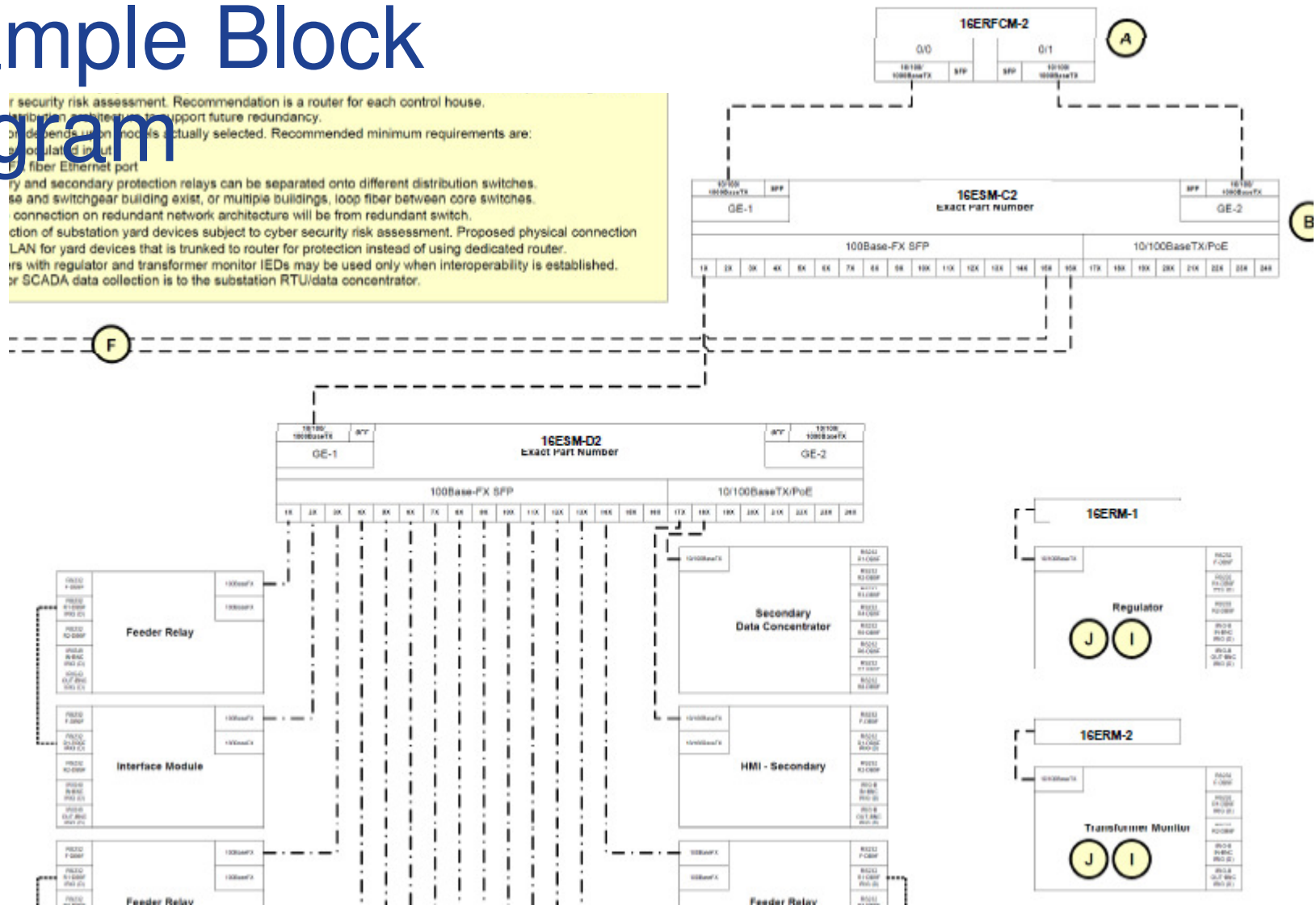
The block diagram should also detail the following connections for each IED:

Ethernet ports with connector type and speed (RJ45: 10/100BaseTX, 10/100/1000BaseTX; ST, MTRJ, LC: 10BaseFX, 100BaseFX) and port number with front or rear indicated

IRIG-B port with connector type (coax, terminal block) and modulation, with port number or terminal block number with front or rear indicated as necessary

Example Block Diagram

For security risk assessment. Recommendation is a router for each control house.
 Distribution architecture to support future redundancy.
 depends upon models actually selected. Recommended minimum requirements are:
 1. Modulated input
 2. Fiber Ethernet port
 3. Primary and secondary protection relays can be separated onto different distribution switches.
 4. If a substation and switchgear building exist, or multiple buildings, loop fiber between core switches.
 5. Connection on redundant network architecture will be from redundant switch.
 6. Protection of substation yard devices subject to cyber security risk assessment. Proposed physical connection
 LAN for yard devices that is trunked to router for protection instead of using dedicated router.
 7. Routers with regulator and transformer monitor IEDs may be used only when interoperability is established.
 8. For SCADA data collection is to the substation RTU/data concentrator.



Substation SCADA Communication

Representing substation SCADA related control/equipment in the schematics

Necessary parts of the points list

Possible worksheet columns in points list

Substation External Communication

Communication System Map

Communication System Layout Diagram

Microwave Radio and Fiber Optic
Communication System Diagram

Communication Channel Circuit Diagram

Database Documentation

Other Forms of Documentation

Design Philosophy Document

Commissioning Documentation

Conclusion

Established methods, though updating, have proved effective, safe, and reliable

The net loss of expertise challenges the continuation of best practices so more papers like this one will be needed

As relaying and communication technologies advance this will require a close relationship between manufacturer and user to facilitate assimilation into existing methods of documentation

Shift from meaning being conveyed by wiring to meaning being conveyed by programmed logic. This can lead to opportunities for translation error

Expertise required to maintain these new systems is different from that needed for older systems



It cannot be overstated how important it will be to the adoption of new relay system technologies that for the maintenance of these systems, documentation is available that emphasizes transparency to the functions that the system is performing. It is crucial that the technology of power system relaying does not outstrip the industry's ability to safely, reliably and effectively implement these technologies into its daily operations.

Questions?