Project Plan for Fire-Induced Failure Modes and Effects Testing of Direct Current Driven Control Circuit Cables

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List of Acronyms

AC	Alternating Current
AOV	Air Operated Valve
AWG	American Wire Gauge
DC	Direct Current
DCCCS	DC Control Circuit Simulator
DOE	Department of Energy
EPR	Ethylene-Propylene Rubber
EPRI	Electric Power Research Institute
IRMS	Insulation Resistance Measurement System
MOV	Motor Operated Valve
NEI	Nuclear Energy Institute
NIST	National Institute of Standards and Technology
NFPA	National Fire Protection Association
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NRR	NRC Office of Nuclear Reactor Regulation
PE	Polyethylene
PORV	Power Operated Relief Valve
PVC	Poly-vinyl Chloride
RES	NRC Office of Nuclear Regulatory Research
SCDU	Surrogate Circuit Diagnostic Unit
SCETCh	Severe Combined Environmental Test Chamber
SNL	Sandia National Laboratories
SOV	Solenoid Operated Valve
SR	Silicone-Rubber
TS/TP	Thermoset-Insulated, Thermoplastic-Jacketed Cable (e.g., XLPE/PVC)
XLPE	Cross-Linked Polyethylene

1. Introduction and Background

Several tests have recently been conducted[1] to explore failure modes and effects of control cables when damaged by fire. In only one known case[2] have these tests included direct current (DC) - powered control circuits, and in that one case the tests conducted were sharply limited in both scope and number. DC circuits constitute a significant fraction of the safety-related circuits in commercial nuclear power plants and they are characterized by significant differences in operating characteristics and design as compared to AC control circuits. Based on industry feedback from the NFPA-805 pilot applications and other ongoing circuit analysis efforts (e.g., inspection and enforcement activities), some of the most challenging potential hot short-induced spurious actuations, from a consequence standpoint, are associated with control circuits powered by ungrounded DC sources (e.g., PORVs, letdown valves, reactor head/pressurizer vents, SRVs, breaker trip circuits).

What remains unclear is the extent to which the existing, largely AC, test data can be extrapolated to DC control circuits. Parameters of particular interest include the likelihood of spurious actuation and hot short duration for DC control circuits of various configurations. The lack of either a sufficient set of DC circuit test data, or a technical basis for extrapolation of the AC test data, represents a significant uncertainty associated with the analysis of DC circuits.

This primary objective of the test program described here is to address these analytical uncertainties by providing fire-induced cable failure modes and effects data for DC control circuits, and to provide that data in a manner that allows for a direct comparison to AC control circuit failure response data. The purpose of this document is to describe the planned experimental investigation. The proposed tests are designed to investigate a number of key variables that may influence the observed failure behavior including cable type, control circuit configuration, fire exposure conditions, and cable routing configuration. The planned tests are patterned on the recently completed CAROLFIRE Project[3].

The test program also involves two secondary objectives. First, use of the AC circuit simulators developed for CAROLFIRE (the “SCDUs”) will expand the data set for AC control circuits. Second, similar to CAROLFIRE, thermal exposure and cable thermal response data will also be gathered such that the observed electrical failures can be correlated to the cable thermal response. This will expand the existing data supporting the further development of cable thermal response predictive models and provide explicit data on cable electrical failure thresholds under DC power conditions.

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[1] For example the EPRI/NEI Cable Tests conducted in 2001; Duke Energy’s tests on armored cable in 2006; and the CAROLFIRE test program in 2006.

[2] The 2006 Duke Energy tests.

[3] CAROLFIRE is the Cable Response to Live Fire project and is documented in NUREG/CR-6931.

2. Overview of Testing Needs

2.1. DC Control Circuit Cable Failure Modes and Effects

There are several characteristics associated with DC control circuits that are unique as compared to AC control circuits. It is because of these unique characteristics that the extrapolation of the AC circuit test results to DC circuits introduces significant uncertainty. Cable failure modes and effects for DC control circuits may differ significantly from the corresponding behaviors in AC circuits. In order to assess behavioral differences and reduce analysis uncertainty, it is necessary to conduct tests using DC circuits.

Without an understanding of how DC circuit faulting differs from AC circuit faulting, the identification of important circuit characteristics is at best speculative. However, at least three DC circuit characteristics that differ significantly from AC control circuits are currently thought to be important to the cable failure modes and effects behaviors. These are the following:

- DC control circuits tend to use significantly larger fuse sizes for over-current protection than do corresponding AC control circuits. Several factors contribute to this design choice. The result of this design difference may be that over-current protection devices would not open as readily as the corresponding devices in an AC circuit. This might allow DC circuit faults to persist for a longer period of time prior to a "fuse-blow" and circuit de-energizing as compared to a corresponding AC circuit. Furthermore, faults in DC-powered cables may involve far more energetic arcing behaviors during the process of conductor-to-conductor and conductor-to-ground shorting. These characteristics may impact hot short behaviors including both likelihood and duration, although the net effect of the higher fusing and the anticipated arcing-fault behaviors remains unknown.

- AC circuits, by definition, have "zero-crossing" points as a result of the sinusoidal waveform signal. DC circuits use a constant voltage potential to operate and by definition have no "zero-crossing" behavior. The impact of a constant circuit voltage on the cable faulting behavior as compared to a zero-crossing fault behavior is unclear. The lack of a zero-crossing characteristic, especially when coupled to a higher amperage over-current protection device, may contribute to the anticipated arcing fault behavior. That is, as noted above, DC-powered conductors will likely experience more sustained arcing type faults and the lack of a zero-crossing feature might contribute to this behavior. Whether this behavior increases or decreases the duration of hot shorts is unknown.

- The information gathered in the development of this test plan (i.e., industry input, NRC staff input, and our own research) indicates that most DC control circuits are powered by ungrounded DC power sources (e.g., ungrounded battery banks). In comparison, most AC power supply systems are grounded. The nature of the cable shorting behaviors possible given an ungrounded power source may be more complicated than those associated with a grounded power source. For example, for an ungrounded power supply, no single conductor-to-ground short will trigger circuit over-current protection. These complexities could impact both hot short duration and spurious actuation likelihood.

The intent of the test program is to provide data that will assess the impact of these and other DC circuit characteristics on cable failure modes and effects behaviors. The test program has been designed to provide a nominal assessment of spurious actuation likelihood and hot short duration for a range of common DC control circuits. The characteristics of the DC control circuits to be evaluated are described in Section 4.2.1.

2.2. AC Control Circuit Cable Failure Modes and Effects

The planned testing will include fielding of the motor operated valve (MOV) AC control circuit simulators (the SCDUs) originally developed for the CAROLFIRE project. The fielding of this equipment serves two purposes. First, these tests represent, in effect, a “target of opportunity” to expand on the existing AC control circuit data set. Second, the use of both the AC and DC control circuits in the same tests will allow for a direct cross-comparison of observed behaviors. The AC equipment will be deployed in a manner similar to that employed in CAROLFIRE, although some changes and variations are anticipated.

The testing of the AC circuits also provides an opportunity to address one lingering issue not fully addressed by the CAROLFIRE study; namely, the impact of control power transformer (CPT) sizing on the likelihood of spurious operations. As noted in the CAROLFIRE report, the results for this specific item were ambiguous at best. The DC testing program offers an opportunity to further explore this behavior. Section 4.2.4 provides a description of the SCDUs and includes a discussion of system design changes that will be implemented in order to address these testing goals.

2.3. Instrument Loop Circuits

The planned testing program will include a limited exploration of instrument circuit performance under fire conditions. A preliminary study of instrument circuit cable failure modes and effects was included in the original NEI/EPRI test program in 2001 as a part of the NRC/RES collaboration in those tests (see NUREG/CR-6776). The preliminary tests indicated that the failure behavior for such circuits was substantially different for thermoset as compared to thermoplastic insulated cables. The current testing program will implement a similar instrument loop circuit to further assess related failure behaviors.

2.4. Fire and Fire Response Characterization

One of two major objectives of the CAROLFIRE project was to explore key behaviors associated with the thermal response of cables exposed to a fire environment. In particular, CAROLFIRE included a substantial effort to characterize cable heating behavior under a range of fire conditions and to correlate the cable thermal response to electrical performance and failure. These efforts led to improvements in the fire modeling area and the development of the THIEF model[4] as documented in Volume 3 of the CAROLFIRE report (NUREG/CR-6931). The DC circuit testing program will also include the gathering of fire exposure and cable thermal response data. However the level and extent of thermal monitoring will not be as extensive as in the previous testing program.

With respect to cable thermal response, testing will again include cables instrumented for thermal response in a manner that will allow for correlation to electrical failure. Testing will also include thermocouples and other instruments deployed to characterize the local thermal environment to which the cables are exposed. It is not generally anticipated that the failure thresholds for the electrical cables under DC conditions will differ substantially from the cable failure thresholds observed under AC conditions. However, no explicit basis for this expectation can currently be cited other than expert judgment. The current base of cable failure threshold data is also based on testing with AC-powered cables. The planned tests will directly establish cable thermal failure thresholds for DC-powered conditions.

One factor that will be pursued in the DC tests that was not explored in CAROLFIRE is smoke generation and development. That is, the planned testing includes a preliminary assessment of smoke development and characteristics for cable fires. At the current time, the plans for smoke measurement have not been fully defined. Nominally, the intent is to include a modest deployment of simple smoke characterization devices in order to provide preliminary data on the quantity of smoke produced by the cable fires and the optical characteristics of that smoke.

[4] THIEF stands for Thermally-Induced Electrical Failure of Cables

3. Experimental Approach

3.1. Overview

To meet the goals of the test program, a fairly large number of tests involving varied arrays of cable types, cable bundling arrangements, heating conditions, circuit types, and cable routing conditions will be performed. The test matrices (described below) include 49 small-scale exposure tests using the *Penlight* facility and 20 intermediate scale tests using the same testing protocol and facility as was used in the CAROLFIRE project.

The test design has been optimized to allow for considerable flexibility as the testing proceeds. In particular, the two test series are designed such that cable and instrumentation configuration changes can be made should insights gained as the tests proceed suggest that changes are in order. Hence, the test matrices should be viewed as a "nominal" test set that will remain subject to change throughout the project.

3.2. The Test Configurations and Matrices

3.2.1. Penlight Small-Scale Radiant Heating Tests

The DC circuit testing program will utilize the SNL facility *Penlight*. This facility is described in detail in Volume 2 of NUREG/CR-6931 and may be viewed in Figure 1 and Figure 2. The same general test protocol established for CAROLFIRE will be followed for the DC circuit tests. The cables under test will be exposed to a constant heat flux condition via heating of the *Penlight* shroud. One specific objective of the CAROLFIRE Penlight tests was to establish appropriate heating levels for each cable type that would induce failure within a 10-20 minute time frame. Given that CAROLFIRE established these relationships, the DC Penlight matrix is based on the application of appropriate heating levels for the cables being tested as established by CAROLFIRE. Using the same thermal conditions that were predominant in the CAROLFIRE tests allows for a direct comparison between the AC and DC circuit failures.

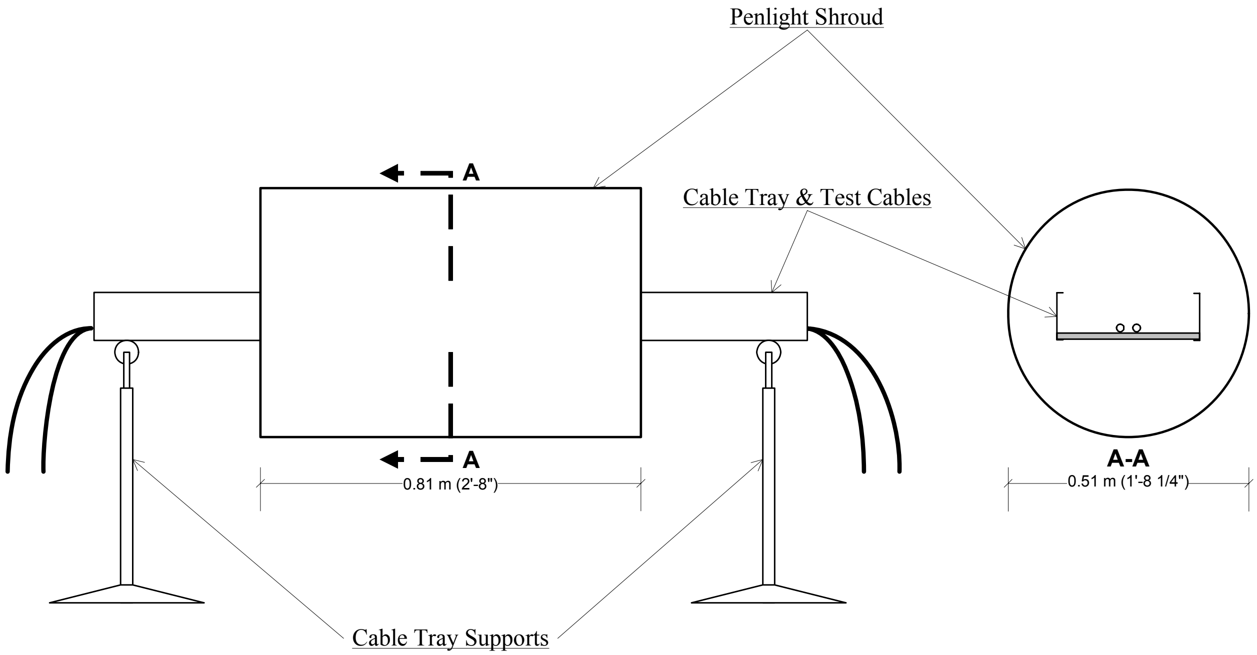


Figure 1: Penlight Testing Apparatus (shown with cable tray)

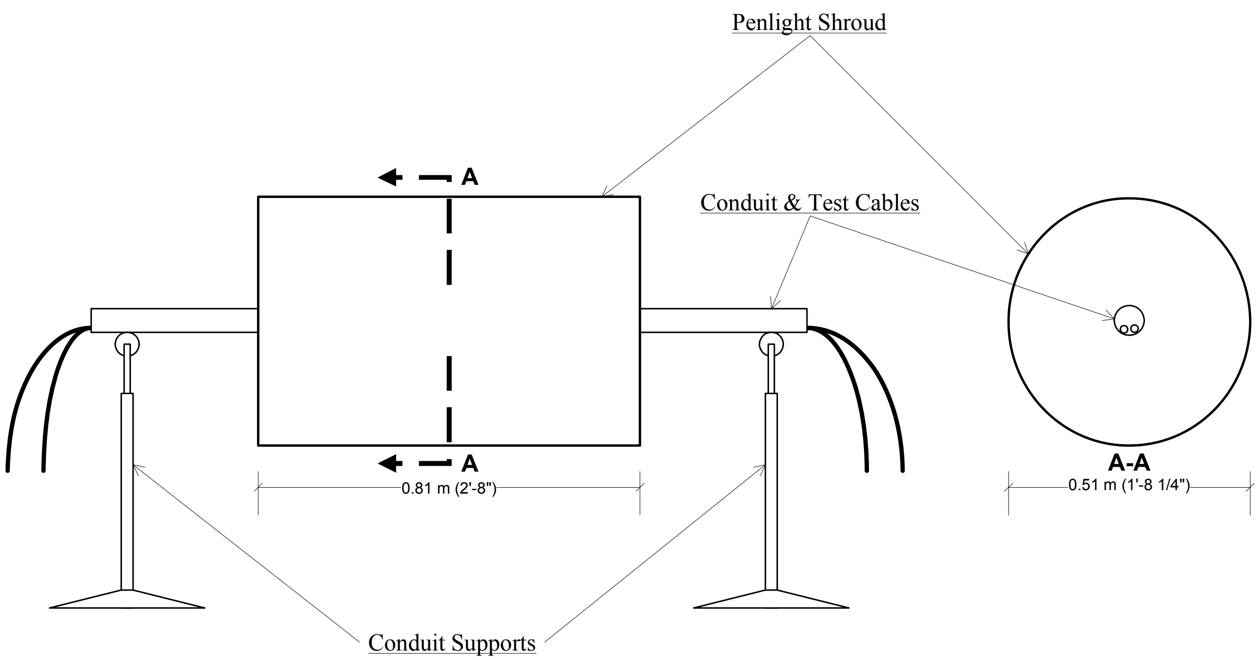


Figure 2: Penlight test setup with conduit

The intent of the Penlight testing is to take maximum advantage of low-cost, smaller scale and less complex testing configurations via the small-scale tests. The small-scale testing involves the following primary objectives:

- The Penlight tests will provide an opportunity to test and verify the performance of each of the DC control circuit simulators, the DC power supply systems, and the circuit performance monitoring instruments.

- The small-scale tests will allow for the exploration of fundamental behaviors associated with the DC circuit failure modes and effects.

- The small-scale tests will also allow for a direct comparison to corresponding AC circuit tests from the CAROLFIRE small-scale tests.

The proposed small-scale test matrix is provided in Table 1. Penlight allows for the exposure of as few as a single cable up to small bundles on the order of 6-8 cables. In general, the Penlight matrix is focused on single cable lengths and bundles of up to three cables. The matrix also includes cables routed in both conduit and ladder-back cable trays. Testing will include cables selected for the CAROLFIRE program with the addition of certain other key cable configurations (see Section 3.3 for details on cable selection).

Table 1: Penlight DC Circuit Cable Testing Matrix

Penlight Test Matrix - Revision B (9-5-2008)

Comments:
1) These tests only involve the DC circuits
2) Conductor Size for the all the proposed experiments is 12 AWG
3) This is a working document

Burn Test #	Cable item #	Cable Insulation Material							Number of Conductors		Cable Bundle size		Exposure shroud temperature						Raceway type		Cable Diagnostic System					
		Thermosets			Thermoplastics			TS/TP					Thermoplastic levels			Thermoset Levels										
		XLPE / CSPE	EPR	SR	Tefzel	PE / PVC	PVC / PVC	XLPE / PVC	3	7	1	3	300	325	400	470	525	700	Tray	Conduit	IRMS (DC)	Pilot Solenoid Valve	4kV Breaker	Power Operated Relief Valve	Motor Starter	Instrument Loop
Prelim 1		X									X					X			X		X					
Prelim 2						X					X			X					X		X					
Prelim 3		X										X				X			X		X					
Prelim 4						X						X		X					X		X					
1		X									X					X			X		X					
2		X									X						X		X		X					
3		X									X					X			X			X				
4		X									X						X		X			X				
5		X									X					X			X				X			
6		X									X						X		X				X			
7		X									X					X			X					X		
8		X									X						X		X					X		
9		X									X					X			X						X	
10		X									X						X		X						X	
11						X					X			X					X		X					
12						X					X			X					X			X				
13						X					X			X					X				X			
14						X					X			X					X					X		
15						X					X			X					X						X	
16			X								X					X			X				X			
17				X							X							X	X				X			
18					X						X				X				X				X			
19							X				X			X					X				X			
20								X			X					X			X				X			
21		XX				X						X					X		X		X	X		X		
22		XX				X						X					X		X		X		X		X	
23		X	XX									X					X		X		X	X		X		
24					X	X	X					X			X				X		X		X		X	
25		X									X					X			X							X
26		X									X					X			X							X
27							X				X			X					X							X
28							X				X			X					X							X
29		X									X					X				X	X					
30		X									X					X				X		X				
31		X									X					X				X			X			
32		X									X					X				X				X		
33		X									X					X				X					X	
34						X					X			X						X	X					
35						X					X			X						X		X				
36						X					X			X						X			X			
37						X					X			X						X				X		
38						X					X			X						X					X	
39			X								X					X				X			X			
40				X							X							X		X			X			
41					X						X				X					X			X			
42							X				X			X						X			X			
43								X			X					X				X			X			
44		XX				X						X					X			X	X	X		X		
45		XX				X						X					X			X	X		X		X	
46		X									X					X				X						X
47		X									X					X				X						X
48							X				X			X						X						X
49							X				X			X						X						X

3.2.2. Intermediate-Scale Testing

The planned intermediate scale testing will utilize the exact same test facilities and will follow the same testing protocol as the intermediate-scale CAROLFIRE tests. A detailed description of the facility, general test arrangements, and testing protocol is provided in Volume 2 of NUREG/CR-6931. Figure 3 provides a general schematic of the intermediate-scale test apparatus. As in CAROLFIRE, this apparatus is located within a larger test enclosure.

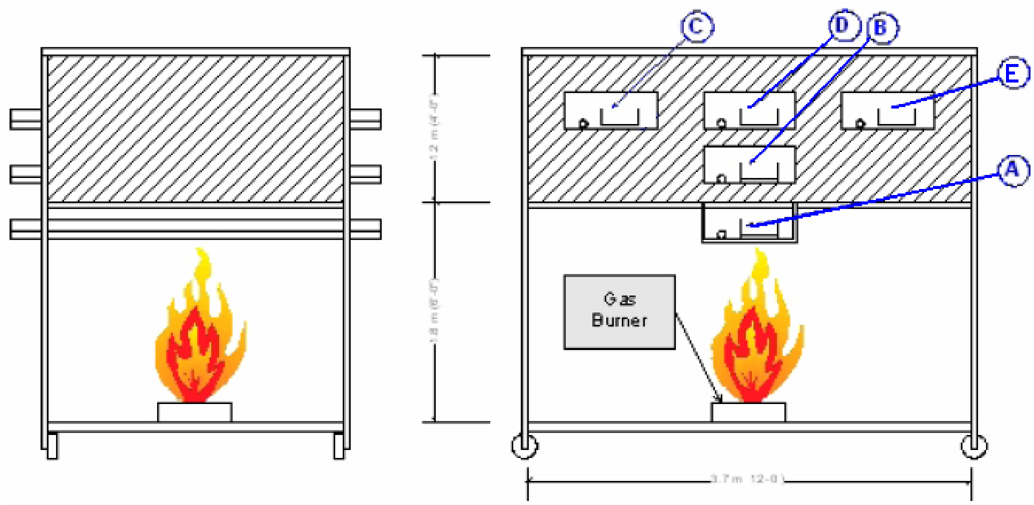


Figure 3: Intermediate Test Apparatus

Based on the results of the CAROLFIRE tests, the DC circuit tests will focus on the three cable raceway locations directly above the fire source (Locations A, B, and D as shown here), and those locations near the ceiling of the test structure (C and E as shown in Figure 3[5]). Testing will again involve a mix of cables in conduits and ladder back cable trays.

In the case of the CAROLFIRE tests, the intermediate scale test arrangements focused on cable bundles involving from three to 12 cables and only a small number of random-fill cable trays were employed. This design decision was based on two factors. First, one specific objective was to explore a range of inter-cable shorting configurations via specific arrangements of different types of cables. Second, the fire modeling goals made the gathering of thermal response data for well defined but limited cable bundles desirable.

In the case of the DC circuit tests, neither of these objectives is predominant and, in the former case, an alternative approach is being pursued to assess inter-cable shorting behaviors for DC-powered cables (see Section 4.2.2). Hence, for the DC circuit tests, most of the cable trays to be tested will involve random-fill cable arrangements rather than structured cable bundles. Various

[5] Note that for CAROLFIRE, the cable raceway locations were labeled somewhat differently because they included two additional locations, one each below locations C and E as shown in Figure 3.

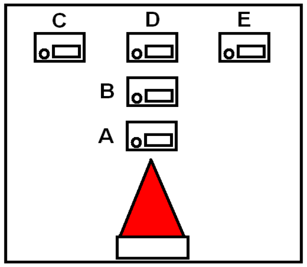
fill configurations are anticipated ranging from a truly random fill pattern to relatively well-ordered arrangements. This approach will provide an important compliment to the CAROLFIRE tests in terms of the cable arrangements explored. In particular, it will provide an additional opportunity to gather cable thermal response and failure data under more representative cable loading arrangements.

The test matrix for the intermediate scale tests is shown in Table 2 and continued through Table 5. Note that the matrix includes four preliminary tests. The preliminary tests involve a very limited number of cables and are designed to verify the operation of the gas burner and the instrumentation systems. The primary test matrix includes 15 individual tests. Also indicated are an additional five contingency tests that will be performed if time and funds allow.

The intent of the testing is to deploy all of the available cable diagnostic systems (see Section 4.2 for details) in each of the intermediate-scale tests in the primary test matrix. The tests involve variations in cable type, cable routing configuration (trays and conduits), and proximity to the fire source (i.e., the 5 planned raceway locations as shown in Figure 3). The matrix also rotates the various cable electrical performance monitoring systems among the locations and raceway types.

One additional aspect of the planned test matrix is that the various cable electrical performance monitoring systems (see Section 4.2 for details) will generally be isolated in separate cable raceways. This is a safety precaution intended to minimize the likelihood of interactions between, for example, the IRMS system and the DC battery banks. Such interactions could be destructive to the test equipment and hazardous to test personnel. The one exception to this is that DC circuits powered from the same battery bank will typically be co-located in the same raceway.

Table 2: Tentative Intermediate Scale DC Fire Test Matrix

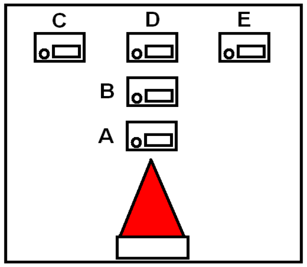


Intermediate Scale Test Matrix - Revision A (8-22-2008)

Comments:
1) All tests will be conducted as open burns with a Propene (Propylene) gas sand burner
2) Conductor Size for the all the proposed experiments is 12 AWG

Burn Test #	Loc.	Cable Insulation Material							Number of Conductors		Cable Bundle Size					Water Spary Options	Raceway Type	
		Thermoset			Thermoplastic			TS/TP										
		XLPE	EPR	Silicone	PE	PVC	Tefzel	TS/TP	3	7	1	3	6	12	Load Tr	*	12" Tray	2.5" Cnd
Prelim 1	A	X							X		X						X	
	A	X								X	X							X
Prelim 2	A	X							X		X							X
	A	X								X	X						X	
Prelim 3	A					X			X		X						X	
	A					X				X	X							X
Prelim 4	A					X			X		X							X
	A					X				X	X						X	
1	A	X								X					X		X	
	B	X								X				X			X	
	C	X								X		X						X
	D	X								X		X						X
	E	X								X				X			X	
2	A	X								X				X			X	
	B	X								X			X				X	
	A	X			X					X				X			X	
	B	X			X					X			X				X	
	C					X				X	X						X	
	E					X				X	X						X	
3	A	X	X							X			X				X	
	B	X	X							X			X				X	
	A		X		X					X			X				X	
	B		X		X					X			X				X	
	C					X			X		X						X	
	E					X			X		X						X	
4	A	X	X		X		X	X		X			X				X	
	B	X	X		X		X	X		X			X				X	
	A	X	X		X	X	X	X		X			X				X	
	B	X	X		X	X	X	X		X			X				X	
	C	X							X		X						X	
	E	X							X		X						X	
5	A	X	X	X	X		X			X				X		X	X	
	B	X	X	X	X		X			X			X			X	X	
	A	X	X		X		X			X				X		X	X	
	B	X	X		X		X			X			X			X	X	
	C		X							X	X						X	
	E		X							X	X						X	
6	A	X	X	X	X		X			X			X			X	X	
	B	X	X	X	X		X			X			X			X	X	
	C	X			X		X			X		X						X
	A		X	X	X		X	X		X			X			X	X	
	B		X	X	X		X	X		X			X			X	X	
	E				X		X	X		X			X					X

Table 3: Tentative Intermediate Scale DC Fire Test Matrix (continued)



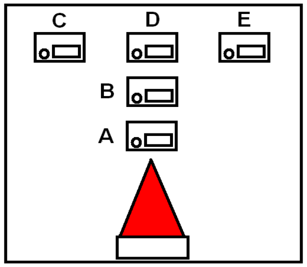
Intermediate Scale Test Matrix - Revision A (8-22-2008)

Comments:

1) All tests will be conducted as open burns with a Propene (Propylene) gas sand burner
2) Conductor Size for the all the proposed experiments is 12 AWG

Burn Test #	Loc.	Cable Insulation Material							Number of Conductors		Cable Bundle Size					Water Spary Options	Raceway Type	
		Thermoset			Thermoplastic			TS/TP										
		XLPE	EPR	Silicone	PE	PVC	Tefzel	TS/TP	3	7	1	3	6	12	Load Tr	*	12" Tray	2.5" Cnd
	A	X	X		X	X		X		X			X				X	
	A	X	X			X	X	X		X			X				X	
7	B		X		X	X	X	X		X			X				X	
	C	X			X	X				X		X						X
	E		X		X	X	X	X		X			X				X	
	A	X			X	X				X			X				X	
	A	X			X	X				X			X				X	
8	B	X			X					X			X				X	
	C	X			X					X		X						X
	E	X			X					X			X				X	
	A	X	X	X	X		X	X		X			X			X	X	
	A	X	X	X	X		X	X		X			X			X	X	
9	B	X	X	X	X		X	X		X			X			X	X	
	C	X			X		X			X		X						X
	E	X	X	X	X		X	X		X			X			X	X	
	A	X	X	X			X	X		X			X			X	X	
	A	X	X	X			X	X		X			X			X	X	
10	B	X	X	X		X		X		X			X			X	X	
	C				X		X	X		X		X						X
	E	X	X		X	X	X	X		X			X				X	
	A	X	X		X	X		X		X			X				X	
	A	X	X		X	X		X		X			X				X	
11	B	X	X			X	X	X		X			X				X	
	C				X	X		X		X		X						X
	E	X	X		X	X		X		X			X				X	
	A	X	X		X	X		X		X			X				X	
	A	X	X		X	X		X		X			X				X	
12	B	X	X			X	X	X		X			X				X	
	C				X	X		X		X		X						X
	E	X	X		X	X		X		X			X				X	
	A	X	X		X		X	X		X					X	X	X	
	B	X	X		X		X	X		X					X	X	X	
	C	X	X							X		X						X
13	D	X	X		X		X			X			X			X	X	
	D	X	X		X		X			X			X			X	X	
	E	X	X		X		X			X			X				X	
	E	X	X		X		X			X			X			X	X	

Table 4: Tentative Intermediate Scale DC Fire Test Matrix (continued)



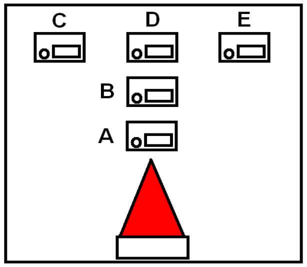
Intermediate Scale Test Matrix - Revision A (8-22-2008)

Comments:

1) All tests will be conducted as open burns with a Propene (Propylene) gas sand burner
2) Conductor Size for the all the proposed experiments is 12 AWG

Burn Test #	Loc.	Cable Insulation Material							Number of Conductors		Cable Bundle Size					Water Spary Options	Raceway Type	
		Thermoset			Thermoplastic			TS/TP										
		XLPE	EPR	Silicone	PE	PVC	Tefzel	TS/TP	3	7	1	3	6	12	Load Tr	*	12" Tray	2.5" Cnd
14	A	X	X		X	X	X	X		X					X		X	
	B	X	X		X	X	X	X		X					X		X	
	C				X	X		X		X		X						X
	D	X	X		X	X	X	X		X			X				X	
	D	X	X		X	X	X	X		X			X				X	
	E	X	X		X	X	X	X		X			X				X	
	E	X	X		X	X	X	X		X			X				X	
15	A	X	X					X		X			X				X	
	A	X	X					X		X			X					X
	B	X	X					X		X			X				X	
	B	X	X					X		X			X					X
	C	X	X					X		X			X				X	
	C	X	X					X		X			X					X
	D	X	X					X		X			X				X	
	D	X	X					X		X			X					X
16	A				X	X	X			X					X		X	
	B	X	X	X						X					X	X	X	
	C							X		X					X		X	
	D				X	X	X			X					X		X	
	D				X	X	X			X			X					X
	E	X	X					X		X			X					X
	E	X	X		X	X	X	X		X					X		X	
17	A	X	X		X	X	X	X		X					X		X	
	C	X	X					X		X				X			X	
	C	X	X					X		X			X					X
	D	X	X					X		X				X			X	
	D	X	X					X		X			X					X
	E				X	X	X			X				X			X	
	E				X	X	X			X			X					X
18	A	X	X							X			X				X	
	A				X	X	X			X			X				X	
	B	X	X		X	X	X	X		X			X				X	
	C	X	X							X			X				X	
	C				X	X	X			X			X				X	
	D	X	X							X			X				X	
	D				X	X	X			X			X				X	

Table 5: Tentative Intermediate Scale DC Fire Test Matrix (continued)



Intermediate Scale Test Matrix - Revision A (8-22-2008)

Comments:

1) All tests will be conducted as open burns with a Propene (Propylene) gas sand burner
2) Conductor Size for the all the proposed experiments is 12 AWG

Burn Test #	Loc.	Cable Insulation Material							Number of Conductors		Cable Bundle Size					Water Spary Options	Raceway Type	
		Thermoset			Thermoplastic			TS/TP										
		XLPE	EPR	Silicone	PE	PVC	Tefzel	TS/TP	3	7	1	3	6	12	Load Tr	*	12" Tray	2.5" Cnd
19	A	X	X					X		X					X		X	
	B				X	X	X			X				X			X	
	B	X	X					X		X			X					X
	C				X	X	X			X					X		X	
	C	X	X					X		X					X			X
	D	X	X		X	X	X	X		X				X			X	
	E	X	X		X	X	X	X		X				X			X	
20	A				X	X	X			X			X				X	
	A				X	X	X			X			X					X
	B				X	X	X			X			X				X	
	B				X	X	X			X			X					X
	C				X	X	X			X			X				X	
	C				X	X	X			X			X					X
	D				X	X	X			X							X	

3.3. Cable Selection Criteria and Results

The issue of cable selection was addressed in detail by CAROLFIRE. The DC circuit tests will be utilizing primarily left-over stocks of cable procured for CAROLFIRE. For a detailed discussion of the cable selection criteria and results refer to NUREG/CR-6931. Note that cables are manufactured to specific voltage classifications, but not generally specific to either AC or DC applications. Hence, the cables procured for CAROLFIRE are entirely appropriate from this perspective to DC control circuit applications.

The DC circuit tests will focus primarily on the following two cable types:

- Rockbestos Firewall III cross-linked polyethylene (XLPE) insulated, chlorosulphonated polyethylene (CSPE, also known as Hypalon) jacketed cable, and

- General Cable's polyethylene (PE) insulated, polyvinyl-chloride (PVC) jacketed cable.

In addition, testing will include use of most of the other CAROLFIRE cables including:

- Ethylene-Propylene rubber (EPR) insulated, CSPE (Hypalon) jacketed cables procured from the BICC-Brand® line of products (now marketed under the General Cable umbrella).

- PVC insulated and jacketed (PVC/PVC) cables procured as industrial grade cables from the BICC-Brand® line of products (now marketed under the General Cable umbrella).

- Tefzel 280 insulated and Tefzel 200 jacketed cables procured as a commercial grade product from Cable USA.

- XLPE insulated, PVC jacketed cables procured as industrial grade from BICC-Brand® line of products (now marketed under the General Cable umbrella).

Note that these cables represent a range of thermoset (TS) and thermoplastic (TP) types, as well as one mixed TS-insulated, TP-jacketed cable. Table 6 provides a description of these test cables.

Table 6: DCC Test Cable List

Cable Function/Service	Insulation & Jacket Materials (I/J)	Material Type (2)	Conductor Size (AWG)	Number of Conductors	Manufacturer	Notes (3)
Control	XLPE/CSPE	TS/TS	12	7	Rockbestos Surprenant	All XLPE cables were selected from the Firewall III product line. All are nuclear qualified.
Control	SR/Aramid Braid	TS/TS	12	7	First Capitol	Industrial grade cable from " sister company to Rockbestos Surprenant
Control	Tefzel/Tefzel	TP/TP	12	7	Cable USA	Based on Tefzel-280 (Insulation) and Tefzel-200 (Jacket) compound
Control	EPR/CSPE	TS/TS	12	7	General Cable	Industrial grade cable
Control	XLPE/PVC	TS/TP	12	7		Mixed type - thermoset insulated, thermoplastic jacketed
Control	PE/PVC	TP/TP	12	7		Industrial grade cable.
Control	PVC/PVC	TP/TP	12	7		Industrial grade cable.

Additional Notes:

(1) - XLPE = Cross-linked polyethylene; CSPE = Chloro-sulfanated polyethylene (also known as Hypalon); SR = Silicone rubber; EPR = Ethylene-propylene rubber; PVC = Poly-vinyl chloride; PE = Polyethylene (non cross-linked).
(2) - TS = Thermoset; TP = Thermoplastic; shown as: (insulation type)/(jacket type).
(3) - All cables are un-shielded.

In comparison to CAROLFIRE, the DC circuit tests will eliminate or sharply limit testing to three cable types. No testing is planned using either the Rockbestos Vita-Link or Rockbestos low-smoke zero halogen cables. These are cable products not currently in wide-spread use in current fleet of U.S. nuclear power plants. Testing of the Silicone-Rubber (SR) insulated cables will be sharply limited. In general, a small number of tests with the SR cable have been included in order to assess whether or not the cables display similar behaviors when powered by a DC source as was observed for the AC circuits.

In addition to the cables cites above, the intent of the testing program is to include two additional cable types. Because these cables have not yet been procured, their configuration details remain undefined. The two additional cable types are:

- Armored multi-conductor control cable: Armored cables are of particular relevance to several plants and previous testing conducted by Duke Energy indicates that under DC conditions, these cables may exhibit a unique failure mode. The cables to be tested will be based on cable specifications as utilized for those plants that use armored cables. In particular, typical cable specification will be based on the specifications utilized by Duke Energy in its 2006 tests.

- Kerite FR cable: Kerite FR is a specific cable product with an uncertain failure threshold. The intent of the testing is to include Kerite FR cables if appropriate test samples can be obtained. The objective here is primarily to resolve the failure threshold question. The challenge is that Kerite FR is no longer available in the marketplace; hence, a source of "new old-stock" cables in needed. Utility contact has identified one source for a single conductor configuration cable originally utilized in NRC equipment qualification testing (i.e., the cable is now in the hands of staff at EPRI). However, the single conductor configuration, while workable, is not ideal given the nature of the cable performance monitoring systems. Other potential leads for obtaining cable samples are being pursued, and we anticipate that a workable test sample will ultimately be identified and procured.

The emphasis for testing has been placed on 7-conductor, 12 AWG cables. This is a very common configuration in AC control circuits, and also appears typical of cables used in DC control circuits. Nominally all of the cable materials will be tested in this (7-conductor, 12 AWG) configuration. The armored cables and Kerite FR cables may deviate from this configuration depending on what cables are ultimately procured.

4. Primary Measurements and Performance Diagnostics

There are a number of variables that need to be investigated in this test program. These variables will be discussed in the context of four general categories; namely, cable electrical performance and failure, cable thermal response, exposure conditions, and fire conditions. Also described in this section is the DC power supply source that will be used to power the cable electrical performance and failure monitoring equipment.

4.1. DC Power Supply Battery Banks

In order to meet testing needs, a DC power supply system is required. In practice, the intent is to build two nominally 125 VDC battery banks to support testing. The battery bank design is detailed in Appendix H. In short, each battery bank will be comprised of ten, 12 VDC automotive batteries connected in series to provide a nominal 125 VDC source. Each battery bank is supplied with a charging system capable of fully recharging the system overnight.

Two supply systems are being planned so that the DC circuit simulators (see Section 4.2.1) can be split between to two power supplies. This will limit the degree of interaction between the various DC circuits, and should ensure that the tests do not result in excessive draw-down of either battery bank.

Note that power will be supplied to each DC circuit simulator through relatively large (50A) DC circuit breakers and disconnects. These high-fault-current disconnects are intended only to protect the batteries from prolonged and excessive fault currents and as a disconnect feature necessary to ensure personnel safety. Separate over-current protection devices will also be included in the design of each of the individual DC control circuit designs.

In addition to the monitoring of individual voltage and current loads on the various cable conductors for the test circuits, monitoring is also provided for the total current draw on each battery bank and bank voltage. For each system connected to each battery bank, two hall-effect current monitors are provided. One device will be a high-range sensor provided to catch surge currents while the second will be a lower-range device provided to more accurately measure the anticipated current loads under non-faulted and early-stage degradation conditions.

4.2. Cable Electrical Performance and Failure

Cable electrical performance and failure will be monitored using four general instrumentation systems. Three of these four systems derive directly from previous testing, while the fourth is unique to the DC circuits testing program.

4.2.1. DC Control Circuit Simulators

Cable performance monitoring will include a set of four DC control circuits specifically designed for this program. Each DC Control Circuit Simulator (DCCCS) unit will represent one common circuit type commonly used in a nuclear power plant. The five primary circuits to be used are all to be based on typical 125 VDC control circuits. These are as follows:

- A 125 VDC control circuit for a small pilot solenoid (e.g., the pilot solenoid for an air-operated valve (AOV)).

- A 125 VDC control circuit for a larger SOV type valve (such as a power operated relief valve (PORV)).

- A 125 VDC trip/close control circuit for a 4160 VAC circuit breaker.

- A 125 VDC MOV control circuit (i.e., a reversing motor control circuit)

- A 125 VDC instrument loop.

The general design of the DCCCS units mirrors that of the SCDUs developed for CAROLFIRE. The SCDU design has, however, been adapted to (1) allow for DC current and voltage monitoring rather than AC current and voltage monitoring, and (2) to draw power from a DC battery bank rather than from AC line power or a control power transformer (CPT).

Proposed circuit designs and parts specifications for the four DC control circuits are provided in Appendices C – G respectively. Each of the specific DCCCS units has been designed to mimic the characteristics of one of the four electrical circuit based on circuit diagrams taken from actual commercial nuclear power plant circuit designs. The description for each DCCCS unit includes the original circuit diagram for the simulated control circuit, a typical plant "block diagram" illustrating the cable routing relationships between electrical cabinets and the controlled component, and the implementation of the circuit via the DCCCS unit.

4.2.2. DC Inter-Cable Short Circuit Investigations

One specific goal of the CAROLFIRE tests was to explore the potential for risk-relevant electrical shorting interactions between two separate cables (i.e., inter-cable shorts that might cause a spurious operation). The DC circuit tests provide an opportunity to explore similar behaviors for DC-powered cables. The intent is to include some exploration of inter-cable interaction potential using the DC battery banks and the DCCCS units.

The approach to investigation of the inter-cable shorting for DC-powered cables will be based on testing paired cables. One cable in the pair would be act as the potential energizing source cable and would be connected via a circuit breaker or fuse to the positive and negative terminals of the DC battery bank (one conductor to each terminal). Two configurations for the second cable in the pair, acting as the target cable, are anticipated as follows:

- In some tests the second, or target, cable will not be connected to anything other than voltage and current monitoring instruments. In this configuration, shorting between the two cables would be indicated by a voltage potential and possibly current flow on the target cables.

- A second configuration would involve connecting the second, or target, cable to one of the DCCCS units in the normal manner associated with that particular unit. In this configuration a potential for an actual inter-cable spurious actuation would exist. In this second configuration, both the source and target cables would be energized via the same battery bank.

It is anticipated that one or both of these two inter-cable configurations will be implemented in a variety of both Penlight and intermediate-scale tests. Specific configurations will be determined prior to finalizing the test matrices.

4.2.3. The Insulation Resistance Measurement System (IRMS)

The Insulation Resistance Measurement System (IRMS) was originally developed as a part of the NRC/RES collaboration on the 2001 NEI/EPRI circuit failure modes and effects tests. The system was also deployed during the CAROLFIRE testing program, and NUREG/CR-6931 provides a detailed description of the IRMS design and operation.

In CAROLFIRE the IRMS was deployed using 120 VAC line power as the energizing source potential. For the DC circuit tests, the IRMS will again be deployed, but will utilize a DC energizing source. The IRMS was designed with DC testing in mind, and will require minimal modifications to allow for DC testing. In particular, the existing power switching relays are not designed to handle DC loads (arcing would quickly destroy the relay contacts). To overcome this issue, the existing relays will be used to control a bank of secondary DC switching relays. In all other respects, the design, operation, and data analysis associated with the IRMS remain as described in NUREG/CR-6931.

One point of note is that the DC power source will be a general DC power supply rather than a battery bank. The IRMS relies on the detection of low levels of current leakage to determine cable insulation resistances. It is not designed to handle high surge current that might result from a dead-short across a battery bank.

The IRMS will be deployed in most of the planned tests. The only exceptions are those early small-scale Penlight tests involving single lengths of cable where the intent is to test the performance of one of the specific DC control circuit simulator units (see Section 4.1.3).

4.2.4. The CAROLFIRE SCDUs

The third cable electrical performance and failure monitoring system to be deployed is the Surrogate Circuit Diagnostic Unit (SCDU) systems developed for CAROLFIRE. The SCDUs are also described in detail in NUREG/CR-6931. Each of the four SCDU systems provides the ability to simulate one AC control circuit. For CAROLFIRE the units were generally deployed to simulate a motor-operated valve (MOV) control circuit. A similar approach will be taken in the DC circuit tests. As in CAROLFIRE, the SCDUs will simulate AC control circuits.

Originally, the option of reconfiguring the SCDUs for DC circuit testing was considered. However, the extent of the hardware and software changes involved was so extensive as to make conversion impractical compared to the efficiencies gained in construction of new DC-specific circuit simulator units. Hence, the SCDUs will be maintained and utilized in their AC configuration. The intermediate scale tests in particular, represent a “target of opportunity” for gathering additional AC circuit data at a minimal additional cost.

The only design change currently planned relative to the SCDUs is replacement of the existing motor starter relays. The motor starters used during CAROLFIRE were, in hindsight, found to require far less motive power to lock in and hold a spurious actuation signal than anticipated. As a result, CAROLFIRE was unable to resolve one of the original Regulatory Information Summary (RIS) 2004-03, “Risk-Informed Approach for Post-Fire Safe-Shutdown Circuit Inspections,” unresolved issues; namely, that item related to how CPT size relative to the nominal circuit required power would impact spurious actuation likelihood. The DC circuit tests provide another opportunity to explore and resolve this issue.

Hence, the existing motor started contactor relays will be replaced with Joslyn-Clark[6] relays of the same type used in the original 2001 EPRI/NEI test program (current part number is T30U031). All other aspects of the SCDU deployment will mirror CAROLFIRE and the AC MOV control circuits.

One final aspect of the SCDU deployment that remains under consideration is the inclusion of mechanical interlock devices for the reversing motor starter relays. That is, a typical motor starter set for an MOV would include mechanical interlocks that prevent both relay coils from being activated concurrently. As deployed in each of the prior circuit failure modes and effects testing programs, the mechanical interlocks have been deleted from the circuit design. The intent in those prior tests was to maximize the shorting information obtained. For the DC circuit testing project, consideration is being given to the possibility of including the mechanical interlocks in the circuit design. This would more realistically represent the actual plant circuit implementation, and provide a new aspect to the test data not previously explored.

4.2.5. Instrument Loop

The final cable electrical performance and failure monitoring system to be deployed will be a mockup of an instrument loop circuit. This circuit is intended to simulate the operation of a typical 4 to 20mA instrument loop. The planned circuit is described in detail in Appendix A.

[6] Note that the EPRI test report (TR-1003326, page 4-13) cites “AO Smith (Clark Controls Division) Catalog #30U031” as the make and model of the motor starters used in that test program. AO Smith has since merged with Joslyn controls. The combined company is known as Joslyn-Clark Controls. The same model motor starter relays are sold under the Joslyn-Clark brand using essentially the same catalog number (T30U031).

The circuit supplies a constant mA-level current through a conductor loop connected to a series resistive network simulating the output display device that would typically be located either in the control room or at a remote monitoring station. By supplying a constant known input current, conductor-to-conductor current leakage is indicated by a drop in current at the simulated output display device.

A similar circuit was used by SNL during the NEI/EPRI testing series in 2001 and the results of these tests are reported in NUREG/CR-6776. The tests indicated that the failure mode experience in the testing was quite different for the TS and TP cable types. Basically the TP cables transitioned from fully operational to complete failure quite abruptly once the threshold of thermal damage was reached. In contract, the TS cable failed over a more extended period (several minutes) with a lengthy period of partial signal (current) loss (leakage) prior to complete failure. The report concludes that if a fire affected a TS instrument cable, it could cause the indication to read an intermediate, but not obviously erroneous, value. This could mislead operators and potentially cause them to take an action based on faulty information (depending on the nature of the signal and the direction of the signal drift). In contract, a fire affecting a TP cable would likely cause and abrupt and obviously faulty off-scale indication. This would be far less likely to mislead operators who would likely diagnose the instrumentation failure. As a result of the limited data from previous testing (4 tests), several tests in the DC testing program (both small- and intermediate-scale) will include instrumentation circuits to further explore these behaviors.

4.3. Thermal Exposure Conditions

The conditions under which the cables will be subjected to thermal insults will be varied in order to meet the overall project objectives. The primary variables here are the source intensity and raceway/routing type. In the case of the *Penlight* tests the variable that characterizes the exposure intensity is the external heat flux (kW/m^2) or equivalently the shroud temperature (ºC).

The Penlight radiant heat apparatus allows heat flux exposures at virtually any exposure level up to 97 kW/m^2 (870°C shroud temperature). This is a heating level well above that typically experienced in real fires anywhere other than within the flame zone itself, or under wind-driven conditions. Given the nature of typical NPP fires, it is desirable to monitor the degradation of cable integrity and behavior over relatively long times (nominally on the order of 10-30 minutes), thus the Penlight test matrix uses three heating levels:

- Based on previous test experience, thermoset cables will fail earlier in the desired time frame at a heat flux of 26.9 kW/m^2 (600 °C).

- Longer failure times for thermoset cables and relatively short failure times for thermoplastics occur at a heat flux of 14.1 kW/m^2 (470 °C).

- A 'low' heat flux of 5.9 kW/m^2 (325 °C) is expected to cause longer thermoplastic failure times.

The raceways to be employed during these tests will be 300 mm (12-inch) wide standard ladder-back cable trays and/or 63 mm (2 ½-inch) diameter standard rigid metal conduit.[7] The trays and conduits to be used are identical to those used in CAROLFIRE as described in NUREG/CR-6931. Note that only single cable or three-cable bundles, along with a single cable instrumented with thermocouples, will be run through the conduits for these tests. This two or four cable loading in the conduits is intended to represent an average utilization at NPPs.

4.4. Cable Thermal Response

Another benefit of this test series will be to provide additional cable thermal response data for the fire model improvement effort started in the CAROLFIRE test program.[8] In this particular program, providing cable thermal response data is a secondary objective. However, measurements of the cable thermal response are important to characterize the environmental conditions leading to the failure, and additional data in this regards is considered quite valuable. As a "target of opportunity," cable thermal response data will be gathered during the tests in a manner similar to that employed in CAROLFIRE, albeit with somewhat less instrument density.

As noted for CAROLFIRE, it is not appropriate to instrument any single cable for both thermal and electrical response. This is because installation of a thermocouple on, or within, a cable could impact the electrical failure behavior. Instead, the approach to be applied involves mirroring a cable being monitored for electrical performance with a second cable (in an adjacent or symmetric location) that will be monitored for thermal response. Figure 4 provides a graphical depiction of this dual-cable setup.

[7] The cable trays are B-Line7 Series 2 style steel trays with (per manufacturer specifications) a nominal 3 inch NEMA VE 1 loading depth, 4 inch side rail, and rung spacing of 9 inches. The specific part number is 248P09-12-144

[8] CAROLFIRE Final Report, 2007.

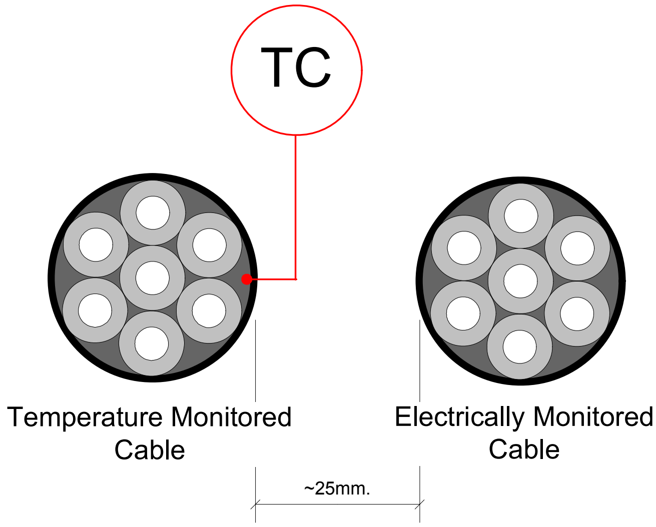


Figure 4: Example thermocouple arrangement for temperature monitoring of 7-conductor cable located near the electrically monitored cable in tray. Cables will be in contact during conduit tests.

Thermocouples will measure the thermal response of cables upon heating. Coupled with each thermal response cable will be thermocouples to measure the surrounding air temperatures. Type K thermocouples placed just below the outer cable jacket will be used for cable thermal response monitoring, a technique proven during the CAROLFIRE tests. A small slit is cut in the jacket allowing insertion of the thermocouple bead. The bead itself can typically be inserted to a distance of approximately 2.5 – 10 cm (1 – 4 inches) along the length of the cable placing it well away from the cut in the outer jacket. Placement distance does vary depending on the cable type. The slit will then be closed and secured with a single layer of fiberglass tape.

In order to better understand the uncertainties associated with thermal monitoring of a cable that is separate from the electrically monitored cable, a limited number of the Penlight tests have been designated as thermal response comparison tests. In those tests, both cables will be instrumented with thermocouples and monitored for the thermal response of their respective cables at a specific heat flux (see Figure 5). The differences in temperature readings between the two cables—at the same thermal environment—will provide a degree of insight to the level of uncertainty inherent in the ‘separate cable’ approach.

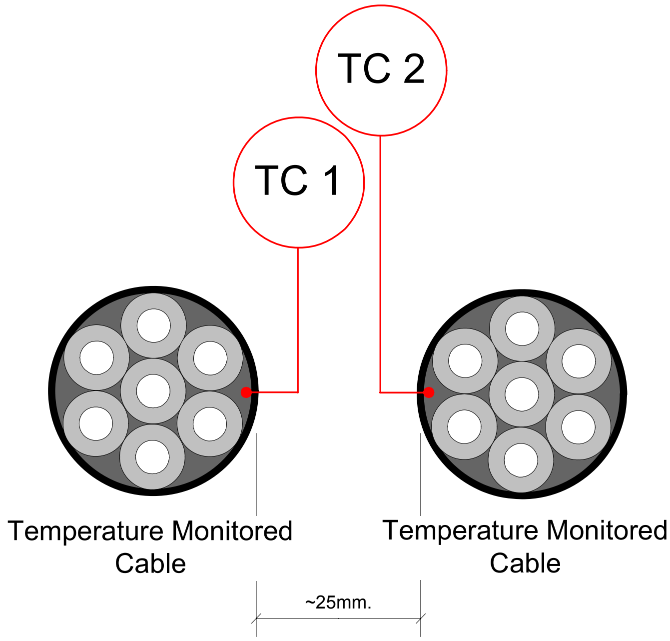


Figure 5: Thermocouple arrangement for two 7-conductor cables during cable thermal response comparison tests in trays.

Within bundles of cables and for the random fill cable trays, additional thermocouples will be included to measure the temperatures at the interfaces between individual cables (i.e., a bare-bead thermocouple within the bundle but not attached to any individual cable) and for the air circulating among the cables in a random fill arrangement. Where it is practical to do so, the configurations of the thermocouple-instrumented cables/bundles will exactly mimic the configurations employed by the electrically monitored cables/bundles. The principal exceptions to this approach will be those cases where three-cable bundles are run through a conduit. Here only a single thermocouple-instrumented cable will be included with the bundle due to space constraints within the conduit.

Thermocouples will also be used to measure raceway temperatures. For cable trays located directly above the fire in the intermediate scale tests, both the side rails and one tray rung (at the middle of the tray) will be monitored since it is fair to assume that the highest temperatures will be recorded at this location. However, for raceways located to the side of the prescribed fire (locations C and E as shown in Figure 3), the tray will be instrumented at both central and outboard (i.e., close to the apparatus side panels) to more accurately capture the room environment. For conduits, thermocouples will be secured to the outer surface at various locations (e.g., central and outboard locations). In each case, corresponding air temperature thermocouples will also be installed.

4.5. Fire Conditions

For the intermediate scale experiments, the characteristic fire was addressed in detail by CAROLFIRE. The DC circuit tests will be utilizing the propane sand burner to initiate cable failure. For a detailed discussion of the cable selection criteria and results refer to NUREG/CR-6931.

As previously described in Section 4.4, thermocouples will be used to gather temperature data from the compartment as well as the cables. Typical cable failure temperatures and heat fluxes may be found in Section 4.3.

This series of tests will also provide an opportunity to begin quantifying the products of combustion produced during the burning of cables. Analyzing the relative soot mass and determining the optical density will be the initial effort towards the study of smoke for these scenarios. As noted in Section 1.1.1, plans for smoke characterization have not been fully formed at this time. It is intended that data on smoke density and optical characteristics as a minimum will be gathered during a subset (on the order of half) of the intermediate-scale tests.

5. Test Matrices

Table 1 and Table 2 through Table 5 provide the test matrices for the tests discussed above. Note that the test program is intended to allow for flexibility and for the adjustment of test configurations and goals as the program progressed. That is, each test configuration in the matrices should be considered nominal reflecting the overall scope and general conditions and configurations anticipated. However, it is intended that the project will maintain the option to adjust the test conditions based on insights gained as the program progresses. Any such adjustments would be based on discussions with the NRC staff and any co-operative research partners.

Each table indicates the test number ("Test #") for the runs conducted in the particular facility, for each test run an "X" in a given column indicates the active choice for each experimental variable. The primary test variables are:

- Cable Insulation Material - specifies the cable insulation material for the cables being tested, the type of cable. This main heading is further subdivided into 'Thermoset' insulating materials and 'Thermoplastic' materials.
- Item # - indicates the unique identification number assigned to the specific cable(s) under test.
- Cable Bundle Size - indicates the number of cables in each bundle of cables to be included in the test.
- Thermal Exposure - specified the thermal exposure conditions which vary somewhat depending on the test facility. For Penlight the thermal exposure is defined by the incident heat flux in kW/m2.
- Raceway Type - indicates how the cable bundles will be supported and may involve either: ladder-back cable trays, or conduits.

All cables tested will be 7-conductor and most cables tested will be 12 AWG conductor size with the exception of the instrument cables. Instrument loop cables will be predominantly 16AWG twisted-shielded pairs, either as individual pair cables or using multiple pair cables (depending on availability).

5.1. Penlight, DC Test Matrix:

Table 1 provides a test matrix for the DC Circuit Cable tests to be conducted in the *Penlight* radiant heat chamber. The first four tests (Prelim 1 – 4) are intended as facility and equipment shake-down tests. These tests will also serve to provide baseline thermal response and failure data for the two primary cable types being used in the program. Each test will measure the temperature response of two separate cables/bundles under the same exposure conditions to help identify and quantify thermocouple measurement uncertainties between the two separate cables or bundles. In the case of the bundle tests, one cable in each bundle will be monitored for failure using a simplified connection to one of the DC battery banks. In each case, one conductor will be connected to the positive terminal and a second adjacent conductor in the same cable will be connected to the negative terminal. In this way a short circuit will be detected via a fuse-blow failure.

The initial tests will expose single lengths of cables (one electrical and one paired thermal response cable). The primary objective of these tests is to provide temperature response data to support the development of the cable thermal response models and to observe the behavior of each of the four DCCCS units. These tests represent the most simplistic of all possible cable exposure configurations. Each test involves a single length of cable either in a cable tray, or in a conduit.

The remaining Penlight tests are designed to provide thermal and electrical failure data for cables bundled in small groups of, generally, three cables. The three-cable bundles will be tested under a variety of exposure conditions. The primary intent of these tests is to demonstrate the ability to operate two or three of the cable electrical performance systems concurrently and to explore the impact of such operation of both the battery banks and monitoring instruments.

5.2. Intermediate-Scale, DC Test Matrix:

Table 2 and continued through Table 5 presents the twenty-four intermediate-scale tests that are planed for the DC testing program. The first four tests (Prelim 1 – 4) are preliminary tests that will be used to "shake down" the testing apparatus allowing the experimenters to ensure that the fire equipment and electrical monitoring equipment is operating properly, while still being able to capture a limited amount of data on simple circuit configurations.

Test # 1-15 are the core intermediate-scale tests. They represent an exploration into a number of different circuit configurations. In these tests, the tray loading will vary from single conductors to bundles of 3, 6, or 12 cables, and will include several tests where a fully loaded cable tray is used. When bundles of cables are used, not all cables will be instrumented for electrical or thermal response, but will be used to represent thermal mass that would typically be found in the NPP cable raceways.

All DCCCS will be used in Tests 1-20, and the particular cable they are attached to will be determined, based on the results of previous tests. A focus will be placed on connecting DCCCS to the same cable type as was used in the small scale testing for comparison purposes. Not shown in the testing matrix are the use and implementation of the CAROLFIRE SCDUs. The use of SCDUs will be left to the discursion of the testing lab and NRC project manager to determine when and where the SCDUs will be used.

6. Data Analysis and Reporting

The data from the tests will be analyzed, and a test report will be written. Data analysis will assess the test results for each tested configuration. The report will establish (as appropriate to the test results) estimates of the failure time, failure mode, and fault durations for each the tested cables. In addition, the test will report on the fire exposure conditions and corresponding cable thermal response data as such data were gathered. The analysis will also explore the potential for generalizing the test results to other untested configurations. The limits of data applicability will be clearly defined.

6.1. Cable Electrical Response

Electrical data collected during the tests will be evaluated regarding the number of separate cable failures likely to occur from the same exposure conditions. The data will be evaluated to account for all intra-cable as well as inter-cable cable failures. Again, the timing, concurrence and modes of failure will be correlated to cable temperature.

Surrogate circuit diagnostic units, setup to mimic DC control circuits will be used to assess the role DC power plays in the number of spurious actuations observed. Analysis will assess the prevalence of multiple spurious operations for each cable type tested.

Additional diagnostic units, set up to simulate MOV or SOV control circuits, will be employed during the tests to provide electrical data concerning the times of onset and duration of fire-induced spurious operation failures. This data would then be used to propose new guidelines in the expected mean duration of spurious operations and to provide information on the range of spurious operation failure durations observed (e.g., histograms of numbers of spurious actuations vs. duration time bins).

The exact nature of the data analysis and reporting tasks will be adjusted as necessary to suit the actual observed test results and to ensure that relevant insights are both highlighted and substantiated.

6.2. Cable Thermal Response

Thermal response of the test cables will be analyzed and discussed in the test report. The analysis will primarily consist of presenting plots of the exposure conditions and cable temperature versus time for those cables instrumented with thermocouples. Additionally, correlations to the time of observed electrical failures in separate, collocated, cables will also be provided.

Appendix A: Generic DCCCS Design

In part, the objectives of the DC test project include the determination of the onset of damage to cables exposed to thermal/fire conditions and the nature and duration of the functional failure. The proposed approach to evaluating the electrical response of the damaged cables is to connect the cable to a simulation circuit that mimics the behavior of an actual DC control circuit.

The electrical response behavior of selected cables will be monitored using surrogate control/instrument circuits connected to some of the cables under test. These "Black Box" circuits are designed to simulate the control circuits representative of nuclear plant safe shutdown components. The specific circuits anticipated are: a 125VDC control circuit for a motor operated valves (MOV), a 125 VDC control circuit for a 4160 VAC circuit breaker (i.e., close and disconnect controls), a 125 VDC control circuit for a small solenoid operated valve (SOV) such as the small solenoid on a larger air operated valve (AOV), and a 125 VDC control circuit for a larger solenoid valve such as a power operated relief valve (PORV).

Electrical parameters to be varied using these SCDU circuits will include the numbers of target, source and ground conductors that make up the surrogate control/instrument circuits.

The concepts we intend to field for these tests is to utilize multiple units of the same base design wherein the choice of components and devices connected to the basic circuit determine its surrogate function. Figure 6 shows the fundamental SCDU design. As shown in the figure, the power source is connected to the supply terminals while the individual conductors of the cable under test are connected to the cable connection terminals on the right-hand side of the figure. The number of energized conductors is determined by the position of switches 1 - 3 and the number of conductors connected to ground is governed by switches 4 - 6. The number and types of targets connected to the cable depends on the nature of the devices installed at the available connection points.

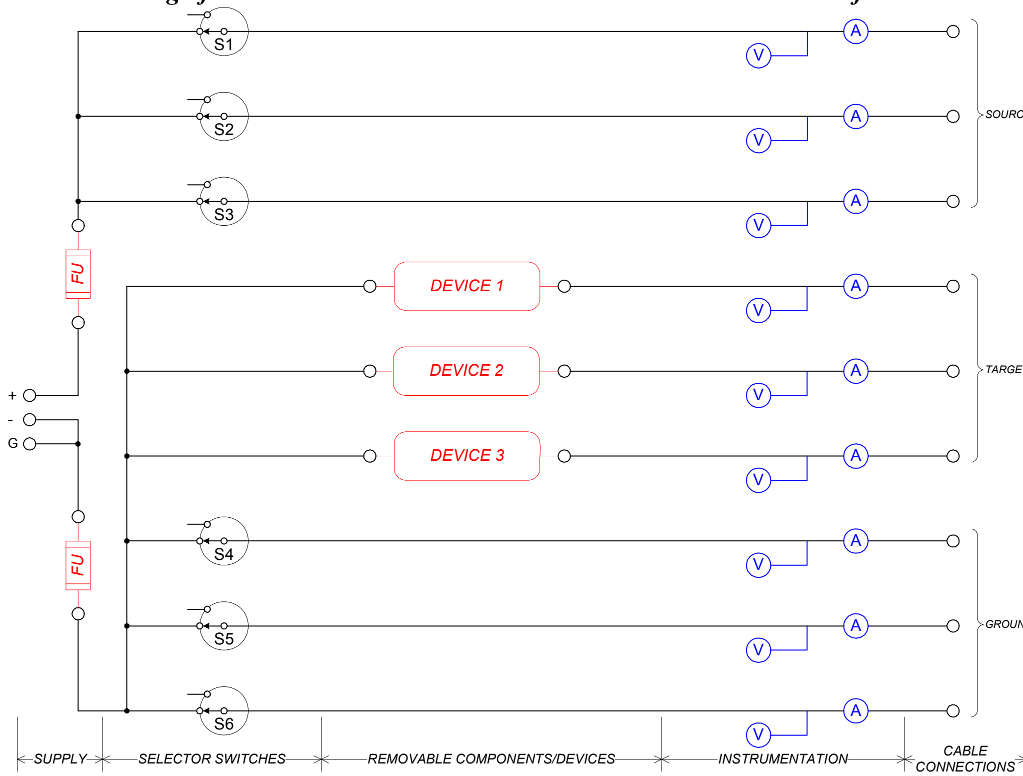


Figure 6: Basic Control Circuit Simulator Design.

Each of the cable connection points is monitored for voltage (referenced to the negative side of the power supply) and current flow. These readings will be used to indicate interactions between individual conductors and/or the conductors to ground. The magnitude of the readings will enable the monitoring of insulation resistance degradation as the cable damage progresses. Also, actuation of the target devices will help demonstrate that the severity of the short circuit is sufficient to meet the pickup and hold requirements of the target component(s). Note that because large surge currents are anticipated given the nature of the DC battery bank power supplies, the use of Hall-effect current monitoring devices (rather than in-line devices) is anticipated. Also note that for specific circuits (i.e., the breaker disconnect circuit) the actual circuit may include separate fusing of two energized source and return conductors (not shown in this illustration).

These surrogate circuit simulation units will be used to obtain circuit behavior data in a manner similar to the motor operated valve (MOV) surrogate test circuits utilized during the EPRI/NEI test series in 2001 and during CAROLFIRE. Specifically we will be interested in the timing and duration of any spurious actuations of the target devices, fuse blows, etc. The intent of this design is: (1) to provide for a wider variety of surrogate test circuits than those previously tested, (2) to simplify and standardize the testing process and procedures while allowing for flexibility in the test circuits, and (3) to allow for portability of the surrogate circuit units to support testing at alternate test facilities.

Appendices B through F show the variety of simulated control circuit application capabilities of these units that are determined primarily by the selection of appropriate target devices and power sources.

Appendix B: AC Motor Operated Valve

Figure 7 shows an analog of the simulated MOV control circuit that was employed during the early EPRI/NEI tests and during CAROLFIRE. The shaded area represents the basic control circuit simulator. An AC power source, a 1750-ohm resistor representing an indicator lamp, and two relay coil targets are connected to the simulated circuit. A seven-conductor cable connected to the SCDU is the device under test.

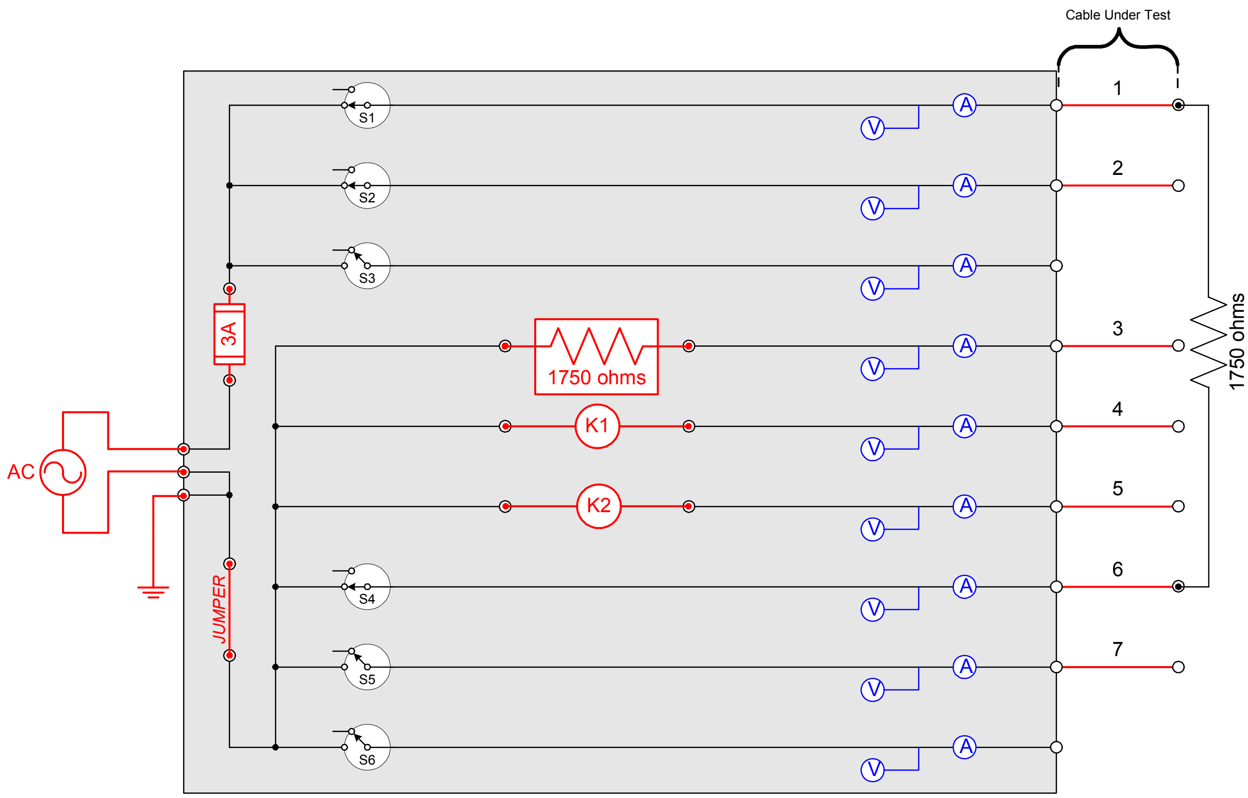


Figure 7: Simulated AC Motor Operated Valve Control Circuit, Without CPT.

Figure 8 shows the same control circuit being powered through a control power transformer (CPT). It should be noted that by changing the switch arrangements, these cable configurations can be easily changed, for example, to connect the ungrounded spare conductor (#7) to ground, or, if desired, to change conductor #2 from an energized state to an ungrounded spare.

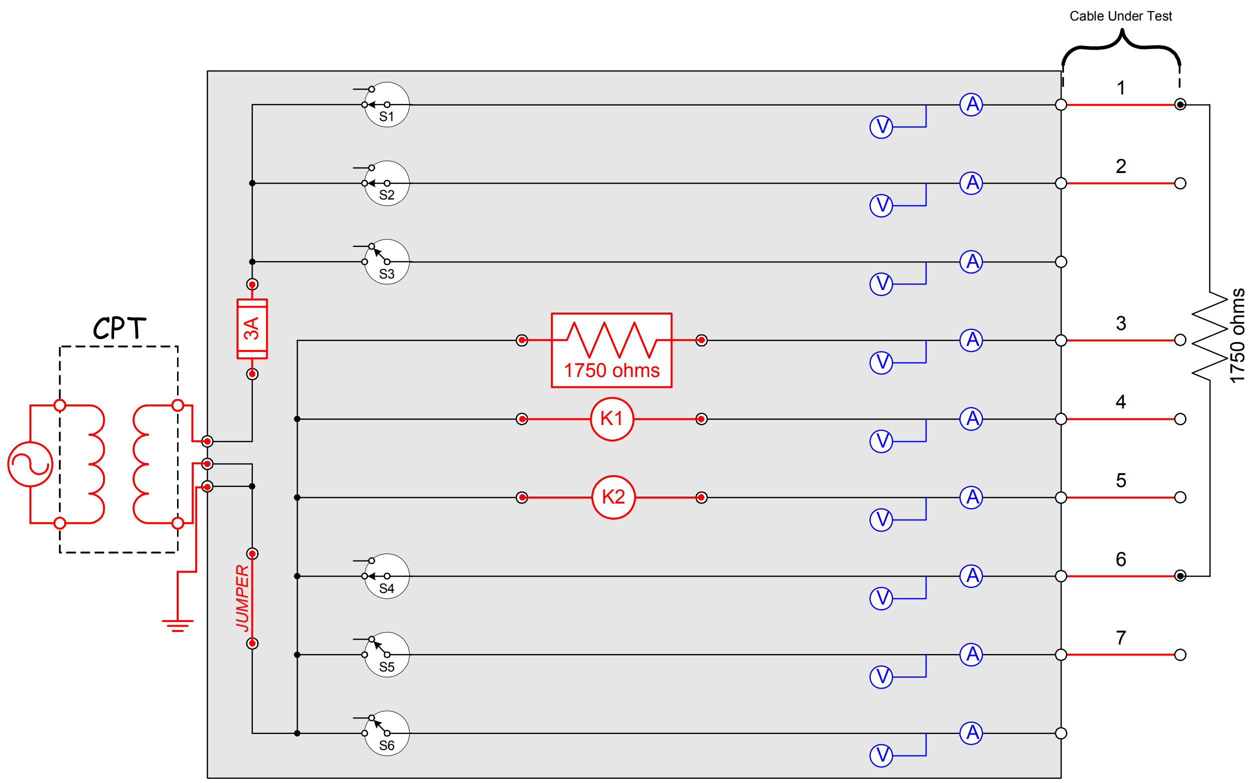


Figure 8: Simulated AC Motor Operated Valve Control Circuit, With CPT.

The only design change currently planned relative to the SCDUs is replacement of the existing motor starter relays. The motor starters used during CAROLFIRE were, in hindsight, found to require far less motive power to lock in and hold a spurious actuation signal than anticipated. The intent in CAROLFIRE had been to obtain motor starters that required a nominal 100 VAC of power to lock in a relay actuation. In practice, while the relays obtained were cited as 100VAC relays, it actually took a much smaller power level to lock in an actuation (on the order of 60 VAC). As a result, CAROLFIRE was unable to resolve one of the original Regulatory Information Summary (RIS) 2004-03, "Risk-Informed Approach for Post-Fire Safe-Shutdown Circuit Inspections," unresolved issues; namely, that item related to how CPT size relative to the nominal circuit required power would impact spurious actuation likelihood. The CPT units used in CAROLFIRE were sized against the anticipated 100VAC power requirement for the relays. Given the actual power requirement of the relays, the CPTs were, in effect, over-sized. As a result the CAROLFIRE tests did not experience the same type of CPT power drawdown observed in the original NEI/EPRI testing program.

The DC circuit tests provide another opportunity to explore and resolve this issue.

Hence, the existing motor started contactor relays will be replaced with Joslyn-Clark[9] relays of the same type used in the original 2001 NEI/EPRI test program (current part number is T30U031). Each of the procured relays will be tested prior to any fire testing to characterize power requirements. However, based on the NEI/EPRI tests, a nominal power load of 100VAC is anticipated. Hence, the originally procured CPTs should be perfectly suitable to the testing objectives and will not require replacement. All other aspects of the SCDU deployment will mirror CAROLFIRE and the AC MOV control circuits.

One final aspect of the SCDU deployment that remains under consideration is the inclusion of mechanical interlock devices for the reversing motor starter relays. That is, a typical motor starter set for an MOV would include mechanical interlocks that prevent both relay coils from being activated concurrently. As deployed in each of the prior circuit failure modes and effects testing programs, the mechanical interlocks have been deleted from the circuit design. The intent of those prior tests was to maximize the shorting information obtained. It is not clear that this objective and approach remains valid.

For the DC circuit testing project, consideration is being given to the possibility of including the mechanical interlocks in the motor starters and the circuit design. This would more realistically represent the actual plant circuit implementation, and provide a new aspect to the test data not previously explored. This change could be important to the CPT power draw-down issue as well. Nominally, the planned approach is to conduct tests both with and without the mechanical interlocks and to compare the results as a part of the CPT drawdown analysis. Each intermediate scale test provides an opportunity to field all four of the AC SCDU systems; hence, there is an opportunity to gather as many as 80 additional test data points relative to unit performance (assuming all 20 tests in the primary intermediate scale test matrix are completed).

[9] Note that the EPRI test report (TR-1003326, page 4-13) cites "AO Smith (Clark Controls Division) Catalog #30U031" as the make and model of the motor starters used in that test program. AO Smith has since merged with Joslyn controls. The combined company is known as Joslyn-Clark Controls. The same model motor starter relays are sold under the Joslyn-Clark brand using essentially the same catalog number (T30U031).

Appendix C: DC Motor Operated Valve

A typical DC MOV control circuit is illustrated in Figure 9. This drawing was derived from a Reactor Core Isolation Cooling (RCIC) MOV found at a currently operating U.S. nuclear facility. This circuit has also been used as an analysis example during the annual RES/EPRI fire PRA training course. The corresponding block diagram displayed in Figure 10 illustrates the basic location MOV with respect to the various control and power distribution cabinets. Note that the specific conductors present in each connecting cable are indicated on the block diagram (e.g., conductors P, N, YC1, G, R, etc.) and these designations correspond to the conductor designations in the circuit diagram.

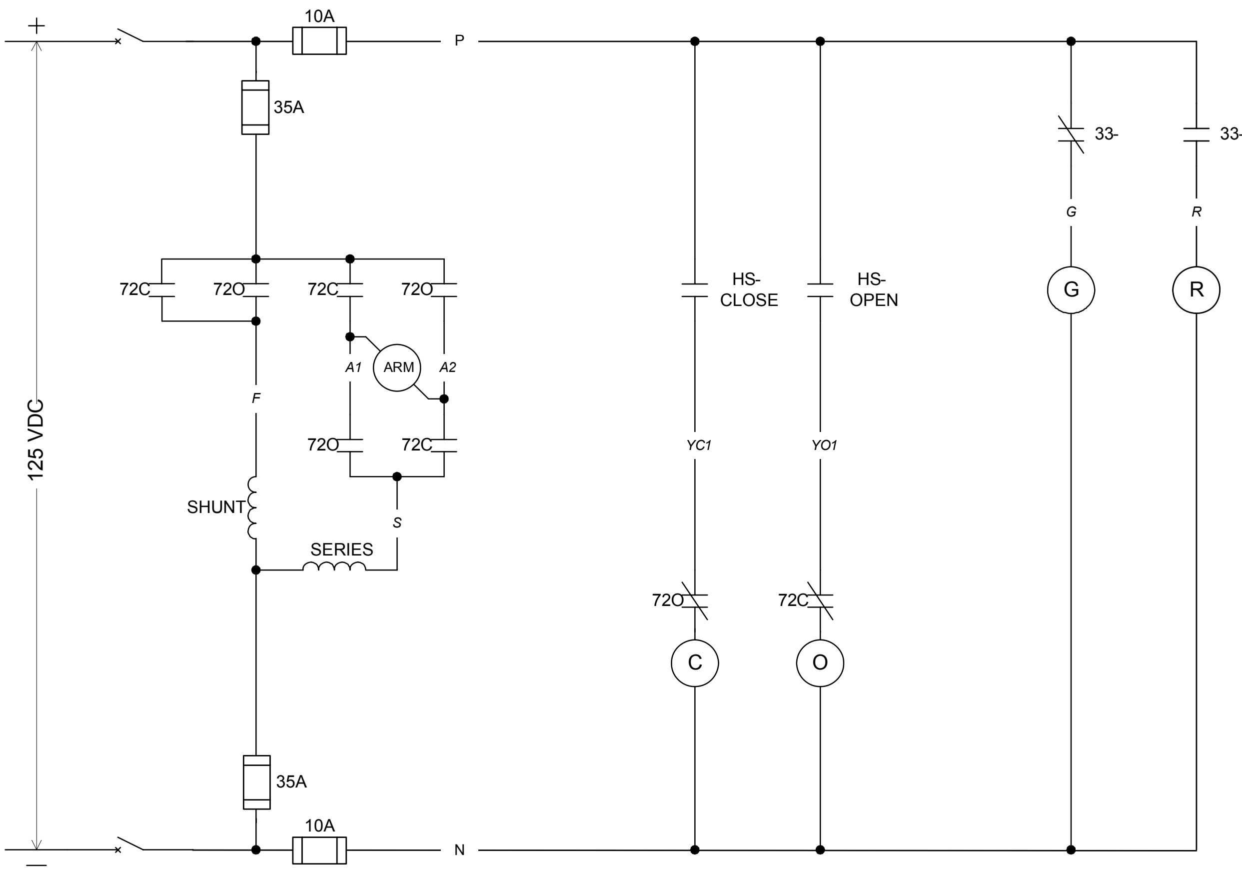


Figure 9: Electrical Schematic Diagram of a Typical DC Motor Operated Value (MOV)

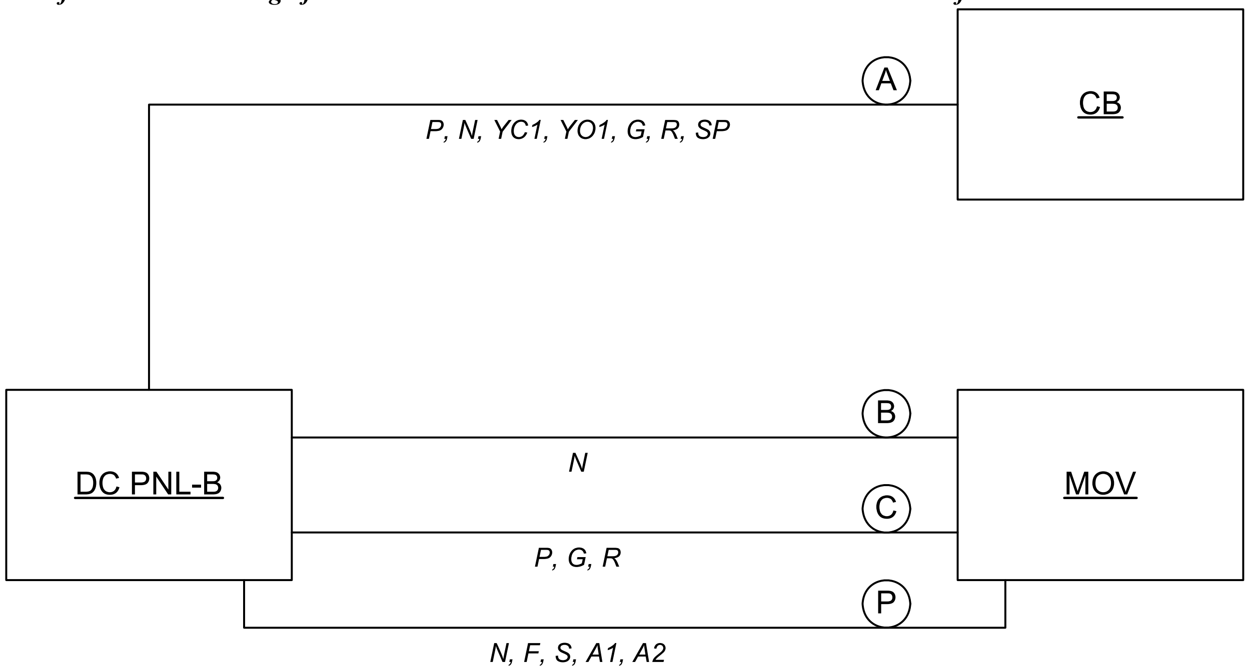


Figure 10: Block Diagram of a DC Motor Operated Valve

The right-hand portion of the circuit schematic diagram (Figure 9) is of primary interest to this effort as this represents the control portion of the circuit. This is that portion of the circuit fed through the two 10-amp fuses. That portion to the left-of-center represents the motor of the MOV itself (that part fed through the 35A fuses). The intent is not to simulate this portion of the circuit.

With respect to spurious actuation potential, Cable A as shown in the block diagram is the target of interest. This cable does contain all of the conductors necessary to cause a spurious actuation of the valve circuit, and the DCCCS for this circuit is based on connections to this cable. The corresponding DCCCS unit implementation is illustrated in Figure 11.

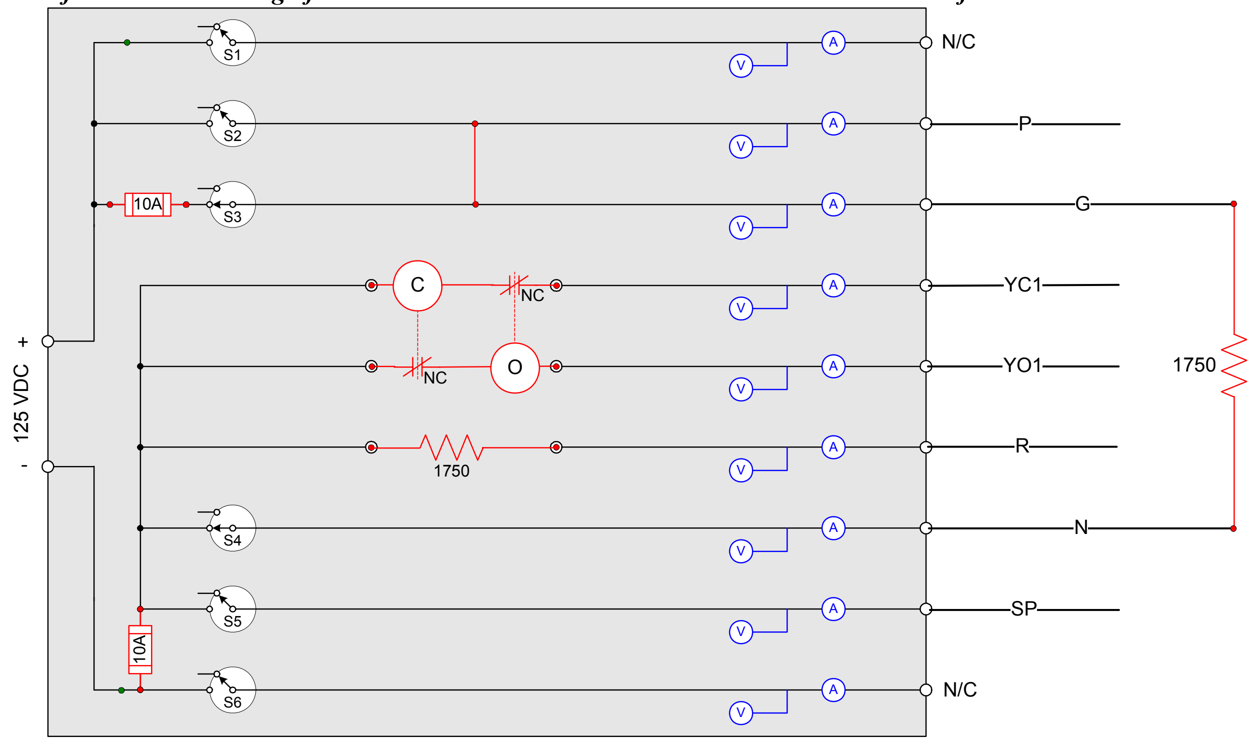


Figure 11: DCCCS layout for the control circuit on a DC MOV.

Appendix D: 4kV Circuit Breaker Control Circuit

Figure 12 shows a representative schematic of a DC control circuit for a 4160V air operated circuit breakers. The anti-pumping circuitry shown in red is of interest in this test program to determine the effects that it has on limiting the occurrence of multiple repetitive spurious actuations, or actuation after the breaker had been tripped by operator actions.

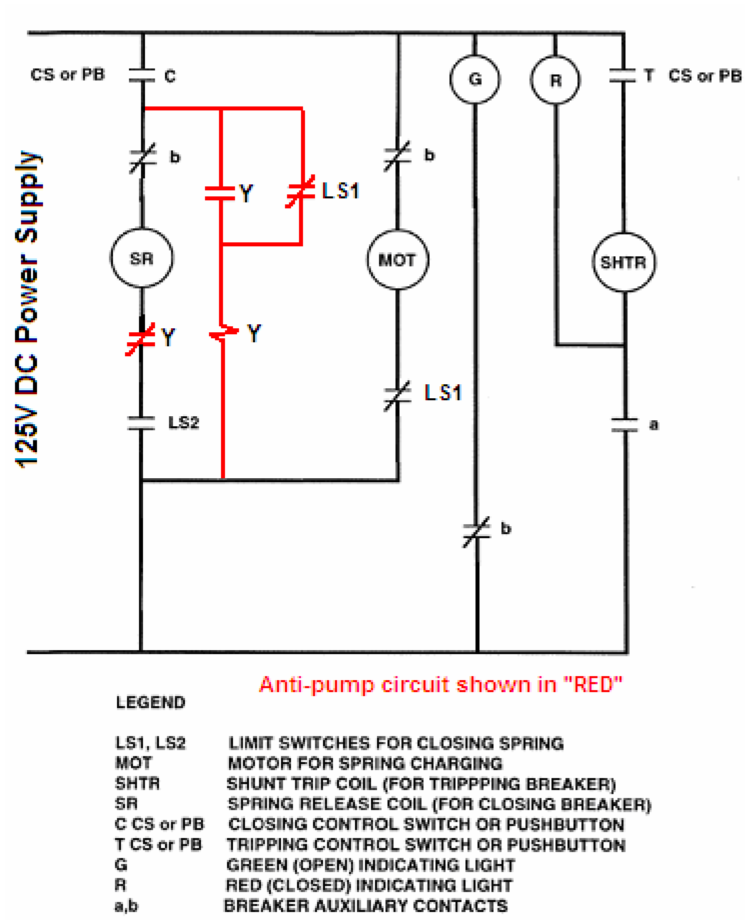


Figure 12: 4.16kV Circuit Breaker Schematic

This one aspect of the circuit, the anti-pumping feature, will not be simulated; rather, the intent is that an actual 4.16 kV breaker will be used. It is believed that using and monitoring the actual circuit breaker will be more representative of the actual device and implementation errors and uncertainties associated with designing a simulation circuit will be reduced. Breaker spurious actuation status and the “Y” anti-pumping coil status will be monitored during the testing and recorded on the data acquisition system.

Figure 13 illustrates a switchgear circuit which was derived from an actual RHR pump circuit breaker control design used by a typical U.S. nuclear power plant. The block diagram provided in Figure 14 depicts the location of the switchgear in the NPP. The corresponding DCCCS implementation is illustrated in Figure 15. Note that the DCCCS breaker design includes both 15-amp and 35-amp fuses each set feeding different portions of the control circuit. In this case, the larger fuse set powers the breaker trip circuit and the smaller set powers the breaker close portion of the circuit. This feature of the DCCCS is similar to the actual circuit breaker diagram shown in Figure 13.

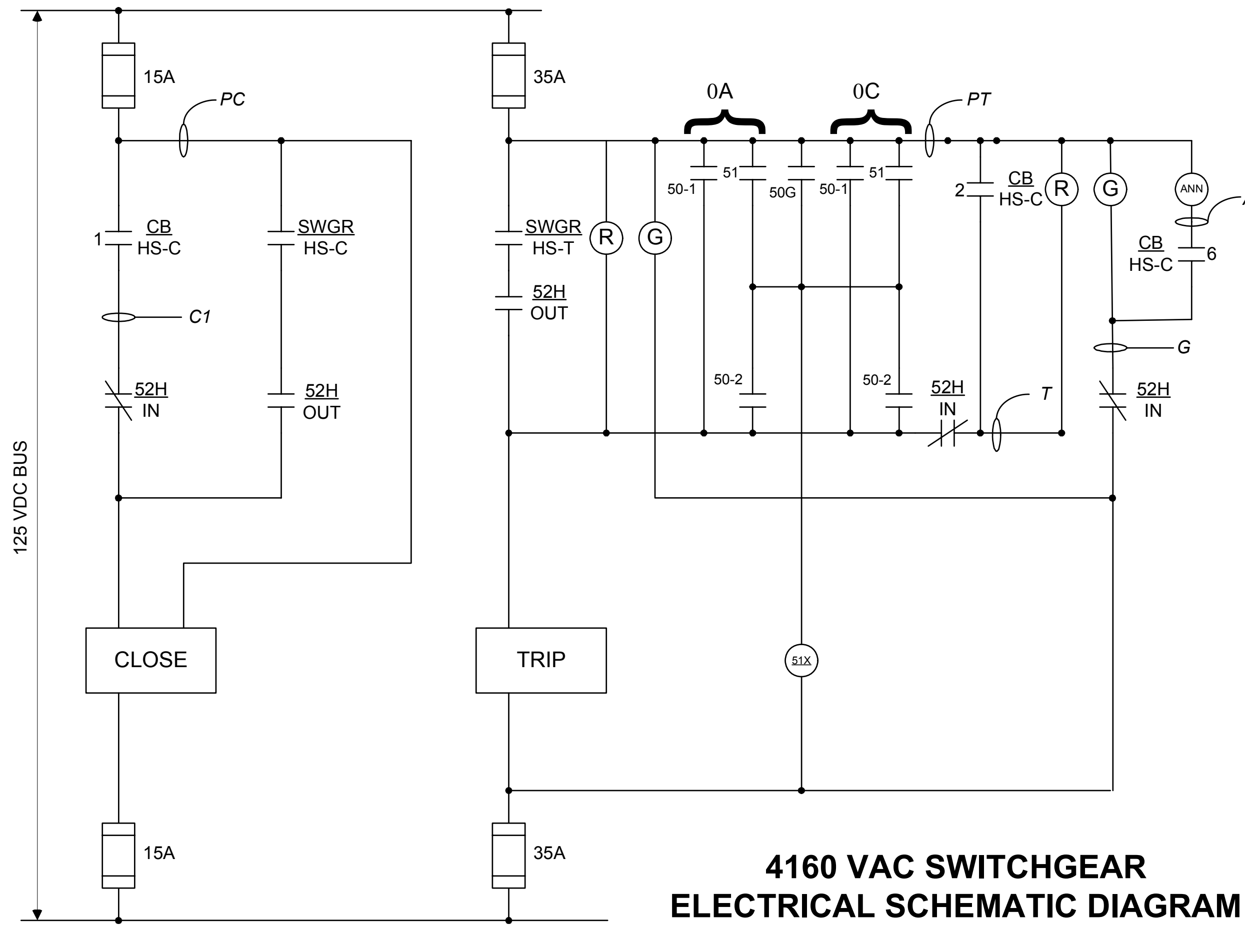


Figure 13: Electrical Schematic Diagram for Typical 4160 VAC Switchgear

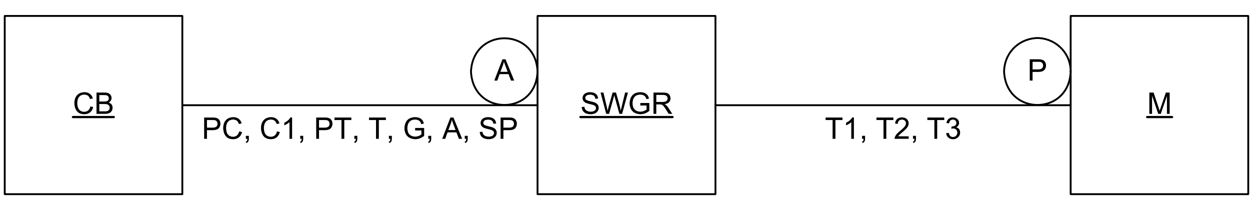


Figure 14: Block Diagram for Typical 4160 VAC Switchgear

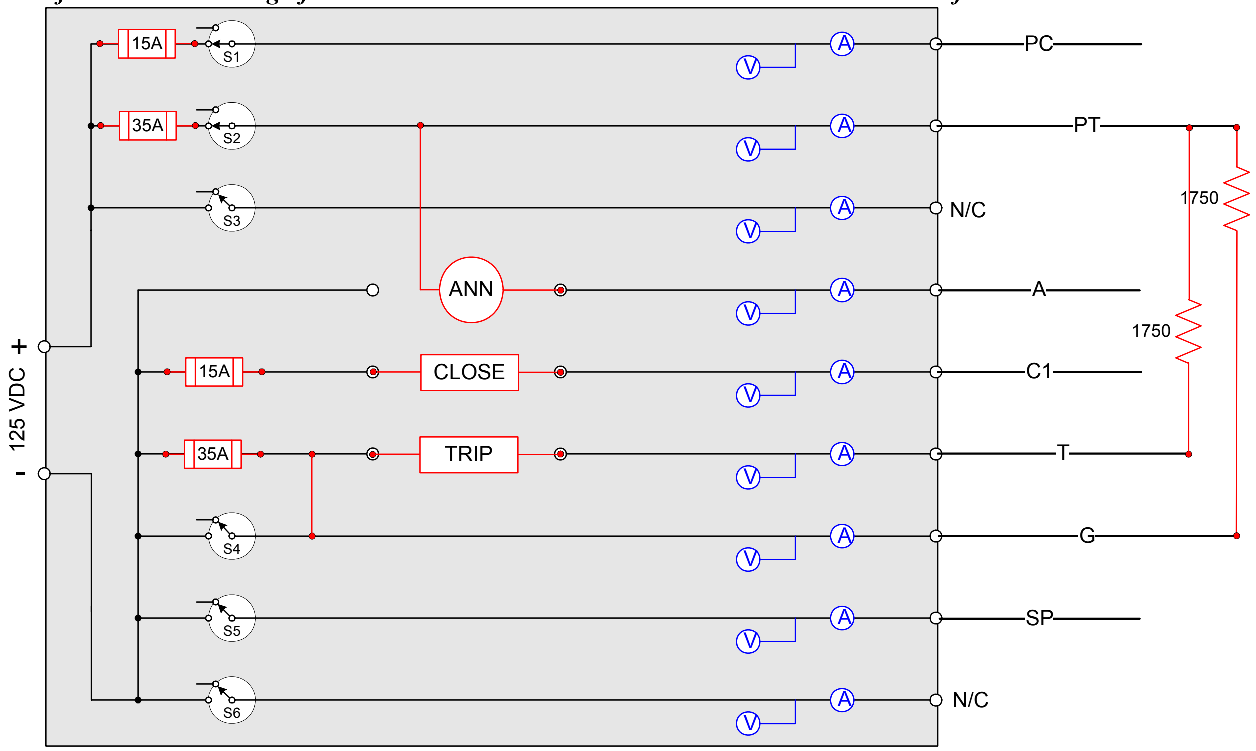


Figure 15: DCCCS Layout for the control circuit on a typical 4160 VAC switchgear

Appendix E: Small Solenoid Operated Valve

A schematic of a typical small SOV control circuit is shown in Figure 16. This schematic was derived from an actual plant circuit, and has been used as an example analysis case in the RES/EPRI fire PRA training program. The corresponding block diagram is shown in Figure 17. The corresponding DCCCS implementation for this circuit, assuming fire-induced failure of cable B as shown in the block diagram is the potential concern, is illustrated in Figure 18.

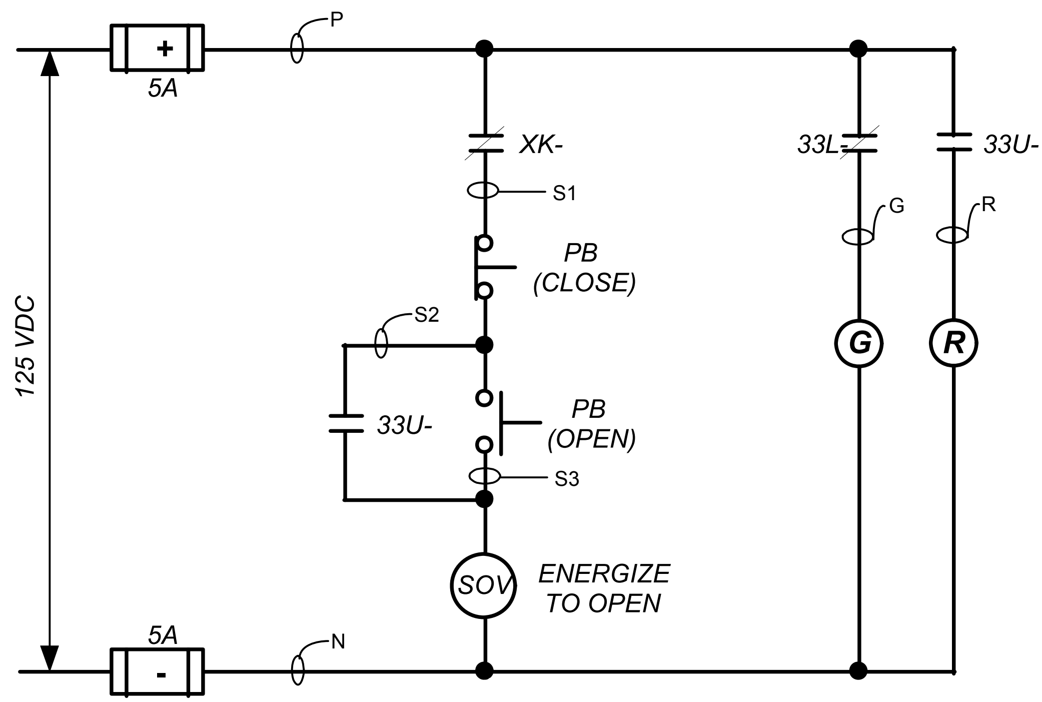


Figure 16: Electrical Schematic Diagram for a Small Solenoid Operated Valve

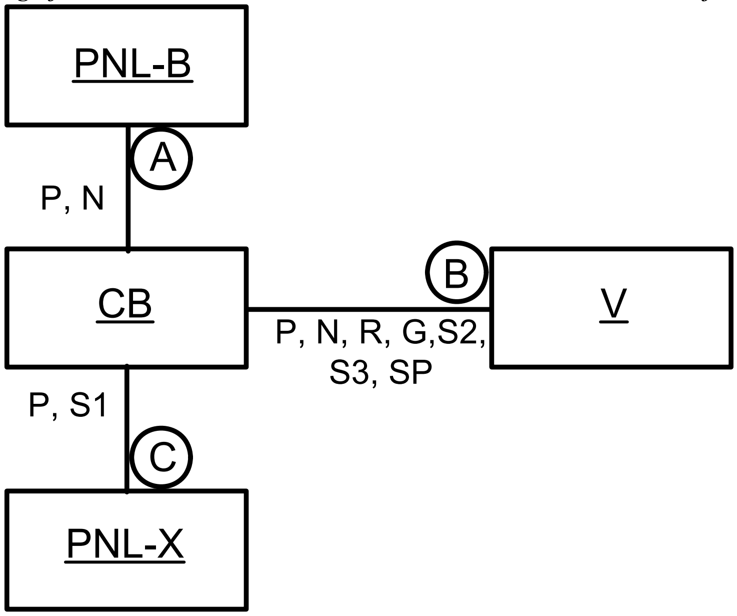


Figure 17: Block Diagram of a Small Solenoid Operated Valve

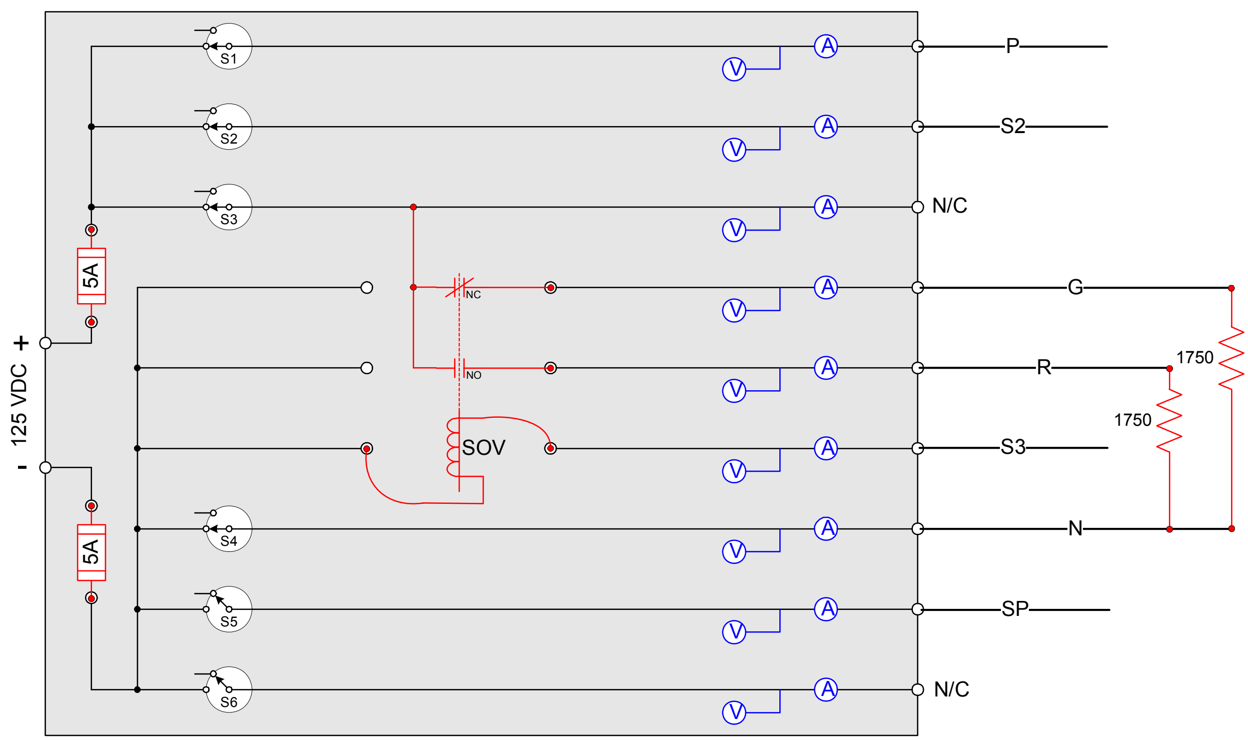


Figure 18: DCCCS Layout for a Small SOV DC Circuit

Appendix F: Power Operated Relief Valve Circuit

The power operated relief valve (PORV) simulated circuit, Figure 19, will be of similar construction to that shown above for the SOV in Figure 16. This design was also based on circuits used in the Fire PRA training course. For the PORV circuit, the valve coil is much larger coil and the fusing is correspondingly larger. The block diagram, Figure 20, is also similar. The DCCCS implementation of this circuit is shown in Figure 21. Again, the DCCCS implementation assumes that fire-induced failure of cable B in the block diagram is the potential spurious actuation concern. PORVs with double contacts will also be investigated to a limited capacity. Figure 23 illustrates the circuit diagram, Figure 24 shows the block diagram, and Figure 25 displays the DCCCS implementation for the double contact design.

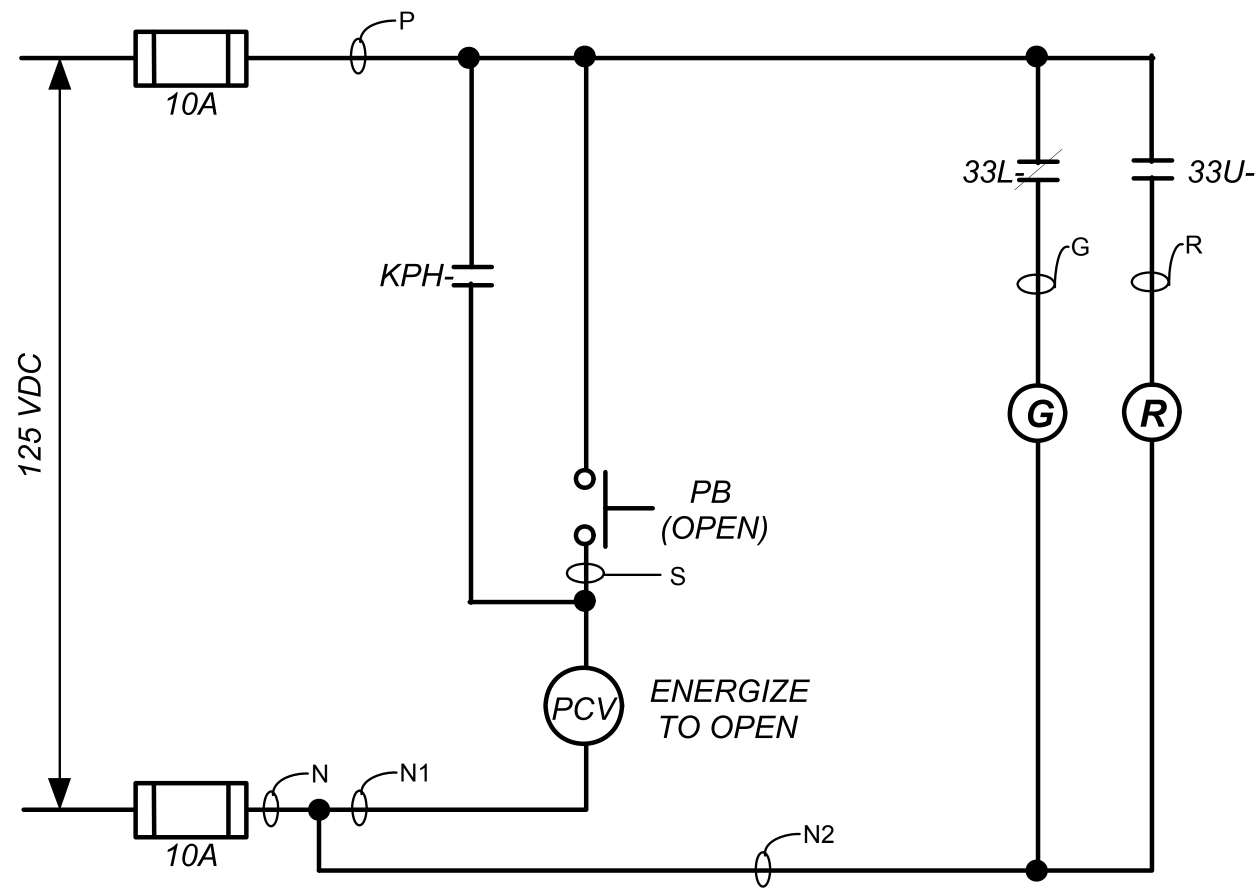


Figure 19: Electrical Schematic Diagram of a Typical Power Operated Valve (PORV)

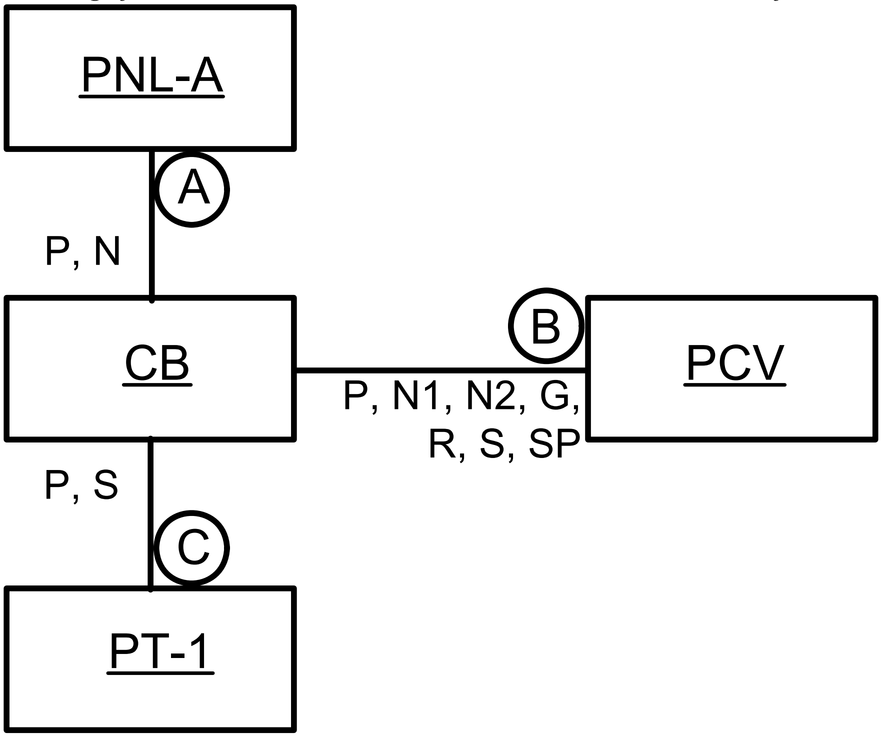


Figure 20: Block Diagram of a DC Power Operated Relief Valve

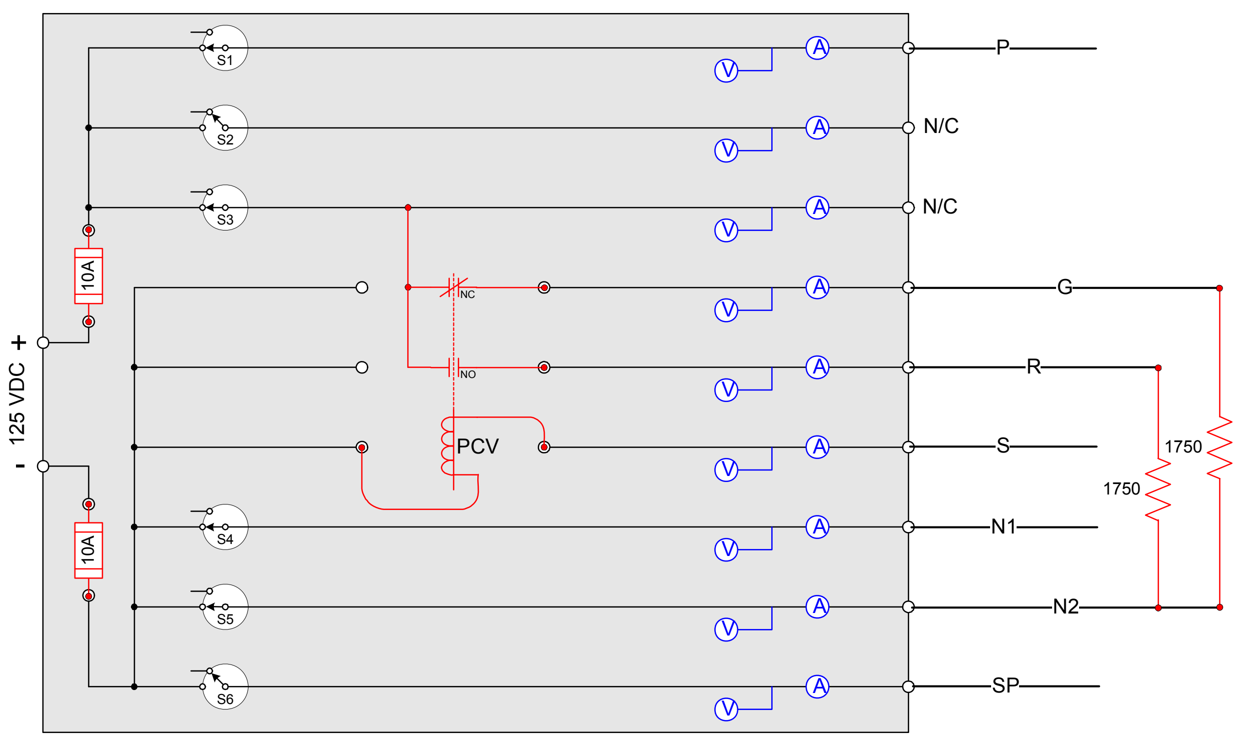


Figure 21: DCCCS Layout of a Typical DC Power Operated Valve (PORV)

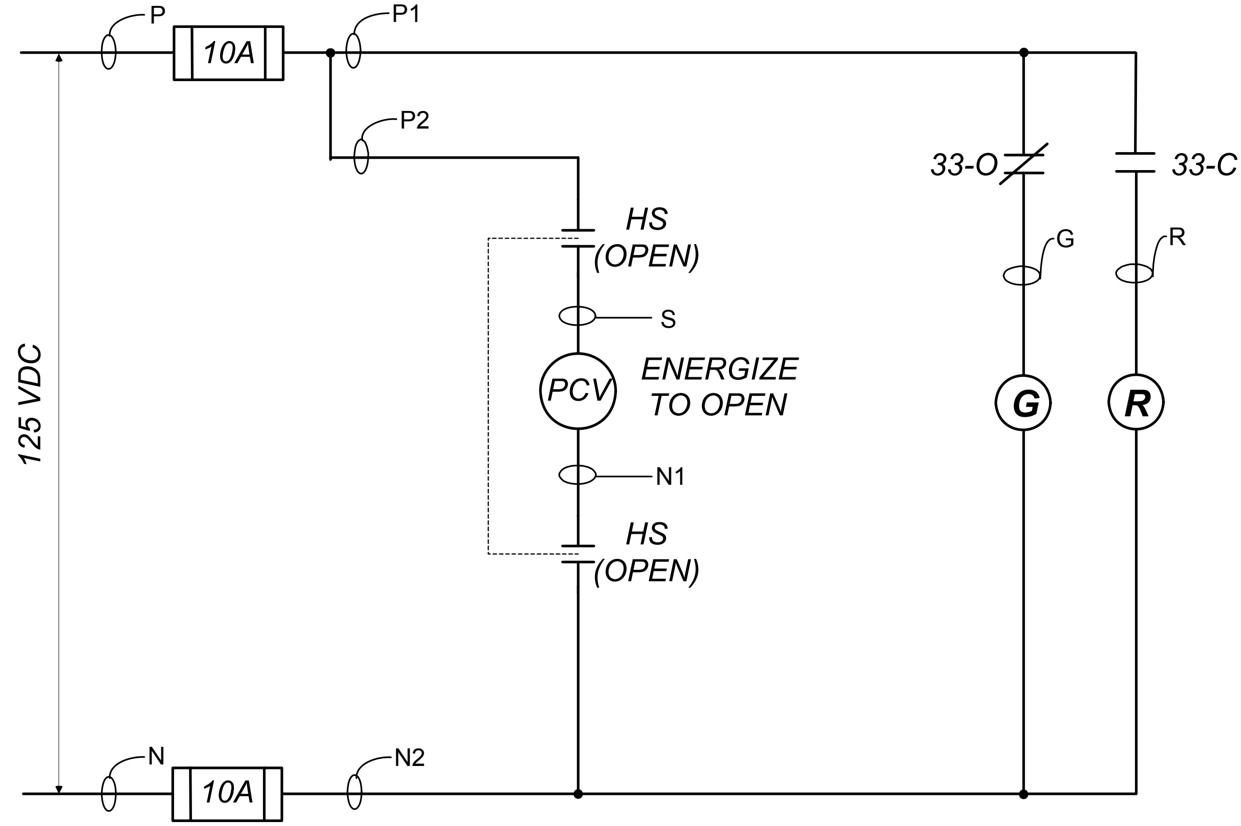


Figure 22: Electrical schematic diagram of a power operated relief valve with double contacts

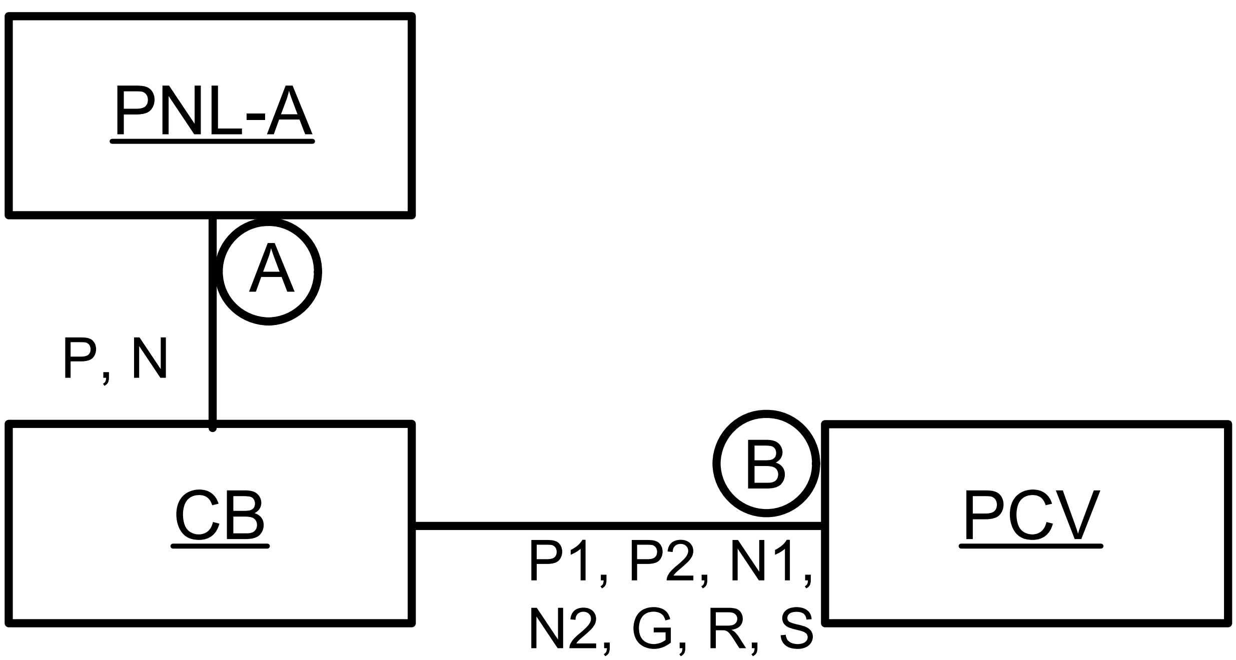


Figure 23: Block diagram of a power operated relief valve with double contacts

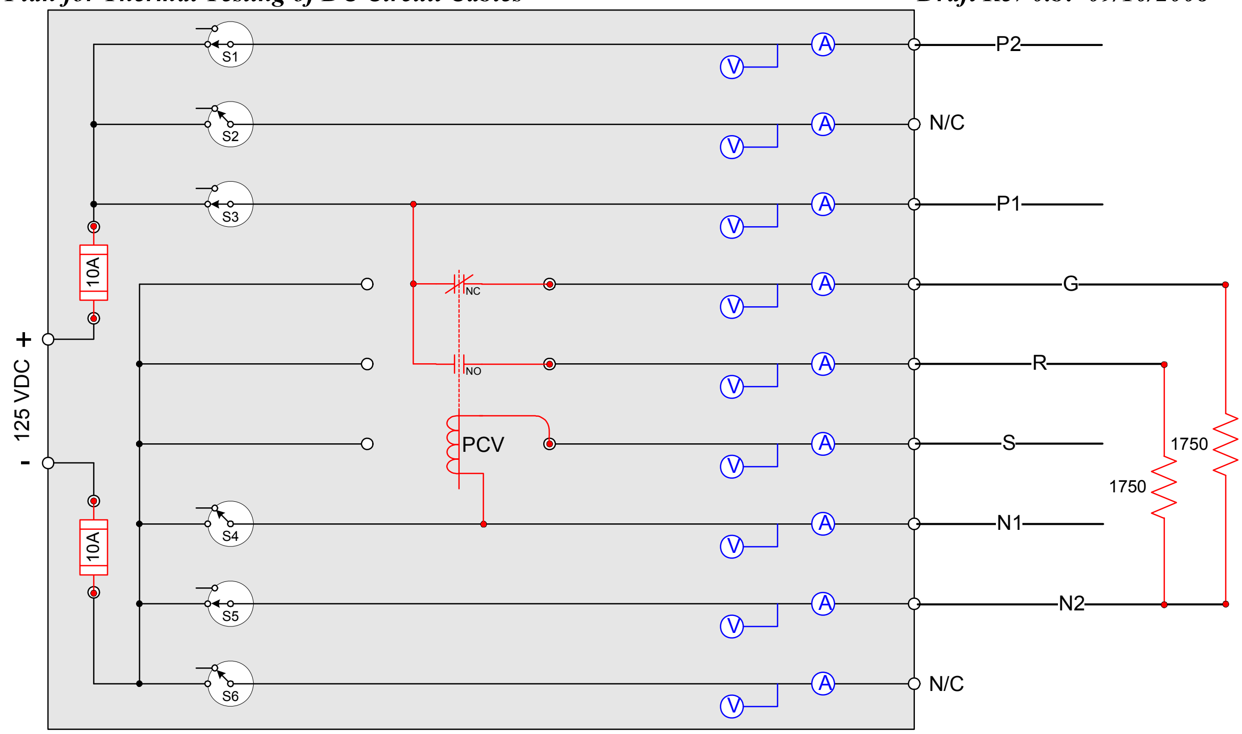


Figure 24: DCCCS Layout for the power operated relief valve with double contacts

Appendix G: Instrumentation Circuit

A schematic representation that simulates a typical 4-20mA instrument loop is shown in Figure 25. The instrument loop circuit consists of a low-power current source, fuses to protect the components in the event of an unwanted voltage surge, two 10 Ω resistors to simulate a long run of instrument cable (~610 m (2000 ft) as opposed to the short length exposed during the fire test), a 250-Ω load resistor, and a voltmeter to provide the simulated readout circuit. Note that the 250-Ω load resistor is analogous to a shunt resistor in an output meter that would convert the 4 to 20 mA signal into a 1 to 5 V signal. Use of such a shunt resistor at the output device is typical of many instrumentation circuit designs.

The circuit will be driven by a constant current output from the current source of nominally 15 mA. As the fire degrades the instrument cable, some current would leak between the cable conductors resulting in an apparent drop in the instrument signal at the display device. That is, portions of the fixed 15 mA current signal could leak directly from conductor to conductor bypassing the load/shunt resistor. This behavior would be reflected as an inaccurate reading at the load resistor/voltmeter assembly.

Note that in presenting the data from this device, the actual measured output voltage can be converted to an equivalent 0 to 100% process variable scale to ease the interpretation of the results. That is, an output reading of 1 V corresponds to 0% on the process variable scale, and an output reading of 5 V corresponds to 100% on the process variable scale. Given the 15 mA constant input current, a reading of about 68% on the process variable scale is expected.

If the two conductors form a “hard” (or very low impedance) short, the reading would go off-scale low on the process variable scale (i.e., a zero voltage would be off-scale low because the minimum anticipated current load under normal circuit conditions is 4 mA).

This circuit is suitable for testing with typical twisted-pair instrument cables in particular. For testing the cable shield wrap (typically present in such cables) will be connected to electrical ground (via a drain wire) as would be typical practice.

In this case the circuit is of such a simplistic nature that implementation via a SCDU or DCCCS type circuit simulator is not necessary. Rather, the instrument loop will be implemented directly as shown.

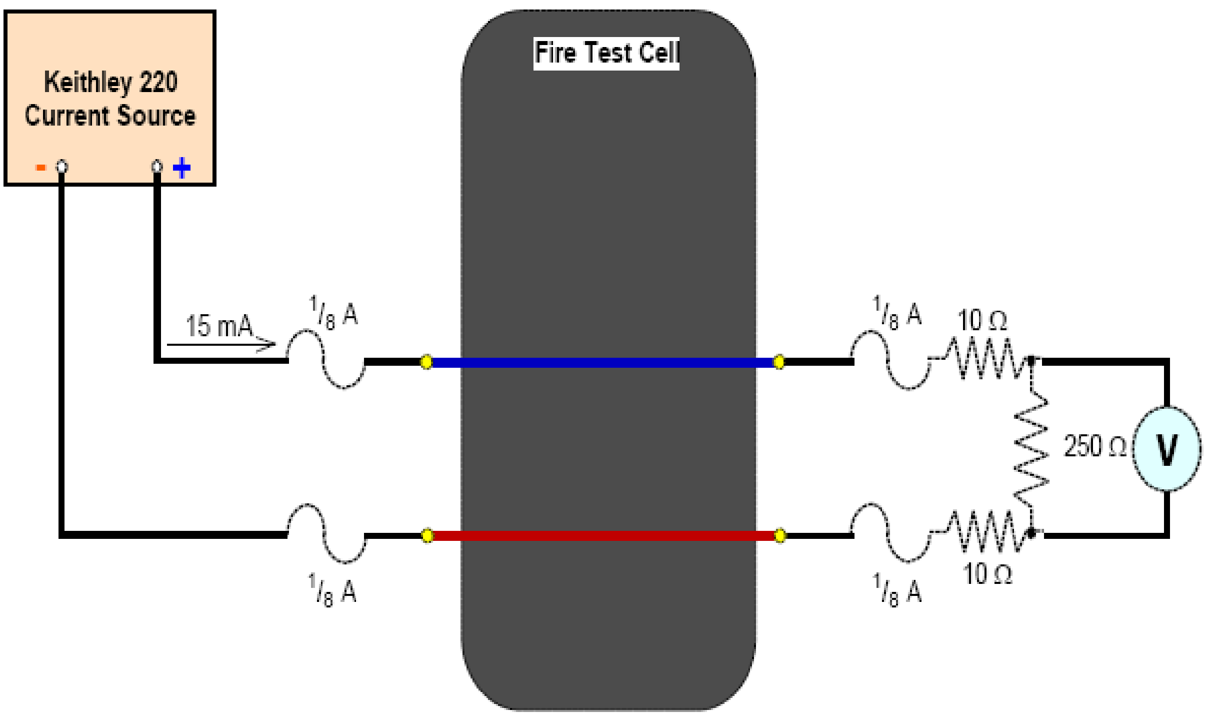


Figure 25: Schematic Representation of the Instrument Loop Mock-Up

Appendix H: Design of the Battery Bank DC Power Supplies

H.1 Working Design Assumptions

Basic Assumptions:

- 125 V DC output or 250 VDC output
- test duration is 20 minutes
- average current draw per test is 20 amps
- three tests per day
- battery charger not operating during experiment

Battery Specifications:

- components mounted on wood skid for 125 VDC module
- 2 skids connected in series to obtain 250 VDC
- 10 batteries connected in series
- each battery
    - 12 volts
    - size - group 24
    - reserve capacity of 110 minutes minimum
- deep cycle is not needed
- terminals are top posts

Battery Charger Specifications:

- Input: 120 V AC - less than 8 amps
- Output: 60 V DC nominal - 5 amps minimum
- Two chargers wired in series is required

Power Distribution Specifications:

- battery case interlock
    - interlock switch inside the battery case is opened when the battery case when it is open
    - interlock switch operates to contactors
        - battery charger input power - 10 Amp contacts – general purpose relay - 24 V DC coil
        - 250 - 125 VDC bus - 200 amp contacts – Albright 2 pole Contactor – 24 VDC coil part number SW 190B
- 200 amp fuse on each of the main output cables
    - 2 each Littelfuse fuse, part number JTD-200ID
    - 2 each Littelfuse fuse holder, part numberLJ60200-1C
    - Littelfuse parts can be obtained through Border States Electric (JIT supplier)

- branch circuit breakers
  - DC circuit breakers rated at 250 volts DC using 2 poles, 600VAC
  - DC circuit breakers are two pole
  - circuit breaker capacities range from 15 amp to over 50 amps
  - Industrial distribution panel manufactured by Siemens
  - suggested source: Border States Electric (JIT supplier)

H.2 Design Description

Figure 26 through Figure 31 provide various representations of the battery bank power supply system. This includes a general power schematic (Figure 26), a physical layout diagram (Figure 27 and Figure 28), voltage wiring diagrams (Figure 29), a breaker layout (Figure 30), and an enclosure layout (Figure 31). Specific aspects of the design are described in the following subsections.

Battery Enclosure

The battery enclosure is provided primarily for personnel safety and for spill containment. The enclosure uses individual ABS plastic boxes as secondary containment for the battery acid. These boxes have tops that can be utilized to prevent access to the battery terminals. The battery boxes are screwed to 2X6 dimensional lumber to form the battery enclosure base. Plywood sides around the 2X6s form a lid platform. The lift-off-lid is made of ½" plywood with a 6" skirt to ensure the lid stays on the battery enclosure. An interlock switch is used to disconnect the battery chargers and battery bank from the distribution panel when the lid is removed.

Battery Charging

The battery chargers are permanently connected to the batteries. This means the batteries can be charged simply by turning on the chargers. The chargers may be operated during the experiment, but it is recommended that the chargers be turned off to eliminate AC ripple from the battery output voltage. The chargers are manual as opposed to automatic. This means the chargers will continue to charge even though the batteries have a full charge. If the charger is allowed to operate for an extended period of time, the batteries will be overcharged and soon destroyed. To avoid the overcharging condition, a 12 hour timer has been included to limit the charging time.

250 Volt Operation

Obtaining 250 V direct current requires that the two 125 V power skids be connected in series. This interconnection is done inside both of the distribution panels with both skids de-energized. The abandoned phase in the distribution panel that becomes a 250 V circuit breaker box is used as interconnect the point. Figure 29 illustrates how the connections are made. The blue / dashed lines are the 250 volt interconnect wiring.

Distribution Panel

The specified distribution panel is normally used to operate as a 480 volt, three-phase AC panel. Using it with direct current requires that one of the phases be abandoned. This means that the placement of the circuit breakers within the panel is position sensitive. Normally, a circuit breaker panel phases are adjacent to each other so three pole breaker can be in one package.

The two pole breakers for the DC system are positioned to skip one slot so the third phase is not used and remains abandoned, see Figure 30.

Safety Discussion
The Direct Current power supply is ungrounded. The battery enclosure lid has an interlock that disconnects the load from the batteries and isolates the battery chargers. Also, load disconnect relay allows the operator to manually disconnect batteries. Disconnecting the load from the batteries while the enclosure lid is open will reduce the chance of sparking when a cable is disconnected. The batteries are laid out in three banks. Disconnecting the Quick Disconnect will reduce the exposed battery voltage to 48 volts maximum. Each battery is contained in a battery box with a top and each terminal has a non-conductive cover to prevent accidental battery bank voltage contact. Each battery charger is connected to five batteries across two battery banks. The charger outputs are isolated through the interlock circuitry. Isolating the battery chargers will prevent unexpected voltages due to charger power or feedback.

The main bus fuses are within the battery enclosure so the load is disconnected when the fuses are exposed.

Special precautions need to be taken when working within the battery enclosure.
The first step in servicing the batteries is to remove all jewelry and put personal protective equipment which includes thick rubber gloves, and a face shield. The second step is to separate the “Quick Cable Connector” (see Figure 27). After the “Quick Cable Connector” is disconnected, the battery banks are electrically separated from each other and the maximum voltage within the battery enclosure is reduced to 48 volts.

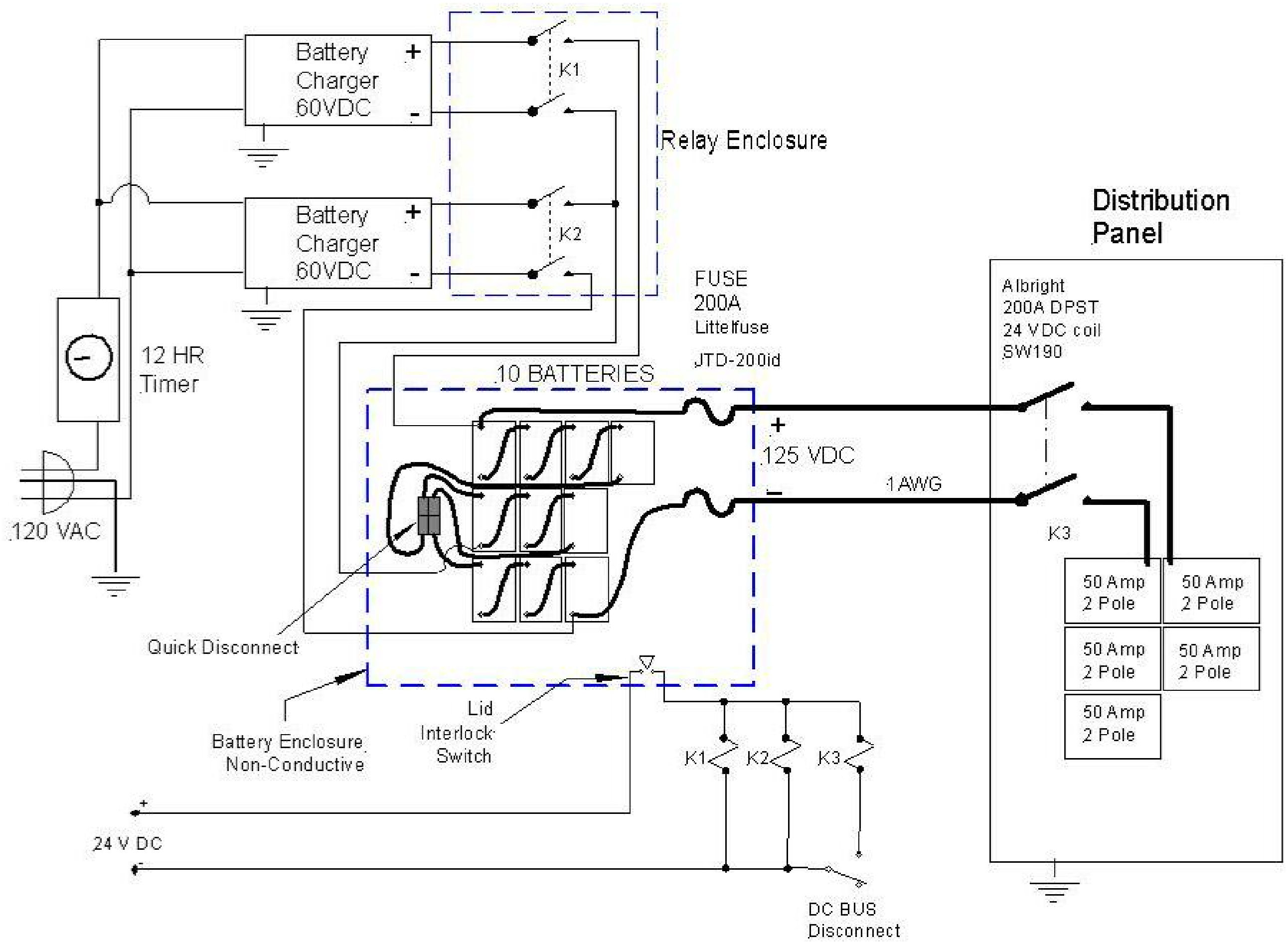


Figure 26: Direct Current Power Skid Schematic

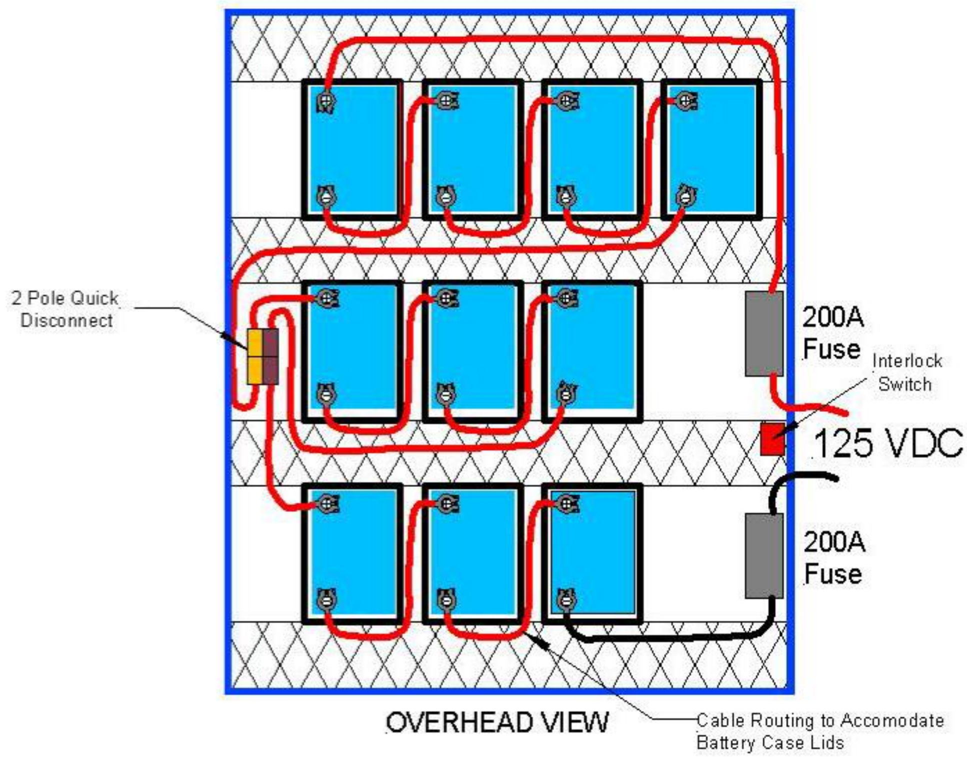


Figure 27: Battery Layout

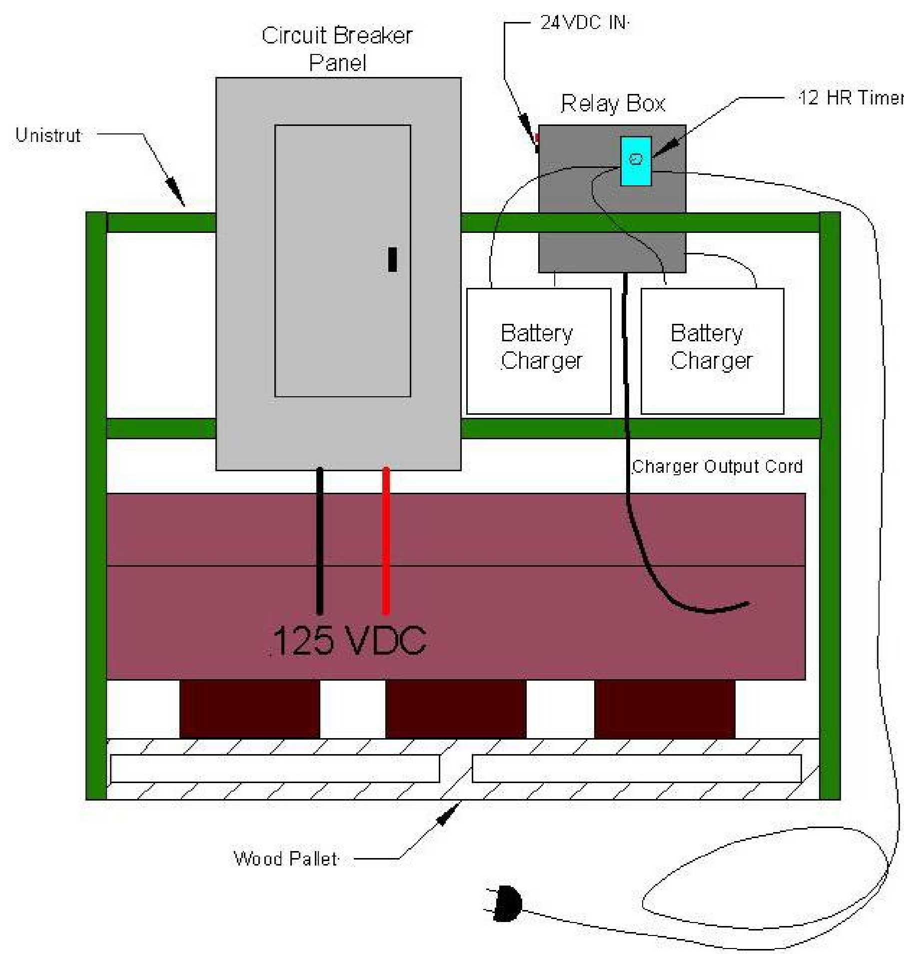


Figure 28: Power Skid Layout

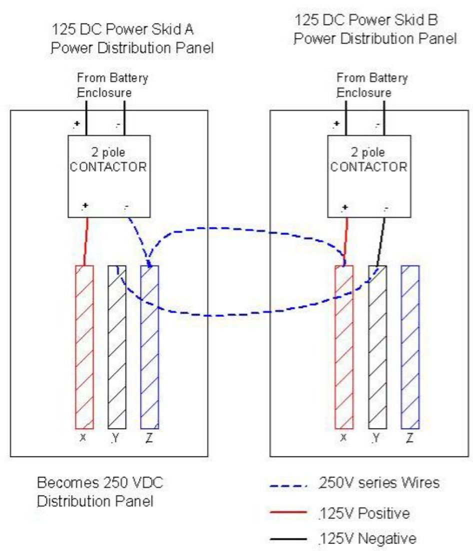


Figure 29: 250 Volt Wiring Diagram

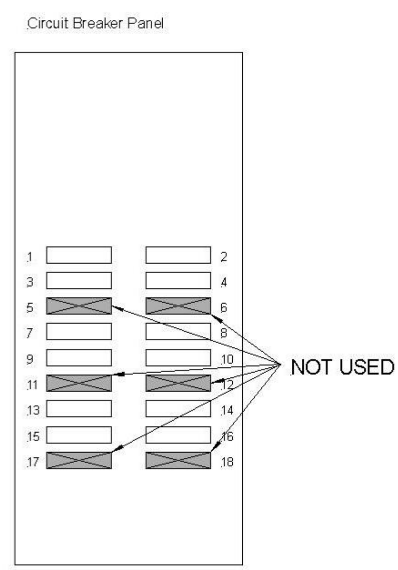


Figure 30: Circuit Breakers Layout

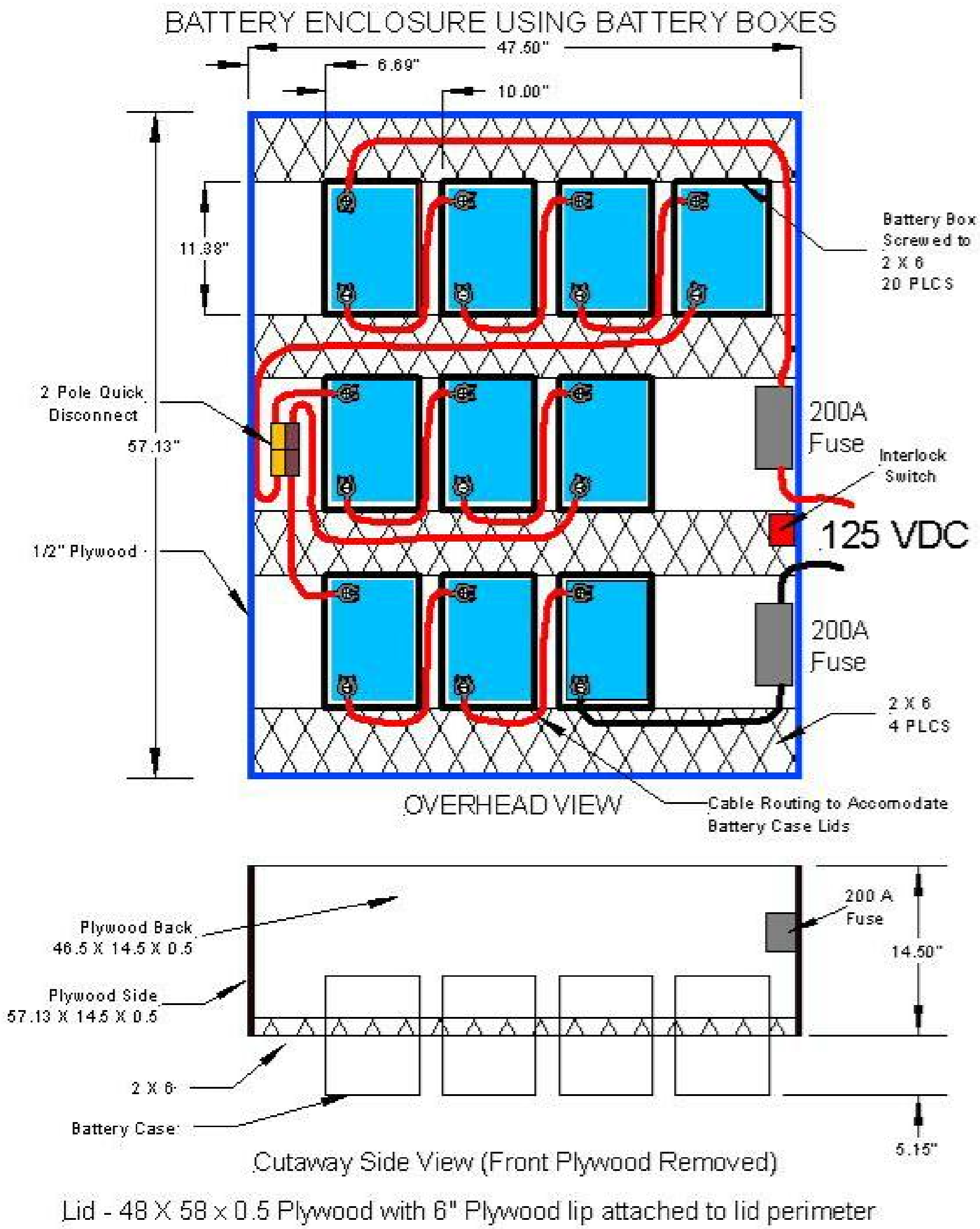


Figure 31: Battery Enclosure

H.3 Required DC Power Source Components for One 125 V Power Skid

Quantity	Description	Manufacturer	Part Number	Distributor
10	Battery, Group 24, Sealed Lead-Acid, 110 Minute Reserve Capacity	NAPA	BAT7524	NAPA Auto Parts
		Interstate	MT-24	Interstate Batteries
		AC Delco	24-7YR	Northeast Auto Electric
10	Battery, Group 24, Containment Box with Lid, Outside Dimensions 16x9.625x10.25 H	Attwood	ATT90651	Internet
10 Pair, Positive & Negative	Battery Post, Lead or Brass Terminals		BTC-1P	Electerm.com
			BTC-1N	Internet company
10 pair	Terminal Post, Protective Covers		BT-2/0R	Electerm.com
			BT-2/0B	Internet company
2	175 Amp, Cable Connector, Gray	Anderson Industrial	AN-6325G1	Electerm.com Internet Company
2	Battery Charger, Multivoltage, 12-72V, 5/10 amp	NAPA	NBC 85400	NAPA Auto Parts
1	Battery, Containment, 58x48x20	Sandia Fabricated	Wood Construction	
80 FT	1 AWG Cable, Locomotive Cable			Border States Electric
1	Contactor, 200 amp DPST, 24 VDC Coil	Albright	SW190B	tecknowledgey.com
				Internet company
2	Fuse, 200 Amp 125VDC	Littelfuse	JTD-200ID	Border States Electric
2	Fuse Holders, 200 amp Capacity	Littelfuse	LJ60200-1C	Border States Electric
1	Relay Enclosure, 12”x 12”x 6”		Fiberglass or steel	Border States Electric
2	Relay 2PDT, 10 A @ 120VAC, 24 VDC coil	IDEC	RH2B-UTDC24V	Newark Electronics, P/N 66M8470
2	Relay sockets for IDEC Relay	IDEC	SH2B-62	Newark Electronics, P/N 13M2864
1	Interlock switch, SPDT			
1	Circuit Breaker Enclosure with 18 Breaker Slots, Lug Main Connect	Siemens		Border States Electric
5	Circuit Breaker, BDQ Series, 2 Pole, 125 VDC Rated	Siemens	BD250 is the part number for 50A 2 pole	Border States Electric
1	Timer, Spring Wound. 120 VAC, 15 Amp SPST	Intermatic	FF12H	Border States Electric

H.4 Rejected Researched Products

Quantity	Description	Manufacturer	Part Number	Rejection Reason
1	Battery Charger, 120 Volt DC, 6 amp	Storage Batter Systems	AT10-130-006-U-240-SX	Price
1	Battery Charger, 120 Volt DC, 6 amp	Schaefer	B3567V-W-U00X Part # incomplete	Price
1	Contactor, 220 amp, 120 VAC Coil	TECO	CN-220-F6	Coil voltage too high to be powered by interlock circuit and the contactor voltage rating is to low
2	Contactor, 200 Amp SPST, 24 VDC Coil	Stancor	586-902	Contactor voltage rating is too low.
2	Fuse, 200 amp, 125 VDC	Bussmann	LPJ-200SP	Price
2	Fuse holder used with above fuse	Bussmann	J60200-1CR	Price and compatibility
10	Circuit Breakers, 1 pole 125 VDC	TYCO / Potter & Brumfield	W58-XC4C12A-30	Current capacity is too small (30 vs 50 needed), Sandia fabrication of a circuit breaker panel would be required

H.5 Specific Part Descriptions

200 Amp Contactor:
Manufacturer - Albright
http://www.tecknowledgey.com/catalog/product_info.php?cPath=57_60&products_id=528&osCsid=777b33f12a81cb5818793190f7dafb0b
Need to specify magnetic blowouts, large tips, DC coil, 24 Volt coil, continuous duty, dust cover, and Hat shaped bracket
120 VDC contact rating, 150 Amp continuous service, 200 amp 60% intermittent, 2 pole so only one relay is needed for each skid.

Protective Battery Terminal Covers:
http://www.electerm.com/battery.html
10 each per skid Red cover Part Number – BT-2/0R
10 each per skid Black cover Part Number – BT-2/0B

Battery Terminals:

Sandia will fabricate the battery cables using the terminals listed below and 1AWG locomotive cable

http://www.electerm.com/battery.html

10 each per skid – Positive terminal Part Number BTC-1P

10 each per skid – Negative terminal Part Number BTC-1N