OVERCURRENT COORDINATION STUDY

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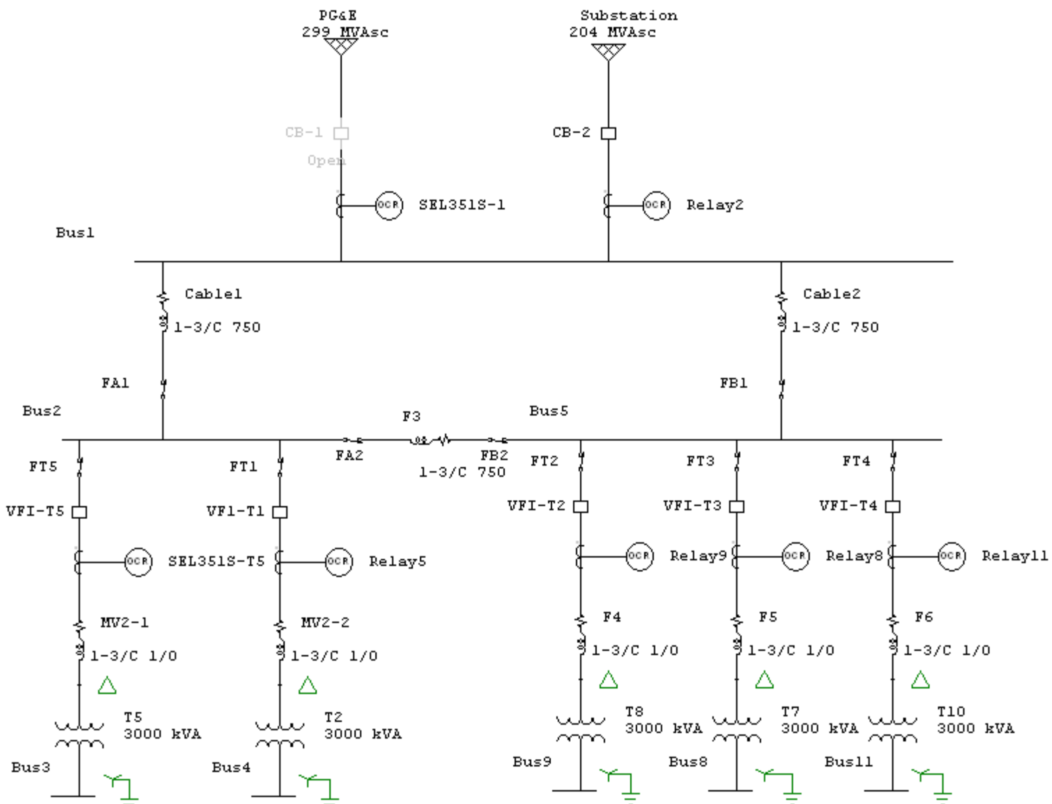
I would like to thank Professor Shaban for his help and guidance throughout the life of this project.

1.0 INTRODUCTION

In a power system, one of the most critical aspects is power protection. Power protection involves using protective devices to insure that in the case of a short circuit or any electrical fault, system components are not damaged and as little of the system is taken down as possible. In order to provide adequate protection for the circuit, these fault conditions must be simulated and analyzed. This can be done using software from Operation Technology, Inc called ETAP. ETAP is comprehensive software that allows the user to design and simulate power systems as well as automate generation, transmission, and distribution schemes. The goal of this project is to analyze the following circuit (Figure 1) and determine protective device coordination to achieve optimum equipment protection and selectivity.

Figure 1: One-Line Diagram of Circuit



2.0 CIRCUIT BACKGROUND

The circuit shown above (Figure 1) is a medium-voltage circuit for Western Digital, located in Fremont, California. This is a radial system, meaning power is transferred only in one direction, in this case, from the uppermost portion of the circuit to the lower portion.

Power is provided to this circuit from two independent sources. The first source, labeled ‘Substation’, is a 204MVA source located on Western Digital’s campus. This primary source provides power to the system under normal conditions. The second source, labeled ‘PG&E’, is a 299 MVA line coming in from the utility. This source serves as a backup source which will only be used for emergency situations or when the primary source needs to be de-energized for maintenance and repair. Both of these sources are fed into ‘Bus 1’ (20.8kV), which in turn distributes the power through ‘Cable 1’ and ‘Cable 2’ to ‘Bus 2’ and ‘Bus 5’ respectively (20.8kV). These 20.8kV busses have feeders coming off of them that connect to transformers (T5, T2, T8, T7, T10) that transform the voltage from 20.8kV on the primary side to 480V on the secondary side.

On each of these feeders, there are two protective devices. Looking at the feeder connected to ‘T5’, there is ‘VFI-T5’ and ‘SEL351s-T5’. ‘VFI-T5’ is a vacuum fault interrupt circuit breaker and ‘SEL351s-T5’ is a Schweitzer Engineering Laboratories 351-S overcurrent protective relay. The purpose of a overcurrent protective relay is to monitor the feeder and sense when an overcurrent situation has occurred and signal the circuit breaker to trip (open). The SEL351-s is connected to a CT (current transformer) with a ratio of 600:5, this scales the current down to a level which the SEL351 can monitor. These three devices, the CT, SEL351-s, and the circuit breaker are what protects any devices upstream, in the case of a fault. This protection scheme is identical in the feeders adjacent in the circuit to ‘T5’. There scheme is also used in protecting the power sources to the system.

In order to effectively protect upstream devices, all protective devices must coordinate with each other. This is achieved by simulating faults and choosing settings which will work effectively. This coordination means that if there is fault on the feeder for ‘T5’, then VF1-T5 will trip and if it fails to do so, CB-2 will see the fault and trip, protecting the power source.

The protective device settings and ratings recommended in this study are based on providing adequate overload and to withstand protection for the cables and transformers as well. (See Sections 3.0 and 4.0, below.) In addition, selectivity will be achieved, in all possible instances, by establishing suitable time margins between device operating points. These time margins shall be consistent with the recommendations of the device manufacturers. Relay coordination requires a time margin between the relay curves to account for interrupting time of the circuit breaker, relay over-travel time, relay tolerances, and a safety factor. Where no recommended time margins are available, a minimum margin of 0.35 second will be used. For this study, the minimum margin between relay curves will be 0.30 seconds.

3.0 PROJECT SCOPE

The scope includes seven Schweitzer Engineering Laboratories 351-S adjustable over current protective devices as shown in Figure 1. This requires the understanding and effective use of ETAP to coordinate the afore mentioned devices.

4.0 CABLE AND BUS PROTECTION

NEC Article 240-101 states that feeders rated over 600 Volts must have overcurrent protection provided either by a fuse, rated not more that 300% of the feeder ampacity, or by a circuit breaker with a long time trip element set not more than 600% of the feeder ampacity.

Low voltage cables, medium voltage cables and medium voltage cable shields must also be protected from sustained short circuit currents. The upstream protective device must clear the fault prior to reaching the withstand capability of the cable or shield. ANSI/IEEE Standard 242-1986, Figure 150, provides the withstand criteria for this protection.

Therefore, the bus and cable protective devices must be set to provide overcurrent protection per the NEC requirements and to provide withstand protection per the ANSI/IEEE.

5.0 TRANSFORMER PROTECTION

NEC Table 450-3(a) establishes the maximum permissible settings or ratings of the primary and secondary overcurrent device for transformers rated over 600 Volts. The limits are shown below:

	PRIMARY > 600 VOLTS		SECONDARY > 600 VOLTS		< 600 V
TFR Z	CB	FUSE	CB	FUSE	CB/FUSE
< 6%	600%	300%	300%	250%	125%
6<Z<10%	400%	300%	250%	225%	125%

The transformer primary protective device must not operate for the normal magnetizing inrush current that occurs when energizing any transformer. The inrush point is established at eight (8) times transformer full load current for a period of 0.1 seconds for transformers under 2500 kVA. For transformers above 2500kVA the inrush point is ten (10) to twelve (12) times the transformer full load current for a period of 0.1 second.

Therefore, the transformer primary and secondary protective devices must be set within the NEC requirements for transformer overload protection, must provide withstand protection per the ANSI/IEEE withstand curve and must allow the normal magnetizing inrush current to flow.

6.0 GUIDELINES FOR RELAY SETTINGS

A. Relays for breakers on the primaries of transformers:

1. Pickup is typically chosen at approximately 140% of nominal transformer current or higher if coordination considerations dictate that. Values up to 600% are allowed by the NEC, depending on system parameters and what other protective devices are used.
2. Instantaneous pickup is greater than or equal to 160% of short circuit current for maximum fault downstream of the transformer to avoid tripping of the primary breaker for an asymmetrical secondary fault. 160% is used for larger transformers.

7.0 FAULT ANALYSIS

To be able to determine device coordination, a short-circuit fault analysis must first be performed. The goal of the short circuit studies is to find the maximum fault current that. An example is shown below (Figure 2). Bus 3 was faulted in ETAP under normal operating conditions (system powered by 'Substation') and the results are shown in red.

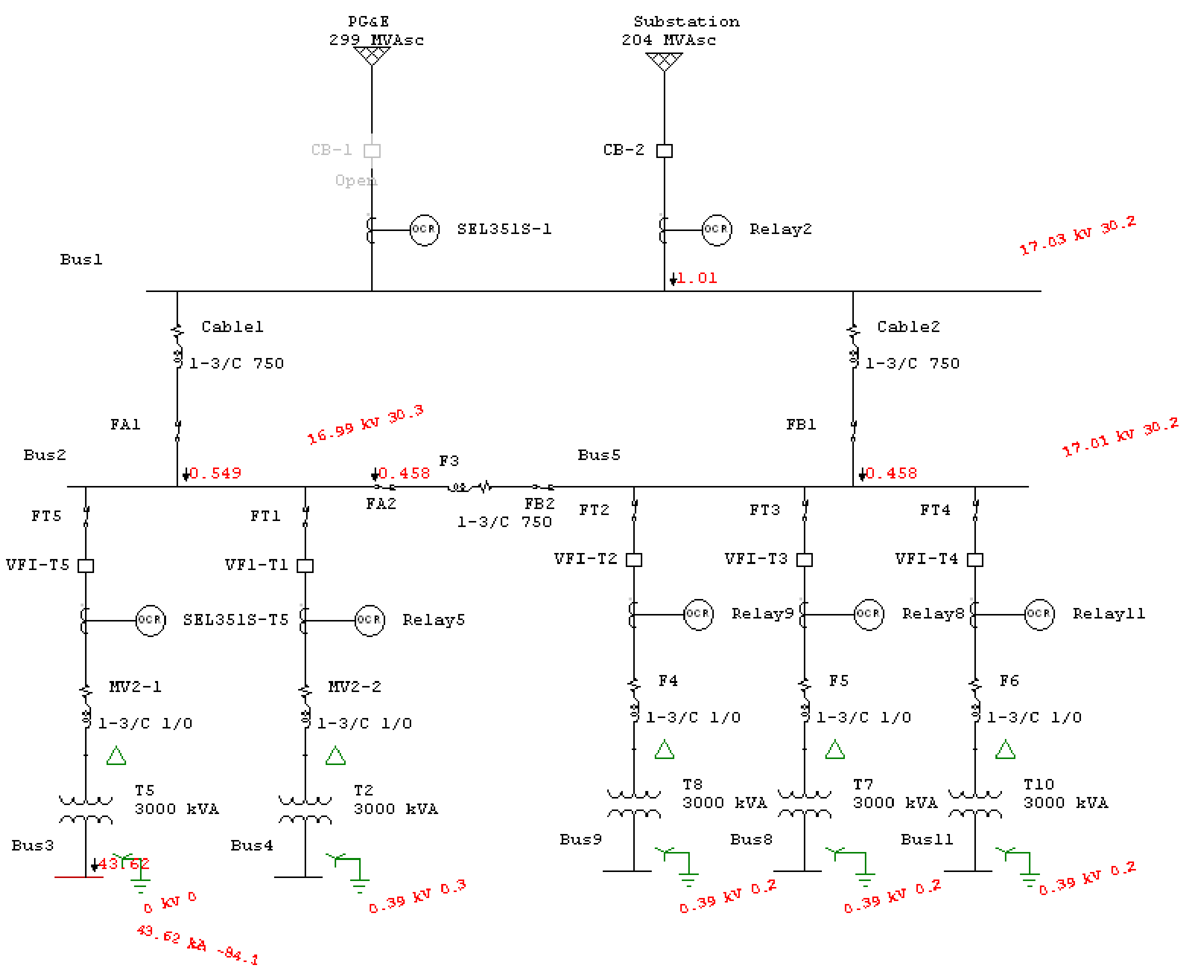


Figure 2 - Short Circuit Study – Substation Feeder (Bus 3 Faulted)

8.0 COORDINATION EVALUATION

ETAP's STAR module was used to coordinate the time-current curves associated with the SEL351-s protective relays. In this study, there is a maximum of two protective devices needing to be coordinated at any given time. This occurs when a fault happens in any of the feeders tied in with the transformers. Since all these feeders are identical, the settings associated with the respective relays will also be identical. As mentioned in section 6.0, there are guidelines in coordinating these devices. There must be adequate time for the relay to sense the fault, transmit to the breaker, and open the breaker. If this does not occur in the downstream device, then the upstream device must perform this function. It is an industry standard that this coordination time is 0.30 seconds. The time-current curves for ideal operation are shown below (Figure 3). The time-current curve for operation under backup power is shown in the appendix.

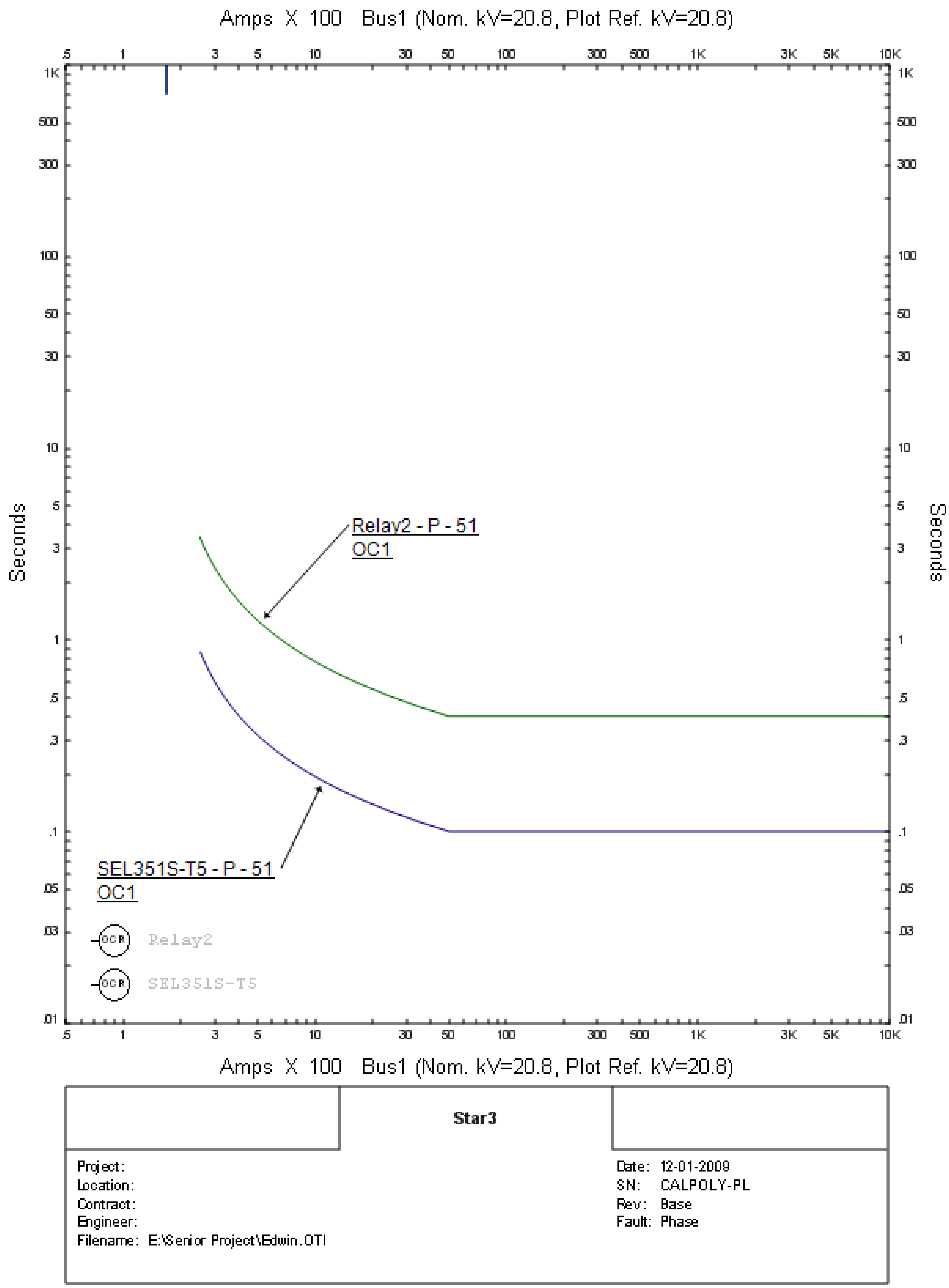


Figure 3 - Time-Current Coordination Curve – Substation Feeder

9.0 CONCLUSION

Overall this project was a success. This project was chosen with the intention of learning ETAP and using it effectively in obtaining protective device coordination of a one-line obtained from industry; this goal was achieved. Difficulties in this project included limited access and learning curve of the ETAP software, specifically STAR, and obtaining data necessary to complete the study.

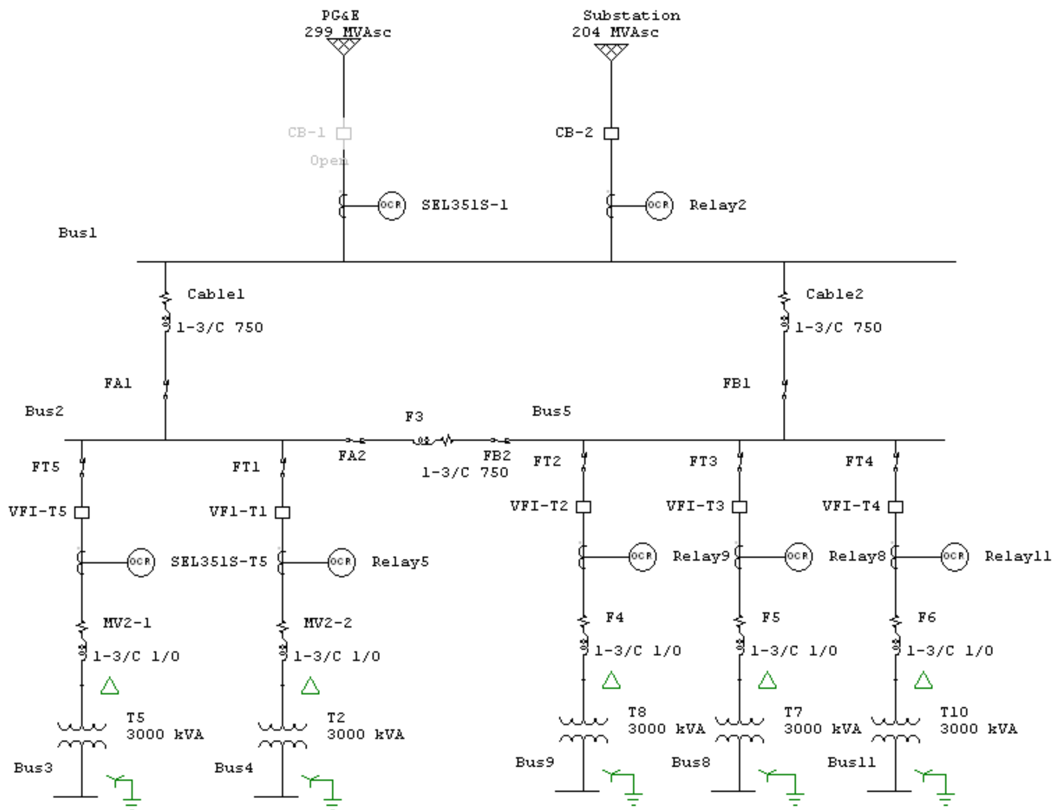
The time-current coordination curves, drawn for this study, are located at the end of this report. Each curve is drawn on the voltage base indicated and the current scale multiplier is as shown. The complete listing of the recommended settings for the protective relays can also be found at the end of this report. A short circuit study for maximum and minimum fault currents is shown for operation with the substation as well as PG&E feeder. All devices do provide adequate equipment protection and selectivity; no deficiencies in either equipment protection or selectivity have been identified.

10.0 BIBLIOGRAPHY

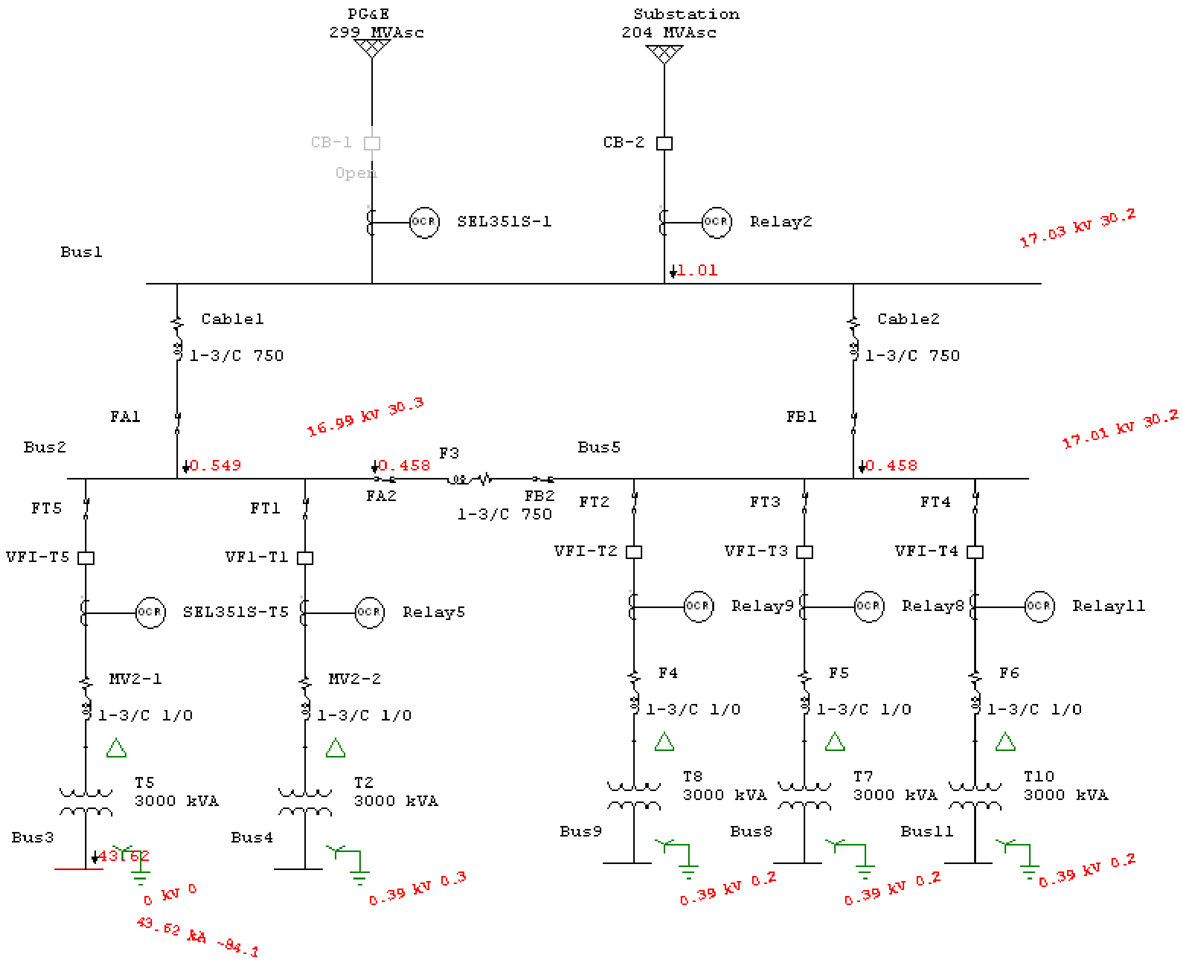
1. NFPA. *National Electrical Code 2008 (National Fire Protection Association Electrical Code.)* Belmont: Cengage Delmar Learning, 2007. Print

2. *Overcurrent Coordination Guidelines for Industrial Power Systems.* Houston: Qual-tech Engineers, Inc., 2004. Print

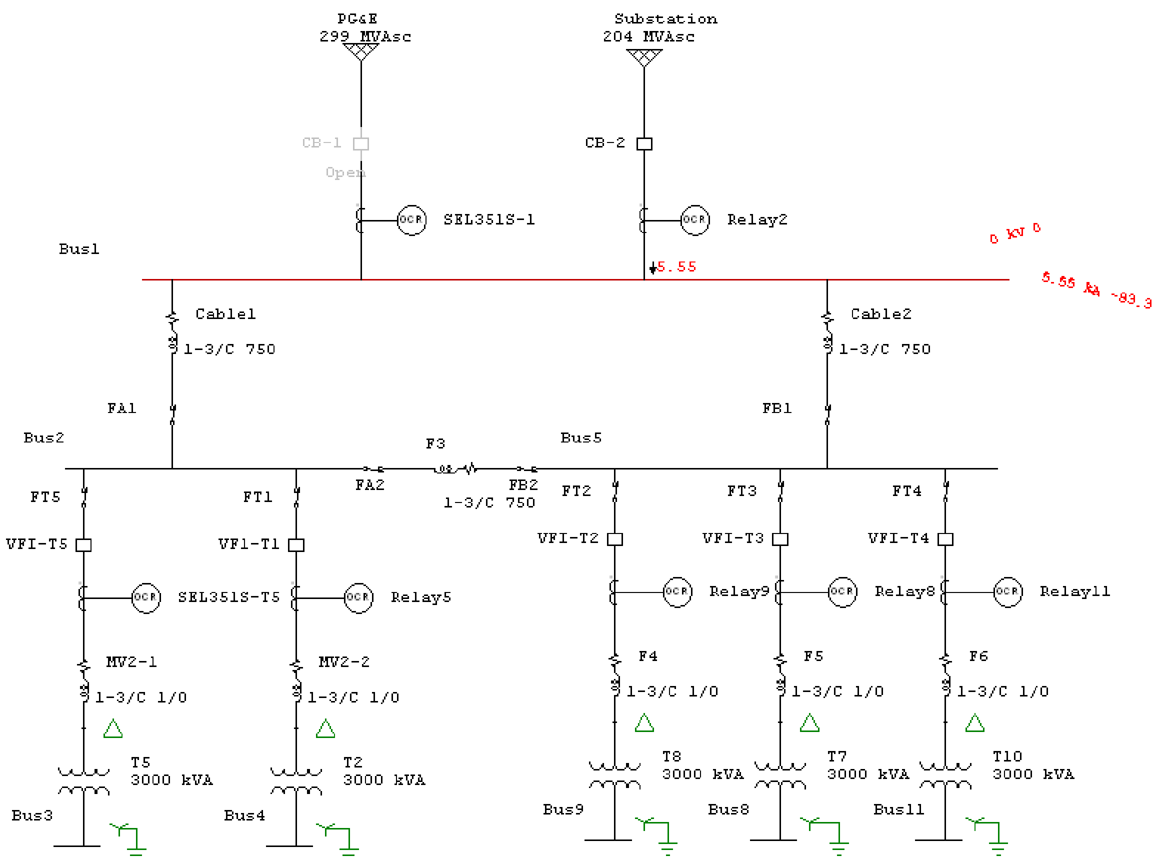
One-Line Diagram



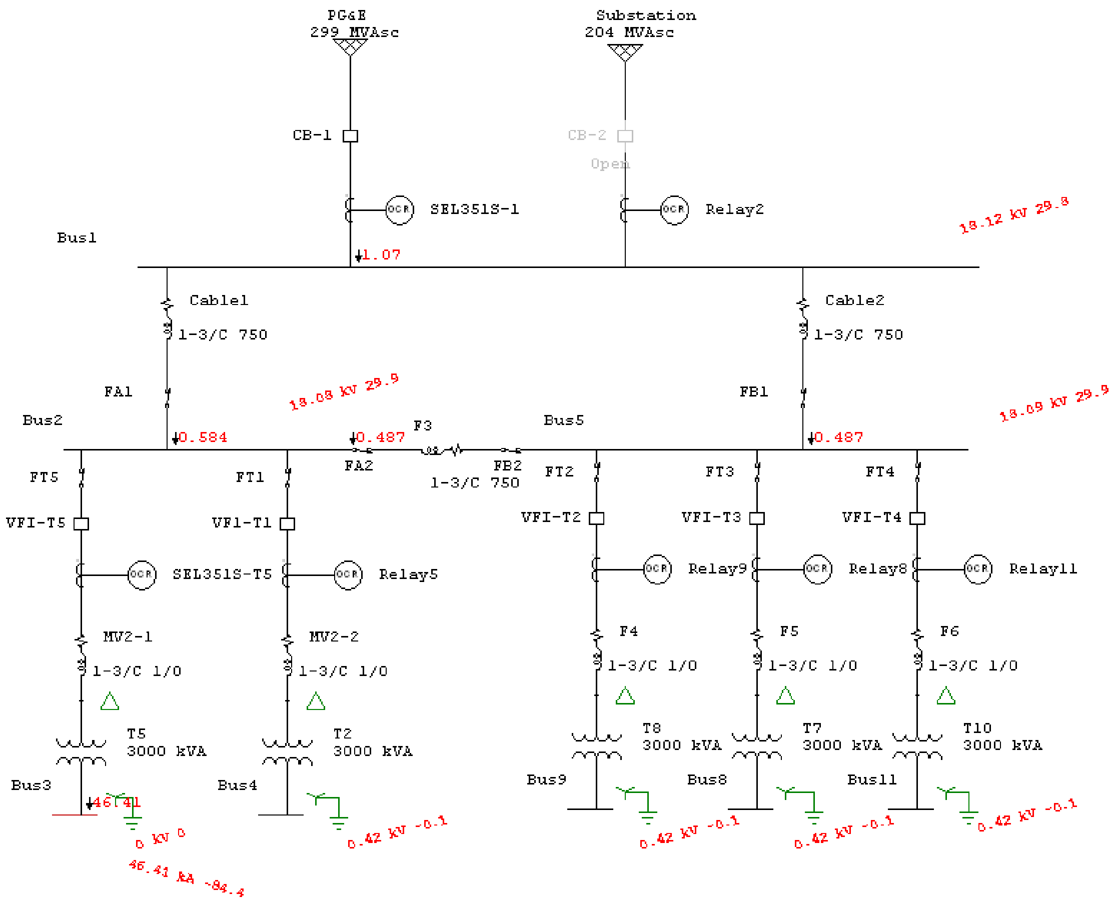
Short Circuit Study – Substation Feeder (Bus 3 Faulted)



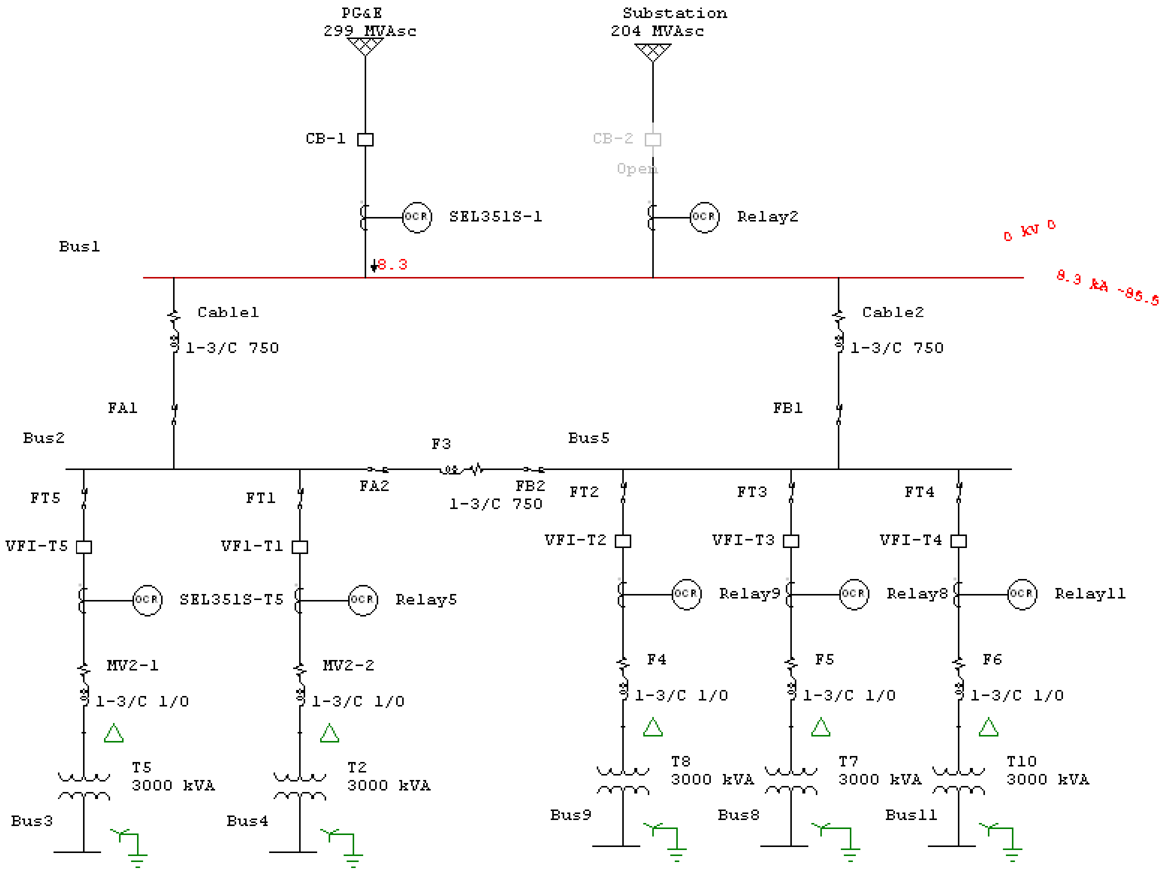
Short Circuit Study – Substation Feeder (Bus 1 Faulted)



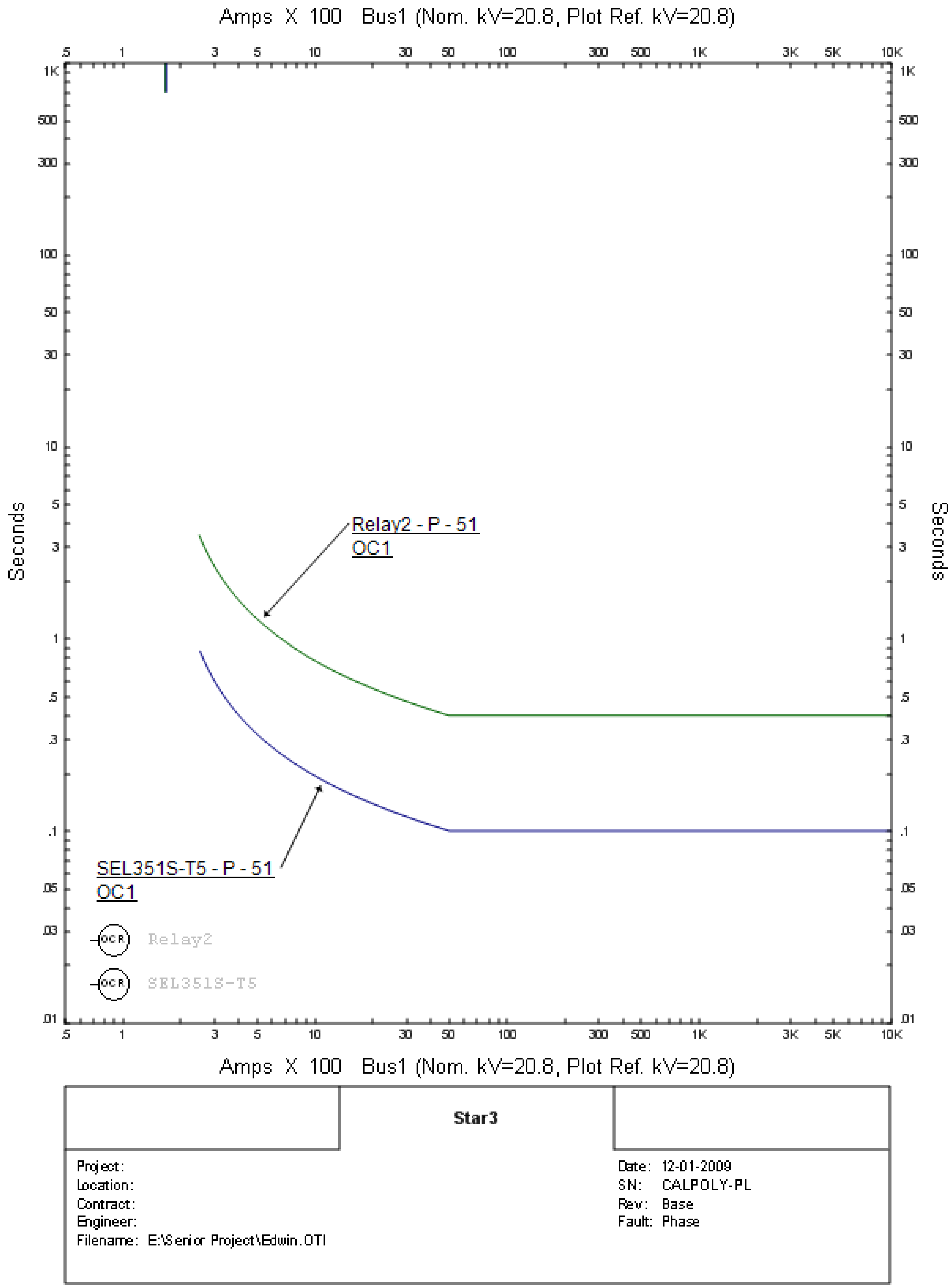
Short Circuit Study – PG&E Feeder (Bus 3 Faulted)



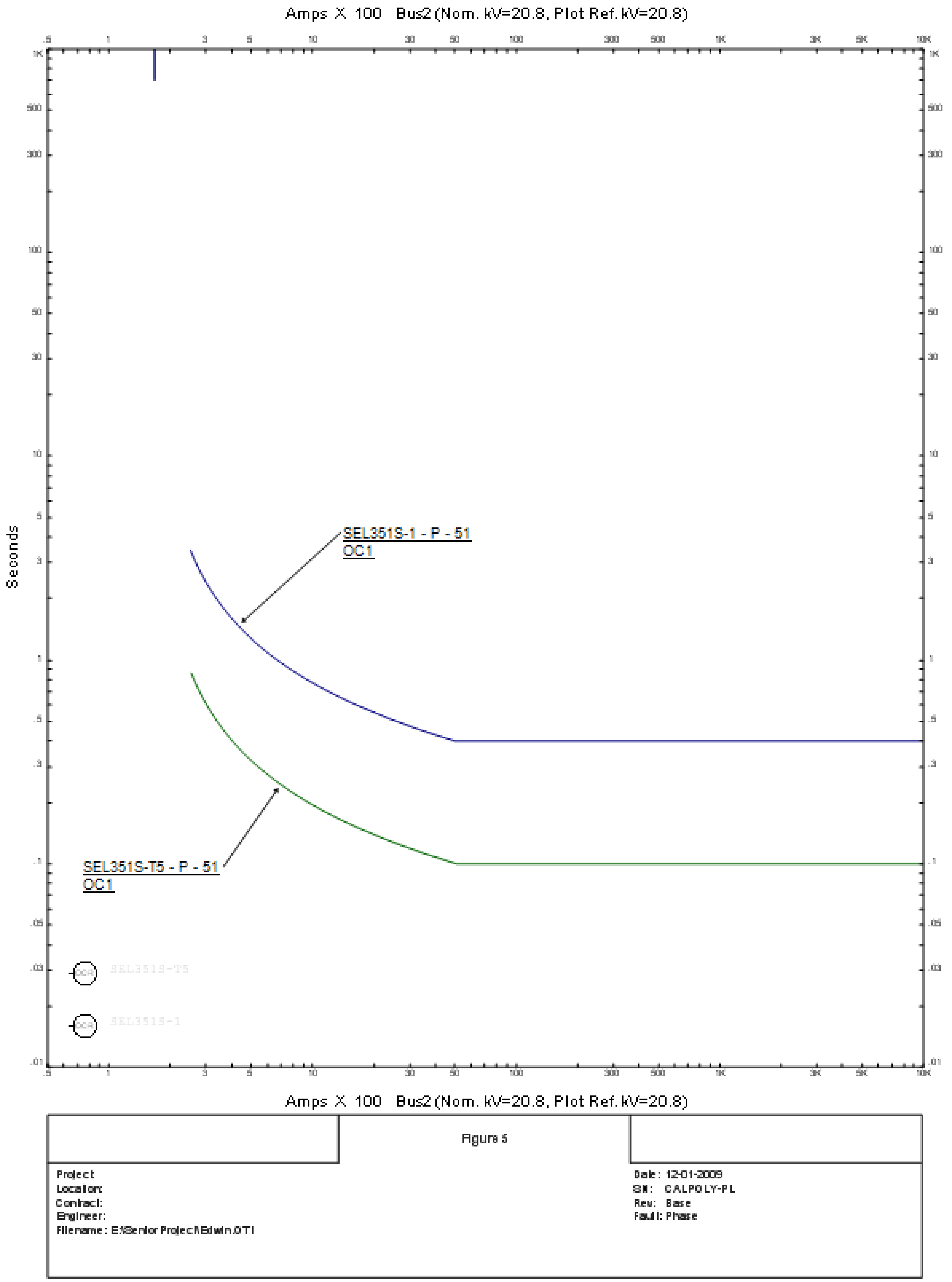
Short Circuit Study – PG&E Feeder (Bus 1 Faulted)



Time-Current Coordination Curve – Substation Feeder



Time-Current Coordination Curve – PG&E Feeder



Protective Device Settings

Relay Name	Relay Function	CT Ratio	Pickup Setting	Time Dial Setting
SEL351S-1	51	600:5	1.4 x Isc	0.2
Relay 2	51	600:5	1.4 x Isc	0.2
SEL351S-T5	51	600:5	1.4 x Isc	0.05
Relay 5	51	600:5	1.4 x Isc	0.05
Relay 9	51	600:5	1.4 x Isc	0.05
Relay 8	51	600:5	1.4 x Isc	0.05
Relay 11	51	600:5	1.4 x Isc	0.05