Massachusetts Technology Collaborative
Network Protector Enabled Generation (NPEG)
Performance Specification

Version 1.0

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Massachusetts Technology Collaborative
&
NPEG Collaborative

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Preface

It is important to note at the outset some of the limitations and inadequacies of this document and the proposed performance specification for the Network Protector Enabled Generation (NPEG) device that it hopes to create. Ideally a document such as this might best be achieved by an inclusive and deliberative stakeholder process which first results in an accepted technical standard and then proceeds, independently, to commercialization. While a variety of interested parties have been engaged in discussions on this matter, the number of entities that could be affected by this issue is very large and the list of participants is anything but comprehensive. The motivation for this performance specification, and the research that it hopes to stimulate, is the desire on the part of several public agencies to promote the safe deployment of distribute generation within urban areas, many of which are supplied by secondary network distribution systems. Because of the complexities and interdependencies of the constituent technologies, because of their separation by the utility/customer boundary, because of the very large and heterogeneous population of DG manufacturers, and because of the incompatibility of tariff structures as an incentive to this configuration, neither the market place nor the regulatory processes by themselves are presently sufficient to facilitate the adoption of this technology.

Because of these obstacles, or in spite of them, the participants in the NPEG collaborative discussions have requested, as a starting point for research, a framework performance specification for an NPEG system. Because this document is not the product of a thorough stakeholder process what follows may have major errors and omissions. For example, while the current state of deliberations of the IEEE (proposed standard) P1547.6 working group on Distributed Resources on Networks is reflected in this document, the work of the IEC TC57 working group 17 that deals with communication for distributed energy resources is only touched upon. Further, while the NPEG discussions have had active participation by some distribution companies, these are only a small fraction of the entities that operate secondary network distribution systems. As such this document may not adequately represent variation in operating practices across the country. While tariff issues must ultimately be resolved for the adoption of this kind of technology, this document ignores these matters entirely and confines itself to the purely technological. In summary, this document lacks the "top-down" genesis that something of this nature might normally possess and we recommend that it be taken only as a kind of "straw man" to be used as a starting point for discussions.

Ultimately we believe that research in this area must be a stakeholder process to successfully and safely move this technology to commercialization. Fundamentally it requires the operational experience of the distribution companies and utilities. It requires the DG manufacturers' knowledge of generator process controls, communications protocols, and ability to cease to energize. And it demands the sensing and communications capabilities that belong to the network protector manufacturers. We recommend that this document be viewed not as a completed specification, or even as a work in progress that is emanating from a central authority, but as an "open source" document to be modified, as the collaborative dialog and research evolve, to fit the needs of the stakeholders.

Glossary & Abbreviations

DR	Distributed Resources
DG	Distributed Generation
DER	Distributed Energy Resources
EPS	Energy Power Systems
NPEG	Network Protector Enabled Generation
PCC	Point of Common Coupling

In this document the terms, “utility” and “distribution company” are used somewhat interchangeably. While there may be little or no difference in the operational approaches of these two types of business entities when it come to the management of their secondary distribution networks, the tariff implications of the technology being discussed here are significant. The tariff issues, however, are outside of the present scope of this document and thus both terms will be used to mean the same thing.

1 Overview

This document represents an attempt to provide a performance specification for a hardware device and associated set of protocols to facilitate the safe and reliable deployment of distributed generation systems on secondary spot network distribution systems. This specification has evolved from work sponsored by the Massachusetts Technology Collaborative (MTC) DG Collaborative. The Massachusetts DG Collaborative has been investigating ways to interconnect distributed generation (DG) on network distribution systems since 2002, at the direction of the Massachusetts Department of Public Utilities (DPU) and with funding from the Massachusetts Technology Collaborative (MTC) and support from other stakeholders. Specifically this hardware concept is the outgrowth of a two-year research study conducted by William Feero, PE, under contract to MTC, of two distributed generation systems located on a building served by a two transformer spot network in Boston, Massachusetts. At present, collaborative discussions are underway to advance the acceptability of DG on networks by developing advanced network protector relays and establishing high-speed communication between network protectors and DG units. This technical approach has been referred to under the headings of, “Advanced Network Protectors,” and, more recently, “Network Protector Enabled Generation” or (NPEG). This document is intended as a preliminary framework to facilitate discussions for the development of the NPEG hardware solution.

Building on the June 2006 recommendation of the Massachusetts DG Collaborative to pursue this approach, utilities and state energy agencies in California, New York and Massachusetts are now coordinating technical projects to develop and test NPEG technology. Current participants in this process welcome the involvement of additional utilities and other technical experts. This document summarizes the history of these discussions and the technical documents which have been recently prepared on this topic. It will serve as the starting point for discussions of experimental design for the next phase of research on this topic.

The core objective of this initiative is to develop a flexible hardware solution to facilitate the installation of distributed generation 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 should include a body of procedural configurations or applications guidelines for the implementation of distributed generation 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
• And, to the maximum extent practical, create a system that is replicable, scalable and extensible to the widest variety of distributed generation technologies possible.

It is essential to note that the NPEG concept suggest the islanding of DG, either intentionally or otherwise, and does not propose to enable conditions that would contradict the interconnection requirements or operational behavior required by IEEE standard 1547.

1.1 Description of Document Structure

This specification is composed of three main sections, ranging from the most abstract and general to the most specific.

1.1.1 Section 2: Information Model

Section 2 of this document is a high level model that addresses the NPEG concept in the context of the wider energy distribution system and some of its business functions of the entities that manage it. This contextual perspective has been taken almost directly from a summary of the IEC Technical Committee 57 Standards.

1.1.2 Section 3: Operational Performance Specification

Section 3, Operational Performance Specification, is intended to specify the necessary timing, coordination and information exchange performance characteristics of the NPEG system. This section describes the (proposed/potential) operation of an NPEG system in the context of the present day operational procedures of some utilities and distribution companies and in the context of current network protector performance capabilities.

1.1.3 Section 4: Material Performance Specification

Section 4 is the most technically specific, least abstract, of the specification sections. It is intended to specify the material characteristics, in terms of required performances, of an NPEG system down to the component level. This section is the least complete and most likely to change and evolve through stakeholder engagement. At the same time, this is the most essential portion of the document for anyone engaged in building a prototype NPEG device.

1.1.4 Section 5: Test Specification

Section 5 is a placeholder. The requirements for testing will come directly from the operational and material performance specifications once they are vetted through a stakeholder process.

1.2 Technical Background

In 2002 the Massachusetts DG Collaborative was initiated at the request of the MA Dept of Telecommunications and Energy (DTE) through Order 02-38 to investigate the barriers to distributed generation. The Collaborative consisted of stakeholders interested in and affected by the continued deployment of distributed generation on the electrical distribution system, including utilities, inverter and generator manufacturers, energy users, renewable energy advocates and state agencies, with the Massachusetts Technology Collaborative (MTC) funding facilitation and studies for the process.

One of the issues taken up by the DG Collaborative was that of interconnection of distributed generation on secondary network distribution systems. In an effort to better understand the technical requirements surrounding the interaction of these systems the MTC hired William Ferro PE (recently retired), a well respected consulting engineer in the utility protection field, to provide analysis and recommendations. Based upon his analysis of the objectives of the members the DG Collaborative, Mr. Ferro proposed a novel control topology for spot networks that offered the possibility of safely enabling the deployment of significant amounts of distributed generation. The topology has been referred to as the Advanced Network Protector or as Network Protector Enabled Generation (NPEG). This technical approach is described in the following document:

http://www.mtpc.org/dg/2007-02-20-DENP-NEO-draft.pdf

With MTC funding and with the cooperation of NSTAR, Mr. Ferro provided technical guidance for implementation of this experimental topology on a two-transformer spot network at GSA federal facility called the Williams Building in downtown Boston. Two forms of distributed generation, a 28kW photovoltaic array and a 75kW gas-fired Tecogen CHP induction generator, were installed at this building. Eaton Cutler-Hammer designed and installed a custom auxiliary control unit in the transformer vault serving the building. The control unit monitored the two network protectors for underpower conditions and, in the event of such a condition, had the ability to force a trip of the Tecogen unit. The Williams Building tests were run from May, 2003, to March, 2005. After nearly two years of monitoring, the study concluded that:

- There are no ratings or types of generation interconnection above the reverse power setting of the network protector relays that can be installed on spot networks without some system fault condition exposing the protectors to undesired trips.
- Photovoltaic systems with ratings less than 30% of the minimum loading of the network will have the lowest probability of experiencing a system fault that would result in an undesired trip.
- Some form of sensing must be provided in each network unit circuit to assure tripping of the interconnected DRs under all network conditions.

This May 2005 report can be accessed at:
http://masstech.org/dg/2005-05-31-FeeroNetworkReport.pdf

As part of its June 2006 report, the Massachusetts DG Collaborative developed the NPEG concept (described in Attachment F) and recommended that this technology be developed and tested soon with the support of MTC and other funding agencies and with the cooperation of Massachusetts utilities. These 2006 documents can be downloaded at:
http://www.masstech.org/dg/collab-reports.htm

1.2.1 Problem Statement

As distributed generation becomes 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. 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.

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

[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.

not intended[2]. If the network protectors are opened they may not reliably re-close once the load has returned and the building may be left without electrical service. There are two scenarios under which have been identified as potential problems that can be caused by DG on spot networks. The first occurs under normal operating conditions of the spot network, and the second occurs as a consequence of a fault on the primary distribution side of the network.

1.2.1.1 Reverse Power: Normal DG Operation

Under normal operating conditions it is possible for a spot network facility to be so lightly loaded that one or more of the network protectors will open due to imbalances or mismatch in the impedance of the network protector transformers. The addition of generation on the customer side of the point of common coupling only exacerbates this problem by further reducing the facility load. But more fundamentally, distributed generation systems, by the very fact of their design to generate in parallel with the electrical power system (EPS), are intended, under normal operating conditions, to export power to the EPS.

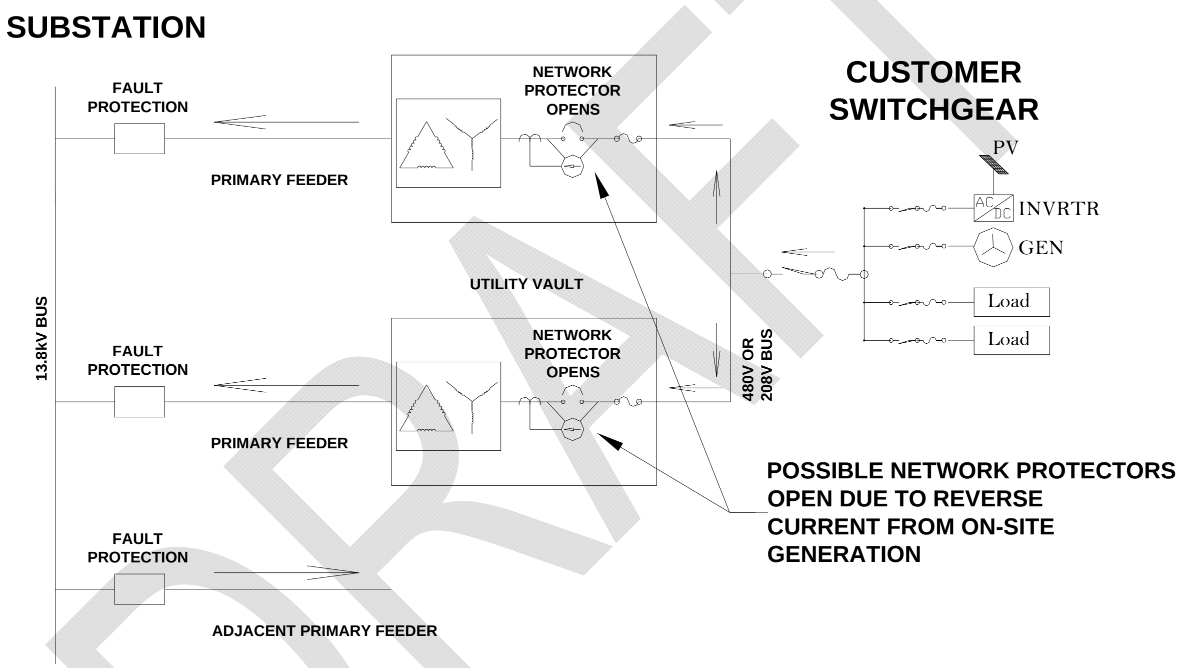

Figure 1: Network protector opening due to normal DG operation during light load condition

If, at any point in time, the facility load is less than the level of on-site generation, the facility will export power to the EPS and the network protectors on a spot network will experience reverse power flow.

[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

1.2.1.2 Reverse Power: Adjacent Feeder Fault

Another scenario that was discussed in the Williams Building study was that of the impact of DG on the system during a fault on an adjacent feeder on the primary network supplying power to the secondary distribution system. In such a case the effect of customer sited generation, especially in the case of rotating equipment, could be to supply power to the fault through the transformers of the secondary system.

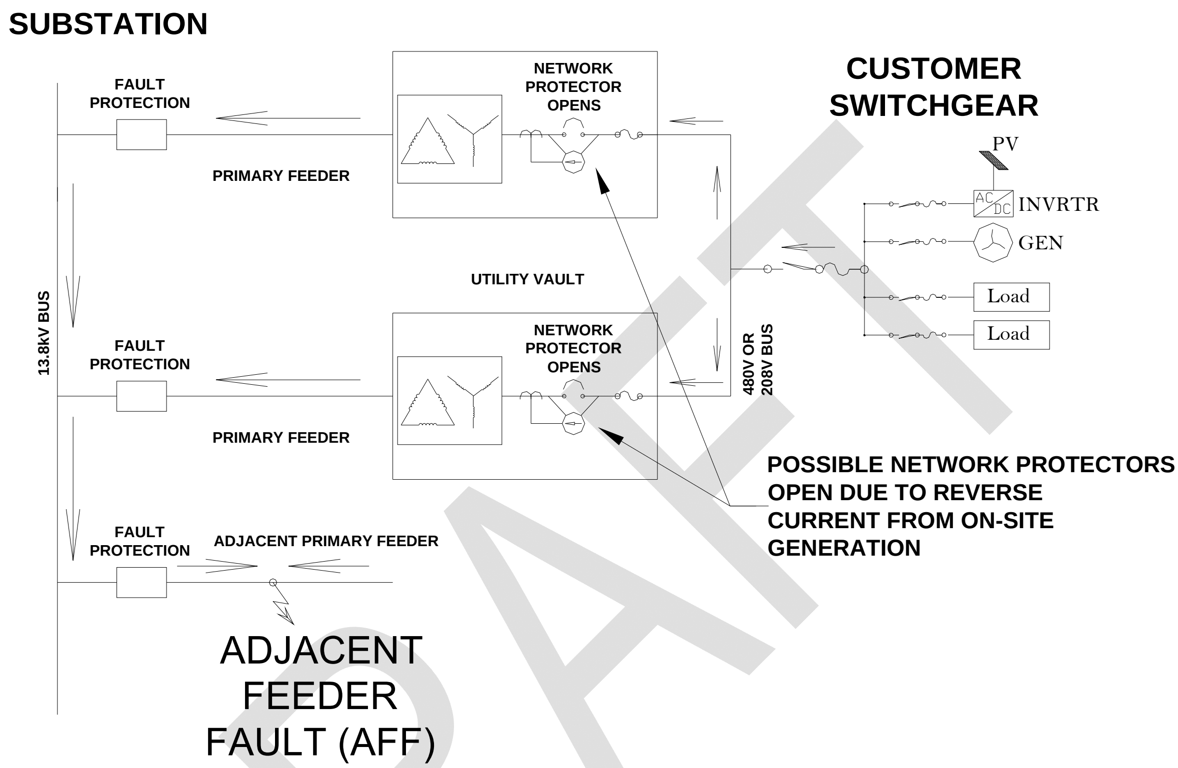

Figure 2: Network protectors opening under adjacent feeder fault condition

Absent the generation on the customer's side of the network protectors the normal response to such an event might be no more than a flicker, depending upon the conditions and proximity of the fault.

1.2.2 NPEG Conceptual Solution to Permit DG on Spot Networks

The conceptual solution to the problem of DG on secondary network distribution systems being proposed here is to insert control of the DG on the utility side of point of common coupling (PCC). The fundamental objective is to eliminate, as far as is practical, the possibility that operation of a distributed generation 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 protectors on a spot network, through an auxiliary relay controller referred to as a Master Control Unit (MCU). Control and monitoring signals would cross the PCC and have the ability to trip the DG in the event that the forward power across the network protectors decreases past a preset threshold or in the event of a fault on an adjacent primary feeder.

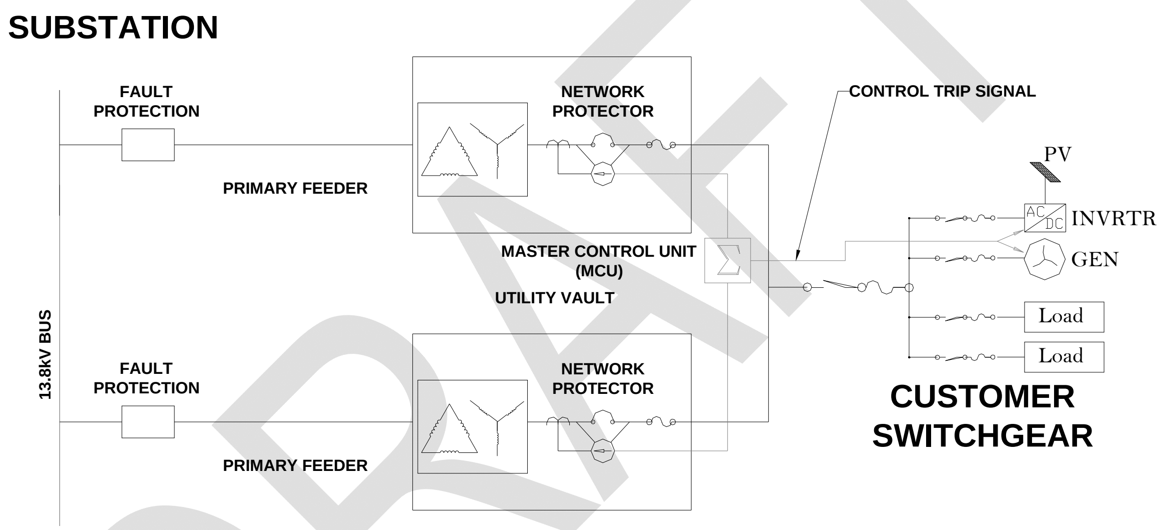

Figure 3: NPEG conceptual solution for control of DG

1.3 Reference 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.

1.3.1 IEC TC 57 Standards

1.3.1.1 TC 57 WG 10

Power system IED communication and associated data models

1.3.1.2 TC 57 WG 17

Communications systems for distributed energy resources

1.3.2 IEEE 1547 2003

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.

1.3.3 IEEE 1547.3 2007

"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[3] [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.

[3] 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.

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.

1.3.4 IEEE P1547.6

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.

1.3.5 IEEE/ANSI C57.12.44 2005

The current version of this standard is IEEE/ANSI C57.12.44-2005 [5] Requirements for Secondary Network Protectors. 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.

1.3.6 California Electric Rule 21

Interconnection of Distributed Resources on Secondary Network Distribution Systems

1.3.7 NFPA 70 - National Electrical Code

Unlike most other utility or distribution company devices the NPEG Data Exchange & Control link transverses the point of common coupling and enters the customer site. As such, portions of this system will fall under the jurisdiction of the locally adopted electrical Code. In most cases, within the United States, this is the National Electrical Code.

1.4 Organization of Research & Development

The performance specification described in this document must meet the operational constraints of all of the stakeholders 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. The three major stakeholders –those with the most immediate technical interests— are the utilities and distribution companies, the network protector manufacturers, and the manufacturers of distributed generation systems.

In additions to the material and operational constraints that derive from the design of the equipment and operational practices of these stakeholders, 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 through research in this area must meet the requirements of IEEE 1547.3 Monitoring, Information Exchange and Control of Distributed Resources Interconnections with Electric Power Systems.

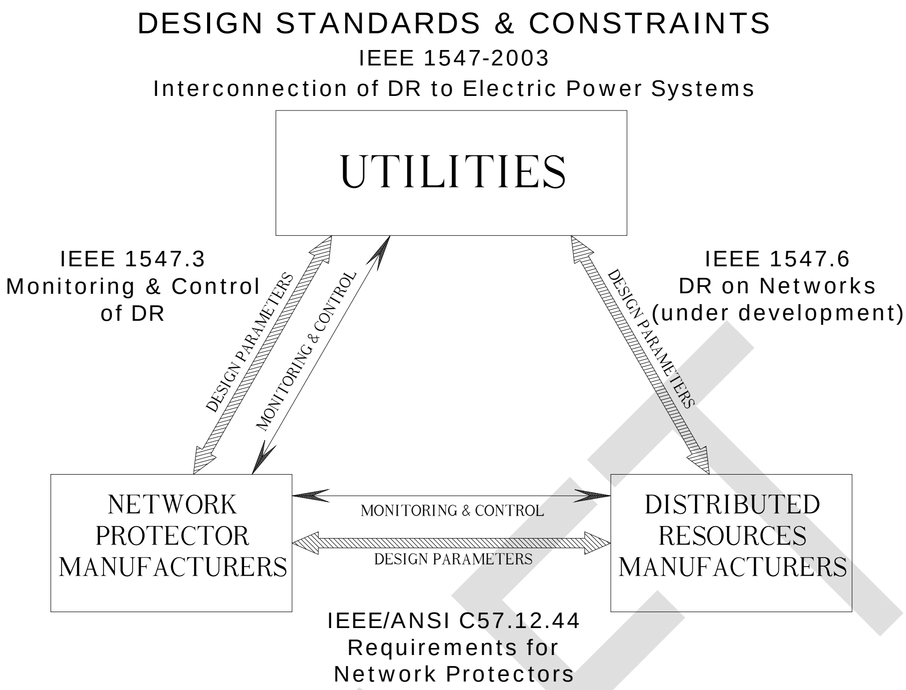

Figure 4: Primary NPEG interactive components

The graphic in Figure 4 illustrates the relationships between and amongst the primary stakeholders and prevailing technical standards.

1.4.1 NPEG Collaboration

In December of 2006 New Energy Options, Inc. (NEO) was hired by MTC to support the procurement and testing of this NPEG technology. NEO's role is to assist with identification of and outreach to other potential stakeholder agencies, to solicit ideas and participation, and to assist with the development of the technical details of future procurements. In this capacity New Energy Options has met with staff members at the California Energy Commission and presented the advanced network protector concept in December 2006. In February of 2007 NEO presented the NPEG concept to the IEEE SCC21 1547.6 Working Group which is developing interconnection standards for DG on network distribution systems. All the presentations and other materials developed by this project can be found at:

http://www.masstech.org/dg/interconnect/network-rfp.htm

In April and June of 2007 a group of stakeholders[4] from three states participated in a web conference call to explore possible ongoing collaboration and roles for interested parties. Presentations of the work to date were made and the issue of a possible mechanism for administering a collective RD&D effort was discussed. The meetings concluded with agreement to continue this collaboration through additional calls with the objective of coordinating the technology development activities of multiple states and utilities. This performance specification was an action item of the June conference call and is intended as a framework for discussions and experimental design in the research going forward.

[4] Participating entities included the Massachusetts Technology Collaborative (MTC), the California Energy Commission (CEC), the New York State Energy Research Development Agency (NYSERDA), the Massachusetts Division of Energy Resources (MA DOER), National Grid Service Company, Pacific Gas & Electric (PG&E), Electric Power Research Institute (EPRI), BEW Engineering (CEC consultant) and New Energy Options (MTC consultant).

2 Information Model

2.1 General

This section is intended to provide a high level system model for the NPEG concept. The intent is to illustrate the potential interaction and integration of the proposed system with the distribution company's wider operational enterprise. The model, at this level, treats as abstractions, the exchange of information and control. This section references broad business and operational objectives, as well as high level technical standards, but is technology independent.

2.2 Distribution Company Business Process

The conceptual model illustrated in Figure 5 is adapted from an IEEE document, "Focus on the IEC TC 57 Standards." The figure shows the basic relationships of information exchange and control. An example of the type of communications that could occur at this level might be a "Trouble" signal from an MCU. The Trouble signal does not indicate an that the MCU has tripped the DG, but just that some aspect of the system status has moved outside of normal specifications. Possible responses to such a signal, at the enterprise level, might be to initiate a work order for a service call or run a diagnostic program for the MCU, to contact the customer, to update the system records database, and so on.

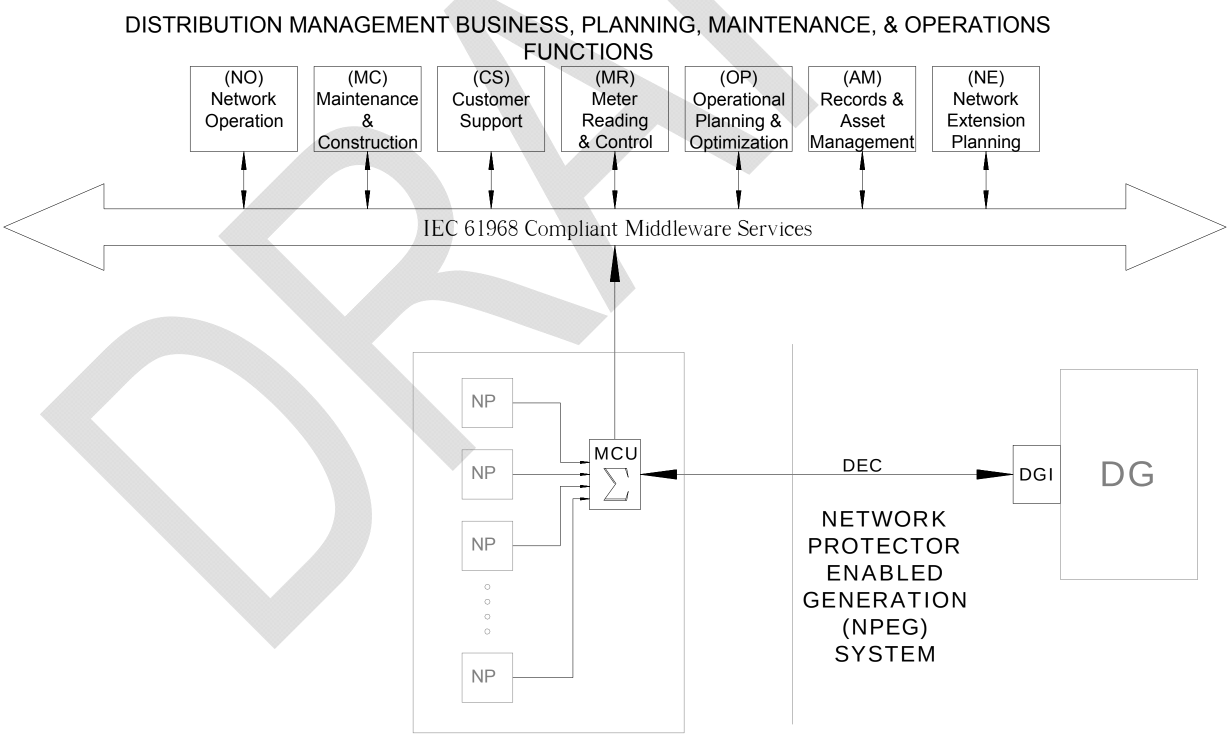

Figure 5: NPEG information exchange with distribution company enterprise network (IEC TC 57 framework)

An overarching objective of the NPEG concept is that it in no way compromise the premier quality of service and level of safety that the present network protector technology provides. To achieve this any exchange of information between existing network protectors and NPEG equipment will be configured as "Read-Only" with no alteration of the network protector's original functionality.

3 Operational Performance Specification

The intent of this section is to describe the operational parameters that pertain to the NPEG device in the context of its role as a control mechanism for the distributed generation unit. It is important to note that this concept has nothing to do with islanding of DG. Fundamentally the NPEG concept places control for curtailment of the distributed generation source with the utility or distribution company. There are three fundamental criteria for sending a cease-to-energy command to the DG.

3.1 NPEG Zones of Operation

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 DG 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

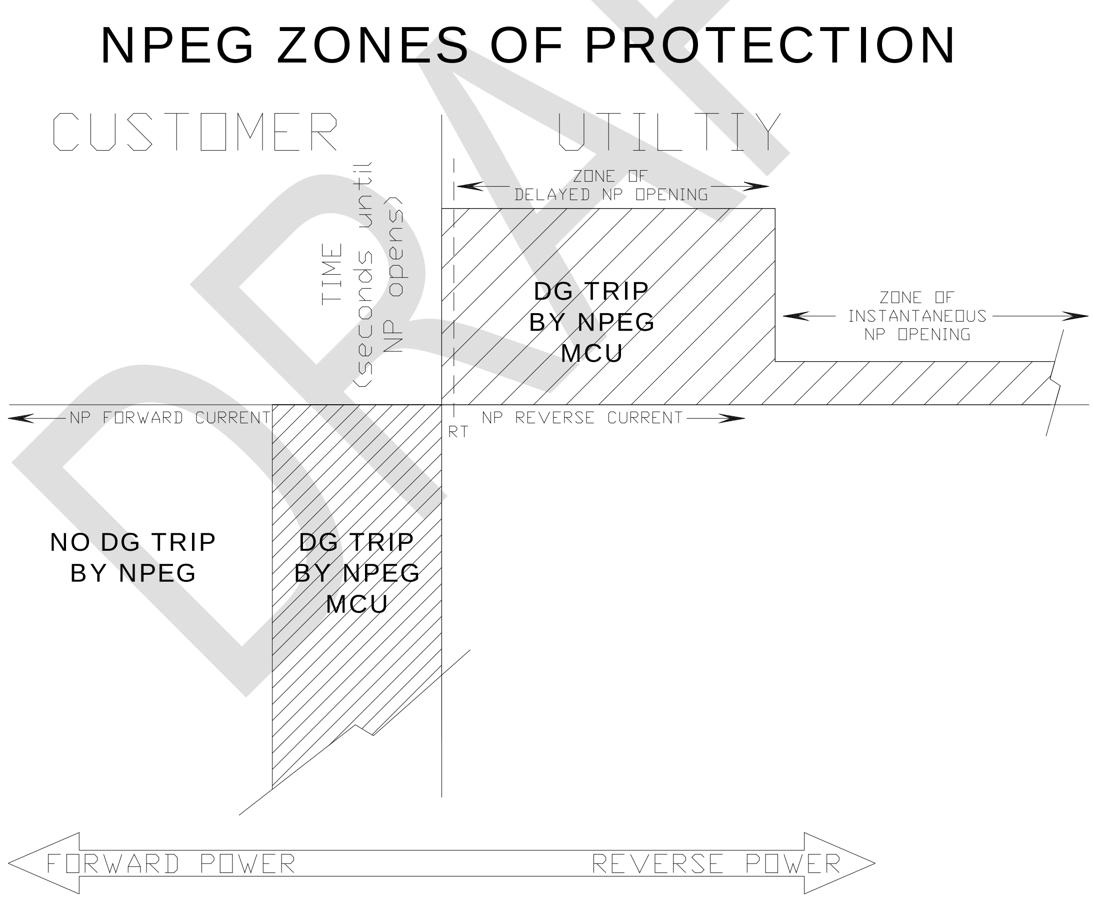

Figure 6: NPEG time/power protective schema

For the diagram in Figure 6, 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.

3.1.1 Forward Underpower Threshold

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.

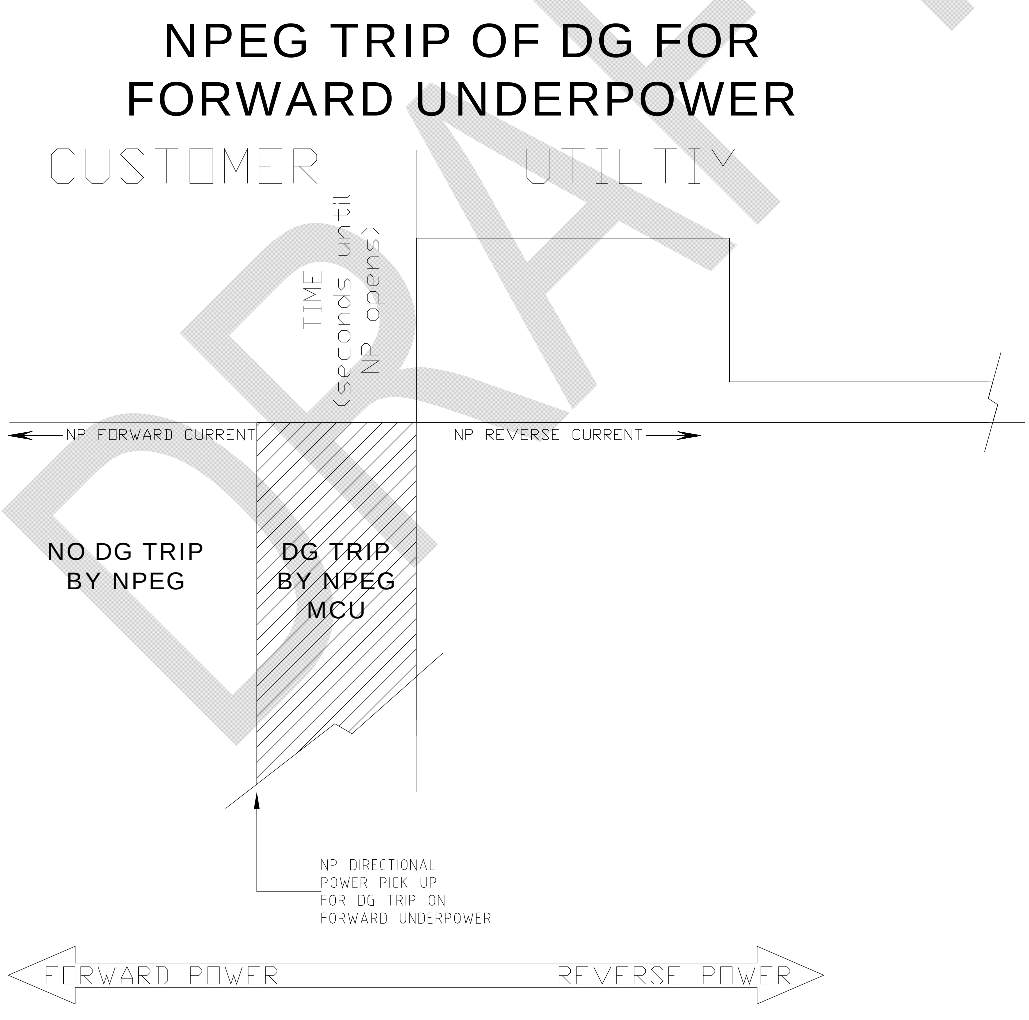

Figure 7: Forward underpower NPEG DG trip configuration

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.

3.1.2 Reverse Power: Delayed NP Opening

For low current faults[5] 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.

[5] 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.

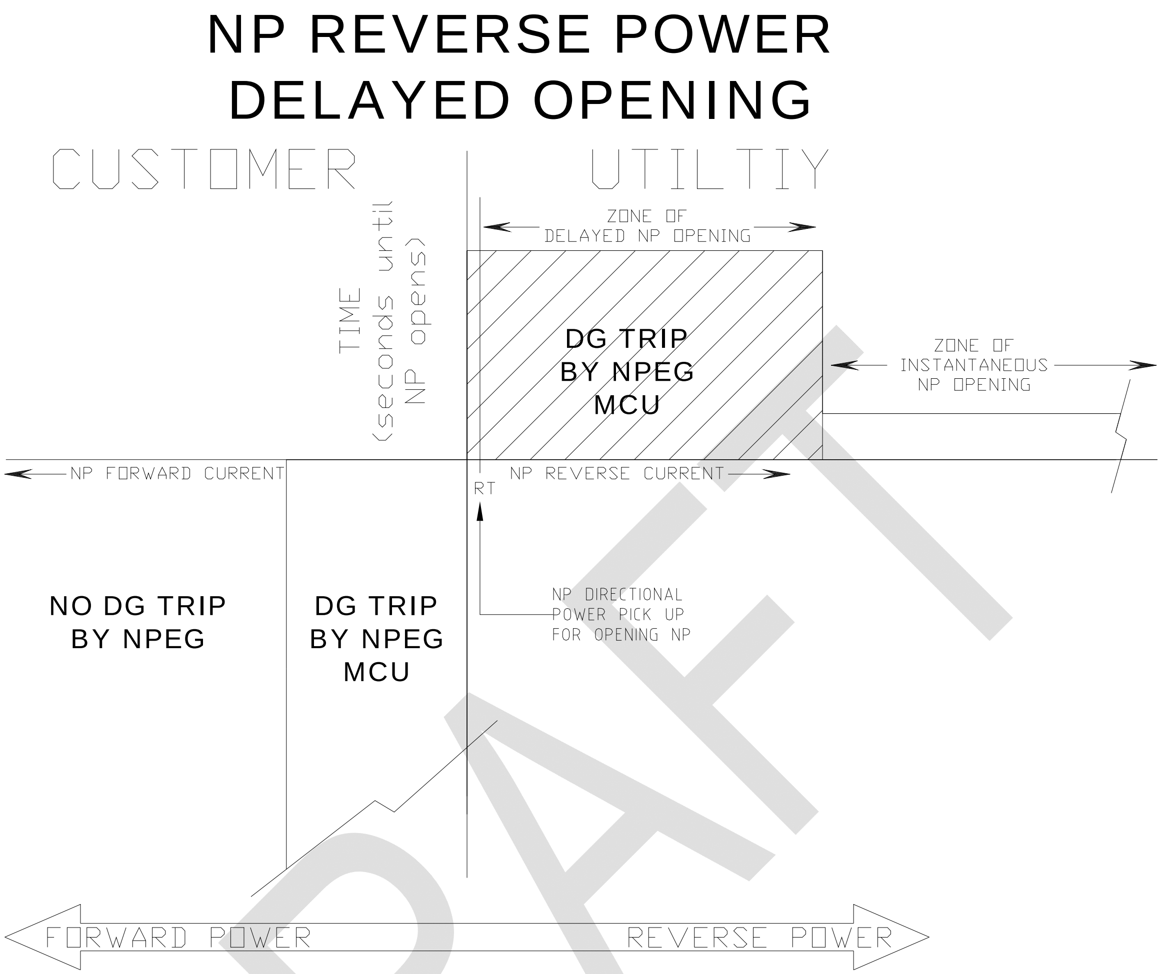

Figure 8: Network protector delays opening while tripping DG

3.1.3 Reverse Power: 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.

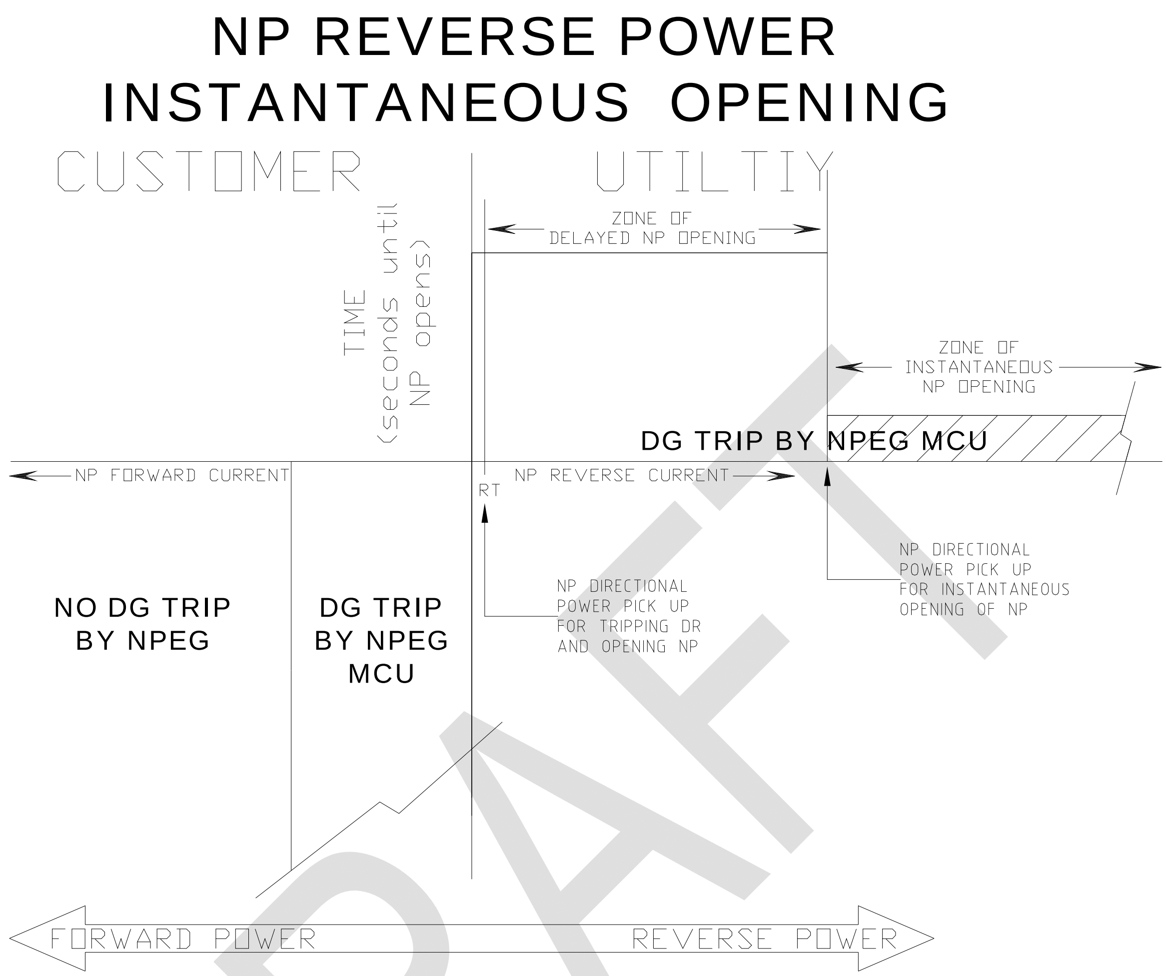

Figure 9: Network protector instantaneous trip zone

3.1.4 Time-Current Coordination of DG 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[6]. 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.

[6] 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.

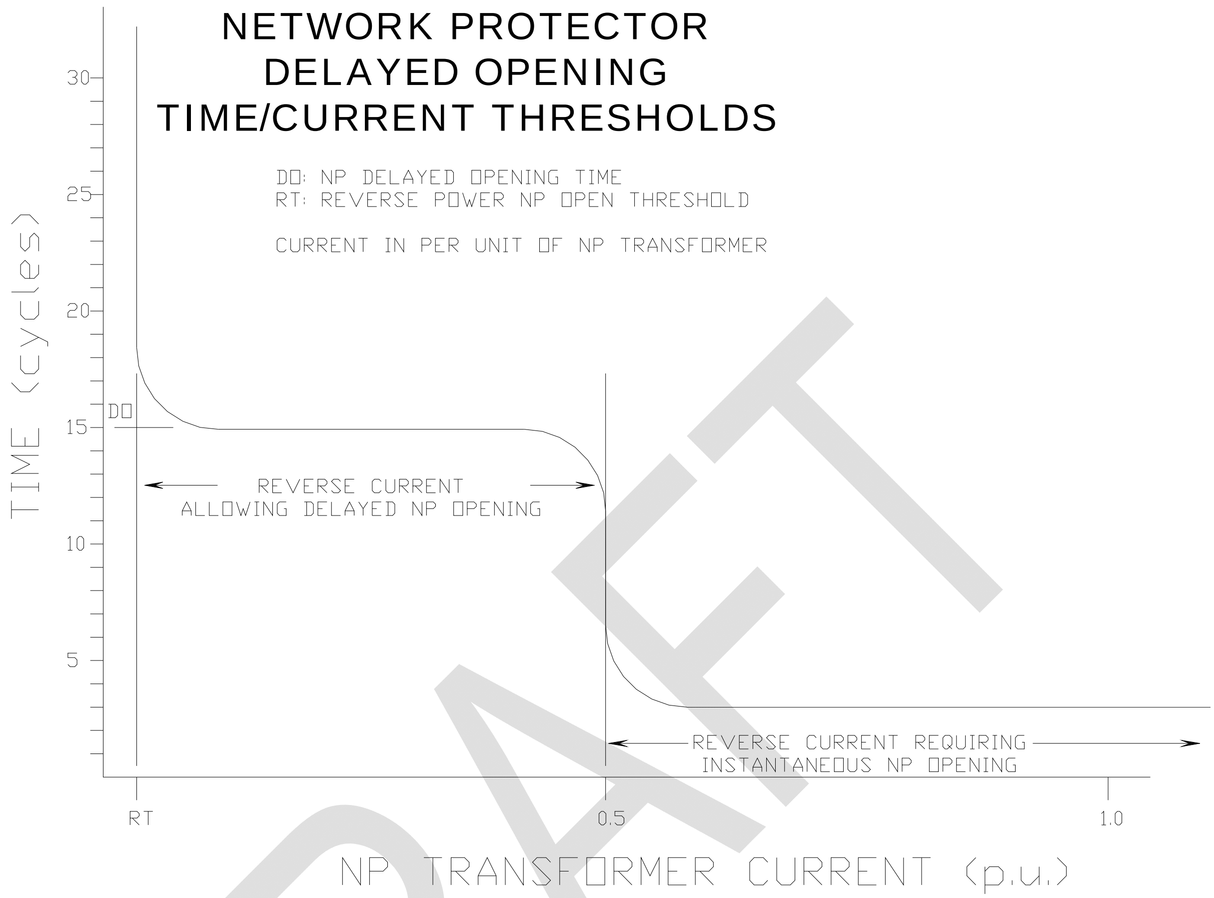

Figure 10: Delayed opening of network protector for predetermined level of reverse power

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.

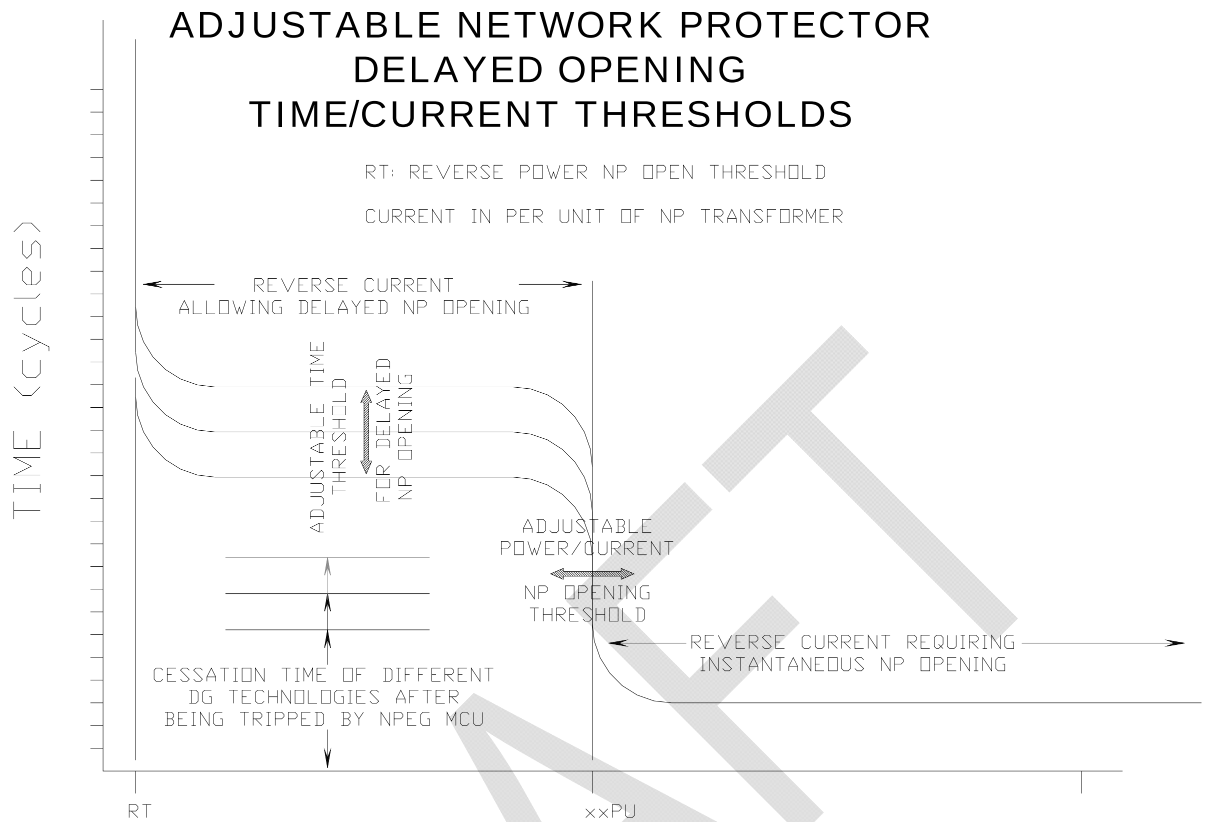

Figure 11: Adjustable network protector time & reverse current parameters to coordinate with NPEG controlled DG

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.

3.2 IEEE 1547: 4.1.4.2

IEEE 1547 2003, article 4.1.4.2 requires that, "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."

In addition to the directional power threshold criteria for tripping the DG by the NPEG Master Control Unit this requirement must also be met. This means that more than 50% of the network must be closed or the NPEG will send a trip signal to the DG, regardless of the direction or level of the power flow at that moment.

3.3 Boolean Logic

The operational criteria of IEEE 1547 4.1.4.2 and the thresholds conceived by the NPEG approach can be combined in a simple logic expression that will indicate when the NPEG MCU will send a trip signal to the DG.

If we represent the number of network protectors on a spot network as “N” then for any spot network the operation of the NPEG MCU can be expressed

If the number of closed network protectors is ≤ N⁄2

OR

If the Forward power is < the predefined threshold for Forward Underpower

OR

If the Reverse power is > 0

Then the NPEG MCU will send a trip signal to the DG. The trip signal will remain in place until all of the all three of the above conditions are false.

For operational purposes time can be added to all of these criteria. For example, the first criterion could be modified by adding a duration of thirty seconds. In this case it would read, “If the number of closed network protectors is ≤ N⁄2 for more than thirty seconds…”

The operational logic of the network protectors themselves is referenced in section 3.1 above. These are operational decisions that are the domain of the utility or distribution company that manages the network. As such, they are outside the scope of a specification for the NPEG concept. However in choosing whether or not to add delay to the network protector operation, and if so how much delay, the utility can choose to accommodate distributed generation by coordinating with the DG while still maintaining quality and continuity of service.

3.4 Supervisory Status Reporting

The NPEG system shall have the ability to continually monitor and report on the status of its constituent components. *[The system is modeled on the type of supervised technology used in intelligent fire alarm systems.]* The supervisory functions of the Master Control Unit (MCU) shall monitor and confirm the presence of the network protectors (NP), the communications link to the network protectors, the DG Interface (DGI), the DG source itself, and the Data Exchange and Control (DEC) link. The status of all of these devices and communications links will then be reported to the enterprise network.[7] The functional specifications of the constituent parts of the supervisory system are:

- The MCU-NP communications protocol
- The MCU-DGI/DG communications protocol
- The MCU to enterprise communications protocol

[7] It is understood that some secondary network distribution systems will not have SCADA communications capabilities. Those networks that lack the ability to communicate to the enterprise level will not be able to include these features of the NPEG system. This description is the preferred form of the systems.

3.4.1 MCU-NP Protocol

The communications exchange between the MCU and each of the network protectors, aside from any required hand shaking and polling, shall be unidirectional. The MCU shall monitor each NP in a “read-only” manner. The MCU will have no control capability over the network protectors and the NPs will operate independently of the MCU. From an operational perspective the NPs will behave as they would absent the NPEG system.

[This topic needs to be informed by the network protector manufacturers’ current capabilities. If their microprocessor-based models have external I/O the protocols and specifications for the existing equipment should be the first choice. In order for the NPEG system to work the NP processing time and communication speed will have to meet the latency requirements of the overall system.]

The MCU will poll the NP at a user adjustable rate of between 1ms and 2000ms.

[The rate of polling of the NP will be determined by the latency requirements of the system as a whole and by the operational requirements of the utility or distribution company. For example, California Rule 21 permits two seconds of delay in the opening of the NP under certain low level reverse power conditions. Coordination for this operational criterion can be met with much greater ease than others that may require single digit cycle response or even sub-cycle times.]

The NPs shall report four parameters:

- The NP unique address
- The NP Open/Closed status
- The NP directional power direction
- The NP directional power magnitude

The MCU shall calculate the total magnitudes and directions for use in its operational decision process.

3.4.2 MCU-DGI/DG Protocol

The MCU will poll the DG Interface at a user adjustable rate of between 1ms and 2000ms.

The DGI will be uniquely addressable. The DGI address will be an extension of the address of the DG address.

[The universe of DG devices is vast and heterogeneous. There are a very large number of communications protocols and processor operating systems. The DGI is intended to bridge the hardware/software/communications gaps that will exist. Issue of communications protocol interoperability between the DGI and the DG will have to be resolved on a case-by-case basis. The issue of timing and latency, as it affects the NPEG system as a whole, will also be DG technology specific.]

The MCU will poll the DGI for status and will be able to log three parameters:

- The GI/DG unique address and the presence of the DG
- The present status of the DG: generating or off-line
- The DG “Ready-to-Trip” status: ready or not ready

The MCU shall be capable of issuing a trip command to the DGI. The DGI shall convert the trip command into the communications protocol of the DG. Once the DG has received the trip command it will initiate the process to cease to energize the output of the DG to the electrical distribution system. When the DG has ceased to energize the electrical distribution system it shall issue an acknowledgement to the DGI indicating that the DG has shut down. The DGI will convert the DG communications protocol to the NPEG protocol and transmit the signal to the MCU.

3.4.3 MCU to Enterprise communications protocol

The communication of system status from the MCU to the enterprise level is the least critical of functions to the operations of the NPEG system described here. Some secondary network protector systems may not presently possess mean to convey information in this direction. This information exchange need not even occur in "real time" and could be implemented through a low frequency power line carrier scheme (or even left for implementation at a later date.)

The MCU shall report four conditions to the enterprise level:

- The MCU unique address
- The DGI Status Normal report
- The DGI Trouble report (communications to DG failed)
- The DGI Alarm report (NPEG has tripped the DG off line)

4 Material Performance Specifications

This portion of the performance specification is a very preliminary attempt at to address the most material conception of the NPEG system. Because of deficiencies in the author's direct experience with the hardware technology of secondary network distribution systems –specifically network protector devices— and because the collaborative process has not had time to permit contribution by stakeholder experts such as network protector manufacturers and utility protection engineers, this section will lack the level of detail that would be preferable when approaching a product development program or even an R&D effort. Having made the previous observation, it may well be that many of the very specific component details, such as physical characteristics of devices or communications protocols, are well established. As has been indicated in the opening sections of this specification, it is the intent of this process to use whatever existing technologies and standards are available and appropriate. The intent of this specification is not to re-invent any technology unnecessarily.

4.1 Master Control Unit (MCU)

The MCU shall be a microprocessor-based controller employing a real time operating system. The clock speed shall be sufficient to allow all necessary detection, processing and response in less time than the required response time of the NP or the DG. The range of operating times shall be determined by evaluating the response times of existing network protectors, DG technologies and disconnection devices such as circuit breakers and contactors.

4.1.1 MCU Physical Characteristics

The physical characteristics that the MCU shall have will include:

• The MCU shall be submersible
• The MCU shall have an operating temperature range of -40°C to 50°C.
• The MCU shall possess the following communications capabilities ______________________?

4.2 Network Protector (NP)

• The NP shall possess the following communications capabilities ______________________?
• The NP, when polled, shall acknowledge the inquiry with a unique address response and shall report Open/Closed status, directional power direction, and directional power magnitude

4.3 Distributed Generation Interface (DGI)

• The DGI shall be designed to be lockable and tamper resistant.
• The DGI shall possess communications capabilities that are compatible with the MCU.
• The DGI shall possess communications capabilities compatible with the DG control unit to which it must interface. This may be either an electronic trip mechanism or an electromechanical device.

4.4 Distributed Generation (DG)

Distributed generation technologies and their associated external communications capabilities, where they exist, are extremely diverse. It is an extremely heterogeneous population and as such the interfaces to their control capabilities –if they exist at all-- must be handled on a case basis. In the those cases where no external I/O exists on the DG which will permit remote shut down of the device a separate electromechanical solution, such as a shunt trip circuit breaker, shall be used and it will dictate the interface requirements of the DGI.

4.5 Data Exchange & Control (DEC)

[This performance specification was "borrowed" wholesale from a technical specification for fiber optic cable published by the University of California, Berkeley. If there is a relevant utility industry standard for fiber optic cable it should be substituted here.]

4.5.1 Fiber Cable Specifications

Fiber cable must meet or exceed the following specifications. Installed cable shall be 62.5/125micron core/cladding, enhanced grade, multimode, and graded index glass fiber. All materials in the cable shall be dielectric.

4.5.1.1 Performance

Installed fiber must meet or exceed the following performance specifications.

Wavelength (nm)	Max. Attn.(dB/Km)	Min. Bandwidth (Mhz*Km)
850	3.0	200
1,300	0.9	500

4.5.1.2 Cable Construction

Installed cable must be manufactured to meet or exceed the following specifications:

4.5.1.2.1 Plenum Cable (Inside Cable)

Plenum rated cable shall be used for all interior installations. Installed cable shall meet or exceed the following specifications:

A. Tight buffered 900 um, mechanical strippable Teflon (for plenum applications). EIA/TIA -598 color coding for fiber optic cable.
B. Aramid yarn strength member, capable of supporting a short-term tensile load of 400 lb. without stretching.
C. Capable of bend radii as small as 20 x outside cable diameter (under installation load) and 10 x outside cable diameter (long term load).
D. Capable of a minimum crush resistance of 850 lb./in.

4.5.1.2.2 Outside Plant Cable

Outside plant cable shall be used for all applications where cable is to be run in underground conduits. Outside plant cable may not be used for interior applications and shall meet the following specifications:

A. Gel filled buffer tube, 250 um, acrylate.
B. EIA/TIA-598 color coding for fiber optic cable.
C. Flooded core
D. Capable of bend radii as small as 20 x outside cable diameter (under installation load) and 10 x outside cable diameter (long term load).
E. Capable of a minimum crush resistance of 850 lb./in.

4.5.2 Termination Standards

The terminal ends of all fibers cable strands shall be field connectorized. The connectors shall be mounted on bulkheads and installed in enclosures called Fiber Integration Centers (FIC). It is CNS's practice to terminate both ends of all fibers within a fiber cable with ST, epoxy and polish style connectors. Termination of older cables may be of several types including mechanical or fusion spliced pigtails. The choice of termination method must be cleared with CNS prior to termination.

4.5.2.1 Fiber Organizers

Fiber cables are to be terminated in one of two types of enclosures. CNS may specify either wall-mounted or rack-mountable stand-alone units for installation. Rack mounted units made by ADC, Avaya, or an equivalent, will be acceptable. The final choice of fiber organizer shall be cleared with CNS prior to installation.

Each enclosure shall be labeled with a machine made label with permanent black ink on a white background. Labels shall be in the format "FIC_NN", with the numbers, "NN", supplied by CNS. In addition, each FIC shall be labeled on the face plate with the identifiers of the cables it contains.

Each fiber optic strand shall be labeled with a unique identifier at the ST coupler in the FIC. Connectors shall be labeled on the identifying sheets on the front of the FIC. Each fiber shall be labeled where it enters the back of the coupler panels. The identifier shall be in the format Cable #-tube- fiber strand #. For tight buffered cables the "tube identifier" shall be "xx".

4.5.2.2 Connectors and Splices

Fiber ends are to be terminated in ST-type connectors with composite ferrules. They must be of the "epoxy and polish". Exceptions may occur when an older UCB installation is being expanded. Some older locations are terminated with connectors such as biconic. In all cases, CNS will specify connector requirements.

If it is necessary to splice pigtails onto an existing, partially terminated fiber cable, the splice type utilized must conform to whatever is already in use at that location. Clearance from CNS must be obtained before installing any type of splice.

4.5.2.3 Miscellaneous

At each end of the cable, sufficient slack (15 - 30') shall be left to facilitate reasonable future relocation of the FIC. Slack shall be mounted on walls or upper ladder racks according to CNS' direction.

4.5.2.4 Testing

4.5.2.4.1 Before Installation

It is suggested that each individual fiber in a cable be tested with an OTDR for length and transmission anomalies while on the reel before installation.

4.5.2.4.2 After Installation and termination

All single mode and multi mode fiber strands shall be tested end-to-end for bi-directional attenuation, 850 nm/1300 nm for multimode and 1310 nm/1550 nm for singlemode fibers. Tests should be conducted in compliance with EIA/TIA-526-14 or OFSTP 14, Method B, according to the manufacturer's instructions for the test set being utilized.

Tests must ensure that the measured link loss for each strand does not exceed the "worst case" allowable loss defined as the sum of the connector loss (based on the number of mated connector pairs at the EIA/TIA-568 B maximum allowable loss of 0.75 dB per mated pair) and the optical loss (based on the performance standard above, 2.1.1 and 2.2.1).

After the cable is in place it shall be tested in the following manner:

A. After termination, each fiber shall be tested with an ODTR for length, transmission anomalies, and end-to-end attenuation. Results are to be recorded and supplied to CNS in the form of hard-copy printouts or photographs of screen traces.
B. After termination and bulkhead mounting, each terminated fiber is to be tested for end-to-end loss with a power meter/light source. As above, results are to be recorded and supplied to CNS.
C. The maximum allowable attenuation for any splice or termination is 0.3 dB.

4.6 Ancillary Sensors

4.6.1 Current Transformers

4.6.2 Voltage Transformers

5 Performance Testing

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