IEEE Smart Grid Series of Standards IEEE 2030 (Interoperability) and IEEE 1547 (Interconnection) Status

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Abstract

The IEEE American National Standards smart grid publications and standards development projects IEEE 2030, which addresses smart grid interoperability, and IEEE 1547, which addresses distributed resources interconnection with the grid, have made substantial progress since 2009 [1]. The IEEE 2030 and 1547 standards series focus on systems-level aspects and cover many of the technical integration issues involved in a mature smart grid. The status and highlights of these two IEEE series of standards, which are sponsored by IEEE Standards Coordinating Committee 21 (SCC21), are provided in this paper. The IEEE Std 2030—"Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads"—was published in 2011. It provides a knowledge base that contains terminology, characteristics, functional performance and evaluation criteria, and the application of engineering principles for smart grid interoperability. IEEE 2030 establishes a globally relevant smart grid interoperability reference model and knowledge base that can be used by utilities who are developing their infrastructure roadmaps, manufacturers who are planning smart grid systems and applications, scientists who are conducting research, governments who are crafting regulations, and standards-development organizations (SDOs) that are writing additional standards for the smart grid. Three additional P2030 projects are underway that address infrastructure for electric-sourced transportation, energy storage systems and applications, and testing energy storage systems. The IEEE 1547 series now includes IEEE Std 1547.4 (planned islands/micro-grids) and IEEE Std 1547.6 (interconnection to distribution secondary networks), and the recently initiated P1547.8, which deals with extended use of IEEE Std 1547.

1. INTRODUCTION

The Institute of Electrical and Electronics Engineers (IEEE) standards development organization has been identified in the Energy Independence and Security Act (EISA) of 2007 under Title XIII, Section 1305 *Smart Grid Interoperability Framework* and in the Energy Policy Act 2005 under section 1254 *Interconnection* in relation to standards development and best practices for the electricity grid. This paper discusses the status of the IEEE American National Standards series IEEE 2030 [2] and IEEE 1547 [3] standards as they relate to smart grid interoperability and distributed resource interconnection.

The IEEE establishes its standards through a rigorous consensus-development process, approved by the American National Standards Institute (ANSI), which brings together volunteers representing varied viewpoints and interests to achieve the final product. Additionally, IEEE often elects to develop many of its standards to qualify for designation as ANSI American National Standards. Not all standards or standards-development organizations choose to meet the development requirements necessary for designation as an American National Standard; however, all of the IEEE 1547 series are qualified as American National Standards, including the new 1547 projects and the IEEE Std 2030 publication.

Development of uniform IEEE 1547 interconnection standards has helped decrease the time and effort associated with DR interconnection. And with the September 2011 publication of IEEE Std 2030, that document is now poised to support the accelerated rollout of the smart grid and realization of the revolutionary benefits—greater consumer choice, improved electric-system reliability, and increased reliance on renewable sources of energy—that it promises for people worldwide.

2. IEEE 1547 AND P2030 BACKGROUND

The IEEE 1547 and IEEE 2030 series of standards and projects are approved by the IEEE Standards Board as sponsored by the IEEE Standards Coordinating Committee 21 (SCC21) [4]. The IEEE SCC21 is responsible for overseeing the development of standards in the areas of fuel cells, photovoltaics, dispersed generation, and energy storage. The board also coordinates efforts in these fields among the various IEEE societies and other affected organizations to insure that all standards are consistent and properly reflect the views of all applicable disciplines.

The IEEE 1547 and the 2030 standards development approach recognizes the interactive nature of the interconnection with the grid and all of its parts, and realizes the significance of the integration of power, communications, and information technologies into the smart grid. In **Figure 1**, the interconnection and the communication and information technologies show the interfaces for the systems approach (system of systems) to the concepts needed for mature smart grid interoperability. Further, IEEE SCC21 members are well aware that the dynamic electric infrastructure system has been successful because it was designed for operation to achieve balance between the generation, the delivery system, and the end user requirements for energy. In part, the system must have adequate energy that may be called upon instantaneously to stabilize the dynamics when abnormal conditions occur. The stabilization requires both real and reactive energy and controls. For significant levels of penetration (of loads, distributed energy resources, electric vehicles, etc.), it is practically assured that the initial stabilization action has to be independent of critical communications having long latency. And, when high penetration of distributed energy resources is incorporated into the interconnected grid, it is especially important to understand and accommodate the electrical and mechanical limitations of this DR and other equipment on the grid. Distribution automation and other smart grid technologies add complexity to help support the safe and reliable operation of the distribution energy delivery system, and it is not uncommon to use these technologies to rapidly reconfigure distribution circuits to address issues such as load balance, or faults. Thus in the smart grid, generation capacities and loading may have to quickly be re-aligned to meet the circuit's technical and operational restraints.

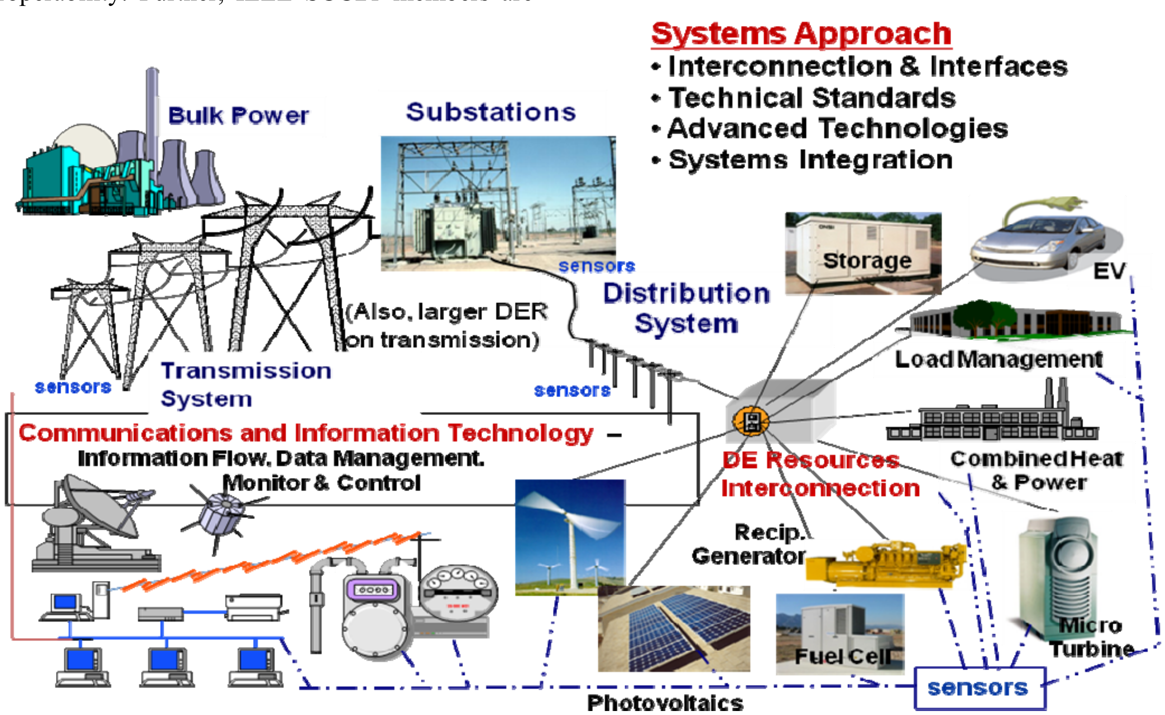

Figure 1. Interoperability smart grid concepts ("system of systems" approach)

3. THE IEEE 1547 SERIES OF STANDARDS

IEEE Std 1547 is the foundational, or root, standard of the IEEE 1547 series. Currently, there are seven additional complementary standards designed to expand upon or support the root standard, five of which are published. The IEEE 1547 series of existing, published standards is as follows:

- IEEE Std 1547–2003 (reaffirmed 2008), *IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems*
- IEEE Std 1547.1–2005, *IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems*
- IEEE Std 1547.2–2008, *IEEE Application Guide for IEEE Std 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems*
- IEEE Std 1547.3–2007, *IEEE Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems*
- IEEE Std 1547.4–2011, *Guide for Design, Operation, and Integration of Distributed Resource Island Systems with Electric Power Systems*
- IEEE Std 1547.6–2011, *Recommended Practice for Interconnecting Distributed Resources with Electric Power Systems Distribution Secondary Network*.

The IEEE SCC21 1547 series of standards development projects that are currently underway is as follows:

- IEEE P1547.7, *Guide to Conducting Distribution Impact studies for Distributed Resource Interconnection.*
- IEEE P1547.8, *Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Std 1547.*

3.1. IEEE Std 1547

The IEEE Std 1547–2003 is the first in the 1547 series of interconnection standards and provides interconnection technical specifications and requirements as well as interconnection test specifications and requirements. The stated requirements of IEEE Std 1547 are universally needed for interconnection of distributed resources that include both distributed generators and energy storage systems that involve synchronous machines, induction machines, or power inverters/converters. The requirements will be sufficient for most installations. In February 2003, IEEE Std 1547 was affirmed by the ballot group of 230 members. IEEE Standard 1547 was approved by the IEEE Standards Board in June 2003, and was approved as an American National Standard in October 2003. In the Energy Policy Act of 2005**,** IEEE 1547 standards were required to be considered for interconnection of distributed resources to the grid. In 2008, the standard was reaffirmed by 181 balloters. Reaffirmation, via consensus vote, means the standard as currently written, is not obsolete, and does not contain erroneous information. In the safety standard *UL1741 Inverters, Converters and Interconnection System Equipment for Use With Distributed Energy Resources*, it is stated for utility interconnected equipment UL 1741 supplements and is to be used in conjunction with IEEE Std 1547 and IEEE Std 1547.1.

3.2. IEEE Standard 1547.1

The IEEE Std 1547.1–2005 provides the test procedures for verifying conformance to IEEE Std 1547–2003. When applied, the IEEE Std 1547.1 test procedures provide a means for manufacturers, utilities, or independent testing agencies to confirm the suitability of any given interconnection system or component intended for use in the interconnection of distributed resources (DR) with the electric power system (EPS). Such certification can lead to the ready acceptance of confirmed equipment as suitable for use in the intended service by the parties concerned. IEEE 1547.1 was reaffirmed in 2011.

3.3. IEEE Standard 1547.2

The IEEE Std 1547.2–2008 provides technical background and application details to support understanding of IEEE Standard 1547. The guide facilitates the use of IEEE Std 1547 by characterizing various forms of DR technologies and their associated interconnection issues. It provides background and rationale of the technical requirements of IEEE Std 1547. It also provides tips, techniques, and rules of thumb, and it addresses topics related to DR project implementation to enhance the user's understanding of how IEEE Standard 1547 may relate to those topics.

3.4. IEEE Standard 1547.3

IEEE Std 1547.3–2007 facilitates interoperability of DR interconnected with an area EPS. The standard helps stakeholders in DR installations implement optional approaches for monitoring, information exchange, and control to support the operation of their DR and transactions among the stakeholders associated with the distributed resources. IEEE Std 1547.3 describes functionality, parameters, and methodologies for monitoring, information exchange, and control related to distributed resources interconnected with an area EPS. The focus is on monitoring, information exchange, and control data exchanges between DR controllers and stakeholder entities with direct communication interactions. This guide incorporates information modeling and uses case approaches, but it is also compatible with historical approaches to establishing and satisfying monitoring, information exchange, and control needs for DR interconnected with an area EPS.

3.5. IEEE Standard 1547.4

The IEEE Std 1547.4–2011 guide covers intentional islands in EPSs that contain DR. The term "DR island systems," sometimes interchanged with "microgrids," is used for these intentional islands. DR island systems are EPSs that: (1) include DR and load, (2) have the ability to disconnect from and parallel with the area EPS, (3) include the local EPS and may include portions of the area EPS, and (4) are intentionally planned. DR island systems can be either local EPS islands or area EPS islands. One reason for the popularity of microgrids is that local power generation and storage allow portions of the grid and critical components to operate independent of the larger grid when needed (**Figure 2**). Another reason is that during planning all interested parties can decide upon appropriate local control and appropriate levels of power quality.

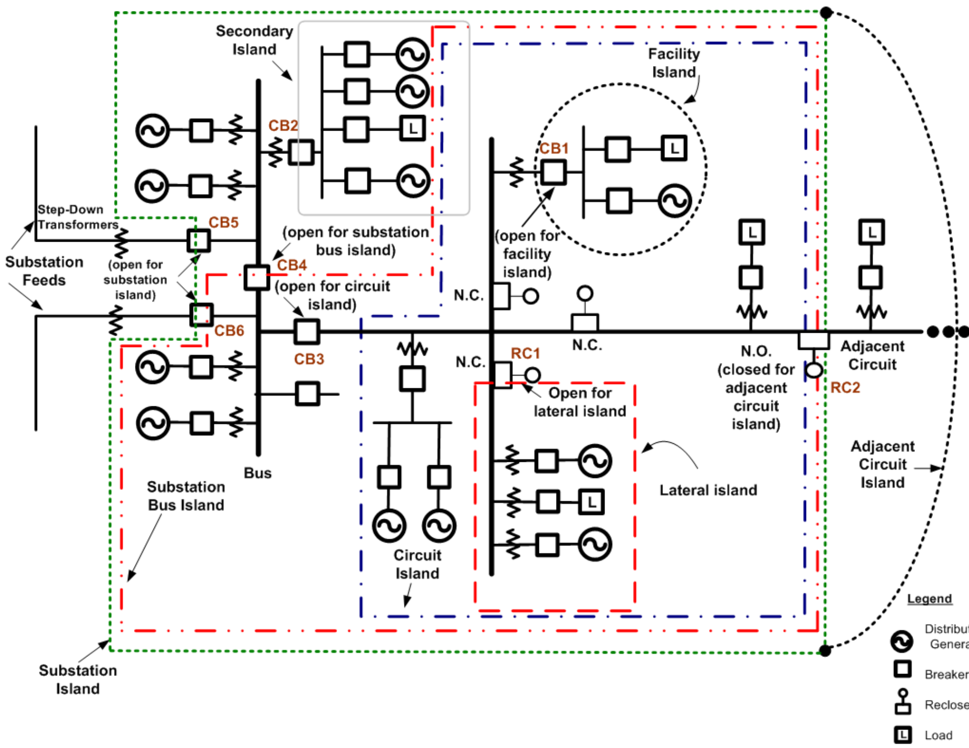

Figure 2. Examples of DR Island Systems. ***Source: IEEE Std 1547.4***

The IEEE Std 1547.4 document addresses issues associated with DR island systems on both local and area islanded EPSs In addition to an introduction and overview, the document discusses engineering concerns related to DR island systems. It also provides alternative approaches and good practices for the design, operation, and integration of DR island systems with EPS. This includes the ability to separate from and reconnect to part of the area EPS while providing power to the islanded EPSs. This guide includes information on the DR, interconnection, and participating electric power systems.

3.6. IEEE Standard 1547.6

The IEEE Std 1547.6–2011 recommended practice builds upon IEEE Std 1547 for the interconnection of

DR to distribution secondary network systems. It establishes recommended criteria, requirements, and tests, and provides guidance for interconnection of distribution secondary network system types of area EPS with DR providing electric power generation in local EPS. The IEEE Standard 1547.6 document focuses on the technical issues associated with the interconnection of area EPS distribution secondary networks with a local EPS having distributed resources generation. The recommended practice provides recommendations relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection. In this IEEE Std 1547.6 document, consideration is given to the needs of the local EPS to be able to provide enhanced service to the DR owner loads as well as to other loads served by the network. Equally, the standard addresses the technical concerns and issues of the area EPS. Further, this standard identifies communication and control recommendations and provides guidance on considerations that will have to be addressed for such DR interconnections.

3.7. IEEE Standard P1547.7

The IEEE Std P1547.7 guide describes criteria, scope, and extent for engineering studies of the impact on area EPS of a DR or aggregate distributed resource interconnected to an area electric power distribution system. The creation of IEEE Std 1547 had led to the increased interconnection of DR throughout distribution systems. This IEEE Std P1547.7 document describes a methodology for performing engineering studies of the potential impact of DR interconnected to an area electric power distribution system. The scope and extent of the impacts study are described as functions of identifiable characteristics of DR, the area EPS, and the interconnection. Criteria are described for determining the necessity of impact mitigation. The IEEE Std P1547.7 guide allows distributed resource owners, interconnection contractors, area electric distribution power system owners and operators, and regulatory bodies to have a described methodology for when distribution system impact studies are appropriate, what data is required, how they are performed, and how the study results are evaluated. In the absence of such guidelines, the necessity and extent of DR interconnection impact studies has been widely and inconsistently defined and applied. The IEEE Std P1547.7 project was initiated in January 2009 and is targeted for balloting in 2012.

3.8. IEEE Standard P1547.8

The IEEE P1547.8 recommended practice expands the use of IEEE Std 1547. This P1547.8 document applies to the requirements set forth in IEEE Std 1547 and provides recommended methods that may expand the usefulness and utilization of IEEE Std 1547 through the identification of innovative designs, processes, and operational procedures. The purpose of the methods and procedures given is to provide more flexibility in determining the design and processes used in expanding the implementation strategies used for interconnecting distributed resources with the EPS. Further, based on IEEE Std 1547 requirements, the purpose of this recommended practice is to provide the knowledge base, experience, and opportunities for greater utilization of the interconnection and its applications. The need for P1547.8 is to address industry driven recommendations and NIST Smart Grid standards framework recommendations (e.g., NIST priority action plans). The P1547.8 considerations include voltage ride thru; volt-ampere reactive support; grid support; two-way communications and control; advanced/interactive grid-DR operations; high-penetration/multiple interconnections; interactive inverters; energy storage; electric vehicles; etc.

4. IEEE STANDARD 2030 SERIES

The IEEE Std 2030–2011 Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation With the Electric Power System (EPS), and End-Use Applications and Loads provides alternative approaches and best practices for achieving smart grid interoperability. It is the first all-encompassing IEEE standard on smart grid interoperability providing a roadmap directed at establishing the framework in developing an IEEE national and international body of standards based on cross-cutting technical disciplines in power applications and information exchange and control through communications (**Figure 3**).

Currently, there are three additional complementary standards designed to expand upon the base 2030 standard:

- IEEE P2030.1, *Guide for Electric-Sourced Transportation Infrastructure*
- IEEE P2030.2, *Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure*
- IEEE P2030.3, *Standard for Test Procedures for Electric Energy Storage Equipment and Systems for Electric Power Systems Applications*.

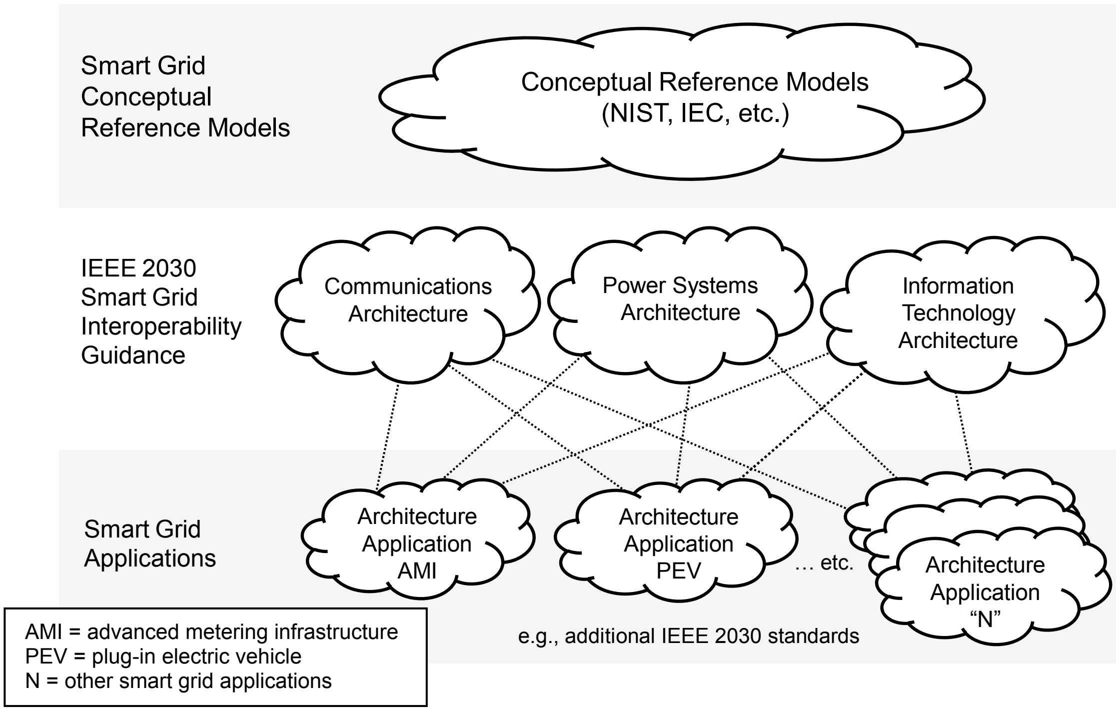

Figure 3. Evolution of smart grid interoperability. ***Source: IEEE Std 2030***

4.1 IEEE Standard 2030

The IEEE Std 2030 provides guidelines for understanding and defining smart grid interoperability. Integration of energy technology and information and communications technology is necessary to achieve seamless operation. IEEE Std 2030 establishes the smart grid interoperability reference model (SGIRM) and provides a knowledge base addressing terminology, characteristics, functional performance and evaluation criteria, and the application of engineering principles for smart grid interoperability of the EPS with end-use applications and loads. A system of systems approach to smart grid interoperability provided the foundation for the SGIRM as a design tool that inherently allows for extensibility, scalability, and upgradeability. The 2030 SGIRM defines three integrated architectural perspectives: power systems, communications technology, and information technology. Additionally, it defines design tables and the classification of data flow characteristics necessary for interoperability. Guidelines for smart grid interoperability, design criteria, and reference model applications are addressed with emphasis on functional interface identification, logical connections and data flows, communications and linkages, digital information management, and power generation usage.

The inaugural meeting to develop IEEE Std 2030 was held in June 2009 and had capacity in-person registration of 150 individuals and close to 200 others registered to participate via webinar. The publication was achieved on a fast-track schedule, going to ballot in spring 2011, which resulted in successful affirmation by the 459 members of the ballot pool. The IEEE Standards Board approved the immediate publication of the IEEE Std 2030 in September 2011.

4.2 IEEE Standard P2030.1

The guide addresses applications for electric-sourced vehicles and related support infrastructure used in road-based personal and mass transit. It provides a knowledge base addressing terminology, methods, equipment, and planning requirements for such transportation and its impacts on commercial and industrial systems. The guidelines can be used by utilities, manufacturers, transportation providers, infrastructure developers, and end users of electric-sourced vehicles and related support infrastructure for road-based personal and mass transportation applications. Standards that exist and research that is being performed are pointed out in this document. Where new standards are needed, they are pointed out in this document. This document supports utilities in planning for the most economic method of production to support increasing transportation loads. It allows manufacturers to understand the standardization requirements and bring products to fruition as the supporting systems and methods are developed and standardized, and it allows end users to understand technologies that can be implemented for their transportation energy needs. A phased implementation is suggested in this document and is based on economic considerations for technologies that are available today and in development. While regional political and regulatory issues may alter these methods, this document does not consider the wide range of regional differences available. It is incumbent upon the user of the guide to understand the financial differences that these factors may have on their specific planning requirements. This document does not consider non-road forms of transportation.

4.3 IEEE Standard P2030.2

This document provides guidelines for discrete and hybrid energy storage systems that are integrated with the electric power infrastructure, including end-use applications and loads. This guide builds upon IEEE Std 2030 *Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation With The Electric Power System (EPS), and End-Use Applications and Loads*. The purpose of P2030.2 is to provide guidance in understanding and defining technical characteristics of energy storage systems and how discrete or hybrid systems may be integrated with and used compatibly as part of the electric power infrastructure. Further, P2030.2 fills the need for guidance relevant to a knowledge base addressing terminology, functional performance, evaluation criteria, operations, testing, and the application of engineering principles for energy storage systems integrated with the electric power infrastructure.

4.4 IEEE Standard P2030.3

Traditionally, utility electric power delivery systems were not designed to accommodate electric storage. In recent years, electric storage has drawn more and more attention as the development of renewable energy distributed resources interconnected with power systems have been deployed. This IEEE P2030.3 standard establishes test procedures for electric energy storage equipment and systems for EPS applications. Electric energy storage equipment or systems can be a single device providing all required functions or an assembly of components, each having limited functions. Additionally, requirements on installation evaluation and periodic tests are included in this standard. Further as stated in 2030, storage equipment and systems that connect to an EPS need to meet the requirements specified in related IEEE standards. Standardized test procedures are necessary to establish and verify compliance with those requirements. These test procedures need to provide repeatable results at independent test locations and have flexibility to accommodate the variety of storage technologies and applications. Conformance to IEEE Std 2030.3 may be established through a combination of type, production, and commissioning tests.

5. MOVING FORWARD

The IEEE 1547 and 2030 series of publications and development activities address priority engineering topics identified by numerous stakeholders, including some listed in the NIST *Framework and Roadmap for Smart Grid Interoperability* [5], as important for the smart grid. Examples of such topics follow.

- Energy storage systems, e.g., for storage system specific requirements
- Distribution grid management standards requirements including communications
- Voltage regulation, grid support, etc.
- Technical management of distributed energy resources and loading, e.g., in planned islands
- Static and mobile electric storage, including both small and large electric storage facilities
- Electric transportation and electric vehicles
- Conformance and testing.

As with all standards, the ultimate proof of success lies in adopting them, validating conformance to the specifications and requirements of the standards, and establishing that the standards indeed help the technology and stakeholders meet the intended use by being in compliance. At the National Renewable Energy Laboratory (NREL), for instance, smart grid interconnection and interoperability testing activities (**Figure 4**) are being extended beyond the initial undertakings. However, it is of paramount importance that conformance testing be qualified to a comprehensive and universally accepted set of applicable standards so that reciprocity among testing labs and uniform acceptance of conforming equipment and best practices is transparent.

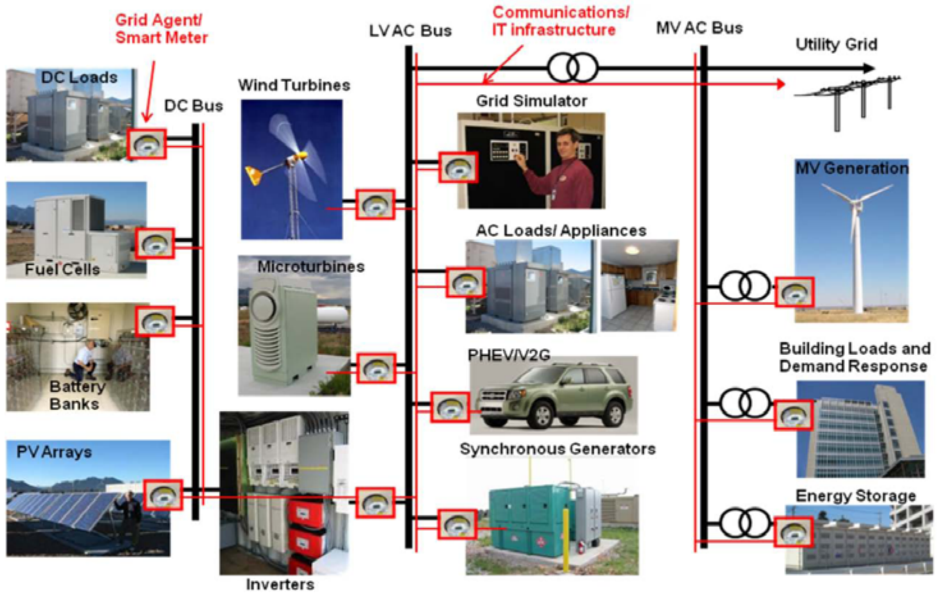

Figure 4. Example smart grid testing at NREL

The IEEE 1547 series of standards provided a model for IEEE 2030 development. The IEEE Std 2030 is a foundational document addressing smart grid interoperability. However, there could never be one single, all-encompassing document that would adequately address all of the standards issues associated with a "system of systems" smart grid paradigm. Building off existing standards and works in progress helps to accelerate standards coverage for the myriad of smart grid concerns. As an example, in the series of IEEE 1547, the IEEE Std 1547.4 (microgrids) addresses many of the technical integration issues for a mature smart grid, including issues of high penetration of distributed generators and electric storage systems, grid support, and load management. However, the details for smart grid interoperability will need to be approached in a layered and evolutionary manner, building on successful experiences and learning from other experiences. The mature smart grid will truly be a complex "system of systems" (**Figure 1**). To reach that maturity in an accelerated timeframe yet rational manner, it seems evident that technology will evolve at widely varying degrees of intelligence. By first establishing device and individual system conformance, the foundation is laid for the fundamental goal of providing smart grid interoperability for the overall system.

Acknowledgments
In closing, the authors want to acknowledge that both the IEEE 1547 and the IEEE 2030 standards development required a significant undertaking by numerous volunteers. The time and resources of all individuals and organizations that participated led to the success of the published IEEE 1547 and 2030 standards and their subsequent adoption. Similarly, the timely completion of priority outgrowth beyond the foundational standards will only succeed through dedicated commitment by the individuals and organizations contributing to smart grid interoperability.

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