APPLICATIONS OF THERMAL REPLICA RELAYS TO OPTIMIZE INTERTIE EMERGENCY CAPABILITY

By:

EDGAR R. TERLAU, II
SCOTT L. HAYES
MOHAMMAD Y. VAZIRI
PACIFIC GAS & ELECTRIC CO.
SACRAMENTO, CALIFORNIA

and

JAY CAMPBELL
SIERRA PACIFIC POWER CO.

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ABSTRACT

This paper describes the application of thermal replica relays. PG&E has designed and built several thermal replica schemes to protect transmission lines from exceeding their thermal capacity. These schemes have allowed PG&E to utilize its existing facilities to the most economic limit with a minimal increase in risk. The scheme described in this paper provides thermal protection to PG&E lines from a potential overloading condition that may occur during exports to a neighbor utility. The scheme consists of nine thermal relays, three transfer trip channels from remote stations, necessary tripping logic to sever the tie to the neighbor utility, and a computer program for monitoring.

The Thermal Replica relay selected for this scheme was the Schweitzer SEL-49 relay. The SEL-49 relay incorporates most of the variables that determined conductor temperature and therefore conductor current capability.

INTRODUCTION

For more than 60 years, Pacific Gas and Electric Company (PG&E) and Sierra Pacific Power Company (SPP) have had an import/export contract for their transmission intertie. The intertie consists of two 115 kV lines and one 60 kV line. For many years, the contract had called for 108 MW of firm capacity support for SPP. Transmission planners projected that increasing loads would quickly reduce the firm capacity that could be provided to SPP without overload problems.

An extensive 115 kV transmission system and significant dispersed hydro generation, with remote 230 kV sources, supports the intertie. Multiple single contingency outages result in severe limitations to the intertie. The intertie itself roughly parallels Interstate 80 over the Donner Pass. The area traversed is rocky and exceeds 7,500 ft. elevation. Winter snow pack occasionally exceeds 30 ft. The pass is named after The Donner Party, who after being trapped in the area by heavy snows during the winter of 1864, resorted to cannibalism for survival.

Sierra Pacific was notified that the 108 MW firm capacity contract could not be continued without remediation to the PG&E system (Figure 1). Discussions began to explore the limitations of PG&E, the needs of SPP, available options and costs. SPP needs had changed due to the installation of several gas turbine peaking units. Their needs would now best be met with 180 MW of emergency capability for 10 minutes. The gas turbines can be brought on-line in less than 10 minutes.

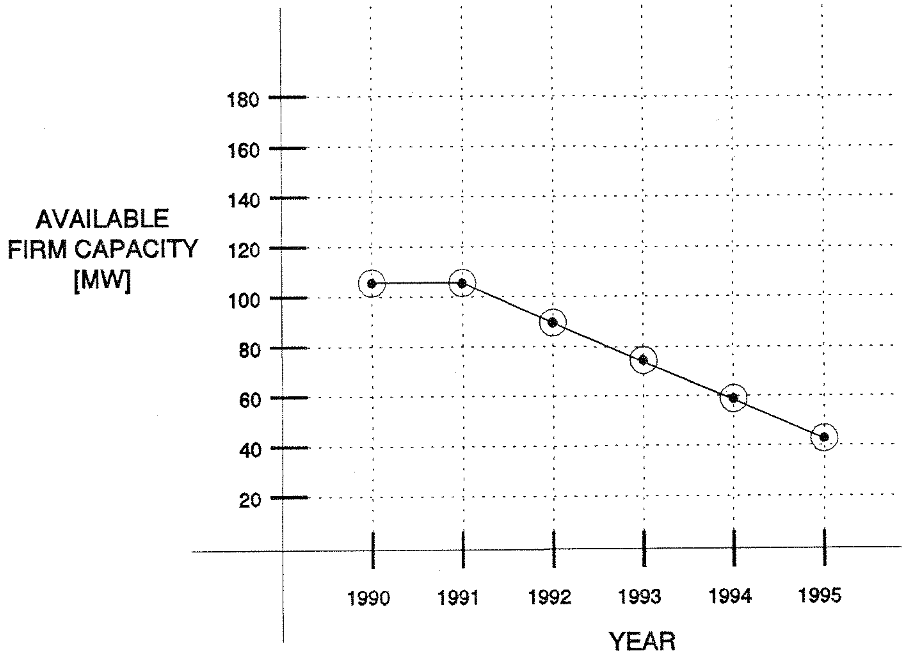


Figure 1: Available Firm Capacity

PG&E presented SPP with eight different alternatives. The approximate cost and resulting capacities are summarized in the following graphs.

Alternative 1:

Do nothing. This results in quick deterioration of emergency support. No cost.

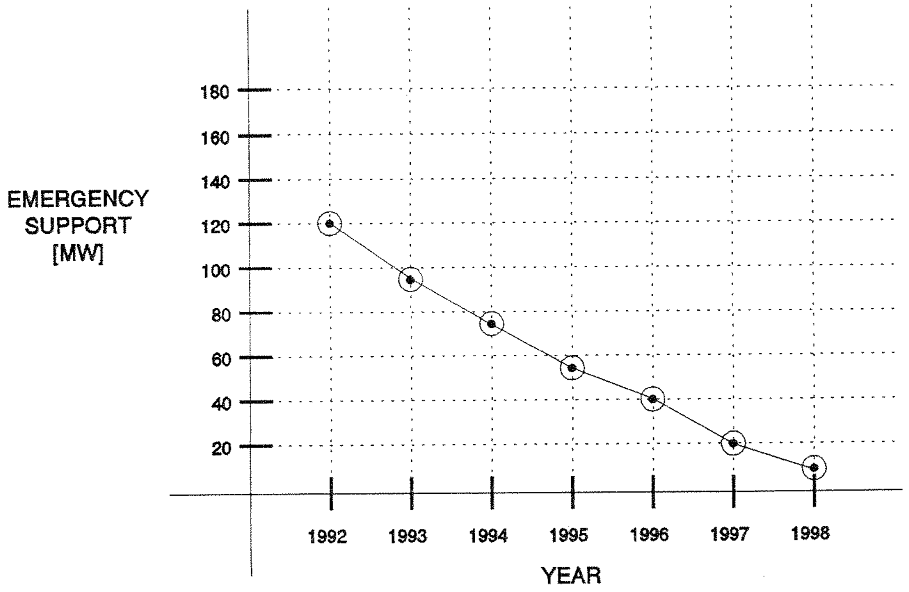


Figure 2: Alternative 1

Alternative 2:

Install a total of nine thermal replica relays at four locations with transfer trip to the intertie. Cost $1,345,000.

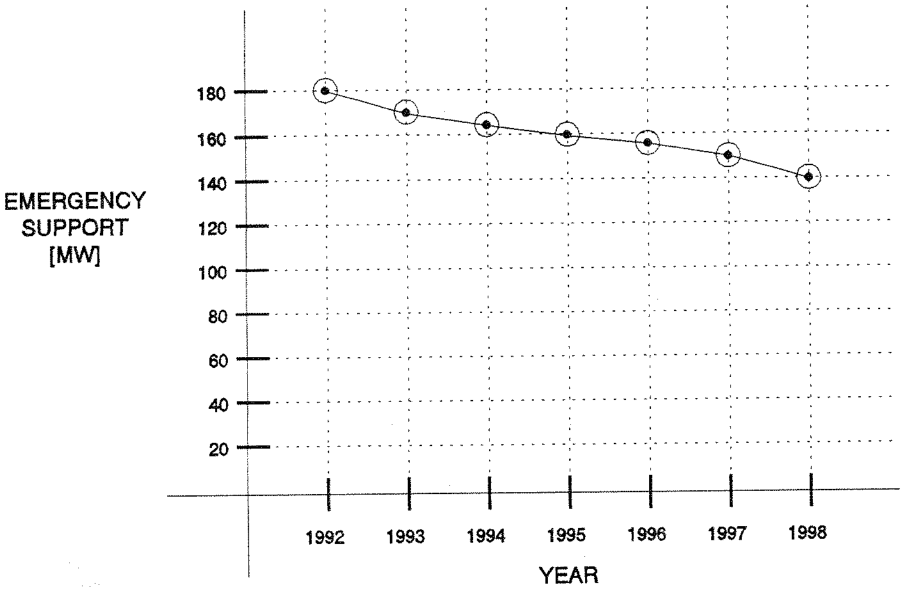


Figure 3: Alternative 2

Alternative 3:

Install nine thermal replica relays with transfer trip to the intertie and transfer 60 kV load to Atlantic Substation. Cost $1,995,000.

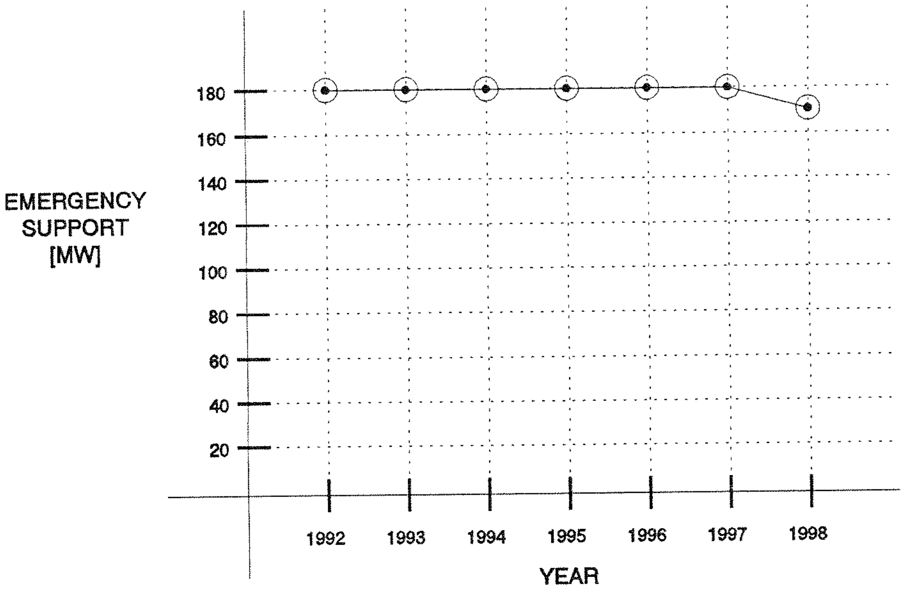


Figure 4: Alternative 3

Alternative 4:

Transfer 60 kV load to Atlantic Substation. Cost $650,000.

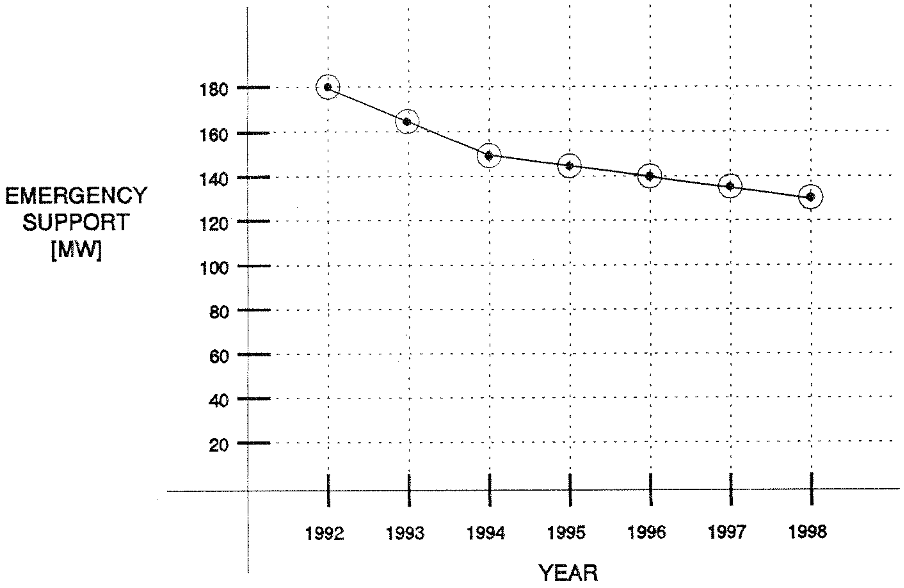


Figure 5: Alternative 4

Alternative 5:

Install nine thermal replica relays with transfer trip to the intertie. Install new 230 kV to 115 kV transformer at Gold Hill in 1993. Cost $6,545,000.

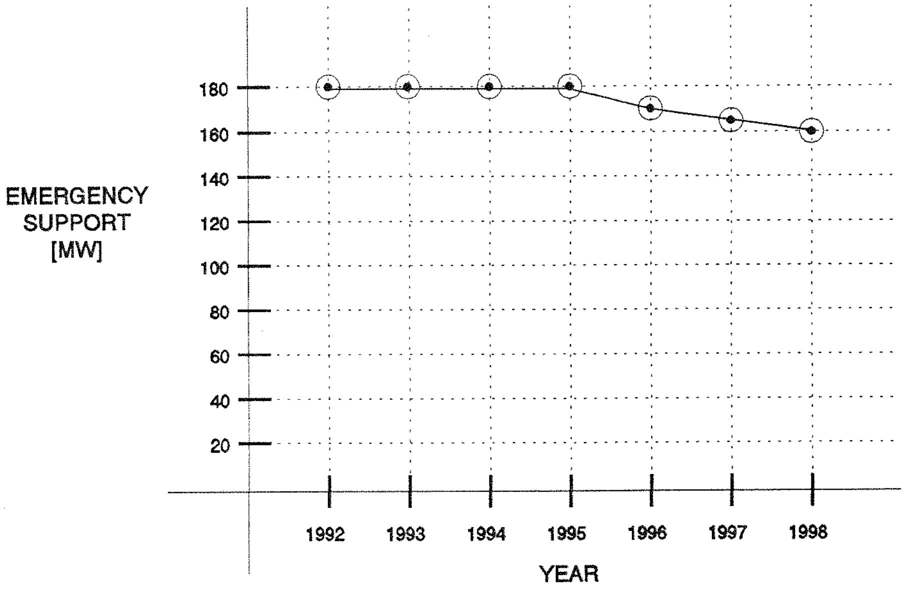


Figure 6: Alternative 5

Alternative 6:

Install nine thermal replica relays with transfer trip to the intertie. Transfer 60 kV load to Atlantic Substation. Install new 230 kV to 115 kV transformer at Gold Hill in 1996. Cost $8,095,000.

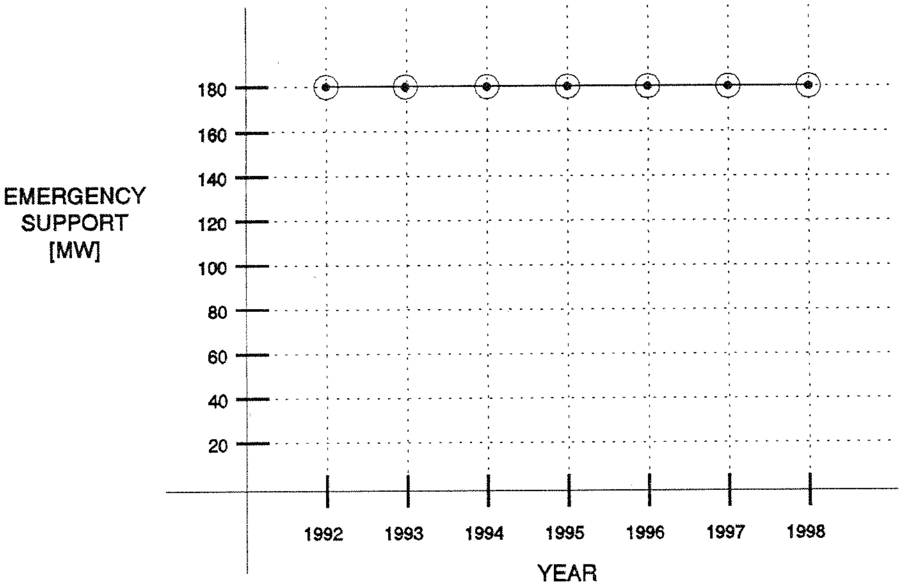


Figure 7: Alternative 6

Alternative 7:

Install nine thermal replica relays with transfer trip to the intertie. Transfer 60 kV load to Atlantic Substation. Install new 230 kV to 115 kV transformer at Gold Hill in 1996. Reconductor two 115 kV lines from Placer to Gold Hill in 1996. Cost $14,095,000.

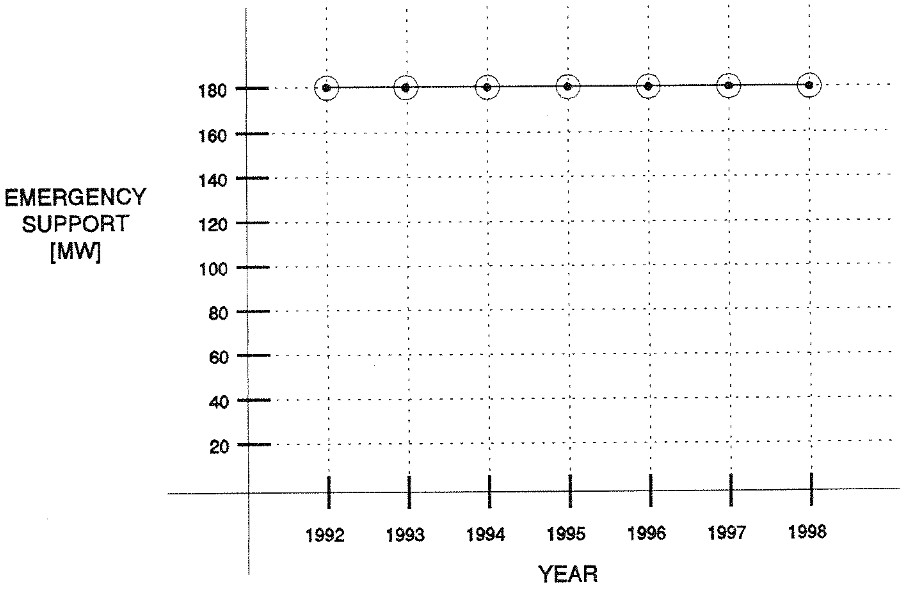


Figure 8: Alternative 7

Alternative 8:

Install nine thermal replica relays with transfer trip to the intertie. Transfer 60 kV load to Atlantic Substation. Install new 230 kV to 115 kV transformer at Gold Hill in 1993. Reconductor two 115 kV lines from Placer to Gold Hill in 1995. Cost $12,545,000.

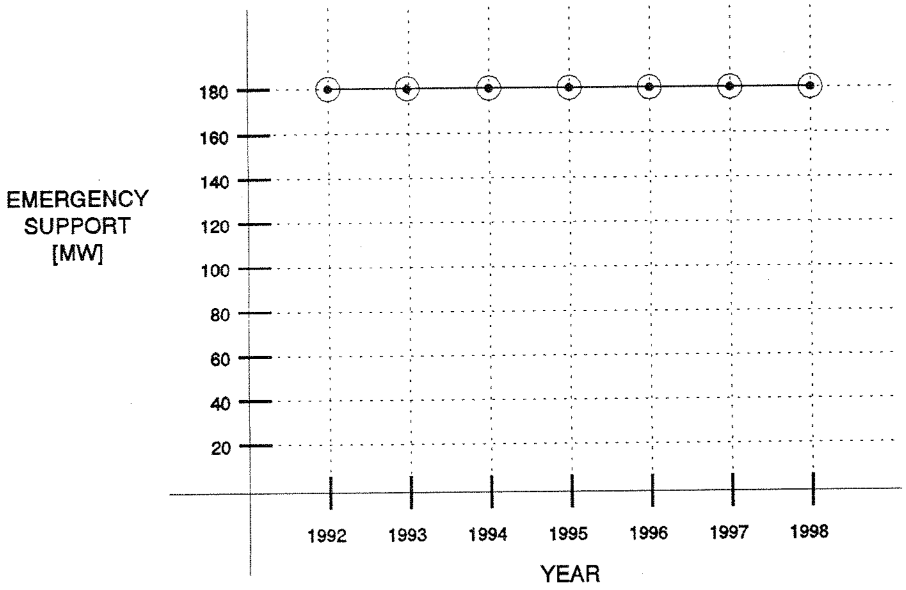


Figure 9: Alternative 8

After examining all of the alternatives, SPP chose Alternative 3.

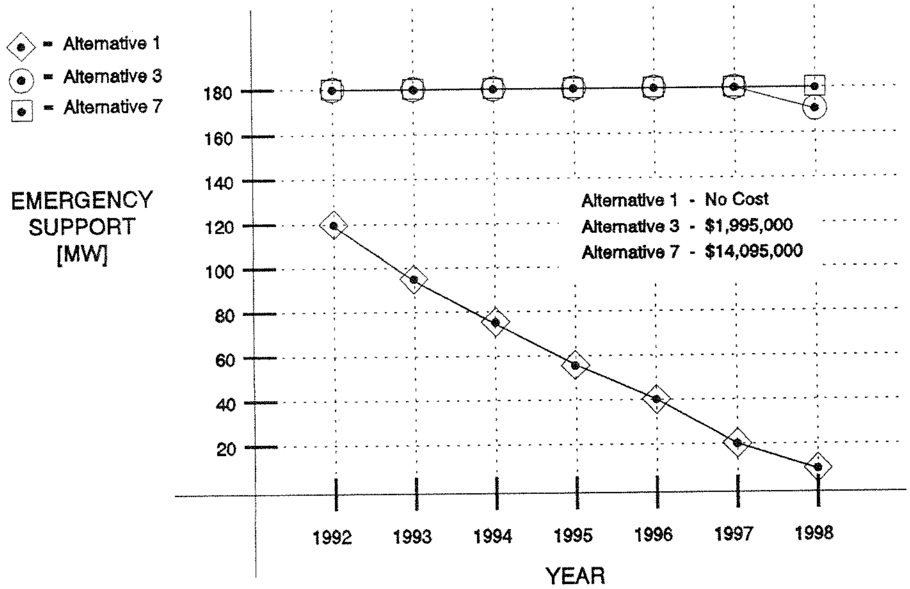


Figure 10: Summary

Alternative 3 provides several years of 180 MW of emergency support for a reasonable cost. The cost of installing 180 MW of generation would be approximately $200 to $400 million. The cost of constantly running gas combustion turbines for spinning reserve is also much higher than Alternative 3. By choosing this option, SPP has provided high reliability at the most economical cost for their rate payers.

ORIGINAL THERMAL SPP SCHEME

The original thermal scheme used to protect the PG&E - Sierra Pacific Intertie (Drum-Summit #1 & 2, 115 kV line) consisted of watt relays, an induction disk overcurrent and an external timer. The currents from the two 115 kV transmission lines were summed, then fed to the watt relays and overcurrent relay (Figure 11). The induction disk overcurrent relay was set at 504 amps (108 MW) primary (total of both lines) as an alarm point. The watt relays were set at 180 MW primary and trip via an external 10 minute timer (Figure 12). This scheme was originally designed with no loading limitations within the PG&E system, but as loads grew, the scheme was no longer adequate for protection of the system from intertie loading.

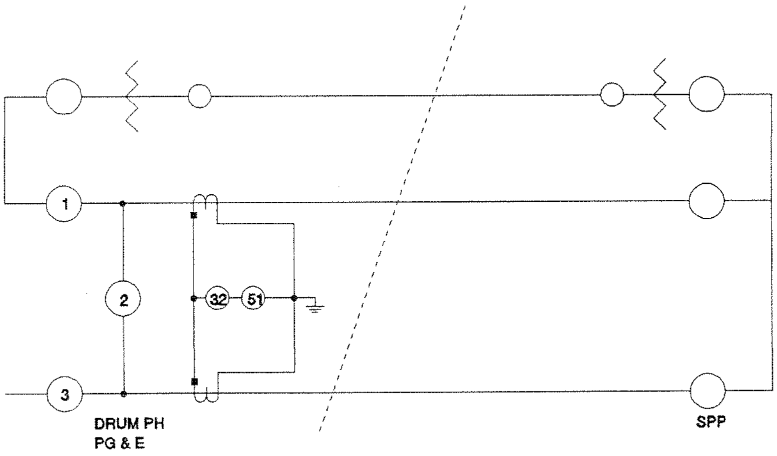


Figure 11

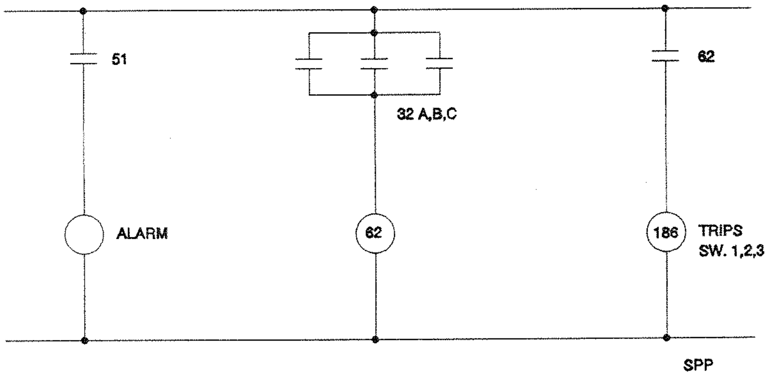


Figure 12

There were several serious shortcomings of this scheme. One was the method of measuring the intertie load. By summing the two 115 kV lines current, compensation of the loss of one of the lines was not possible. If either 115 kV transmission line was open ended or out of service, the scheme would not operate until the remaining line was loaded above 180 MW for 10 minutes. The results of this loading would cause significant damage to the conductor. Second, the scheme had no method of a conductor "cooling time constant". The timing relay (Device 62) would instantaneously reset if the line load momentarily dropped below 180 MW (watt relays dropped out). If this occurred after nine minutes of timing, it would take at least 10 more minutes (a total of 19 minutes) before tripping would occur. Third, the loading on the 60 kV tie line was not included nor was the tripping of this tie. Apparently, the original designers believed the 60 kV intertie would open by a low set phase overcurrent relay.

HISTORY OF PG&E THERMAL RELAYING

One of the first "thermal overload relay schemes" used in PG&E consisted of an Induction Disk (inverse curve) and a pneumatic timer. Typical time dial settings were 10 and the pneumatic timer set at 10 - 15 minutes. The minimum tap setting was selected close to the transmission line rating and then the spring was adjusted (i.e., tap 4 adjusted to 4.15 amps) to get the desired pickup point.

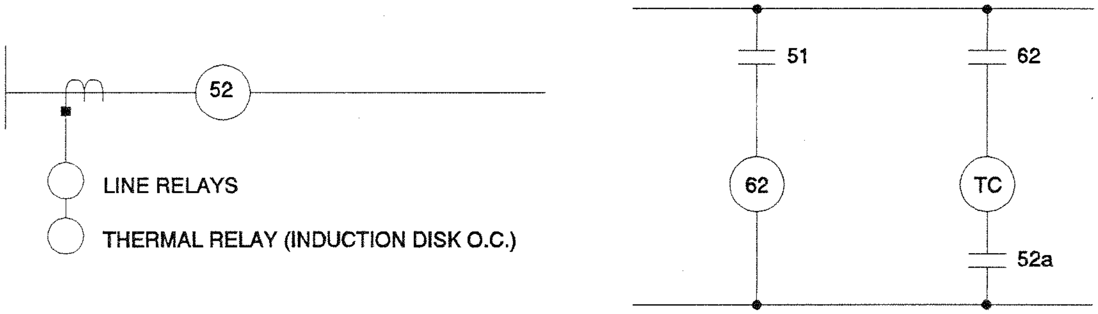


Figure 13

Forty years ago, this type of scheme seemed to serve the purpose, but there were obvious shortcomings of this scheme. First, the resulting time vs. current curve only resembled one point on the actual transmission line capability curve, usually the pickup point of the pneumatic timer setting. The time constant of an induction disk/pneumatic timer scheme varies with the fluctuation of the line current. If the line current is 1.2 times pickup of the overcurrent relay, then the scheme time constant will be about one-third of the pneumatic timer setting for pickup only. If the line current has been at 1.2 pu for 90% of the timing cycle, and then drops below pickup just long enough to drop out the overcurrent relay (maybe a second or so), then the timer will reset and start re-timing from zero. The result of this sequence would cause significant conductor damage.

As technology evolved, the schemes changed and became more sophisticated. Induction Disk overcurrent relays, directional watt relays, watt relays, seasonal setting changes, transfer trip schemes, and various logic schemes were developed and used. All of these things were aimed at optimizing the loading of transmission lines or transformer banks. Figure 14 shows part of one of the more sophisticated attempts to use three transmission lines to serve a large customer with a thermal overload scheme. Figure 15 shows the tripping logic.

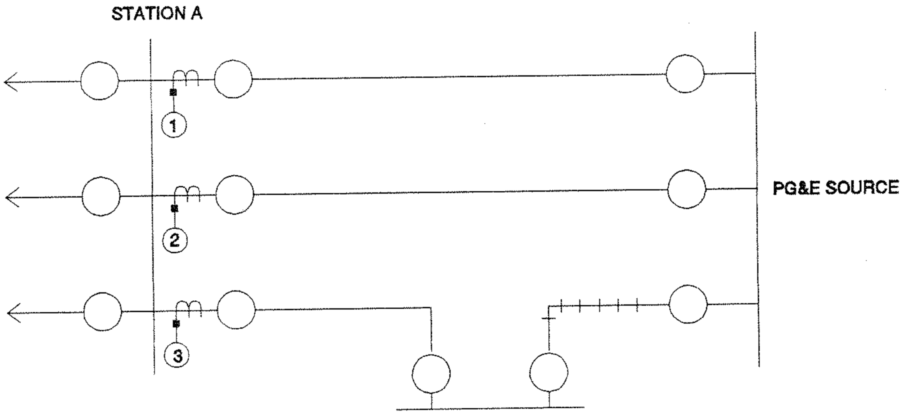


Figure 14

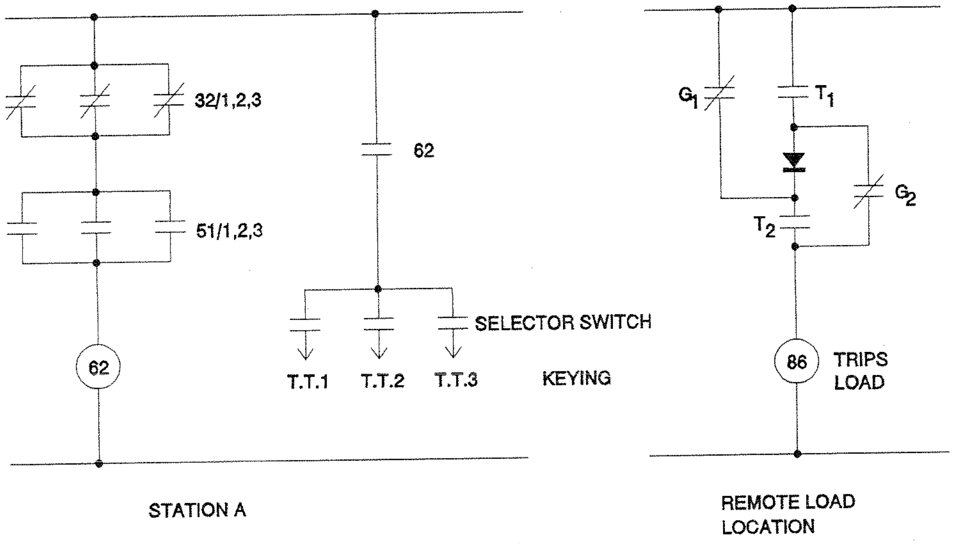


Figure 15

If loading of the large customer was near peak, and a loss of a critical line, bus or breaker, an overload would occur. In order to monitor line loading and various breaker status, a scheme was installed at Station "A" to protect the system from overloading (Figure 14). Induction Disk Overcurrent Relays were installed at Locations 1, 2, and 3. Minimums of these relays were set at the line capability. A suitable external timer was used to provide the necessary time delay. This part of the scheme was essentially the same as previous schemes. It was known that overloads could not occur unless a line was out of service, breaker open, or bus out of service. Also, it was desired to have a high level of security; therefore, directional watt relays were installed on each line. If the watt relays were picked up, this meant the system was continuous (all lines in service, no breakers open). If any watt relay dropped out, then this meant the system was abnormal and the overload relay scheme would be armed (Figure 15).

The tripping of this scheme was via redundant/secure transfer trip schemes. The customer's remote load was tripped via a manual selector switch. This switch was operated at the customer's request depending on which part of their system was most critical.

Several schemes such as these two mentioned here were used throughout the PG&E system with considerable success for the technology of that time. However, as the technology evolved, better schemes were developed.

Several other variations of these schemes were designed and installed. Most worked as designed but none of them came close to monitoring the true time constants of conductors, or the effects of ambient temperature. Once reliable microprocessors became available to relay manufacturers, it was not long before a more sophisticated thermal replica relay was developed.

THERMAL REPLICA RELAY OPERATION

The Thermal Replica relay selected for the SPP intertie project was the Schweitzer SEL-49 relay. The SEL-49 relay incorporated most of the variables that determined conductor temperature and therefore conductor loading capability.

The SEL-49 relay requires three-phase currents, three-phase potential, a temperature probe input, DC and various contact connections to operate properly in the scheme used in this project. Each phase current is used in calculating the line thermal capability. The voltage inputs are required for determining line MVA capability, phase and ground distance relaying and fault locating. The remote temperature probe/RTU provides the local ambient temperature. Figures 16 and 17 show the basic connections to the relay as used in this project.

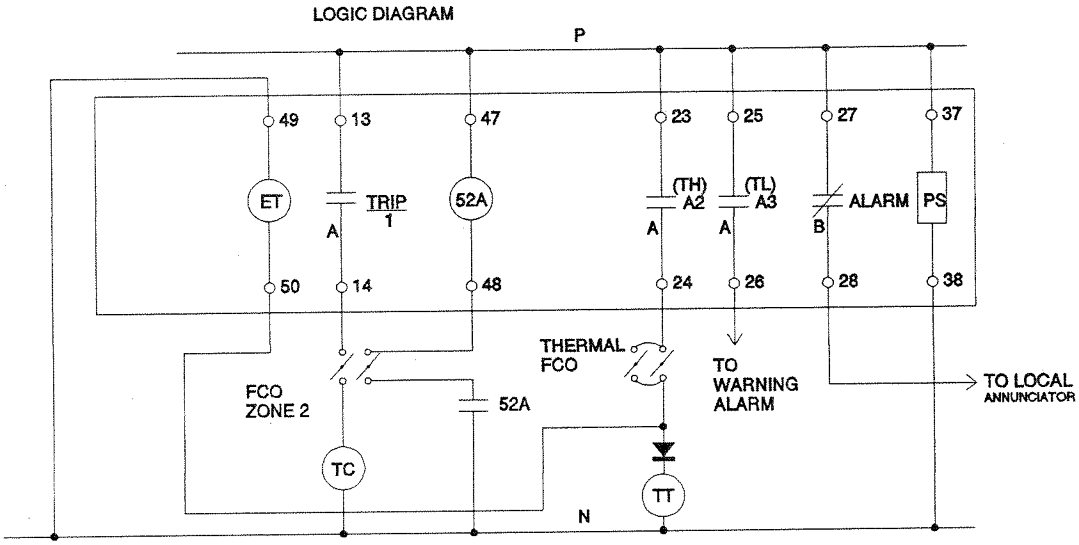
The thermal part of the SEL-49 relay operates similar to a non-directional overcurrent relay; with a few differences. The minimum to trip and time to trip are determined by the following inputs:

1. The conductor's physical properties.
2. Effects of solar heating.
3. Wind speed across the conductor.
4. Geographic location (longitude and latitude).
5. Ambient temperature.
6. Time of year (date).
7. Time of day.

With the above information, the Thermal Replica relay is able to accurately model the conductor temperature.

However, there are some limitations to this relay. First, the wind speed past the conductor is a fixed setting in the relay. The actual wind speed will be different from the setting. The setting of two feet per second is generally used and is consistent with PG&E conductor ampacity tables. The actual wind speed past the conductor at higher conductor temperatures has shown to be more than the two feet per second setting. Therefore, the two feet per second setting is conservative and was acceptable to the planning engineers.

Second, the ambient air temperature probe is usually installed in a special weather enclosure in the substation where the relay is installed. The weather enclosure is mounted far enough away (50 - 100 feet) from buildings and equipment to insure the best possible ambient temperature reading. However, this is still not the same as the actual conductor location. Some investigation must be made to determine the location with the hottest ambient temperature along the transmission line path. Once this is determined, then the difference between this location and the relay probe location can be estimated. This difference in temperature becomes the offset temperature setting. In most of the Sierra Pacific thermal overload scheme area, this offset value was less than 3° C so this was used as the offset temperature setting.



THIS SCHEME SEPARATES THE THERMAL TRIPPING AND ZONE 2 DISTANCE TRIPPING. ALSO, A THERMAL TRIP WILL TRIGGER AN EVENT VIA THE EXTERNAL TRIGGER INPUT.

Figure 16

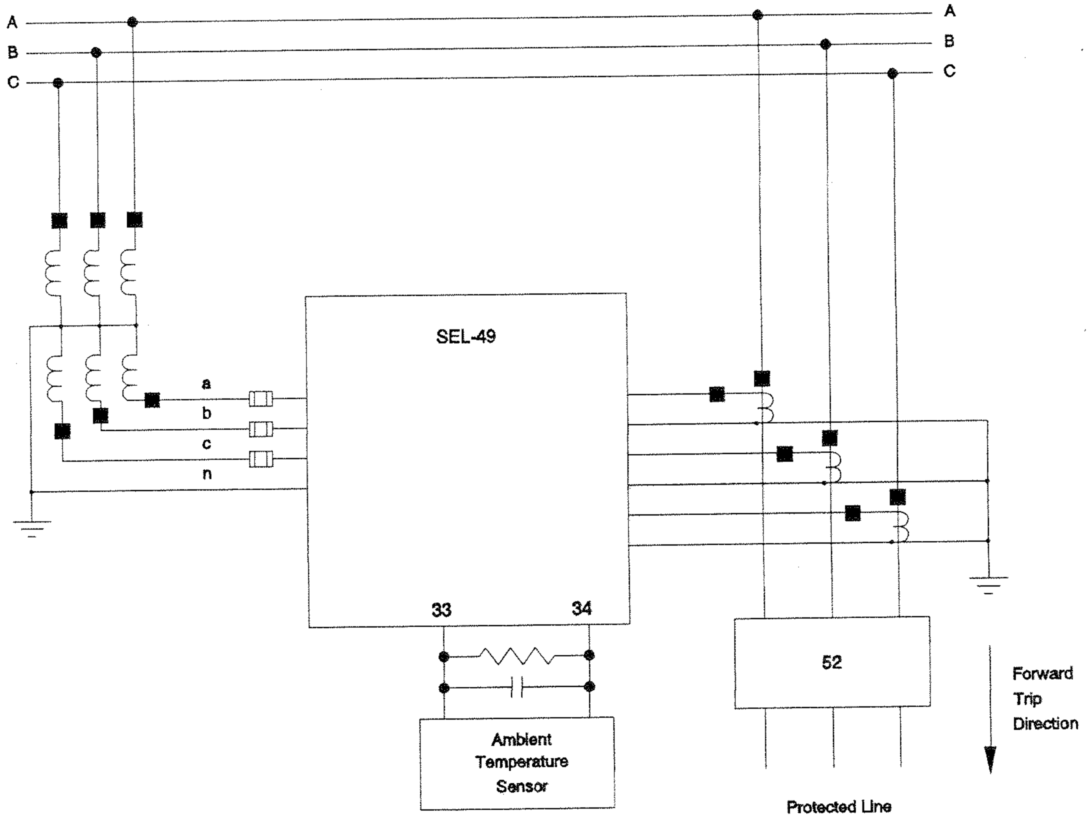


Figure 17

REMOTE DATA ACQUISITION PROGRAM

As for most microprocessor relays, the thermal overload relays used in this scheme have some form of event recording. The event recording will record the voltage current and various logic states when triggered. The trip temperature and loading are not stored internal to this relay but are automatically sent (via a RS232 port) to a local printer. Our desire was to be able to have all of the nine thermal relays' thermal status, if any relay got to the warning or trip stage. Our existing SCADA (Supervisory Control And Data Acquisition) system was not installed in this area and did not have the software to communicate with the SEL-49 relays. Since it was still desired to know the status of all the thermal relays, a special computer program was written for this scheme.

The PC Program used to monitor the performance of the S.P. thermal scheme retrieves the line loading and predicted line temperature information. The program is designed to perform these tasks manually or automatically on a given schedule.

PCPlus is the program selected to handle the communication requirements. PCPlus was modified by writing "script" files to perform predetermined keyboard functions and data retrieval. Various script files are similar to PC batch files, whereas, a given list of commands are executed in a given sequence.

Each station with a thermal relay required a specific script file. The script file would poll the relay(s), perform a "meter" command, perform a "TEMP L" command and then proceed to the next relay or exit and hang up. The PC would automatically print the results of each "meter" and "TEMP L" command. The operator uses this information to make operating decisions.

The program menu provides the choices for the operator to status one specific station or all stations with the thermal relays. The average retrieval time for obtaining all of the relays "meter" and "TEMP L" data is about 6 minutes.

Other script files were written to automatically pole each relay every 6 hours, 24 hours a day, 7 days a week. We ran this program for the first 9 months of operation. This data was used to verify communications and relay reliability. The resulting load data was provided to the responsible PG&E planner for load flow data base case comparison.

Figure 18 shows the typical time current thermal characteristic (capacity) of 397.5 AA for ambient temperatures of 30° F and 109° F. A Very Inverse Induction Disk Time Dial 10 Curve is also plotted to demonstrate the difference in required thermal protection of 397.5 AA and what has previously been used. It is obvious that the old Induction Disk Timer schemes were inadequate.

Figure 19 plots the time current characteristic of the SEL-49 relay if the conductor has been preloaded near the capability. The relay has calculated a conductor temperature of 80° C (approximately 95% of the current capacity). With a trip temperature setting of 85° C, there is little thermal capacity remaining in the conductor and a small increase in current would cause a trip.

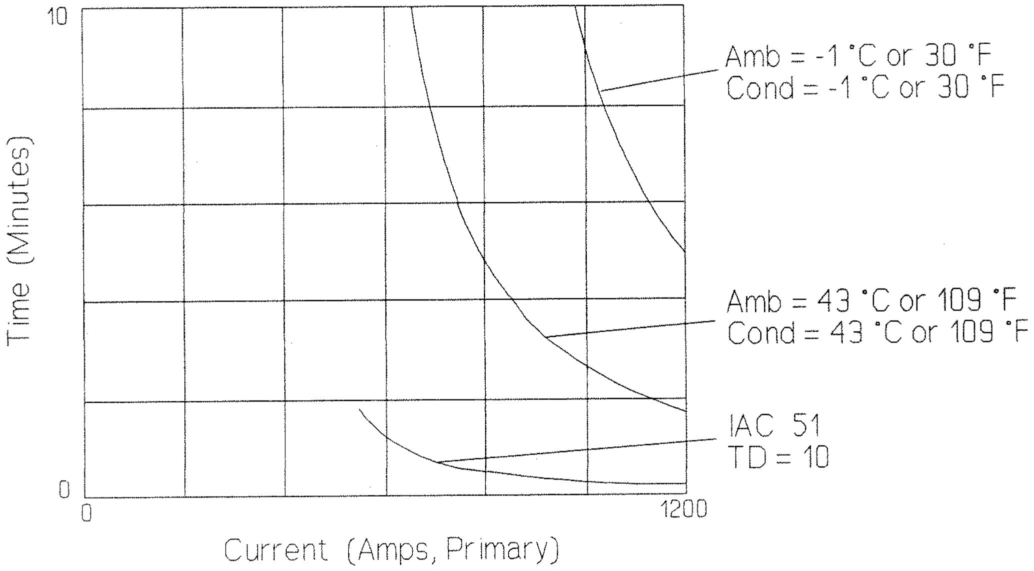


Figure 18

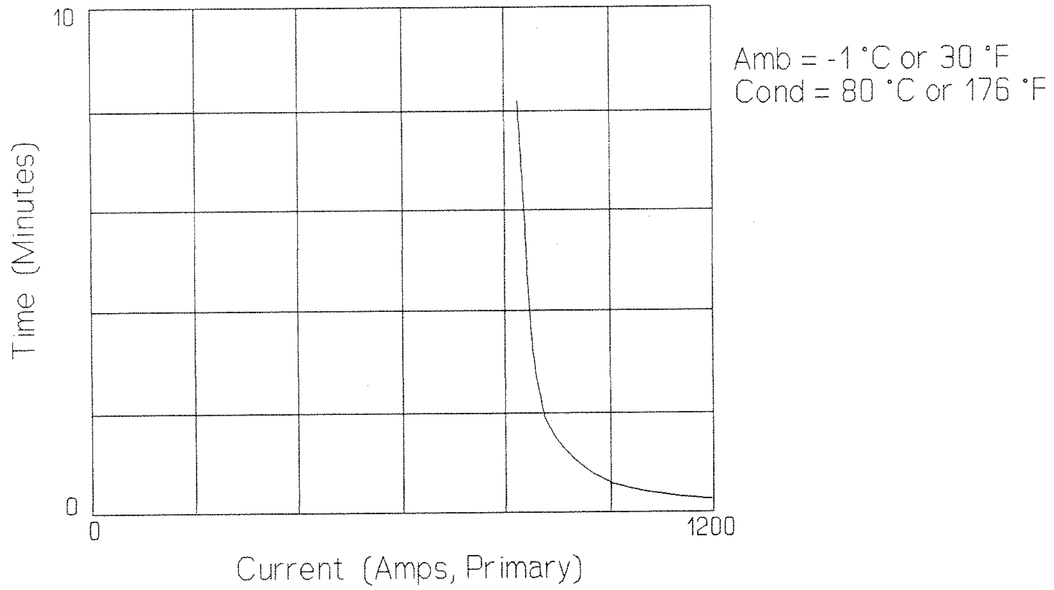


Figure 19

A Solution to the Intertie Emergency Demand

The intertie between PG&E and SPP consists of one 60 kV line and two 115 kV lines through mountainous terrain (Figure 20).

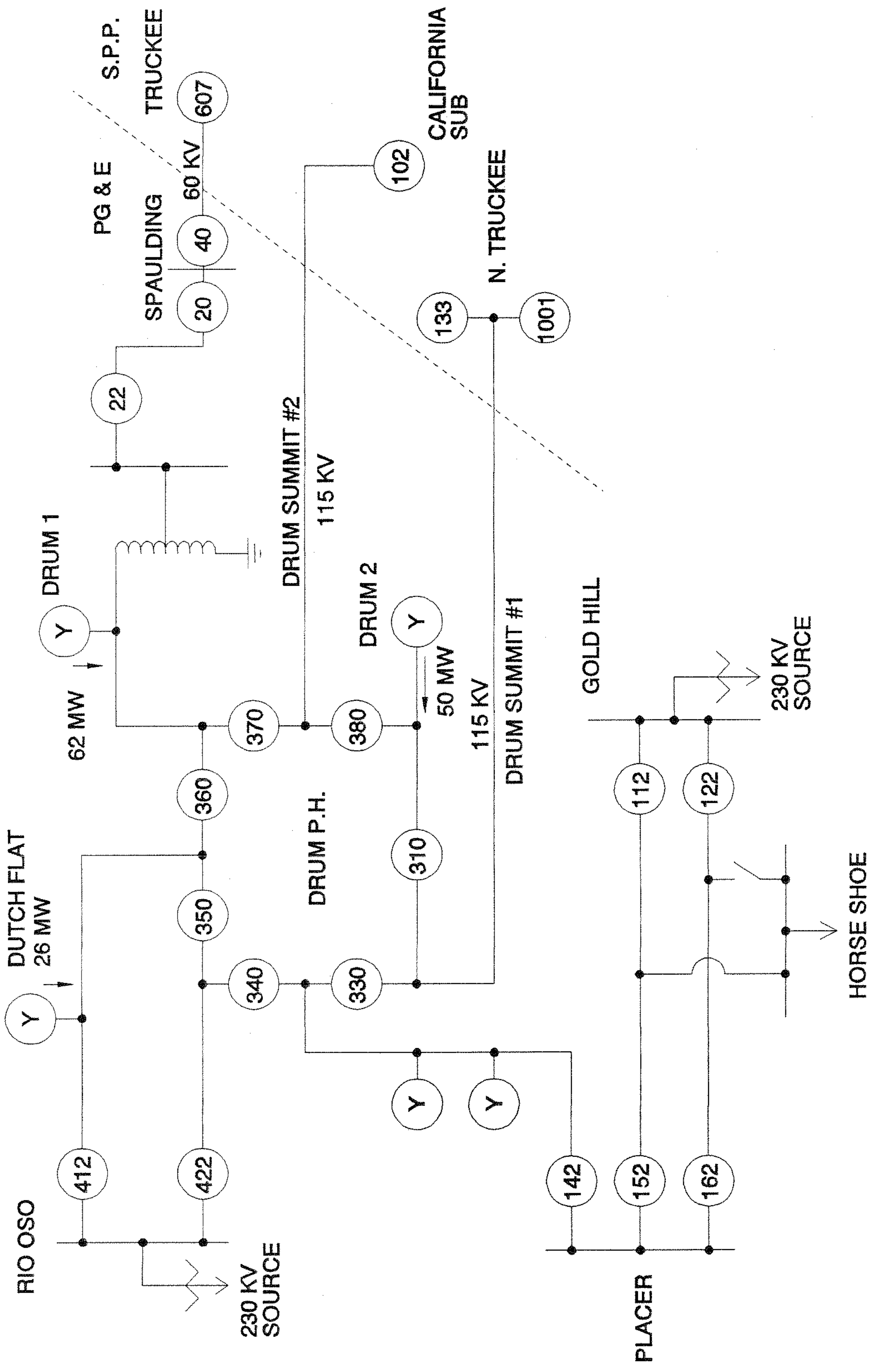

RIO OSO
412
422
230 KV SOURCE
Y
DUTCH FLAT
26 MW
350
360
340
330
310
Y
Y
142
152
162
PLACER
DRUM P.H.
62 MW
Y
DRUM 1
370
380
DRUM 2
Y
50 MW
115 KV
DRUM SUMMIT #1
DRUM SUMMIT #2
115 KV
22
20
SPAULDING
40
PG & E
60 KV
607
TRUCKEE
S.P.P.
102
CALIFORNIA SUB
133
1001
N. TRUCKEE
GOLD HILL
112
122
230 KV SOURCE
HORSE SHOE

Figure 20

The SPP demand on the intertie is 180 MW for at least 10 minutes.

There is approximately 160 MW of local hydro generation in the vicinity of Drum P.H. (Figure 21).

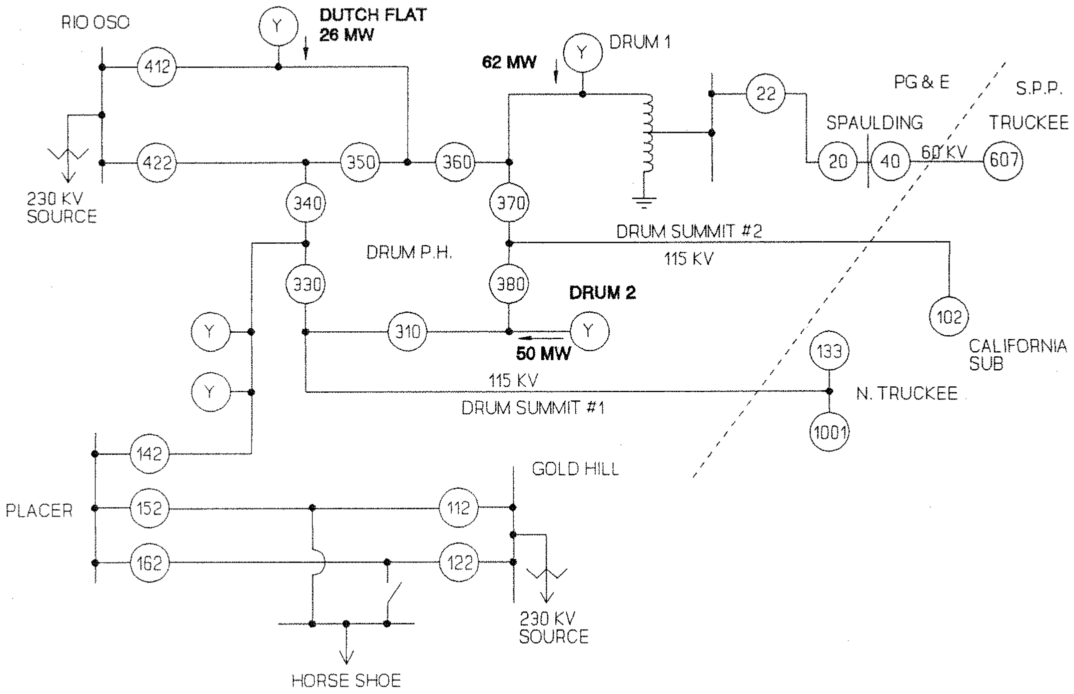


Figure 21

The load flow analysis determined that serving this demand would cause overload conditions on the following line sections during single contingencies determined by transmission planners (Figure 22):

1. Drum-Rio Oso #1, 115 kV line.
2. Drum-Rio Oso #2, 115 kV line.
3. Halsey Jct.-Newark (Placer-Gold Hill) #1, 115 kV line.
4. Halsey Jct.-Newark (Placer-Gold Hill) #2, 115 kv line.
5. Drum-Placer 115 kV line.
6. Drum-Spaulding 60 kV line.
7. Drum-Summit #1, 115 kV line.
8. Drum-Summit #2, 115 kV line.

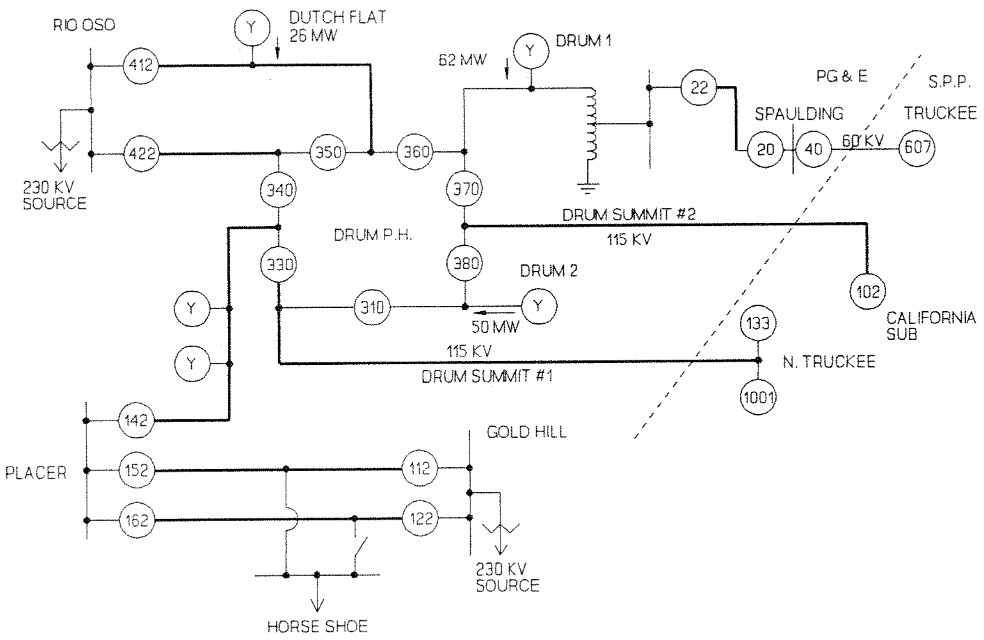


Figure 22

Figure 23 shows the thermal overload relays at Drum P.H. These relays detect the overload conditions on the intertie and one of the 115 kV lines to Rio Oso Substation.

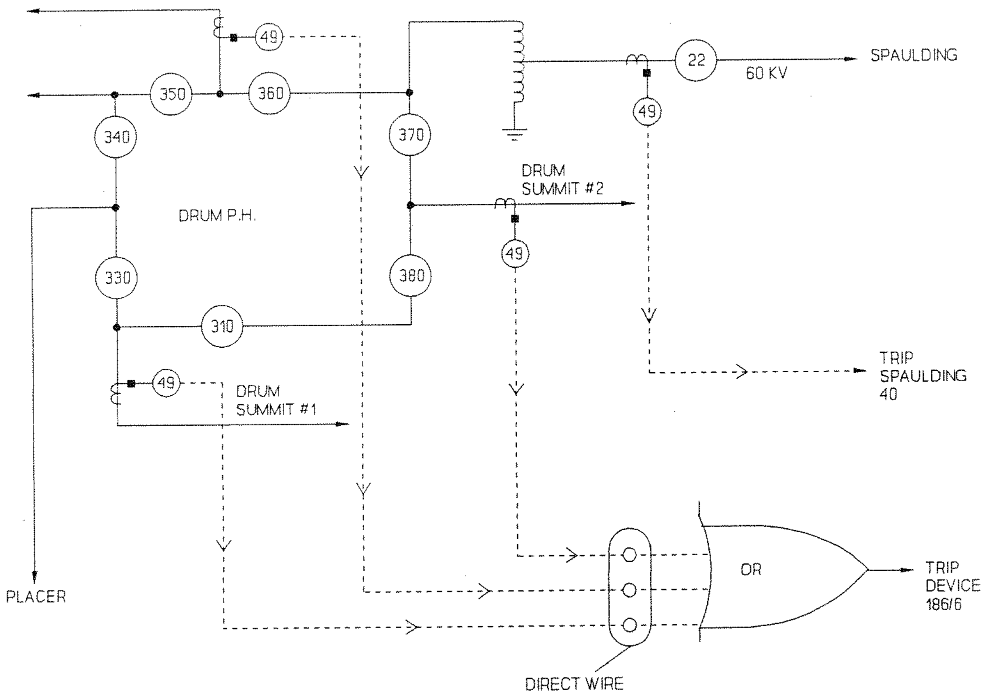


Figure 23

The "alarm" and "trip" contacts have been wired to the annunciator panel and the tripping relay respectively.

Figure 24 shows the thermal overload relays at Gold Hill and Placer Substations.

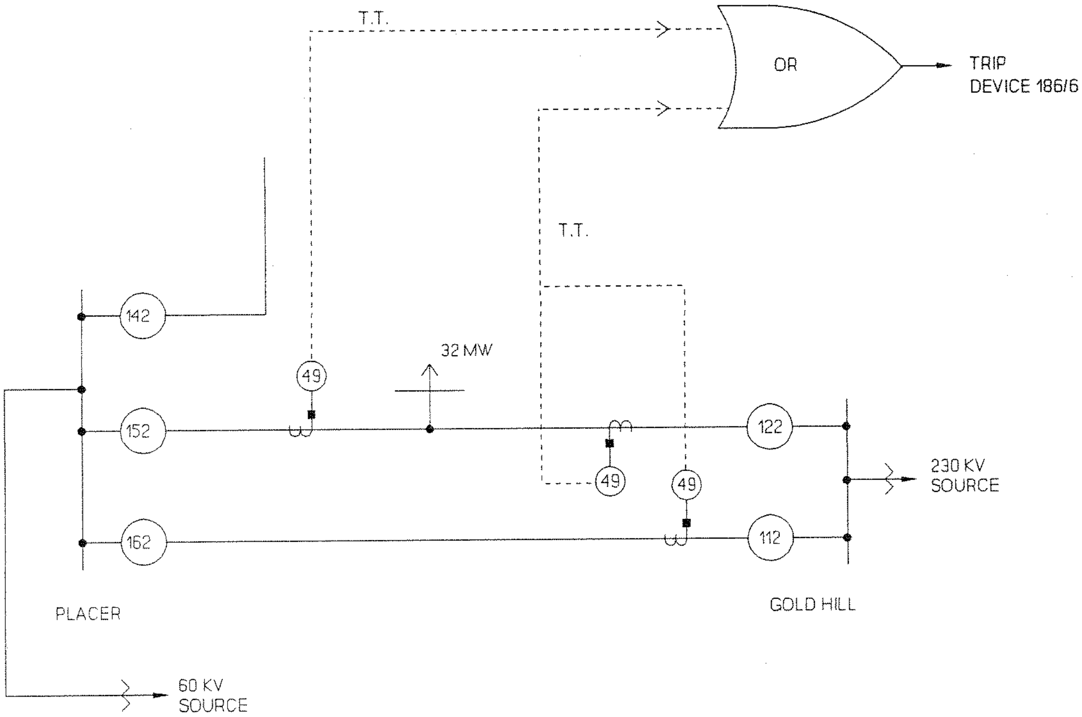


Figure 24

These relays monitor the loading on the Placer-Gold Hill 115 kV lines. Due to the 32 MW tap load which is normally fed from one of the lines, only one overload relay was required at Placer Substation.

The "alarm" and "direct trip" signals are sent to Drum P.H. via a dual tone frequency shift communication channel using dedicated lines for optimum reliability.

Figure 25 shows the thermal overload relays at Rio Oso Substation and Drum P.H. which detects the overload conditions on the Drum-Rio Oso lines.

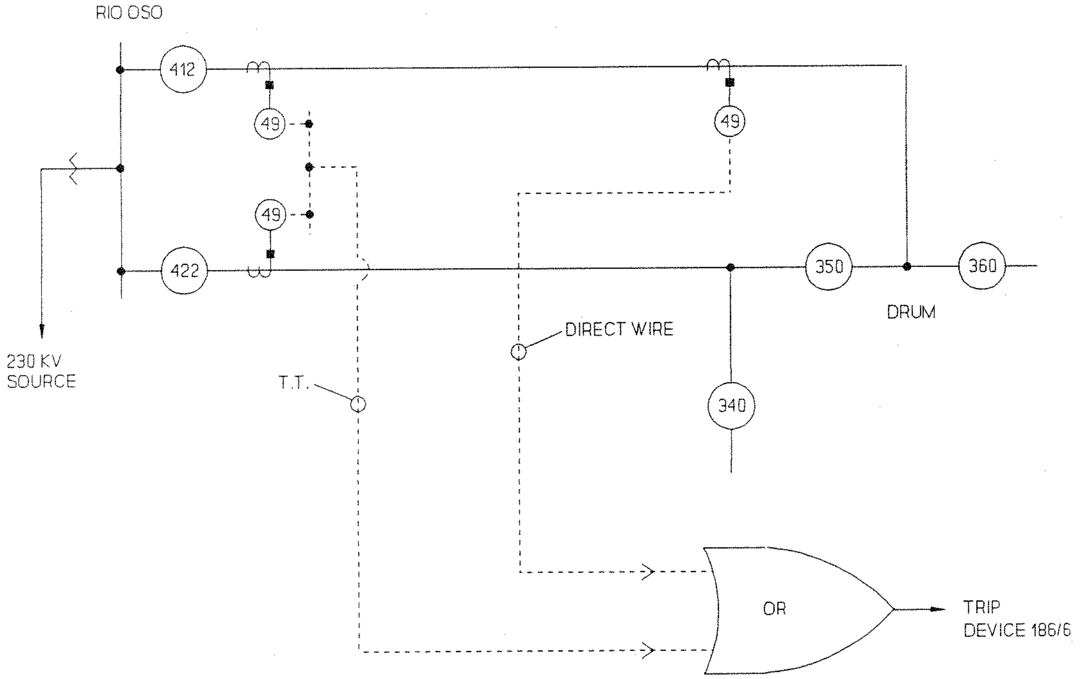


Figure 25

These relays monitor the loading on the Drum - Rio Oso 115 kV lines. Due to tapped loads on one line, only one thermal overload relay is required at Drum.

The "alarm" and the "direct trip" signals are sent to Drum P.H. via a dual tone, frequency shift communications channel.

Dedicated lines using microwave, fiber or cable have been leased from the local phone companies for optimum reliability. These communication paths were carefully selected. Reliability has been excellent.

Figure 26 shows the tripping scheme for the thermal overload relays. Trip signals from all overload relays (except the one from Drum SW22) are connected to pickup a lock-out relay (Device 186/6). This lock-out relay opens the intertie by tripping Switches 310, 330, 370, and 380 at Drum P.H. as well as Switch 40 at Spaulding.

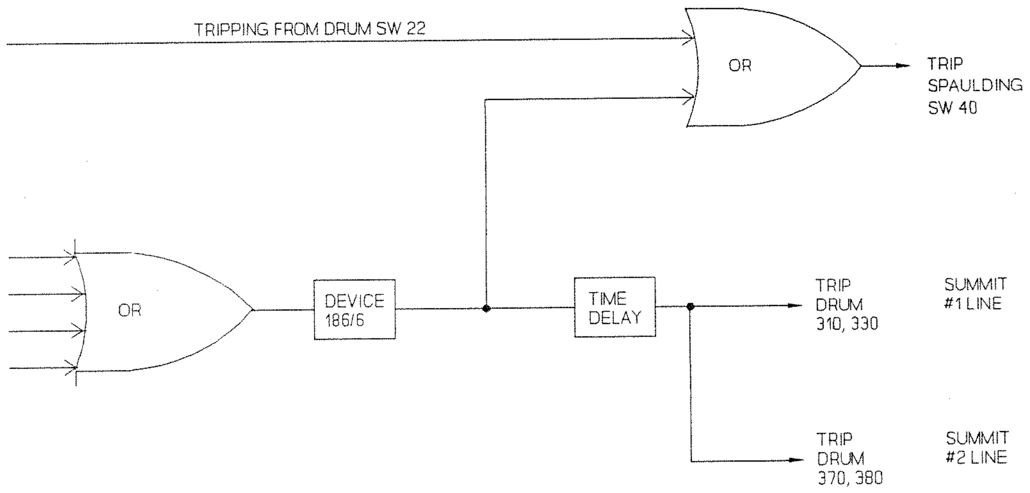


Figure 26

The signal received from the relay of Drum SW22 would only trip Spaulding SW40. This was due to the fact that the 60 kV tie could overload without the two 115 kV ties being overloaded.

The tripping of the 115 kV ties were delayed to insure that the 60 kV tie trips first. This must be done to prevent instability or severe instantaneous overloads that could occur if the only tie line between SPP and PG&E is the 60 kV line.

SUMMARY

As of the writing of this paper, the reliability of this thermal overload scheme has been excellent. There have been no failures or misoperations of any part of the scheme except communication channel problems. Communication channel problems have been traced to non-air conditioned microwave equipment at Gold Hill Substation. Under extreme heat, the microwave equipment shifted frequency and caused the transfer trip and remote data acquisition program channels to fail. This problem is being eliminated by installing the necessary air conditioning to Gold Hill Substation.

Other schemes using the same technology (although less complicated) are presently being used or are in the design state within the PG&E system. Although thermal schemes do not provide the same benefits as new transmission lines, transformers, or generation, when considering the economic and technical climate of today, they are often the chosen solutions. It is our opinion (whether we like it or not) that thermal relay schemes are not only here to stay, but will become more common in the future.