

Power Quality and Protective Device Coordination: Problems & Solutions Part 1 “Undersizing of Utility Main Service Transformers”

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INTRODUCTION

The use of electronic equipment has dramatically increased during the last 20 years. Some of these electronic devices include variable speed drives, programmable controllers, computers, and even solid state protective relays. Electronic equipment is much more sensitive to power quality. A lot of attention has been given to power quality in the last several years. Most of this focus has been on harmonics, power sags, and surges.

One important aspect of power quality that is extremely important is Protective Device Coordination. Protective Device Coordination Studies determine settings for circuit breakers and relays. These studies also verify the correct fuse size and determine the protection required for conductors, transformers, and other equipment. The goal of this study is to determine settings which would reduce damage to equipment and to isolate only the circuit that has a short circuit or fault. This causes the least amount of disturbance to the remainder of the distribution system.

POWER QUALITY AND PROTECTIVE DEVICE COORDINATION: PROBLEMS & SOLUTIONS Part 1 & Part 2 will focus on two unique problems that are affecting power system protection, owners, and design engineers. These two problems are:

- Part 1 - Under-sizing of utility main service transformers for buildings, plants, and facilities.
- Part 2 - High inrush currents on low temperature or K-Rated transformers.

This article will address Part 1 - Under-sizing of utility main service transformers for buildings, plants, and facilities.

BACKGROUND

When a building is designed by electrical engineers, the engineers are required to use the National Electric Code (NEC). This code is a safety code which is designed to protect life and property. The code has minimum requirements for the number of outlets in a room, number of receptacles on a circuit, and the size of equipment. The designer must use these minimum requirements when they design the electrical distribution system for a building or facility. The use of the NEC results in a distribution system that is initially oversized.

The design engineer calculates the anticipated loads for the building using the National Electric Code (NEC). The designer uses:

1. Estimated motor horsepower determined by the mechanical design engineers.
2. Estimated lighting loads based upon the type of fixtures used, square footage of the building, and the governmental energy requirements.
3. Estimated receptacle loads based on NEC and type of building loads.
4. Known client purchased equipment loads.
5. Fudge factors for those unknown loads.
6. Load growth factors for future loads.

Together with the NEC code calculations, estimations, requirements, and the future growth factors, the

distribution system becomes oversized.

During the design process, the electrical designer contacts the utility company to determine the location and transformer size for the building. The design engineer needs to know the size of the transformer to perform a short circuit study.

The short circuit calculations are needed to specify the electrical equipment. Panelboards, switchboards, motor control centers and most other electrical distribution equipment all have a short circuit rating. This is similar to a full load current and voltage rating. The short circuit rating is a rating given to a piece of equipment by the manufacturer or electrical testing laboratory. This rating indicates the amount of short circuit or fault current that a device can withstand or interrupt. Section 110-10 of the NEC requires that all equipment that is installed must have a short circuit rating larger than the calculated short circuit at the equipment location.

The utility engineer will usually supply the design engineer the transformer size and impedance based upon the load that the design engineer calculated.

Initially, the utility companies are not required by the Authority Having Jurisdiction (AHJ) to use the NEC. The utilities can use whatever methods or means that work for them, regardless of safety or equipment protection issues.

Due to experience, the utilities have seen that buildings designed using the NEC result in an over-designed distribution system. The actual demand load will be much less than the load that the electrical engineer calculated. They know that the actual demand load will be 40-60% of the load calculated by the design engineer.

The utilities are also facing major industry changes due to de-regulation. This is forcing them to look for ways to be more efficient and reduce costs. Therefore, most utilities are now ordering and installing smaller transformers. This has a negative impact on protective device coordination.

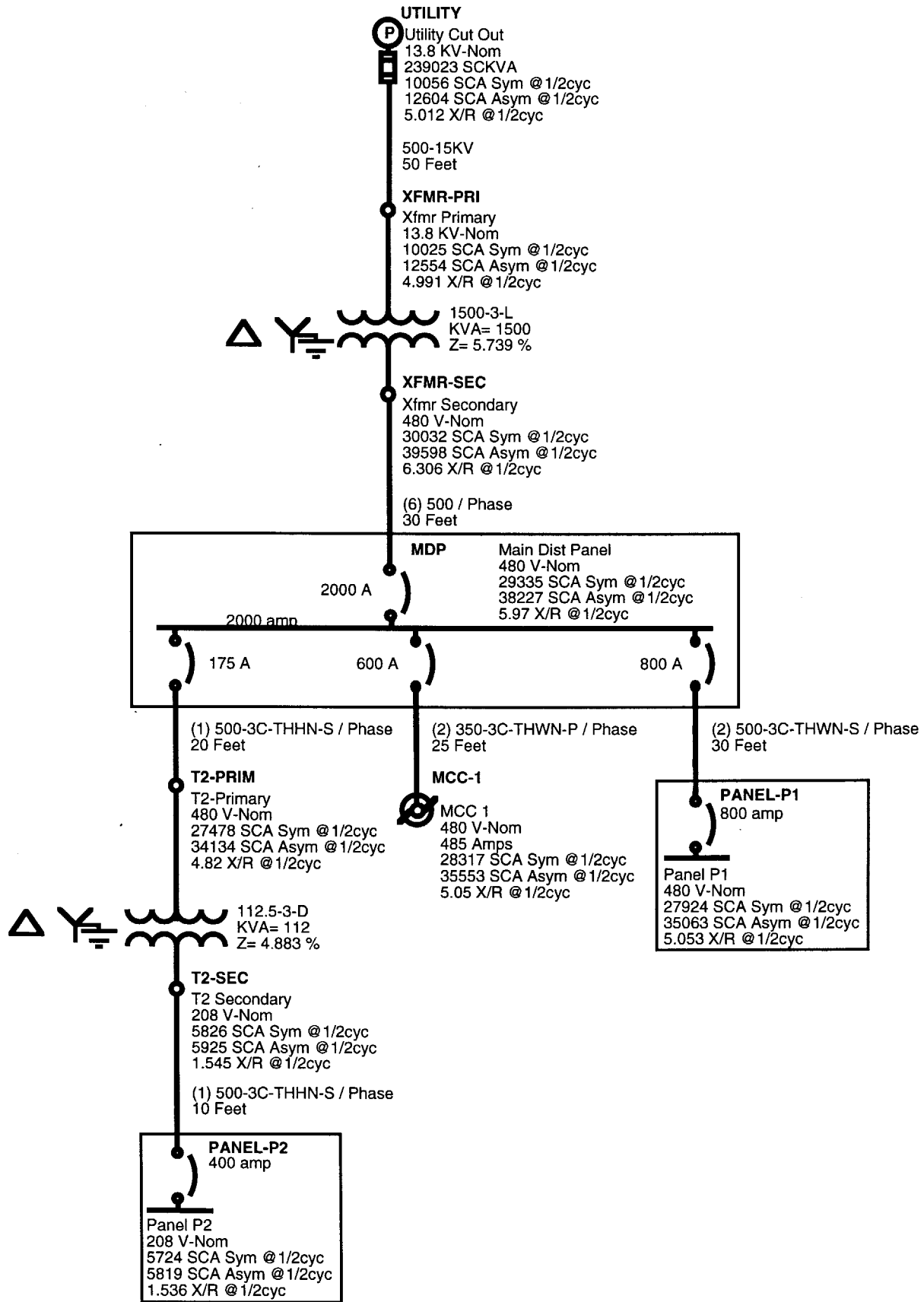
After the contractor or owner has ordered the facility's electrical equipment and before the contractor installs it, a protection engineer must perform a protective device coordination study. Section 240-12 of the NEC also requires that this study be performed. The engineer is usually hired by the contractor or equipment manufacturer to perform this study. As stated earlier, the protective device coordination study is needed to determine the settings for the main service, for both main and feeder breakers. Determining breaker settings becomes increasingly complex, as many of today's circuit breakers are equipped with solid state trip units. These devices have numerous pick up and time delay adjustments.

PROTECTIVE DEVICE COORDINATION PROBLEMS

The protective device coordination problem occurs due to the smaller utility transformer. This size reduction makes it impossible to coordinate the main breaker with the utility transformer and the primary fuse. A fault downstream from the main service switchboard can take out the switchboard feeder breaker or transformer primary fuse. The result is an uncoordinated system that is susceptible to prolonged outages. This affects the facility's overall power quality.

An example distribution system one line is shown on Sheet P1-1. This is a simple distribution system with a 2000 ampere Main Distribution Switchboard. It is being fed by a normally sized 1500 kVA AA/FA transformer. The full load current of this transformer is 1,807 amperes without fans and 2,349 with fans. The design engineer has specified a 2000 ampere main breaker equipped with solid state trip units.

An 800 ampere feeder breaker with solid state trip units feeds Panel P1. The main breaker in Panel P1 is an 800 ampere breaker with thermal magnetic trip units. The protection engineer performs a protective



device coordination study by plotting the protective device time current curve characteristics on a graph called a Time Current Curve (TCC).

The graph is a log-log graph of time versus current. Each breaker, fuse, and relay has a time current characteristic curve published by the manufacturer that is plotted on industry standard log-log graph paper. An example of a time current curve is shown on Sheet P1-2. The curve shows the available fault current, which is a phase to phase short circuit. The curve shows the time current characteristic of the 800 ampere thermal magnetic molded case circuit breaker.

The curve also shows a transformer protection curve. This curve represents the transformer withstand level. They are defined by the ANSI/NEMA Standards below:

- ANSI/NEMA ST20 (1972), R (1982) for Specialty Transformers
- ANSI C57.12.00 (1980), for Liquid Immersed Distribution & Power Transformers
- ANSI C57.12.01 (1979), for Dry Distribution & Power Transformers

These standards are design requirements for transformer windings. The transformer is required to withstand without injury or damage, thermal and mechanical stresses caused by short circuits on its terminals for a defined period of time. The curves are based upon the transformer:

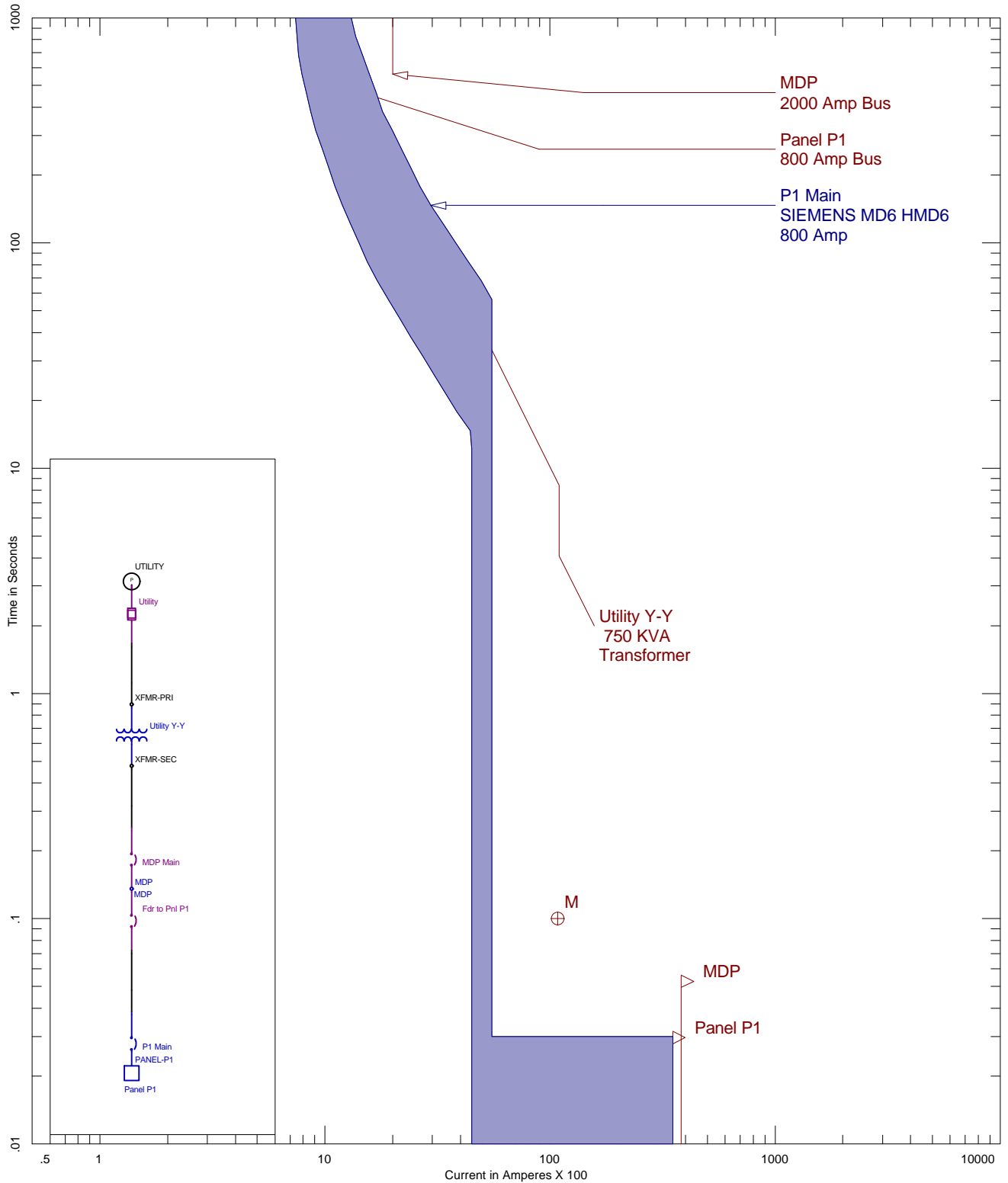
1. Type (liquid, dry, or low voltage)
2. Size (kVA)
3. Impedance (Z%)
4. Primary and Winding connections (Delta, Wye, Wye Grounded)

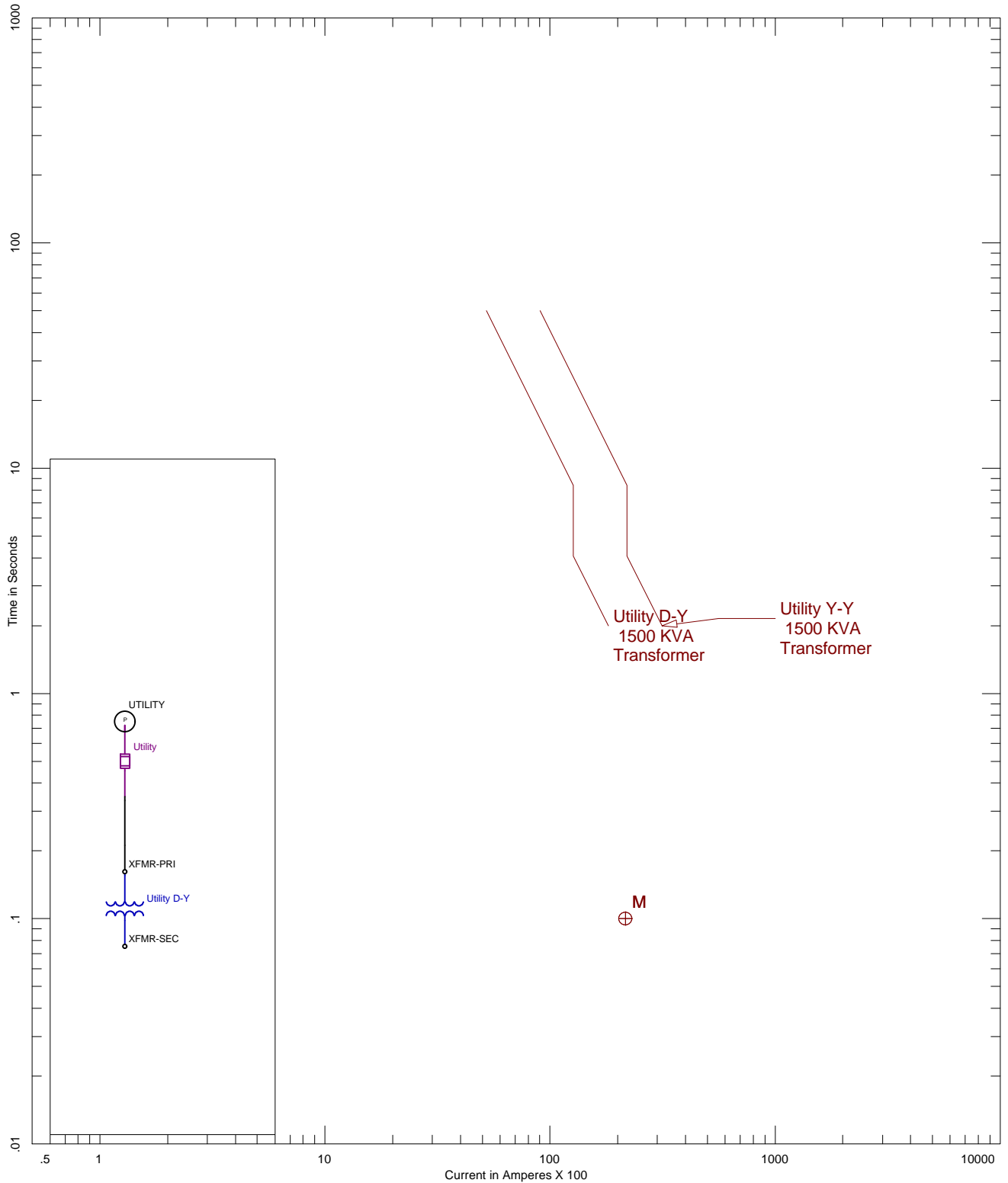
The curve is shifted by an ANSI Factor which is based upon the primary and secondary winding connections. Table P-1 shows these factors for the various types of transformer winding configurations. Sheet P1-3 shows a 1500 kVA transformer connected Delta-Wye and the same transformer connected Wye-Wye. Note that the Delta-Wye solidly grounded transformer curve is shifted to the left by a factor of 0.58.

Transformer Winding Connections			Type of Fault			ANSI Factor
Primary Winding Connection	Secondary Winding Connection	Tertiary Winding Connection	Three Phase	Phase to Phase	Line to Ground	
Delta	Delta		1.0	0.87	N.A.	0.87
Delta	Wye-Grounded		1.0	1.16	0.58	0.58
Delta	Wye		1.0	1.15	N.A.	1.0
Wye-Grounded	Wye		1.0	1.0	N.A.	1.0
Wye-Grounded	Wye-Grounded		1.0	1.0	1.0	1.0
Wye	Wye-Grounded	Core Type	1.0	1.0	0.87	0.87
Wye	Wye-Grounded	Shell Type	1.0	1.0	N.A.	1.0
Wye	Wye		1.0	1.0	N.A.	1.0
Wye-Grounded	Delta		1.0	1.0	N.A.	1.0
Wye	Delta		1.0	1.0	N.A.	1.0
Delta	Delta	Wye-Grounded	1.0	1.15	1.0	1.0
Wye-Grounded	Delta	Wye-Grounded	1.0	1.0	0.87	0.87
Wye	Delta	Wye-Grounded	1.0	1.0	0.87	0.87
Wye	Delta	Wye	1.0	1.0	N.A.	1.0

Table P1-1 Transformer ANSI Factor List

For the transformer to be protected properly, all the downstream secondary devices and the primary fuse must lie to the left of the curve. The primary fuse can lie on top of the curve but it should never be completely to the right of the transformer protection curve.





The protective devices and transformer curves are plotted on the time current curve. The devices are selectively coordinated for all levels of fault current (a short circuit going phase-to-phase, line-to-line, or line-to-ground) and time if they do not touch or lie on top of each other.

An example of some selectively coordinated devices is shown on Sheet P1-4. If a 20,000 ampere fault occurs in the Panelboard P1, the main breaker will trip instantaneously. If it fails to operate, then the upstream 800 ampere feeder in the main switchboard will trip between 0.08 and 0.12 seconds. If this fails to trip, then the main will trip between 0.16 and 0.2 seconds. The primary fuse, main and feeder breakers are selectively coordinated for phase-to-phase faults. The 800 ampere thermal magnetic breaker, however, is not coordinated. The breaker overlaps with the feeder and main solid state trip breakers.

On Sheet P1-4, the devices are selectively coordinated using the 1500 kVA Delta-Wye transformer and a 100T fuse. On this sheet, the devices do not overlap each other. Sheet P1-5 shows what can happen if the utility installs a 750 kVA Delta-Wye transformer and a 50T fuse.

The transformer protection curve is shifted to the left and now overlaps the downstream protective devices. The primary fuse is shifted over because its size is reduced to protect the smaller transformer. The result is an uncoordinated system with the transformer and fuse curves overlapping the downstream devices. This results in mis-coordination.

For some faults, the primary fuse will operate before or at the same time as the downstream devices. This results in a total facility outage. This reduces the power system reliability and thus the facility power quality.

SOLUTIONS

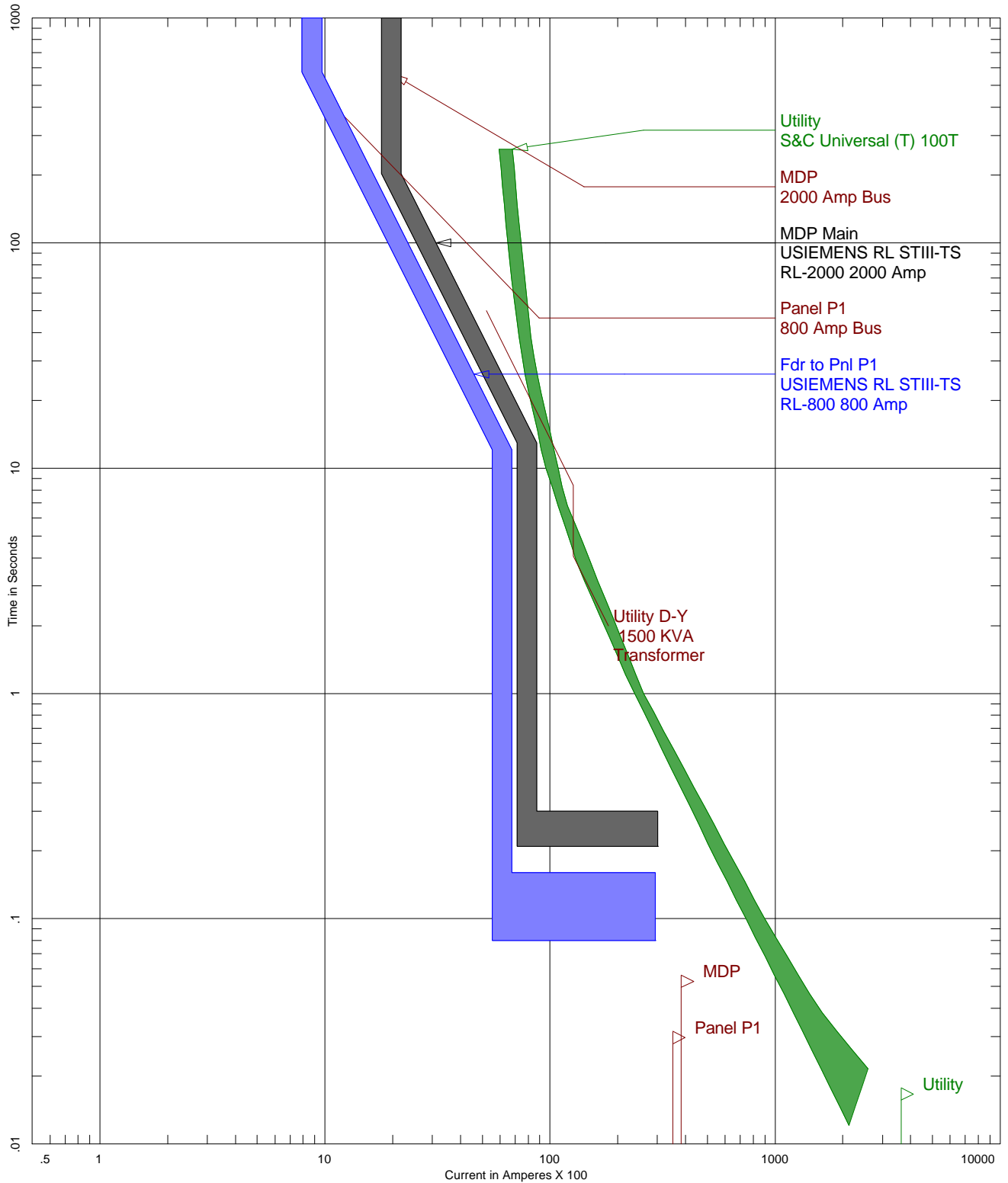
Sheet P1-6 shows the same 750 kVA transformer but it is now a wye-wye unit. The primary fuse is now an 80T. The transformer curve is shifted to the right. This improves the coordination between the secondary devices. The 80T fuse does overlap the main breaker curve. This represents a compromise, but is still an improvement.

What can the protection engineer, designer, and the utility do to avoid this problem? The first step is to improve the communication between the engineers and the utility. They all must work together and solve the problem.

There is a compromise that will satisfy both the designer and utility engineer. The utility will be able to install a smaller transformer and the protection engineer will be able to achieve coordination. This win win situation will occur if the utility installs a wye-wye transformer and increases the primary fuse size. The wye-wye connection shifts the ANSI/NEMA transformer protection curve to the right and away from the downstream device curves. The primary fuse can be increased because the transformer curve has been shifted.

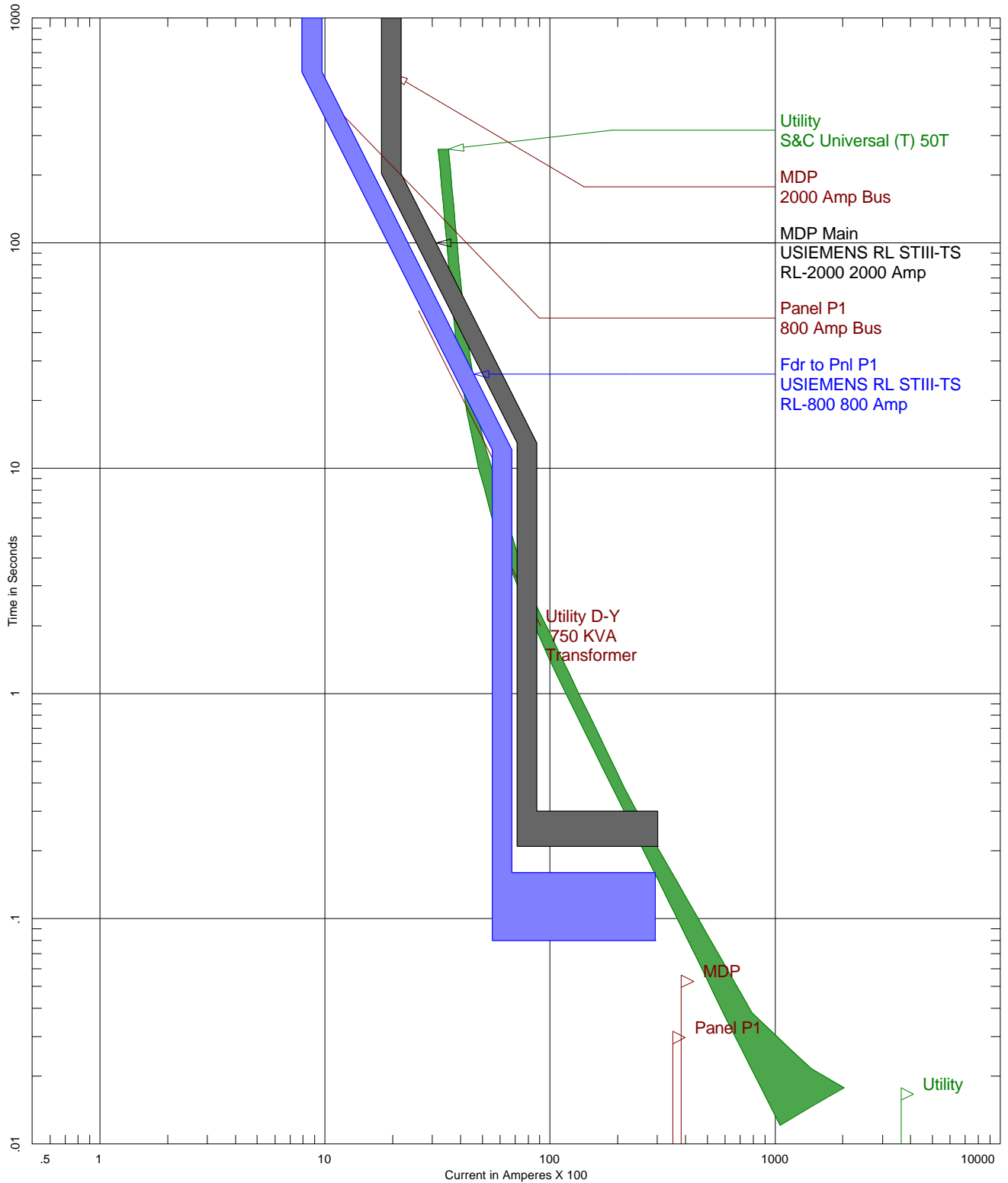
SUMMARY

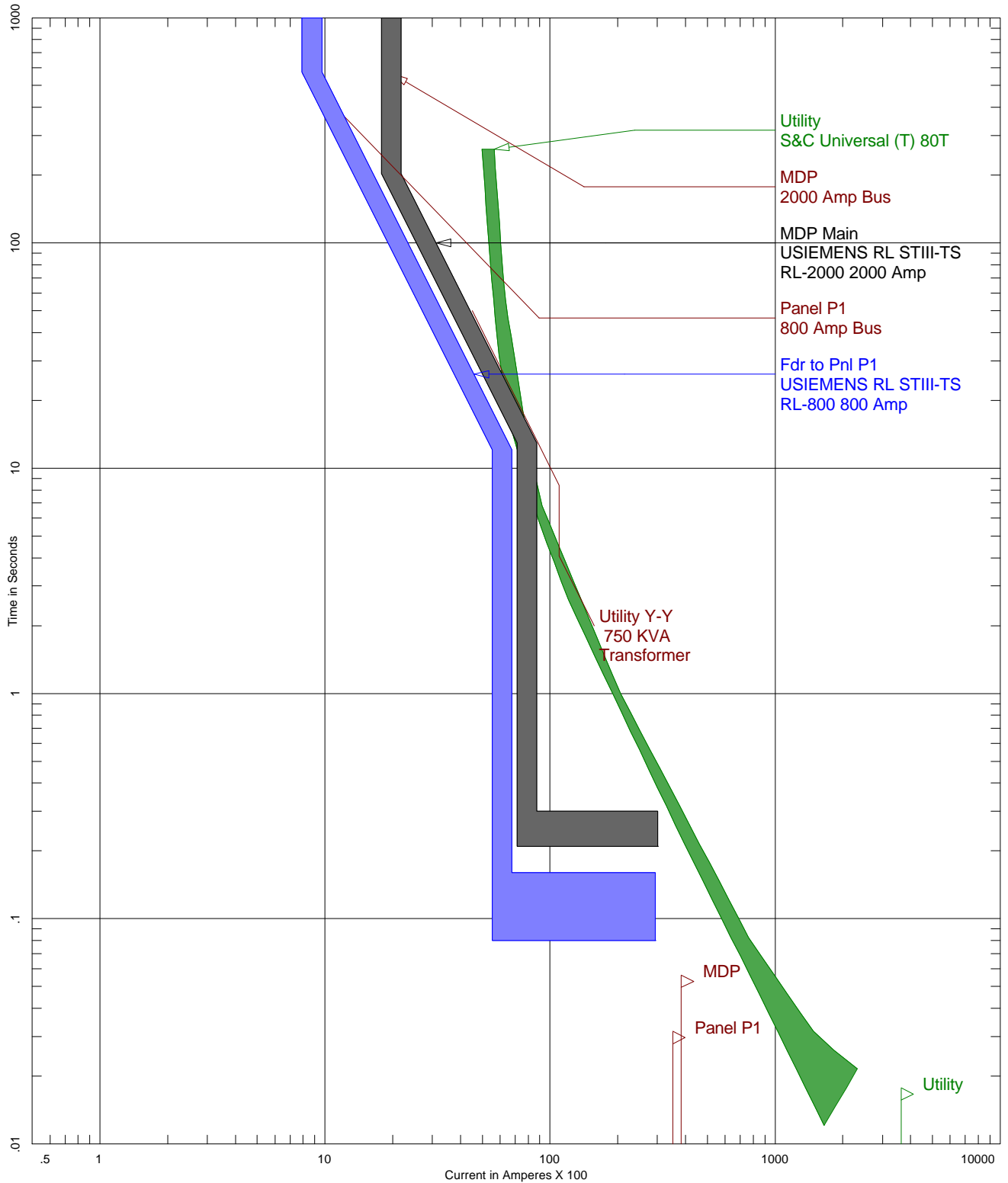
Power Quality is a very important issue that is affecting every building and facility. Good facility power quality starts with a reliable power distribution system. A reliable power system must be properly coordinated with the facility and the utility protective devices. If the protection, design, and the utility engineers work closely together and communicate with each other, then the utility engineer can order the correct transformer size and winding connection, thereby eliminating any protective device coordination problems.



480 Volt Phase
 Time-Current Characteristic Curves
 Sheet P1-4 1500 Xfmr D-Y, MDP Main, Fdr to Pnl P1, & P1 Main

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Robert E. Fuhr graduated with a B.S.E.E. from the University of Wisconsin in 1980. Before graduating, Mr. Fuhr worked for Madison Gas and Electric in Madison, WI and Tennessee Valley Authority in Knoxville, TN. After graduation, he worked for General Electric Company from 1980 to 1986 as a Field Engineer. From 1986 to 1989 he worked as a Senior Facilities Engineer at the University of Washington. In 1986, he established Power Systems Engineering, a consulting firm that specializes in power systems studies. As Power Systems Engineering's Senior Electrical Engineer, he has performed power studies for many commercial buildings and large industrial facilities. He is the sales agent for EDSA Power System Analysis Software. He also teaches classes in electrical safety, power factor correction, harmonics and filter design. Mr. Fuhr is a Professional Engineer registered in Washington, Oregon, California, and Alaska.

Bob has been actively involved in IEEE and the Industrial Applications Society since 1986. He has served as an officer for IAS from 1988 to 1992. He was the 1991 to 92 Chairperson of IAS. He was a Member-at-large for the Seattle Section of IEEE for 1992-93. He is a board member of Power Quality Interest Group and is a member of the Electric League of the Pacific Northwest.