Massachusetts Technology Collaborative
Advanced Network Protector RFP Initiative

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Table of Contents

Table of Figures

Preface

This presentation of the Advanced Network Protector concept for facilitation of deployment of distributed resources on spot networks is derived, almost entirely, from original research conducted by William Feero, PE, under contract to MTC as part of their DG Collaborative initiative. Relevant reports and conference papers are cited and appear in the Reference section at the end of this document.

Executive Summary

The intent of this initiative is to sponsor the development of an advanced network protector monitoring and control mechanism that will facilitate the acceptance of distributed resource technologies by utilities on spot networks. The goal is to develop a technical solution that will address the concerns that utilities have regarding the security and quality of the premier service that is presently delivered to their spot network customers while accommodating higher levels of distributed resources at these sites. Two predominant concerns of utilities are:

1) That the determination of abnormal conditions on the utility system that would require action (or non-action given the presence of a DR interconnection) should be maintained by the utility.
2) That the intentional addition of time delay to provide NP-DR trip coordination should not adversely affect network protector performance or the utility system generally.

The fundamental objective is to eliminate, as far as is practical, the possibility that operation of a distributed resource technology on a spot network will result in the unintended opening of a network protector and the associated loss of service to the customer. The proposed method for accomplishing this goal is to transfer a portion of the control of the distributed resource, in the form of a “Go/No-Go” signal, to the utility through an enhancement of the presently available network protector technology. That control would reside with the network protector or, in the case where multiple network protectors are in use on a spot network, with a auxiliary relay controller. Control and monitoring signals would cross the point of common coupling (PCC) and have the ability to trip the DR in the event that the forward power across the network protectors decreases past a preset threshold.

Objective

The core objective of this initiative is to develop a flexible hardware solution to facilitate the installation of distributed resources on spot networks. The chosen approach should be based upon presently available technology, which is currently being used in the area of network protection. In addition to the hardware component, the complete solution will include a body of procedural configurations or applications guidelines for the implementation of distributed resources on spot networks which:

- Avoid negative power flow across the PCC
- Create a system that meets a utility’s most stringent (possibly sub-cycle) coordination requirements
- Create a monitoring and control system with security acceptable to utilities
- Are, to the maximum extent practical, replicable, scalable and extensible to the widest variety of distributed resource technologies possible.

Technical Background

Interconnection of Distributed Resources on Networks

As distributed resources (DR) become more common, utilities and distribution companies are more frequently being asked for interconnection of these systems. Some of these requests for interconnection are being made in sections of the grid where the distribution is configured as either a spot or a grid network system[1]. Interconnection to these types of secondary distribution networks presents special challenges to operational safety, power quality and reliability. Presently there is no single standard or universally accepted policy for these interconnections.

The fundamental difficulty in connecting distributed resource technologies to secondary networks lies in the fact that the protection systems for spot and grid networks are not designed to accept reverse power flow from the customer's facility going back in the direction of the utility. A typical two-transformer spot network is shown in figure 1. In the case where a fault occurs on the primary side of a network protector transformer power can flow backwards (reverse) from the secondary 480 volt bus, through the transformer to the fault. The network protector is designed to sense the reverse power and open to protect the primary feeder cables and other components.

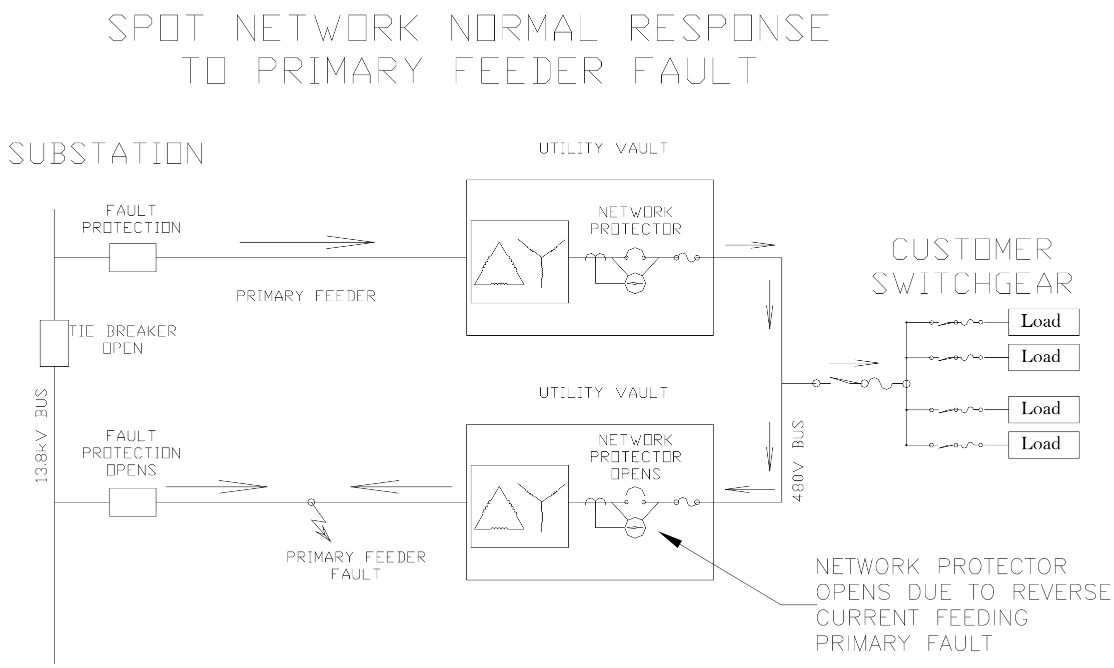

Figure 1: Typical spot network with normal response to primary fault

Even under normally occurring light load conditions, absent customer sited generation, it is possible for network protectors to open. Generation located on grid or spot networks has the potential to produce reverse power flow and by doing so cause network protectors to open when not intended[2]. The RFP in this initiative seeks to develop a technical solution that will permit the safe and efficient interconnection of DR on spot networks.

[1] There are a number of different terms used to describe "grid" network configurations. Among them are, "street" networks and "area" networks. In this report we will use the IEEE terminology, "grid" network.

[2] For a more detailed explanation of the issues surrounding the interconnection of distributed resources on networks see: http://www.mtpc.org/RenewableEnergy/public_policy/network/2006-04-05_Feero_Network_review.pdf

GSA Williams Building Case Study

In 1999 a 30 kW Xantrex photovoltaic inverter was installed at the GSA Williams building in downtown Boston. Later, in 2002, a 75 kW Tecogen CHP induction generator was installed at the same facility. With the cooperation of the local utility, NSTAR, the two network protectors serving the building were upgraded to microprocessor-based units and the network protector manufacturer, Cutler-Hammer, designed and installed a custom auxiliary control and monitoring system (CH unit). The CH unit monitored the flow of power across both network protectors and had the ability to trip the Tecogen if the forward power reversed or dropped under predefined limits. The firmware of the photovoltaic inverter was modified to custom trip settings[3]. The system was monitored for a period of two years, between 2003 and 2005, after which a report of the results of the study was submitted to the sponsoring agency, the Massachusetts Technology Collaborative (MTC) [1]. The full study can be downloaded from:

http://www.masstech.org/renewableenergy/public_policy/DG/resources/network.htm

The fundamental question embodied within this experiment was whether, by monitoring the flow of power at the network protectors and controlling the DR from the network protectors, could the DR be operated in a manner that would assure reliable tripping for all fault conditions where tripping was necessary. The study findings concluded that to meet this criterion, "some form of detection of conditions that require tripping of the DRs must be installed at each network transformer."

GSA NP-DR Control Topology

The monitoring and control configuration that was implemented at the GSA Williams Building is illustrated in Figure 2. The present RFP seeks to refine this concept to a prototype device that

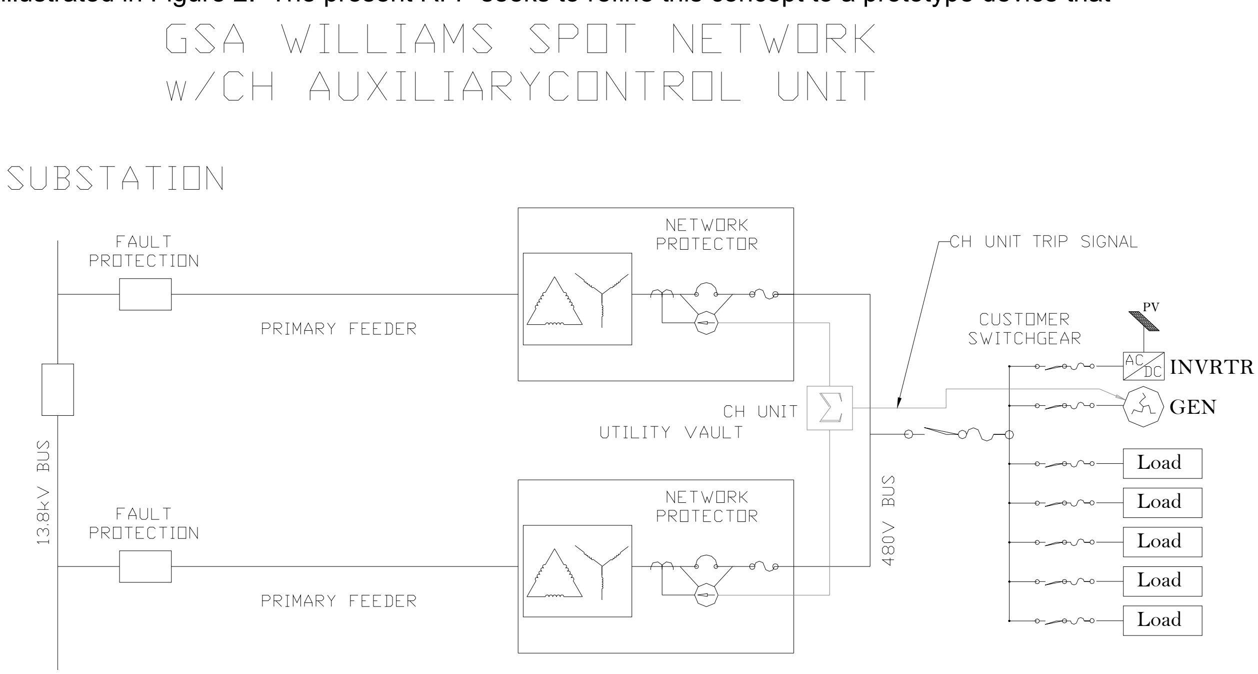

Figure 2: GSA Williams Building experimental design

[3] The inverter response to abnormal voltage was modified to trip after 2 cycles for voltages less than 75% of the nominal AC voltage. The standards in place at the time of the installation of the inverter were IEEE 929 and UL 1741. Those standards dictated a trip in response to abnormal voltages of 120 cycles for 50% ≤V nominal≤ 88%.

would be capable of operating with a wide range of DR technologies and under a wide variety of conditions and constraints. The range of variables that the prototype system should accommodate include, but are not limited to:

• NP trip time delays
• DR reset scenarios: trip thresholds & reset thresholds
• NP-DR communications protocols
• DR hardware trip mechanisms

The prototype controller will first be demonstrated at the manufacturer's facility and then at a third party test facility. In a subsequent phase of this research effort, not covered under this RFP, a host utility will be sought to provide a field test setting for the device.

Zones of Operational Protection

This spot network protection configuration proposal conceives of three modes or zones of operation for the protection protocol [3]. These three adjustable zones of operation represent three different responses by the network protector controller to directional power flow measured at the network protector. The response by the network protector, which is dependant upon the direction and magnitude of the power flow, effects the tripping of the customer sited DR and the decision of whether and when to open the network protectors. The three zones are:

1) Forward Underpower
2) Low Reverse Power: network protector delayed opening
3) High Reverse Power: network protector instantaneous opening

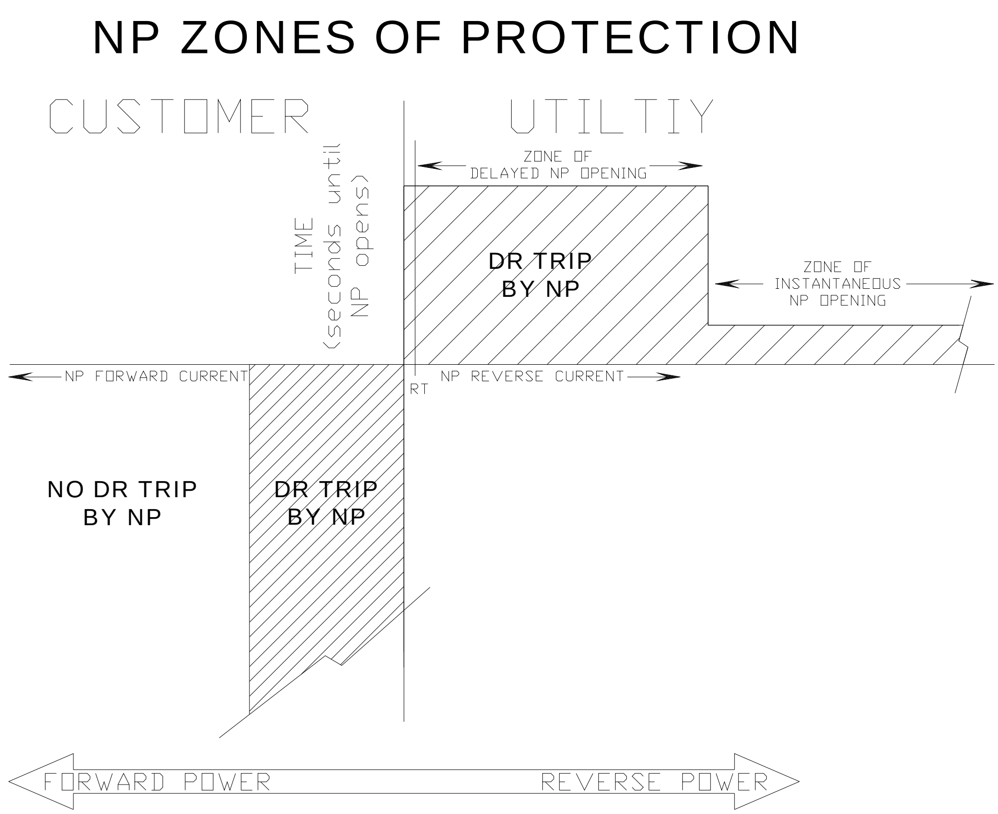

Figure 3: Zones of protection by NP controller.

For the diagram in Figure 3, time is represented on the vertical axis and directional power on the horizontal. The time axis above the horizontal axis, expressed in seconds or cycles, is positive elapsed time between detection of reverse current and the point at which the network protector opens. Time below the horizontal axis represents all past time before the detection of a reverse power event. The horizontal axis represents power flow toward the customer (forward) on the left of the vertical axis and power flow back to the utility (reverse) to the right of the vertical axis.

Low Load Condition: NP Trips DR on Forward Underpower

Protection in the forward underpower zone is a kind of safety margin of operation. The intent is to monitor the flow of power across the network protectors and if the forward flow drops below a predefined threshold the network protector control unit will send a trip signal to the DR dropping it off line. This would be a preemptive control measure that would be invoked before any abnormal occurrences on the network and prior to any actual reverse power flow at the network protector. In response to this temporary shut down of the on-site generation the net load (forward power into the facility) will increase above the forward underpower trip threshold. To avoid cycling the DR the threshold to restart the DR will set higher than the trip threshold, there by designing hysteresis into the control system.

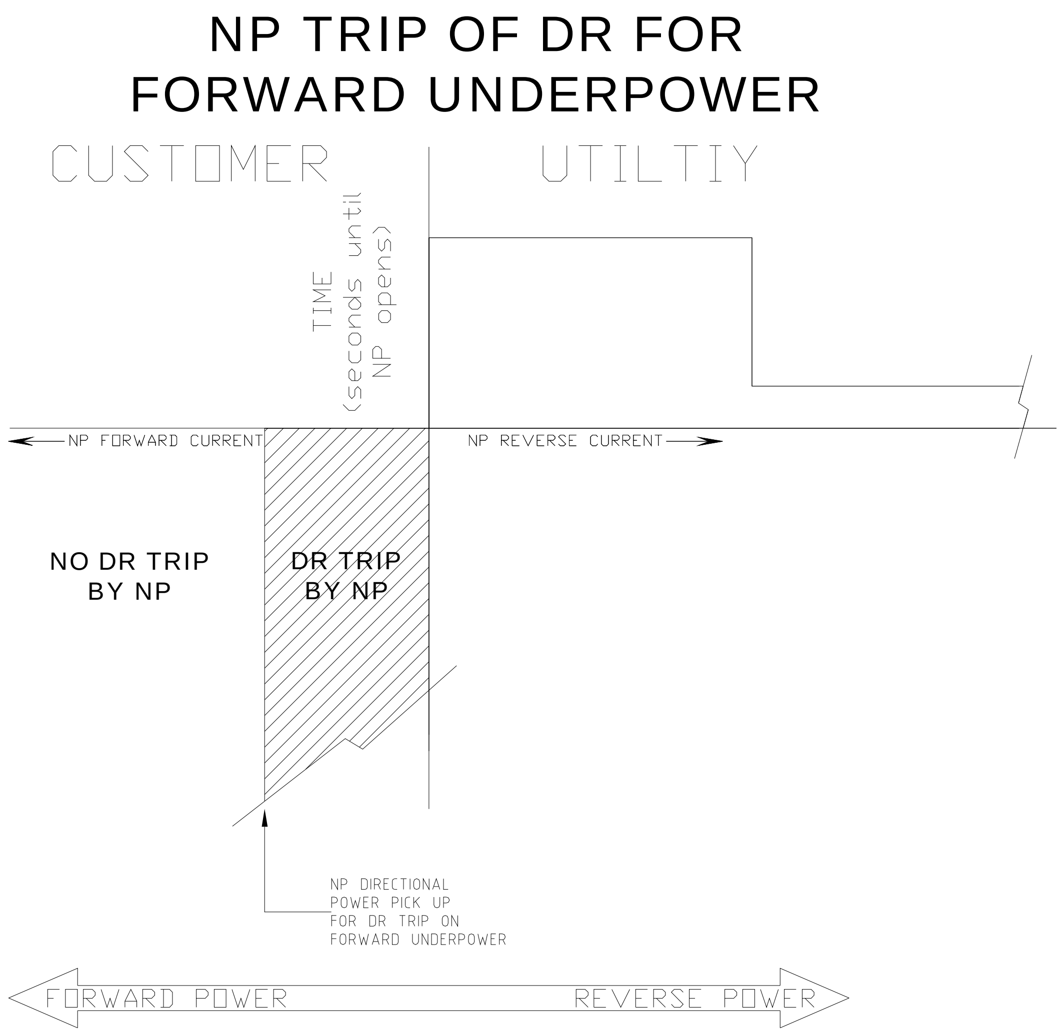

Figure 4: Forward under power NP-DR trip configuration.

The intent of the advance network protector controller concept is that the forward underpower threshold be an adjustable setting suited to the specific characteristics and requirements of the network and the DR in question. Related concepts have been discussed including a 2-stage configuration where the higher threshold provides a warning signal of some kind to the DR or the customer's on-site energy management system. Another concept that has been discuss, but which is outside the scope of this current RFP is for the network protector to have some form of continuous control over the DR with the ability "throttle back" the energy production at times of low forward power.

Primary Fault Condition 1: Delayed NP Opening

For low current faults[4] on the primary network the advanced network protector concept envisions the use of an adjustable time delay in the control mechanisms that open the network protectors. This approach has two main parameters that govern its operation. The first parameter is the reverse current threshold for which the network low voltage bus can tolerate short term voltage sags. This threshold is expressed as a current as percent of the full rating of the network protector transformer. The report, "Generation Monitoring at the GSA Williams Building and Modeling of Feeder Fault Cases Recorded," provides a formula for calculating this value. The selection of the reverse current threshold will derive from the specific physical characteristics of the network transformers and the risk tolerance of the utility.

The second selectable parameter is the length of the time delay itself. The intent of the time delay is to provide sufficient time for the DR to cease to energize the system after it has received the trip signal from the network protector controller and before the network protector opens due to reverse power. The objective is to select a time delay that will be greater than the cessation time of the DR with minimum necessary margin to assure coordination, thus avoiding an unnecessary network protector opening. This parameter will be defined by the physical characteristics of the DR and its associated disconnecting mechanism, and the network, as well as the risk tolerance of the utility.

Without specific units, figure 5 illustrates the zone of operation for reverse power levels that are sufficiently low to permit time delay. In the case of the GSA Williams building the time delay was 15 cycles. The threshold defining "low reverse current" was set at 50% of the rating of one network transformer.

[4] The definition of what constitutes "low current" will likely be decided by the local utility protection engineers. The research conducted at the GSA Williams building suggests an analysis based upon a percentage of the network protector transformer rating.

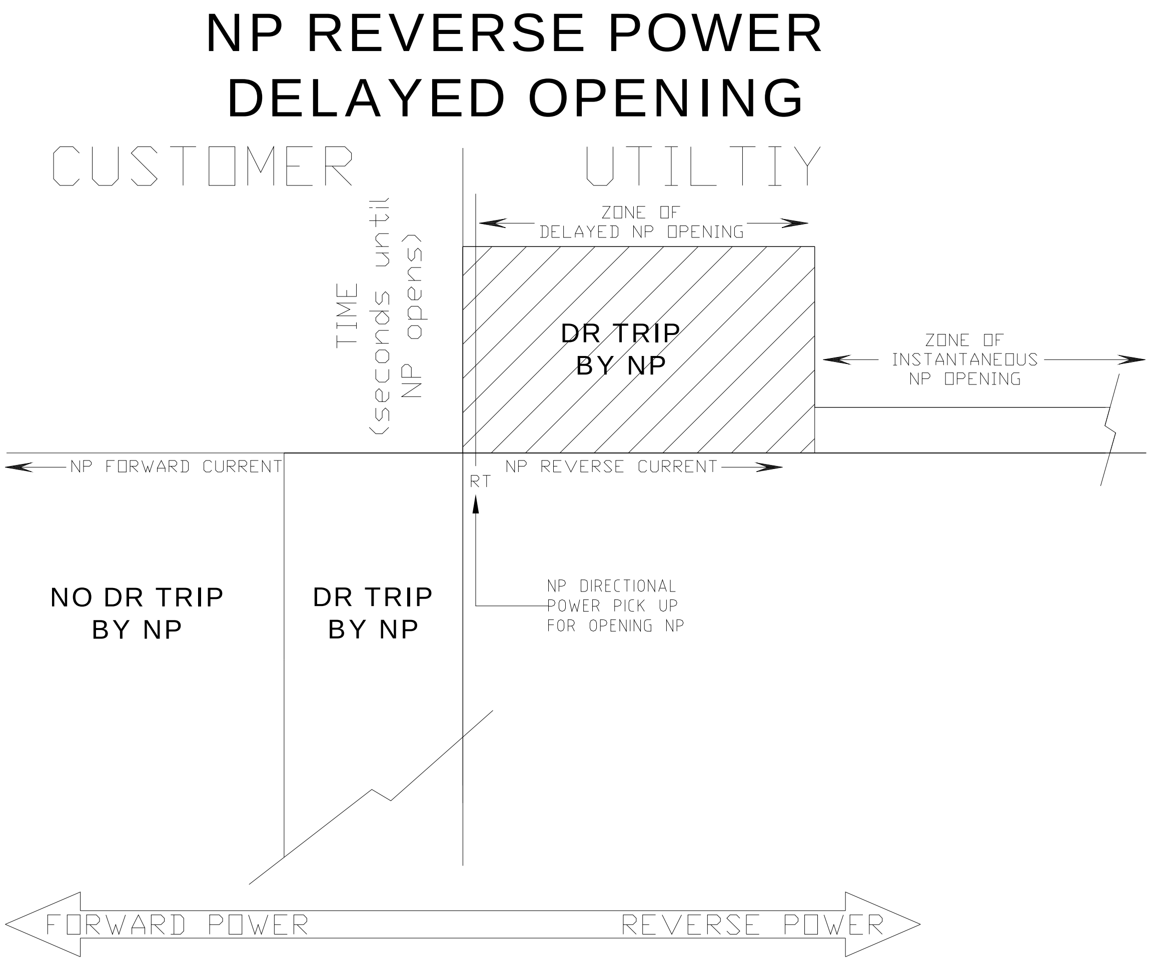

Figure 5: Network protector delays opening while tripping DR

Primary Fault Condition 2: Instantaneous NP Opening

For high current faults, those in excess of preset limits established by the local utility, the network protector must open instantaneously in order to protect the spot network service and other elements of the larger network up stream. The latency shown in this zone of operation (the short vertical band above the horizontal axis) is only the delay between the time at which reverse current is detected and the time at which the network protector opens. This is in the range of three to six cycles. For utilities that do not presently permit time delays on network protectors this would be the zone of operation regardless of the magnitude of the reverse power.

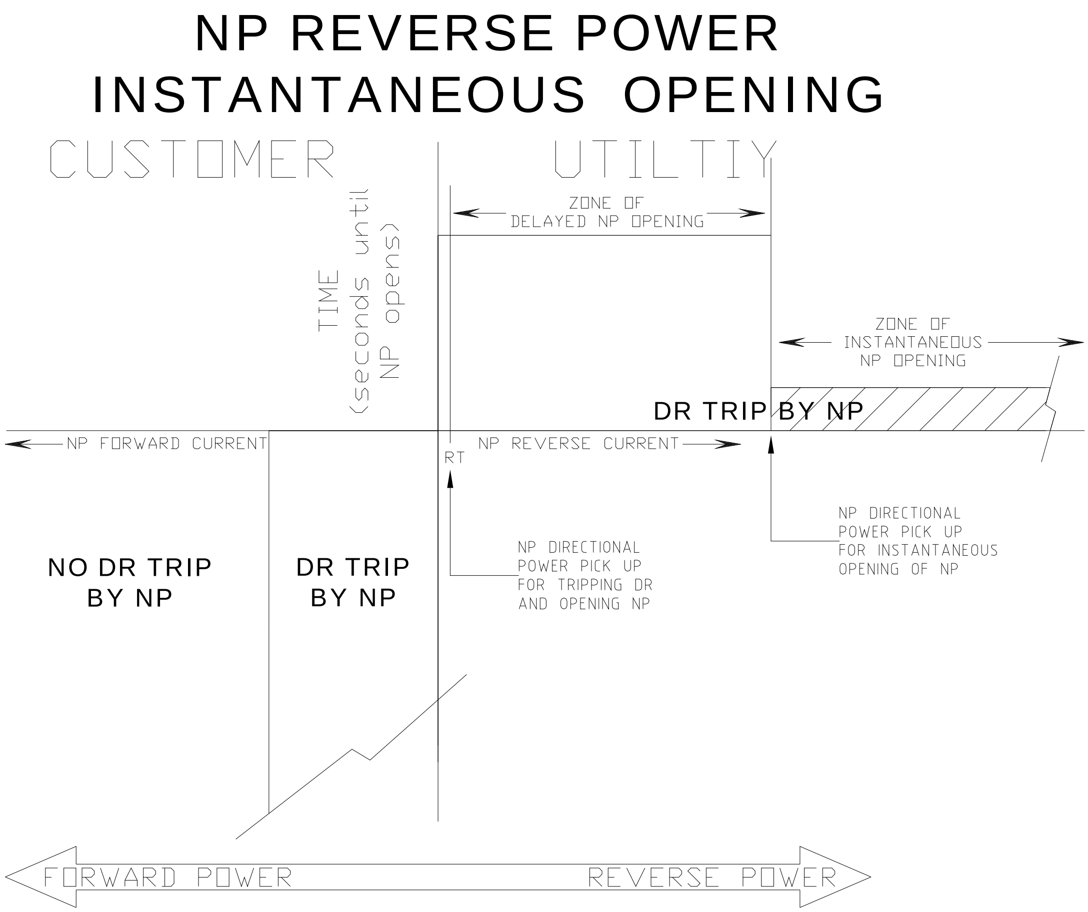

Figure 6: NP instantaneous trip zone

Time-Current Coordination of DR Tripping & NP Opening

A key feature of this control configuration is the necessary coordination of network protector status (closed/open) and DR system trip times. The time required for opening for a network protector can be on the order of three to six cycles [2]. In the GSA Williams building study, with permission the utility, a delay of 15 cycles was programmed into the CH unit microprocessor control. For reverse power conditions that were less than fifty percent of the network protector transformer's rating, rather than opening immediately after detection of the condition the network protector sent a trip signal to the DR and waited 15 cycles before opening[5]. If the power contribution by the DR ceased in less than 15 cycles, resulting in a changed of direction of power flow across the network protector from negative to positive, then the network protector would not open.

[5] In engineering terminology this threshold is expressed on a "per unit" basis (p.u.). This is a system by which values, such as power, current, voltage, etc., are referenced or scaled to a base value. In the case of the parameter of reverse current it is referenced to the rated current of the network protector transformer. The value of the reverse current for which a time delay was permitted at the Williams building was 0.5 p.u. (50%) of the network transformer full current rating.

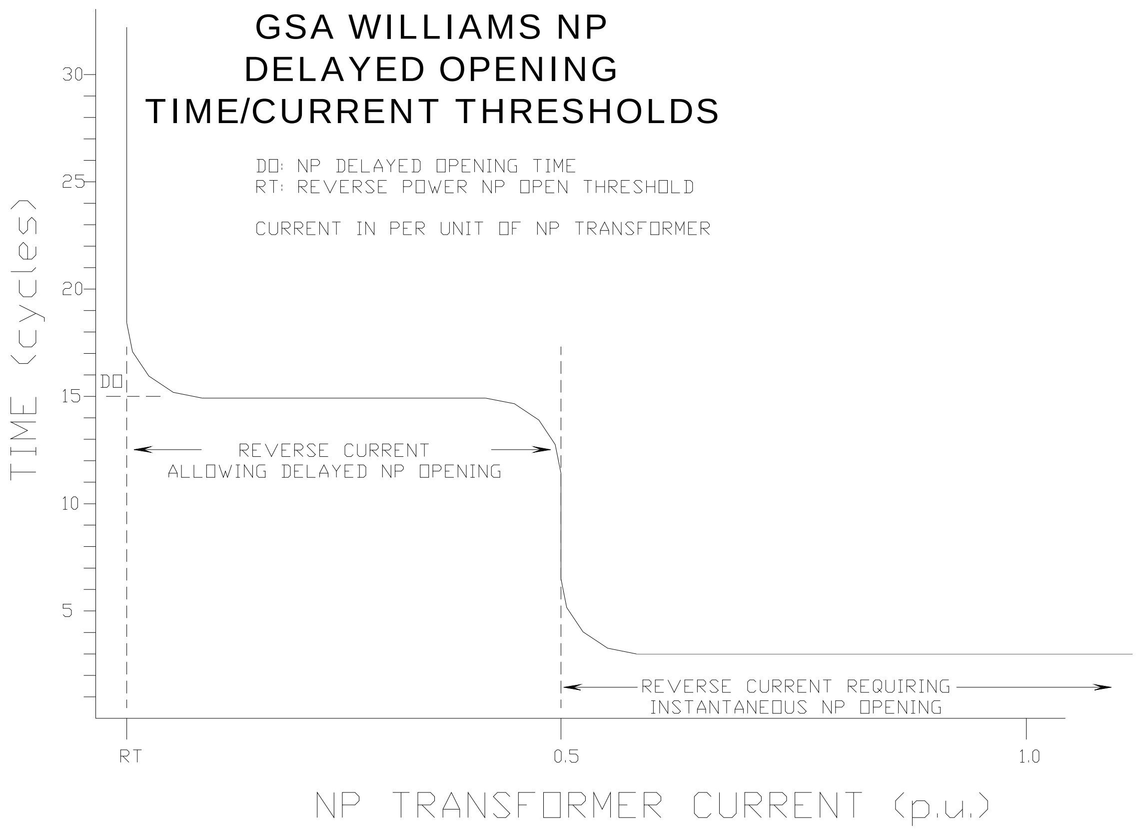

Figure 7: GSA Williams Building network protector programmed trip time delay

This time delay window was used to assure that the trip signal from the CH unit to the DR resulted in the cessation of current from the DR before the initiation of the network protector opening. For reverse currents greater than 50% of the rating of the network protector transformer the network protector was set to open instantaneously. The solution sought in this RFP should include the ability to adjust both the time delay and the reverse current threshold at which the network protector would open instantaneously.

The adjustment of time delay and instantaneous network protector opening thresholds will be based upon the site specific characteristics of the spot network configuration and equipment (number of NPs, size of transformers, characteristics of the primary network, etc.), the characteristics of the DR (inverter-based vs. rotating machinery, type of disconnecting means, etc.) and the operating policies of the local utility.

Significant factors in the assessment of these parameters include the potential fault current contribution of the type of DR being considered. As noted in the GSA Williams study, in fault scenarios, machine-based generators can, for brief periods of time (on the order of three cycles) contribute as much as ten times their full rated current. This can be compared with the fault characteristics of inverter-based technologies which are on the order of 1.5 to 2 times their full rated current.

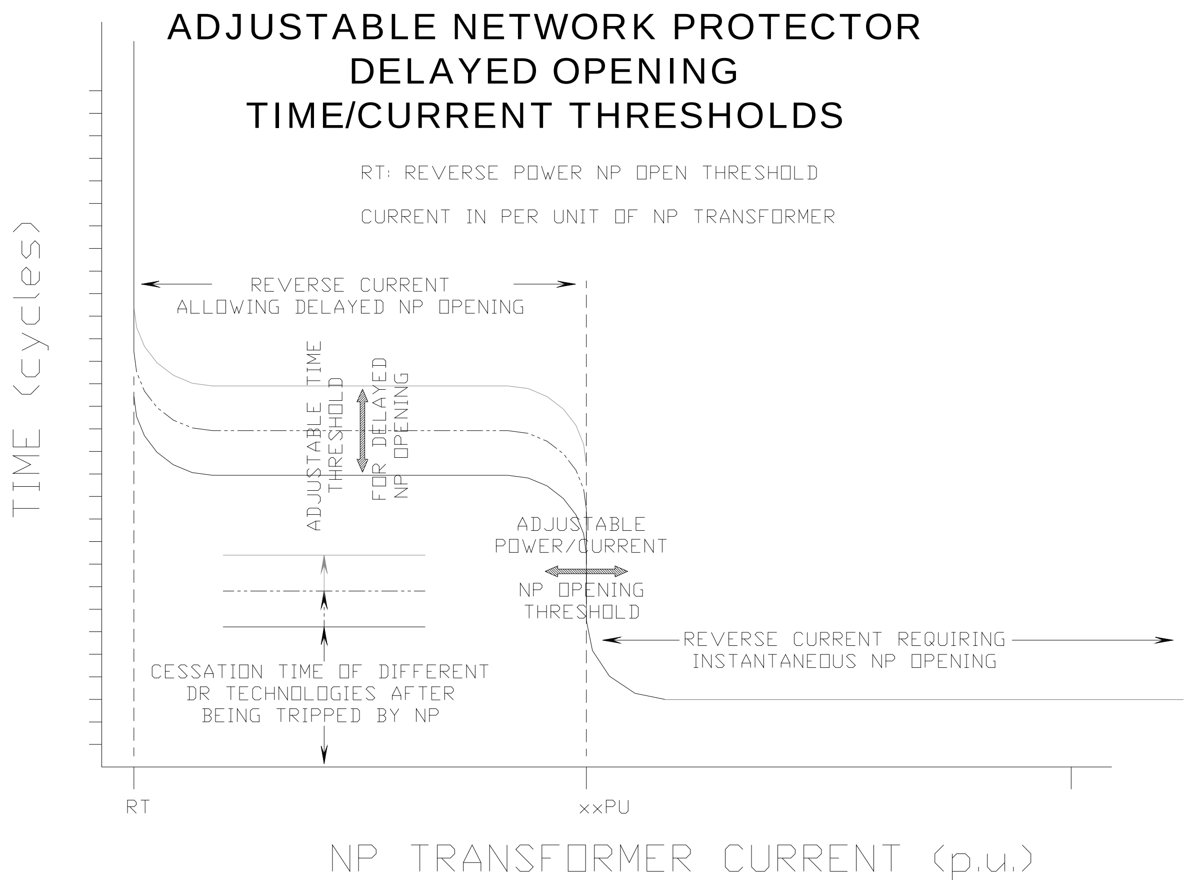

Figure 8: Adjustable time & reverse current parameters in advanced network protector

The switching/opening time of disconnecting devices, whether external or integrated into the DR, will also have a major influence on the required delay time. Inverter-based technologies may be able to be shut down in less than a full cycle. Static switches may also be a solution with opening times in the sub-cycle range. Electronic circuit breakers will have different trip times than thermo magnetic breakers, which will have different response times than electro-mechanical contactors. Depending on the switching technology used to trip the DR the latency between the initiation of the trip signal from the network protector controller and the cessation of current contributed by the DR will vary. The technical solution developed under this Advanced Network Protector initiative will need to address, to the greatest extent practical, as many of the characteristics of different DR technologies as possible.

RFP Development Approach

Numerous organizations at the national and state level have investigated the issue of interconnection of distributed resources on spot and grid networks. These organizations include, but are not limited to, the Electric Power Research Institute (EPRI), National Renewable Energy Laboratory (NREL), California Rule 21 Working Group, IEEE Standards Coordinating Committee 21 (SCC21) and the 1547.6 Working Group, Distributed Utility Integration Test (DUIT). In addition several states, within their standard interconnection policies, have addressed the issue of network interconnection to greater or lesser degrees. In general there appears to be a significant degree of consensus regarding the challenges and issues of concern with interconnection of DR on spot networks. However, outside of this initiative, none of the materials reviewed identified to specific engineering solutions to these concerns. This initiative, from the organization of the solicitation process to the formulation of the performance specification for the deliverables to the experimental design and testing protocol seeks to take into account as many of the concerns of stakeholders as is possible. While it is not possible to design a performance specification that will address the needs of all forms of DR in all utility settings, proposals are sought that allow flexibility for future adaptation. To the greatest extent possible it is our objective to accommodate the requirements of novel operating environments and emerging standards. IEEE and ANSI standards will be the context for this development effort. Other standards, such as International Electrotechnical Commission (IEC) and International Organization of Standards (ISO) may also be relevant, however the winning design team will only be accountable for those standards and design constraints explicitly listed below.

Advanced Network Protector Development Requirements

The RFP seeks a development team, led by a network protector manufacturer, including one utility and one or more distributed resource manufacturers (one machine-based and one inverter-based). The design of the network protector controller must integrate and function with existing network protectors in the company's product line. The device operation and its monitoring and control protocols must comply both with the requirements of the utility team member and with the DR team members.

The design solution must meet the operational constraints from each of the team members for the development of the prototype unit. Issues such as maximum delay time for network protector opening, physical data interface, data protocol, and trip coordination must be resolved without compromising the approved procedures, functionality or listings of any of the interacting systems.

In additions to the constraints that derive from the design of the equipment and operational practices of the development team members, the prototype solution must also comply with the prevailing standards that pertain to both network protector technology and interconnection of distributed resources to electric power systems generally and secondary networks specifically. In addition the solution developed under this solicitation must meet the requirements of IEEE 1547.3 Monitoring, Information Exchange and Control of Distributed Resources Interconnections with Electric Power Systems[6].

[6] IEEE 1547.3 is presently in draft form and is being voted on now. It is assumed that if standard has not been finalized by the time of this award the development team will use the draft version of the standard.

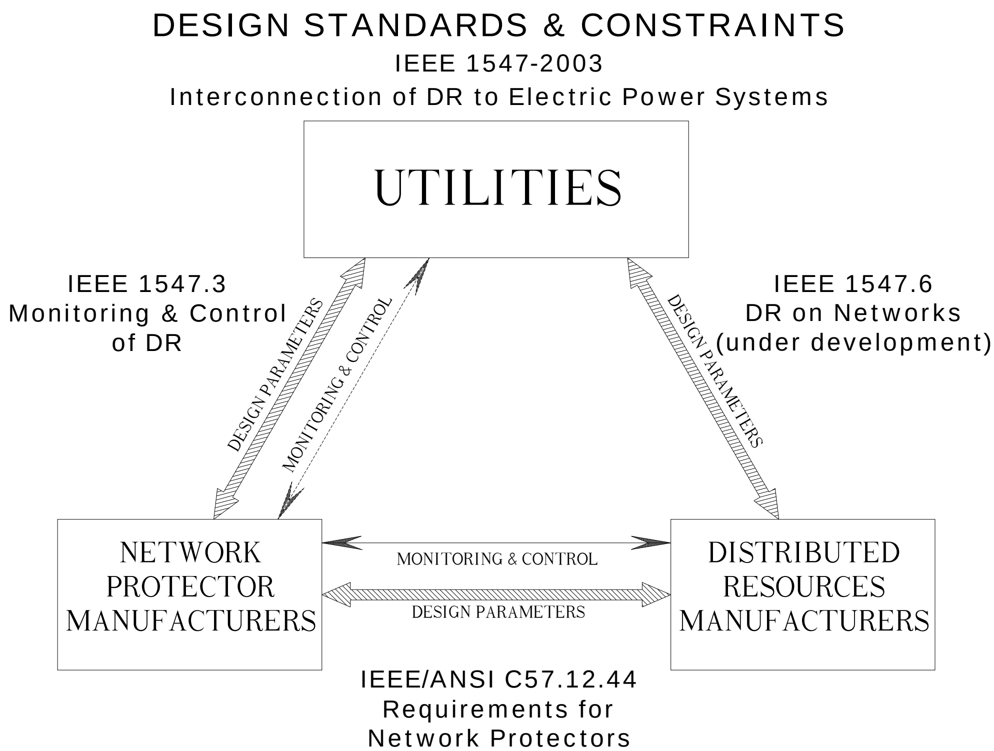

Figure 9: Advanced network protector development methodology

Key Standards

The standards that are relevant to this development effort are listed below. IEEE 1547-2003 is the core standard on which this development effort is based. It is the most well established and nationally accepted of the standards and was developed through a very broad consensus process. C57.12.44 is both an IEEE and an ANSI standard and pertains primarily to the physical specifications for network protectors. IEEE 1547.3 is a consensus standard that defines data monitoring and control functions for distributed resource technologies. IEEE 1547.6 is under development by IEEE standards working group and deals specifically with interconnection of DR to secondary network distribution systems.

In addition to these standards, for any actual system being installed in the field there will likely be a number of other local standards that may be applicable. In responding to this RFP the design team is only obligated to devise a solution that is compliant the design constraints of the development team member's hardware and operational practices and with the standards listed here.

IEEE 1547 Interconnection of DR to EPS

IEEE 1547-2003, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, is the fundamental reference standard for this development process [4]. The DR technologies considered for participation in this initiative must comply with the requirements of 1547. 1547 gives little guidance for interconnection of DR on spot networks (and no guidance at all for grid networks at this time.) Five of the six requirements for spot networks do pertain to the advance network protector concept:

"4.1.4.2 Distribution secondary spot networks

Network protectors shall not be used to separate, switch, serve as breaker failure backup or in any manner isolate a network or network primary feeder to which DR is connected from the remainder of the Area EPS, unless the protectors are rated and tested per applicable standards for such an application.

Any DR installation connected to a spot network shall not cause operation or prevent reclosing of any network protectors installed on the spot network. This coordination shall be accomplished without requiring any changes to prevailing network protector clearing time practices of the Area EPS.

Connection of the DR to the Area EPS is only permitted if the Area EPS network bus is already energized by more than 50% of the installed network protectors.

The DR output shall not cause any cycling of network protectors.

The network equipment loading and fault interrupting capacity shall not be exceeded with the addition of DR."

This section of the standard represents the most basic requirement for the advanced network protector concept.

IEEE/ANSI C57.12.44 Standard Requirements for Network Protectors

The current version of this standard is IEEE/ANSI C57.12.44-2005 [5]. The design solution for RFP must not violate any of the requirements of this standard. The intent of this solicitation is that the design solution be based upon existing, commercially available, network protector technology that is already compliant with C57.12.44.

IEEE 1547.3 Monitoring, Information Exchange & Control for DR

"IEEE P1547.3 Draft Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems" is a communications standard for distributed generation systems[7] [6]. The development of this standard is presently complete and it is in the balloting stage. This standard is theoretical and broad in it scope. It is written in extremely general language, covering a range of topics from meta-issues of interoperability and extensibility to more specific topics of security and protocols for data exchange. The communications solution in the prototype controller delivered by the development team must comply with the broad principals outlined in 1547.3 and the documentation that accompanies the prototype must be structured to reflect that.

The universe of monitoring and control protocols is vast. Appendix B of 1547.3, "Annotated list of protocols," describes a wide range of data formats, both generic and proprietary. The deliverable sought by this RFP must be a working prototype and as such must the development team must commit to specific hardware and software platforms. At a minimum the development team will deliver solutions for both the machine-based DR and the inverter-based DR monitoring and control functions. That being the case the preferred architecture will be the one with the maximum level of adaptability to other hardware and software platforms.

IEEE 1547.6 Distributed Resources on Secondary Networks

1547.6,"DR on Networks," deals specifically with the technical requirements for interconnecting distributed resources to spot or grid networks. Because the standard is still under development it is not required that the final prototype system comply with its requirements. It is, however, required that the development team have at least one person in attendance at meetings of the 1547.6 Working Group during the course of the development effort.

[7] Note that the standard specifically refers to "Monitoring, Information Exchange, and Control" and omits the term "communication." This is intentional as "Communications" is a large and distinct area of standards development within IEEE.

Design Constraints

Utility Criteria

The electrical service provided to grid and spot network customers by utilities is a premium service. It is a high reliable, high quality service. At a recent meeting of the IEEE 1547.6 working group standards meeting it was pointed out that the downtown portion of Worcester, Massachusetts that is served by a grid network has not had a distribution level outage in forty years. For the development effort sought here the operational norms of the utility team member will serve as one set of performance standards.

One of the primary design constraints in this development effort is the coordination requirement for tripping of the DR by the network protector under reverse power conditions. The most demanding version of this scenario is when no time delay is permitted by the operational practices of the utility between the detection of reverse power and the opening of the network protector. Regardless of the stated policy of the utility team member this time constraint will be one of the design objectives. The specific objective will be for the system to cause the DR to cease to energize the low voltage bus in less time than the latency of the network protector.

Network Protector Manufacturers

At this point in time there are only two domestic network protector manufacturers in the United States. They are Eaton/Cutler-Hammer and Richards Manufacturing Company. The intent of this RFP is for the control solution developed here to be based upon currently available network protector technology.

Distributed Resources Manufacturers

An exhaustive list of all presently active manufacturers of distributed resource technologies would be extremely difficult, if not impossible, to formulate. The list would include such technologies as fuel cells, reciprocating gas engines, wind turbine technologies, steam turbines, micro turbines, photovoltaic inverters, combined heat and power systems, energy storage systems, micro-hydro systems and many more.

For the purposes of this initiative, the possible alternatives can be divided into two broad categories:

- Inverter-based system
- Machine-based systems.

Within the machine-based systems these devices can be further differentiated into induction and synchronous generators. The development team is required to have at least one inverter-based DR manufacturer and one machine-based DR manufacturer.

General Requirements

In addition to any security requirements for information exchange of the utility, the network protector manufacturer, or the inverter and generator manufacturers, the system monitoring and control component will have the following capabilities. The information links will be supervised such that the disconnection of the tripping device at the generator is indicated at the auxiliary controller, initiating an alarm condition. Regardless of whether the utility team member has SCADA capability within its secondary network distribution system, the auxiliary controller will have capability to interface with an external monitoring and control system. The auxiliary controller will be capable of conveying information regarding the status of all network protectors, and DR trip mechanisms to a central monitoring and control location.

Deliverables

Prototype Auxiliary Network Protector Relay

The development team selected for this effort will be required to deliver three fully functional prototype network protector controllers that meet the design constraints outlined in this document. The network protector manufacturer should design and build the devices so that they may be integrated into real world field conditions in vaults that typically house the manufacturer's compatible network protectors. The final prototype should be suitable integration with either submersible or non-submersible network protectors.

System Demonstration

The team will demonstrate the operation of the prototype at two stages in the development effort. The first stage demonstration will be in the manufacturer's facility. This demonstration will be followed by a formal design review and comments by the funding agencies. The second stage demonstration will take place at a third party test facility (location to b determined at a later date.)

Manufacturer's Factory Tests

The demonstration and testing performed at the manufacturer's facility should occur as soon in the development process as possible. After award of the development contract a formal schedule will be negotiated between the development team and the funding agency. This demonstration is intended to be a "board level" test between the control components of the network protector auxiliary controller, the network protector, and the DR control mechanism. This stage of the demonstration and testing does not require the operation of energized high power circuits such as the network protector circuit breaker, the inverter output, or the machine-based system disconnecting means. This test does require the demonstration the signals required for the timing and coordination features that will be employed in the final prototype. The development team will need to physically demonstrate the monitoring, detection, and control capabilities required of the final prototype. *This demonstration is not a simulation.* The intent of the first stage demonstration is to provide an opportunity for commentary by the funding agency.

Third Party Test Facility Tests

Upon completion of the development of the prototype the manufacturer will conduct a field test at a third party test facility. The prototype controller will be mounted in an enclosure appropriate for installation in a utility application. In addition to the enclosed prototype the manufacturer will provide at least two fully functional network protectors, with circuit breakers, for the test. The test fixture components will be sufficient to form a two-protector spot network configuration. The test facility will be selected by the funding agency and will be capable of accommodating the test fixture.

Documentation

In addition to the prototype auxiliary controllers the development team will provide an operations and maintenance manual for the devices. This manual will include detailed instructions regarding the hardware and software interfaces between the auxiliary controller, the network protectors, and the DRs. It will provide a detailed specification and instructions on installation and configuration of all components.

In addition to the O&M manual the development team will provide a set of applications guidelines for configuring the auxiliary controller with alternate DR technologies. The guidelines will include a matrix based upon the monitoring and control protocols listed below, with recommended approaches for integration with these hardware and software platforms. The requirement of this component of the documentation is not to design the interface or write the software applications, but to list the relevant parameters and specification for each of the alternate technologies. The objective is to leave open as many configuration options as practical. The delivered prototype in not obligated to meet the requirements of each of the standards listed, but the development team must explain how those standards could met by a modification or adaptation of their technology.

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