

IEEE Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure

IEEE Standards Coordinating Committee 21

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IEEE Standards Coordinating Committee 21 on
Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

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IEEE Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure

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Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage**

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Abstract: This guide applies the smart grid interoperability reference model (SGIRM) process (IEEE Std 2030™-2011) to energy storage by highlighting the information relevant to energy storage system (ESS) interoperability with the energy power system (EPS). The process can be applied to ESS applications located on customer premises, at the distribution level, and on the transmission level (i.e., bulk storage). This guide provides useful industry-derived definitions for ESS characteristics, applications, and terminology that, in turn, simplify the task of defining system information and communications technology (ICT) requirements. As a result, these requirements can be communicated more clearly and consistently in project specifications. This guide also presents a methodology that can be used for most common ESS projects to describe the power system, communications, and information technology (IT) perspectives based on the IEEE 2030™ definitions. From this framework, a seemingly complex system can be more clearly understood by all project stakeholders. Emerging cybersecurity requirements can also be incorporated into the framework as appropriate. Additionally, this guide provides the templates that can be used to develop requirements for an ESS project and goes through several real-world ESS project examples step by step.

Keywords: battery, communications technology, electric power system, energy storage system, IEEE 2030.2™, information technology, interoperability, power system, Smart Grid

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Introduction

This introduction is not part of IEEE Std 2030.2™-2015, IEEE Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure.

IEEE Std 2030.2 is part of the IEEE 2030™ series of standards. The IEEE 2030 series was created to provide guidelines in understanding and defining smart grid interoperability of the electric power system (EPS) with end-use applications and loads. To achieve this, integration of energy technology and information and communications technology (ICT) is necessary to achieve seamless operation for electric generation, delivery, and end-use benefits to permit two-way power flow with communication and control. The IEEE 2030 series is also intended to build a knowledge base across relevant topics including interconnections, intra-facing frameworks, strategies, and design definitions. This expanded knowledge base is needed as a key element in grid architectural designs and operation to promote a more reliable and flexible EPS.

IEEE Std 2030.2 was specifically developed to address the interoperability of energy storage systems (ESSs) with electric power infrastructure. Implementing the IEEE 2030 smart grid interoperability reference model (SGIRM) approach, IEEE Std 2030.2 provides a framework for identifying and organizing the key information that is required to help assure that any given ESS can connect, and be interoperable, with the EPS to which it is connected. The document provides guidance in understanding and defining technical characteristics of ESSs and methods by which discrete or hybrid systems may be integrated with, and used compatibly as part of, the electric power infrastructure. Further, IEEE Std 2030.2 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 ESSs integrated with the electric power infrastructure.

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1. Overview

1.1 Scope

This document provides guidelines for discrete and hybrid energy storage systems (ESSs) that are integrated with the electric power infrastructure, including end-use applications and loads. This guide builds upon IEEE Std 2030™-2011.¹

1.2 Purpose

The purpose is to provide guidance in understanding and defining technical characteristics of ESSs and methods by which discrete or hybrid systems may be integrated with, and used compatibly as part of, the electric power infrastructure. Further, the document 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 ESSs integrated with the electric power infrastructure.

¹ Information on references can be found in Clause 2.

1.3 Why and how to use this guide

This guide provides useful industry-derived definitions for ESS characteristics, applications, and terminology. These definitions simplify the task of defining system information and communications technology (ICT) requirements. As a result, these requirements can be communicated more clearly and consistently in project specifications.

This guide also presents a methodology that can be used for most common ESS projects to describe the power system, communications, and information technology (IT) interoperability architecture perspectives (IAPs) based on the IEEE 2030™ definitions and the smart grid interoperability reference model (SGIRM). From this framework, a seemingly complex system can be more clearly understood by all project stakeholders. Emerging cybersecurity requirements can also be incorporated into the framework as appropriate.

Additionally, this guide provides the templates that can be used to develop requirements for an ESS project and goes through several real-world ESS project examples step by step.

This guide is useful for any stakeholder involved in an ESS project regardless of technology, size, and point of grid interconnection. Over time, this work will drive modularity in the ESS.

1.3.1 How to use this guide

This guide can be used at the start of an ESS project to ensure the project components described in the project specification follow industry-standardized terminology and to help define the power system IAP (PS-IAP), communications technology IAP (CT-IAP), and IT-IAP. To derive the most benefit from the resulting framework, the following steps are suggested:

- Review the ESS characteristics and applications to better define an ESS project.
- Review the PS-IAP, CT-IAP, and IT-IAP SGIRM diagrams and descriptions for relevant ESSs.
- Read through the real-world ESS projects described in this guide.
- Break down the ESS project by completing the template forms provided in this guide.
- Continue to use the template forms to document the analysis of the ESS project.

This complete documentation will serve to benefit most projects in the clarity it presents and the visibility of the choices the system designers have made.

1.4 SGIRM and the three IAPs

This guide applies the IEEE 2030 SGIRM process to energy storage by highlighting the information relevant to ESS interoperability with the electric power system (EPS). The process can be applied to ESS applications located on customer premises, at the distribution level, and on the transmission level (i.e., bulk storage).

The smart grid interoperability reference model (SGIRM) defined in IEEE Std 2030-2011 organizes all the functions and interconnections of a Smart Grid in terms of three separate interoperability architecture perspectives (IAPs). The three IAPs primarily relate to logical, functional considerations of power systems, communications interfaces, and IT data flows for smart grid interoperability:

- Power systems IAP (PS-IAP): The emphasis of the power system perspective is the production, delivery, and consumption of electric energy, including apparatus, applications, and operational concepts. This perspective defines seven domains common to all three perspectives: bulk

- generation, transmission, distribution, service providers, markets, control/operations, and customers.
- Communications technology IAP (CT-IAP): The emphasis of the communications technology perspective is communication connectivity among systems, devices, and applications in the context of the Smart Grid. The perspective includes communication networks, media, performance, and protocols.
 - Information technology IAP (IT-IAP): The emphasis of the information technology perspective is the control of processes and data management flow. The perspective includes technologies that store, process, manage, and control the secure information data flow.

The IAPs of the SGIRM comprise domains, entities, interfaces, and data flows:

- Domains common to all of the SGIRM IAPs are as follows:
 - Bulk generation. The generators of electricity in bulk quantities. May also store energy for later distribution.
 - Transmission. The carriers of bulk electricity over long distances.
 - Distribution. The distributors of electricity to and from customers.
 - Service providers. The organizations providing services to electrical customers and utilities.
 - Markets. The operators and participants in electricity markets.
 - Control/operations. The management of the movement of electricity.
 - Customers. The end users of electricity.
- Entities (e.g., devices, communication networks, computer systems, software programs) are generally located inside a domain and are connected to each other through one or more interfaces. Each perspective has entities that more closely map to its technology. However, each entity can map to an appropriate entity or entities in another perspective.
- Interfaces are logical connections from one entity to another that support one or more data flows implemented with one or more data links.
- Data flows are used instead of interfaces in the IT-IAP. These data flows are application-level communications from entities that provide data to entities that consume data.

In this guide (IEEE Std 2030.2™), the SGIRM is applied to ESSs by defining the PS-IAP, CT-IAP, and IT-IAP for specific applications and use cases of ESSs.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 2030™-2011, IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads.^{2, 3}

² IEEE publications are available from The Institute of Electrical and Electronics Engineers (<http://standards.ieee.org/>).

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3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁴

This information includes definitions that are critical to understanding interoperability of ESSs connected to the EPS. A glossary has been included in Annex B to provide other commonly used terms.

cycle (charge/discharge cycle): An energy storage system (ESS) discharge followed by a complete recharge. A deep (or full) cycle is described as the removal and replacement of 80% or more of the ESS's design capacity.

cycle life: The number of charge-discharge cycles after which electricity storage becomes inoperable or unusable for a given application.

demand: The electrical load at the receiving terminals averaged over a specified interval of time. Demand is expressed in kilowatts, kilovoltamperes, kilovars, amperes, or other suitable units.

discharge: The process of extracting stored energy from the energy storage system (ESS).

dispatch: The process of varying the output from a distributed energy resource (DER) on a moment-to-moment basis to meet changing supply requirements.

end-use application: A process that administers or controls the consumption or production of electricity at a device (equipment or system) or facility.

energy balancing: Periodic balancing of energy supply and demand between two or more entities. For example, during one 15-minute period, entity 1 needs more energy than its scheduled resources can provide. So entity 1 receives the necessary energy from entity 2. During the next 15-minute period, entity 1 supplies an amount of energy to entity 2 equal to the extra energy used (from entity 2) during the previous 15-minute period.

energy capacity (available from the energy storage system (ESS)): The energy available for transfer to the grid, usually expressed in kilowatt-hours.

energy capacity (available to store in the energy storage system (ESS)): The energy available for transfer to the ESS, usually expressed in kilowatt-hours.

energy storage system (ESS): Commercially available technology that is capable of absorbing energy, storing it for a period of time, and thereafter dispatching the energy in response to an external control input according to some predefined control function.

interoperability: The capability of two or more networks, systems, devices, applications, or components to externally exchange and readily use information securely.

islanding: The concept where distributed energy resource (DER) island systems are parts of electric power systems (EPSs) that have DER and load, have the ability to disconnect from and parallel with the EPSs, include the local EPS and may include portions of the area EPS, and are intentional and planned.

⁴ *IEEE Standards Dictionary Online* subscription is available at
http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

net metering: Energy use involving measurement of energy used and energy fed into the utility grid by a customer with generation capacity. In other words, each unit of energy fed into the grid directly offsets use and cost incurred for one unit of energy purchased from the grid.

power available from the energy storage system (ESS): The power available for transfer to the grid, usually expressed in kilowatts.

power available to store in the energy storage system (ESS): The power available for transfer to the ESS, usually expressed in kilowatts.

ramp rate: The rate of change in instantaneous output from a power source. Typically ramp rate is expressed in units of megawatts per second.

roundtrip efficiency: The amount of energy that an energy storage system (ESS) can deliver relative to the amount of energy injected into the system during the immediately preceding charge. *Syn:* **efficiency.**

state of charge (SOC): The degree to which an energy storage system (ESS) is charged relative to the maximum possible amount of energy that can be stored by the system, typically expressed as a percentage.

use case: An established methodology for defining interactions in systems analysis and determining functional requirements. A use case is one way to define specific deployment of an energy storage system (ESS) for one or more applications and/or one or more benefits.

3.2 Acronyms and abbreviations

AGC	automatic generator control
AMI	advanced metering infrastructure
BESS	battery energy storage system
CAES	compressed air energy storage
CT-IAP	communications technology interoperability architecture perspective
DER	distributed energy resource
DESS	distributed energy storage system
DOD	depth of discharge
DR	demand response
EMS	energy management system
EMT	electromagnetic transient
EPS	electric power system
ESS	energy storage system
FAN	field area network
GWAC	GridWise [®] Architecture Council
HEMP	high-altitude electromagnetic pulse
IAP	interoperability architecture perspective
ICS	industrial control system
ICT	information and communications technology
IED	intelligent electronic device
IEMI	intentional electromagnetic interference

IP	Internet Protocol
ISO	independent system operator or International Organization for Standardization
IT	information technology
IT-IAP	information technology interoperability architecture perspective
LAN	local area network
M2M	machine-to-machine
MAN	metropolitan area network
NAN	neighborhood area network
NPV	net present value
OSI	Open Systems Interconnection
PAN	personal area network
PCC	point of common coupling
PCS	power conversion system
PS-IAP	power systems interoperability architecture perspective
PV	photovoltaic
RTO	regional transmission organization
SCADA	supervisory control and data acquisition
SGIRM	smart grid interoperability reference model
SMES	superconducting magnetic energy storage
SOC	state of charge
T&D	transmission and distribution
TOU	time of use
UPS	uninterruptable power supply
WAN	wide area network

4. Energy storage systems (ESSs)

4.1 Introduction

As renewables take a bigger share of generation capacity and where electrical systems cannot keep up with the increasing demand, ESSs could provide services and improvements to power grid systems, so “storage may one day be ubiquitous in our power systems” (EPRI-1001834 [B14]). It is believed that energy storage “will be a key asset in the evolving smart grid” (Rastler [B85]).

As more ESS options become available and nations around the globe continue to enrich their portfolios of renewable energy, the use of energy storage is increasing. For example, increased deployment of energy storage devices in the distribution grid could make this process more effective and could improve system performance (Roberts and Sandberg [B86]). Mainly, energy storage mediates between variable sources and variable loads; works by moving energy through time (SAND2013-5131 [B91]). ESSs are highly versatile and can meet the needs of various users including renewable energy generators, grid equipment, and end users.

4.2 Energy storage technologies

The following are the most common energy storage technologies that provide benefits and added value to power grid services:

- Battery energy storage, which includes lithium ion, lead acid, nickel cadmium, and sodium sulphur technologies. Flow battery energy storage technologies include vanadium redox, polysulphide bromide, and zinc bromine. Battery energy storage can also include electric vehicle storage capabilities.
- Supercapacitor energy storage.
- Pumped hydroelectric energy storage, which includes underground pumped hydroelectric energy storage.
- Compressed air energy storage (CAES).
- Adiabatic compressed air.
- Flywheel energy storage.
- Thermal energy storage, which could include air-conditioning thermal energy storage and thermal ESSs.
- Superconducting magnetic energy storage (SMES).
- Hydrogen energy storage system.

Expanded discussion of the most commonly used technologies follows:

- a) **Battery.** Battery energy storage systems (BESSs) typically have an operational life in years and a cycle life based on the number of charge/discharge cycles that have taken place. This value is typically in the thousands or ten of thousand cycles. The charging capability typically degrades over time for almost all battery technologies. Most battery systems use materials that must be disposed of properly. Therefore, the end of life disposition is an important consideration for battery technologies. The reliability of most battery systems is dependent not only on the reliability of the battery but the system of ancillary devices. Likewise the roundtrip efficiency reflects not only that of the battery but also the parasitic loads of the battery system. Most battery systems can be used in either intermittent or continuous mode with practical limitations only being the size of the charge/discharge energy and the energy storage rating of the batteries. Response time of most battery systems is very quick. Battery systems are usually connected to the electric power system (EPS) by an inverter. Battery systems can be located anywhere on the distribution system or transmission system.

The state of charge (SOC) and depth of discharge (DOD) are critical elements in the optimal operation of battery systems. These elements are essential for determining the amount of energy that can still be delivered and the degradation of the ESS.

The operational requirements for battery ESSs depend on the size of the system. For large systems quick information exchange is required since the battery ESS is meant to correct issues on the distribution or transmission system. Speed of information exchange, except for protection, is not necessary for smaller systems since they are not typically critical for ongoing EPS operations.

- b) **Supercapacitor.** Supercapacitors typically have extremely fast response time and are usually used for intermittent service. They are usually more focused on loads needing fast and intermittent response and are usually connected to the EPS as an adjunct to that purpose. They are either directly coupled to DC load systems or connected through an inverter.

- c) **Pumped hydroelectric energy.** Pumped hydro has a long operational life with only very little degradation over time and practically no cycle life limitations. It is ideally suited for continuous operation but because of the limited number of sites available, its connection to the EPS is limited to relatively few locations. The interconnection is usually direct using synchronous or induction machines.

Pumped hydro is generally a slow response application in comparison to applications for battery systems.

- d) **Compressed air.** The characteristics of compressed air are similar to that of pumped hydro. Depending on the size of the storage chamber, the CAES could be intermittent or continuous.
- e) **Adiabatic compressed air.** This form of compressed air application stores heat from compression of air and uses that stored heat during expansion. There is no combustion stage.
- f) **Flywheel.** The flywheel characteristics are similar in many ways to that of battery systems. The major exceptions are that flywheels are for intermittent use.
- g) **Thermal energy.** High-temperature examples are molten sodium and magnesium block thermal storage used coincident with concentrated solar power. Low-temperature examples include ice energy storage used for demand-side applications.
- h) **Superconducting magnetic energy.** SMES is used for grid stability and very short term (10-second) transient timeframe support applications.

4.3 ESS major components

An ESS comprises three primary components (Connolly [B11]):

- Storage medium. Can be mechanical (e.g., hydro, compressed air), chemical (e.g., batteries, hydrogen), or electrical (e.g., supercapacitors, SMES) storage.
- Power conversion system (PCS). Converts AC to DC and vice versa. PCSs are typically used for all storage devices except mechanical storage devices. These devices are usually directly connected to the power grid through an isolating and protective device.
- Balance of plant. Includes all the devices that are used to support the equipment, including power interconnection, communications, monitoring and control, and environmental control equipment.

Figure 1 shows the basic block diagram of storage, calls out some storage variables that may useful to a grid operator (e.g., SOC), and makes a distinction between those storage state variables and the power variables that would be monitored at the junction to the grid (e.g., VARS).

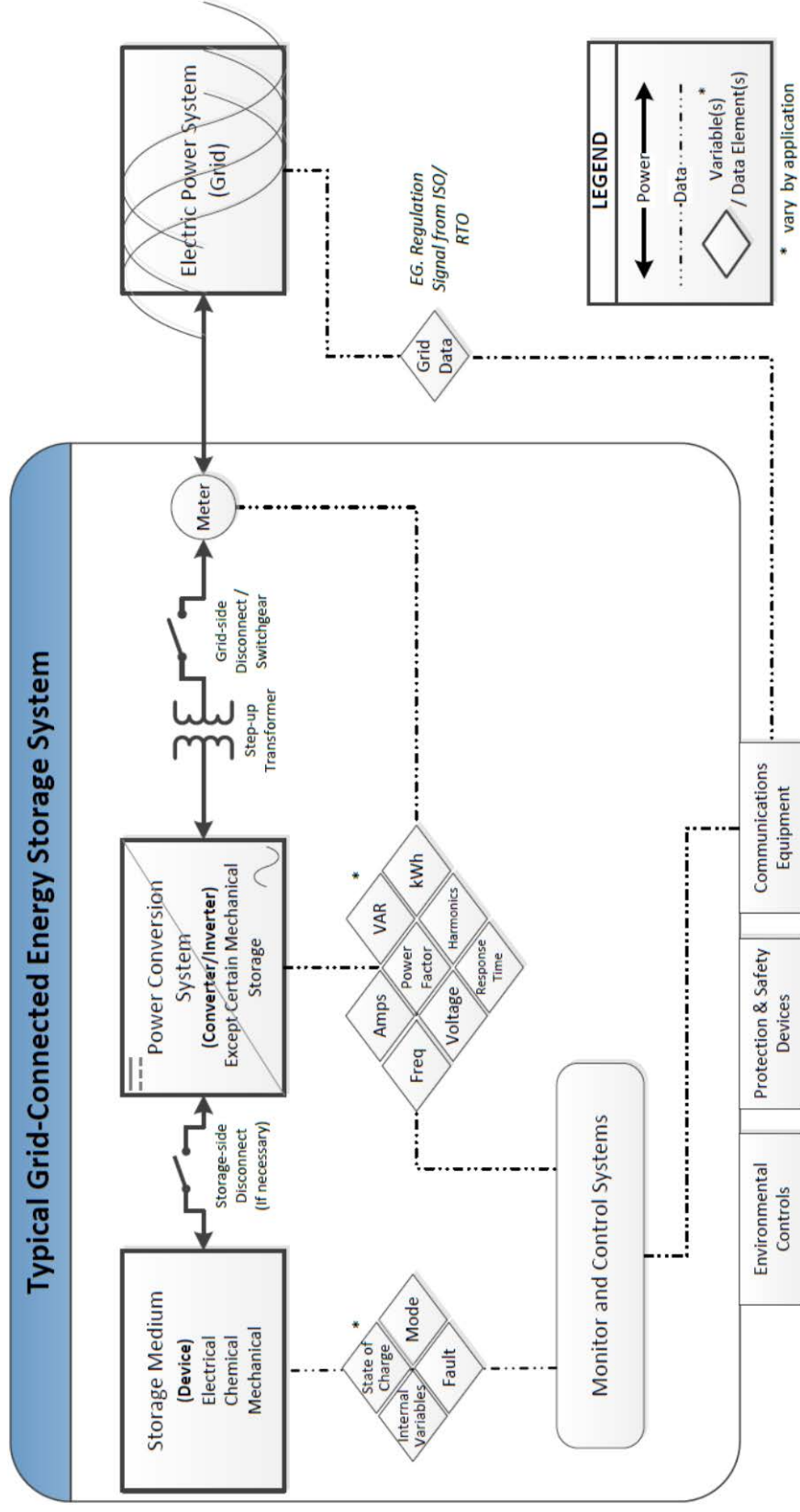


Figure 1—Storage system block diagram

4.4 ESS characteristics

4.4.1 Overview

This clause describes the fundamental power system-related characteristics of ESSs. Each type of ESS device has characteristics that often are considerably different from other ESS devices. This clause attempts to capture the different type of characteristics as they apply for application of ESS devices to the EPS. These characteristics are based on particular technologies and types of interconnections to the power system.

4.4.2 ESS unique characteristics

Each type of ESS has unique characteristics. These characteristics can be classified as fixed characteristics (ratings), interconnection characteristics, and interconnection technology.

ESS fixed characteristics include the following:

- Power capacity
- Energy storage capacity
- Operational life, i.e., years of useful life
- Cycle life, i.e., charge/discharge cycle
- Reliability/Availability of the ESS
- Roundtrip efficiency
- Intermittency, i.e., intermittent or continuous
- Response time
- SOC/DOD
- Charge-to-discharge ratio

ESS interconnection characteristics include the following:

- Grid connection location (domain)
- Interconnection technology, i.e., direct or inverter ESS interconnection

4.4.3 ESS fixed characteristics

4.4.3.1 Power capacity

Power capacity is the maximum instantaneous output that an ESS can provide, usually measured in kilowatts or megawatts.

4.4.3.2 Energy storage capacity

Energy storage capacity is the amount of electrical energy the ESS can store, usually measured in kilowatt-hours or megawatt-hours.

4.4.3.3 Operational life

Every ESS has a useful life ranging from years to decades depending on the technology and application of the device. This is typically a life based on age of equipment. However, an ESS may also be limited by cycle life.

Energy storage subsystems may have varying life durations, e.g., interconnection equipment versus energy storage medium. On battery-based systems, the battery is typically the limiting subsystem for defining ESS life.

4.4.3.4 Cycle life

Many ESSs have not only an operational life rating but also a cycle life rating. The cycle life rating may be based on the number of operations, which in turn may be based on charge and discharges. In many cases the depth of discharge may be an important factor in accumulating the cycle life degradation of an ESS. There is a cycle life relationship to DOD, or average utilization, that should be considered.

4.4.3.5 Reliability/Availability of the ESS

The reliability of the ESS, in EPSs, reflects the probability that the ESS is available when it is needed. This is based on the reliability of the components and the system as a whole. Manufacturers of ESSs and subsystems often measure reliability by mean time to failure.

ESSs may not be available because of the SOC, maintenance requirements, and operational requirements. The EPS operator may need to know the status of ESS availability in many applications.

4.4.3.6 Roundtrip efficiency

Roundtrip efficiency is the quantity of electric energy that can be recovered as a percentage of the electric energy used to charge and discharge the ESS. The roundtrip efficiency is based on total power in and total power out. It takes into account all uses of power (parasitic loads) in the charging and discharging of the ESS. The physical point of reference is generally at the point the ESS is integrated within an application. An ESS as balance of plant for photovoltaic (PV) and wind may have a different point of measurement for efficiency than a standalone ESS delivering output to the point of common coupling (PCC) with the power system.

An ESS's SOC often has an impact on the roundtrip efficiency. The efficiency measurement should start and end at a common SOC.

The specific sources of losses should be identified and incorporated in roundtrip efficiency investigations. These can include parasitic load, load-related losses, self-discharge, etc.

4.4.3.7 Response time

Response time is the length of time it takes the ESS to start releasing power. Each ESS technology has a characteristic response time. This response time usually reflects the limitations of the technology and the interconnection.

The differing technologies have a wide range of response times. For example, mechanical ESSs like CAES have response times ranging from seconds to minutes, and inverter interfaced advanced batteries have response times in milliseconds. Consideration should be given to the underlying aspects influencing overall

ESS response time, latency, ramp rate, startup up, delay, etc. Other consideration should be given to application. For example, the response time for automatic generator control (AGC)/dispatched and autonomous response applications can be very different.

IT-IAP and CT-IAP address control-related impacts ESS response time characteristics.

4.4.3.8 SOC/DOD

The state of charge (SOC) and depth of discharge (DOD) are important parameters for all forms of ESSs. These provide guidance for the amount of energy that remains in the ESS and the amount of energy needed to fully recharge the ESS. DOD is the percentage of the capacity that is discharged during a cycle.

4.4.3.9 Charge-to-discharge ratio

The charge-to-discharge ratio is the ratio of the time it takes to charge the device relative to the time it takes to discharge the device (i.e., if a device takes 5 times longer to charge than to discharge, it has a charge-to-discharge ratio of 5:1). This is an important factor for some ESSs since relatively fast charging times are needed in some applications.

Table 1 also presents key characteristics of ESSs, some of which expand on the list given above. For each of these characteristics, several columns of information are shown. This information includes typical

- Range of characteristics for most applications
- Relative range for power applications
- Relative range for energy applications
- Relative range for capacity applications

Power applications require high power output for relatively short periods of time (a few seconds to a few minutes). Technologies best suited for power applications include supercapacitors, SMES, flywheels, and some types of batteries.

Energy applications require relatively large amounts of energy for an extended period of time (minutes to hours). Examples of technologies include CAES, pumped hydro, thermal energy storage, and most battery types.

Capacity applications use ESSs to defer or to reduce the need for other equipment, e.g., reduce the need for generation or transmission and distribution (T&D) equipment. Capacity applications tend to require relatively limited amounts of energy discharge throughout the year.

ESSs can be used for multiple applications if the capabilities of technologies satisfy the requirements of applications. Technical and/or operational conflicts often limit the application of storage systems for multiple applications.

Table 1—Summary of energy storage technology characteristics

Characteristics	Technology capability ranges	Application ranges	Power application ranges	Energy application ranges	Capacity application ranges
Power/energy capabilities	Power capabilities (kW and MW) and energy capabilities (kWh and MWh) can vary from <1 kW to >100 MW and from <100 kWh to >100 MWh.	<1 kW to >100 MW <100 kWh to >100 MWh	High power output; relatively low energy requirements	Larger energy storage than storage used for power applications	Relatively limited amounts of energy
Discharge duration	The duration may be from seconds to tens of hours.	<10 seconds to >2 hours	Relatively short periods of time: a few seconds to a few minutes	Many minutes to hours	Can vary from minutes to tens of hours
Charge rate	For most cases, storage charges are at a rate similar to discharge rate. For some cases, storage may charge more rapidly or more slowly.	Charge at 10% discharge rate to charge at 10 times discharge rate	Relatively low charge rates to high charge rates; very application dependent	Low to medium charge rates	Low to medium charge rates
Discharge rate	For most cases, discharge rate is similar to charge rate. For some cases, discharge rate may be slower or faster than charge rate.	Discharge at 10% to 10 times charge rate	Relatively high discharge rates; to charge rates; very application dependent	Medium to low discharge rates	Medium to low discharge rates
Power density	Density is important when space is valuable or limited and/or if weight is important. It varies widely by technology.	Size of footprint limited; weight usually not a problem	Small to medium footprint	All sizes of footprints	All sizes of footprints
Energy density	Density is important when space is valuable or limited and/or if weight is important. It varies widely by technology.	Size of footprint limited; weight usually not a problem	Small to medium footprint	All sizes of footprints	All sizes of footprints
ESS roundtrip efficiency	Typical values are as follows: 60% to 75% for conventional electrochemical batteries 75% to 85% for advanced electrochemical batteries 73% to 80% for CAES 75% to 78% for pumped hydro 80% to 90% for flywheel ESS 95% for capacitors and SMES	Typically >70%	Medium to high efficiency	High efficiency	Medium to high efficiency

Characteristics	Technology capability ranges	Application ranges	Power application ranges	Energy application ranges	Capacity application ranges
Cycle life: lifetime discharges (degradation)	Shallow or deep discharge; most energy storage media degrade with use (i.e., during each charge-discharge cycle). Rate of degradation depends on the type of storage technology, operating conditions, and other variables.	<1000 to >30,000 cycles	Large cycle life	Small to large cycle life	Medium to large cycle life
DOD ratio	This ratio is the percentage of the battery capacity that is discharged during a cycle (batteries).	0% to 100%	10% to 90%	50% to 90%	10% to 90%
Response time	Most types of storage have a response time of several seconds or less. Electromechanical technologies have a slower response (e.g., CAES and pumped hydroelectric storage)	<10 seconds to hours	Seconds	Minutes to hours	Seconds to minutes
Ramp rate	Ramp rates vary widely by technology from seconds to hours to reach full rating.	<10 seconds to hours to reach full rating	Very rapid ramp rates	All ramp rates reasonable	Medium to rapid ramp rates
Energy retention	Retention time is reduced when energy losses occur or self-discharge (e.g., electrochemical batteries due to self-discharge); it is to be less important for storage that is used frequently.	Decay <1% per month to >10% per month	Full range of retention rates	High energy retention	Medium to high energy retention
Standby losses	Energy dissipation is a concern for mechanical medium (e.g., pumped hydroelectric storage may be lost to evaporation; CAES may lose energy due to air escaping from the reservoir).				
Modularity	Desired optimal levels and types of capacity and/or discharge duration (e.g., used to increase or decrease storage capacity, in response to changing conditions) can be achieved.	Extremely fine modularity to no modularity	Extremely fine modularity to no modularity	Extremely fine modularity to no modularity	Extremely fine modularity to no modularity
Power factor	Power factor capabilities should be in acceptable range.	No variability to highly variable	No variability to highly variable	No variability to highly variable	No variability to highly variable
Life (calendar life)	Calendar life can vary from years to decades depending on the technology.	Years to decades	Years to decades	Years to decades	Years to decades

Characteristics	Technology capability ranges	Application ranges	Power application ranges	Energy application ranges	Capacity application ranges
End of life disposition (possibilities)	Disposal and recycling is technology specific.	Easy to medium expense disposal and recycling	Easy to medium expense disposal and recycling	Easy to medium expense disposal and recycling	Easy to medium expense disposal and recycling
Reliability	Reliability is medium to high for most mature technologies.	Medium to high	High	Medium to high	High
Voltage stability	For most technologies, voltage can be very stable or made to vary to meet utility requirements.	Stable voltage with desired operational characteristics	Stable voltage with desired operational characteristics	Stable voltage with desired operational characteristics	Stable voltage with desired operational characteristics
Harmonics	Harmonics are produced by most technologies. Controls and filtering help to minimize harmonics.	No harmonics to IEEE 1547™ limits	No harmonics to IEEE 1547 limits	No harmonics to IEEE 1547 limits	No harmonics to IEEE 1547 limits

4.4.4 ESS interconnection characteristics

4.4.4.1 Grid connection location (domain)

The location (domain) at which the ESS is connected to the grid is relevant for determining the operation of the ESS. The location maps to the IEEE 2030 SGIRM domains. ESS connections can be at the distribution or transmission level as well as at the secondary distribution level, including customer-sited connections, if the interconnection permits transfer of services or operational impact to the power system. In general, the impact of the ESS on the power system is determined by the impedance between the ESS and power system as well as ESS voltage:

- The ESS can have a greater effect on the distribution system. In particular, the ESS can have a greater effect on power flow, reactive power flow, and voltage levels at the distribution system level.
- A distribution-system-connected ESS typically has less of an effect on the upstream transmission system.
- However, when the impedance between the transmission system and ESS is low, the ESS can affect the transmission system, especially if the ESS's capacity is large.

4.4.4.2 Interconnection technology

4.4.4.2.1 Overview

The interconnection technology identifies how the ESS is connected to the grid. The most common interconnections include the following:

- PCSs
- Directly connected rotating machine
- Directly connected DC networks

4.4.4.2.2 Power conversion systems (PCSs)

The PCS provides an interface between the EPS and the ESS. Generating equipment connected to the inverter could include DC equipment (e.g., batteries) and AC equipment (e.g., synchronous machines, induction machines). The controls on the inverter equipment provide a mechanism to control the kilovoltampere output for normal operation and to provide a quick means of dropping inverter output to zero amperes. During short-circuit events, the PCS short-circuit level is typically limited to 200% or less of full-load rating. If a step-up transformer connects the ESS to the power system, electrical parameters such as short-circuit levels, operational voltage characteristics, and harmonics may be affected.

The PCS high-speed controls provide an opportunity for fast action on the EPS.

Voltage-source and current-injection PCSs have unique capabilities. A major distinction is that voltage-source PCSs can operate independent of the grid, and current-injection PCSs cannot.

IEEE 1547 compliance is an important factor for interconnection. A major factor for consideration for grid-tied applications is that they may be subject to IEEE 1547 compliance (dependent on the project-specific interconnection authority's requirements). Off-grid applications may not require IEEE 1547 compliance.

4.4.4.2.3 Directly connected rotating machines

Both synchronous and induction machines used in ESSs are usually connected directly to the electrical power system at power system voltage and frequency. Usually the connection is via a disconnect device or circuit breaker.

Since a rotating machine is closely coupled with the EPS, changes in the EPS may have a large impact on the operation of the machine while changes in the operation of machine may have a large impact on the EPS. Impacts may occur due to the changes in power output, kVAR input or output, and short-circuit events. Short-circuit currents are typically a multiple of 6 to 12 times full-load current for synchronous machines.

The time constants of the machines and disconnection devices mean that these machines will typically take a longer time to react than inverters.

4.4.4.2.4 Directly connected DC networks

An ESS can be directly connected to a DC distribution network (i.e., server farm). These systems may be more efficient when distributing energy to electronic equipment. Applications include railroads, server farms, and office and home DC distribution. PV and ESS DC-DC interfaces are included in this classification.

4.5 Energy storage applications

4.5.1 Overview

Energy storage technologies provide a range of services to the electric grid and can be positioned around their power and energy relationship. Although electricity storage systems provide services similar to those of other generation devices, their benefits vary (examples of applications are discussed in 4.5 and Clause 9). Finally, energy storage devices can reduce emissions by aiding the transition to newer, cleaner technologies such as renewable resources and the hydrogen economy. However, the type of technology, which is suitable for some types of applications, is primarily defined by its potential power and storage capacities that can be obtained. The spectrum of applications is dependent on systems planners, requirements, capabilities and advances of energy storage technologies, and grid needs.

Energy storage applications differ from other distributed energy resource (DER) options, such as distributed generation or energy efficiency, and have unique characteristics such as the following:

- No typical operating profile or load shape that can be applied prospectively.
- Limited energy resources with a narrow band of dispatch and operation.
- Support participation in multiple wholesale markets.
- Ability to provide several benefits simultaneously to the wholesale power system, electric distribution companies, and customers.
- Deficient in monetizing multiple stakeholder benefits. (EPRI-1020676 [B16])

Due to the unique characteristics of the various technologies available, there are a wide range of applications for ESSs.

Table 2 was prepared by Sandia National Lab and presents an overview of different energy storage applications. It is based on Sandia's report SAND2010-0815 [B90].

Subclauses 4.5.2 through 4.5.17 elaborate on many of the ESS applications.

Table 2—ESS applications

Storage power			Discharge duration (hours, unless otherwise specified)		
Application	Low	High	Low	High	Note
Electric energy time-shift	1 MW	500 MW	2	8	Depends on energy price differential, storage efficiency, and storage variable operating cost.
Electric supply capacity	1 MW	500 MW	4	6	Peak demand hours.
Load following	1 MW	500 MW	2	4	Assume 1 hour of discharge duration provides approximately 2 hours of load following.
Area regulation	1 MW	40 MW	15 min	30 min	Based on demonstration of beacon flywheel.
Electric supply reserve capacity	1 MW	500 MW	1	2	Allow time for generation-based reserves to come on line.
Voltage support	1 MW (MVAR)	10 MW (MVAR)	15 min	1	Time needed for either system stabilization or orderly load shedding.
Transmission support	10 MW	100 MW	2 s	5 s	Per EPRI-1001834 [B14].
Transmission congestion relief	1 MW	100 MW	3	6	Peak demand hours. Low value is for “peaky” loads.
T&D upgrade deferral 50th percentile	250 kW	5 MW	3	6	Same as above.
T&D upgrade deferral 90th percentile	250 kW	2 MW	3	6	Same as above.
Time-of-use (TOU) energy cost management	1 kW	1 MW	4	6	Peak demand hours.
Demand charge management	50 kW	10 MW	5	11	Maximum daily demand charge hours, per utility tariff.
Electric service reliability	0.2 kW	10 MW	5 min	1	Time needed for either shorter duration outages or orderly load shutdown.
Electric service power quality	0.2 kW	10 MW	10 s	1 min	Time needed for events ride-through depends on the type of power quality challenges addressed.
Renewables energy time-shift	1 kW	500 MW	3	5	Depends on energy cost/price differential, storage efficiency, and variable operating cost.
Renewables capacity firming	1 kW	500 MW	2	4	Low and high values for renewable generation/peak load correlation (>6 h) of 85% and 50%.
Wind generation grid integration, short duration	0.2 kW	500 MW	10 s	15 min	For power quality (depends on type of challenge addressed) and wind intermittency.
Wind generation grid integration, long duration	0.2 kW	500 MW	1	6	Backup, time-shift, and congestion relief.

4.5.2 Electric energy time-shift

Electric energy time-shift involves purchasing inexpensive electric energy, available during periods when price is low, to charge the ESS plant so that the stored energy can be used or sold at a later time when the price is high.

4.5.3 Electric supply capacity

Depending on the circumstances in a given electric supply system, ESSs could be used to defer and/or to reduce the need to buy new central station generation capacity and/or to “rent” generation capacity in the wholesale electricity marketplace.

4.5.4 Load following

Load-following capacity is characterized by power output that changes as frequently as several times a minute. The output changes in response to the changing balance between electric supply (primarily generation) and end-user demand (load) within a specific region or area. ESSs can be used effectively for both load following up (as load increases) and for load following down (as load decreases), either by discharging or by charging.

4.5.5 Load leveling

Load leveling uses off-peak power to charge the ESS, which can then be discharged during peak demand. This price can vary significantly over a 24-hour period due to the relative change in electricity demand. Therefore, ESS can be charged during these off-peak hours at night and then used to generate electricity when it is the most expensive, during short peak production periods in the evening. Not only does this enable the ESS to maximize its profits, but it can also reduce the cost of operating the system.

4.5.6 Regulation (area frequency regulation)

Regulation involves managing interchange flows with other control areas to match closely the scheduled interchange flows and moment-to-moment variations in demand within the control area. In more basic terms, regulation is used to reconcile momentary differences between supply and demand. In other words, at any given moment, the amount of electric supply capacity that is operating may exceed, or be less than, load. Regulation is used for limiting that difference.

4.5.7 Electric supply reserve capacity

Prudent operation of an electric grid includes use of electric supply reserve capacity (reserve capacity) that can be called on when some portion of the normal electric supply resources become unavailable unexpectedly. At a minimum, reserves should be at least as large as the single largest resource (e.g., the single largest generation unit) serving the system. Note that an ESS can provide two times its capacity as reserve capacity when the ESS is charging because the ESS can simultaneously stop charging and start discharging. The two-times-capacity-for-reserve-capacity practice assumes that the ESS suspends charging as a load and starts discharging as a resource.

4.5.8 Voltage support

An important technical challenge for electric grid system operators is to maintain necessary voltage levels with the required stability. In most cases, meeting that challenge requires management of reactance. Reactance occurs because equipment that generates, transmits, or uses electricity has characteristics like those of inductors and capacitors in an electric circuit.

To manage reactance at the grid system level, grid system operators rely on an ancillary service called *voltage support*. The purpose of voltage support is to offset reactive effects so that grid system voltage can be maintained.

4.5.9 Transmission and distribution (T&D) support

An ESS used for transmission support improves the T&D system performance by compensating for electrical anomalies and disturbances such as voltage sag, unstable voltage, and sub-synchronous resonance. The result is a more stable system with improved performance (throughput). Benefits from transmission support are highly situation and site specific.

Stabilization of the system is also important after a fault occurs on the network. These faults induce phase angle, voltage, and frequency irregularities that are corrected by the ESS. Stabilization can be achieved by absorbing or delivering power to generators when needed to keep them turning at the same speed. At the regional transmission scale, this includes inter-area synchronization support.

4.5.10 Transmission congestion relief

In many areas, transmission capacity additions are not keeping pace with the growth in peak electric demand. Consequently, transmission systems are becoming congested during periods of peak demand, and this congestion drives the need and cost for more transmission capacity and increased transmission access charges.

ESSs could be used to avoid congestion-related costs and charges, especially if the charges become onerous due to significant transmission system congestion. In this application, ESSs would be installed at locations that are electrically downstream from the congested portion of the transmission system. Energy would be stored when there is no transmission congestion, and it would be discharged (during peak demand periods) to reduce transmission capacity requirements.

4.5.11 T&D upgrade deferral

T&D upgrade deferral involves delaying—and in some cases avoiding entirely—utility investments in transmission and/or distribution system upgrades, using relatively small amounts of storage. Consider a T&D system whose peak electric loading is approaching the system's load-carrying capacity (design rating). In some cases, installing a small amount of energy storage downstream from the nearly overloaded T&D node will defer the need for a T&D upgrade.

4.5.12 Time-of-use (TOU) energy cost management

TOU energy cost management involves ESSs used by energy end users (utility customers) to reduce their overall costs for electricity. Customers charge the ESSs during off-peak times when the electric energy price is low and then discharge the energy during times when on-peak TOU energy prices apply.

4.5.13 Demand charge management

ESSs could be used by electricity end users (utility customers) to reduce the overall costs for electric service by reducing demand charges, that is, by reducing power draw during specified periods, normally the utility's peak demand periods and/or peak usage by the end user. Demand charges are not typical for residential or very small commercial end users.

4.5.14 Electric service reliability

The electric service reliability application entails using ESSs to provide highly reliable electric service. For a complete power outage lasting more than a few seconds, an ESS capable of intentional islanding could provide energy to serve load during system power outages of extended duration, to complete an orderly shutdown of processes, and/or to transfer to on-site generation resources.

4.5.15 Renewables energy time-shift

Many renewable energy generation resources produce a significant portion of electric energy when that energy has a low financial value (e.g., at night, on weekends, and during holidays)—periods generally referred to as *off-peak times*. ESSs used in conjunction with renewable energy generation could be charged using low-value energy from the renewable energy generation so that energy may be used to offset other purchases or sold when it is more valuable. Or, the energy can be time-shifted-based to correlate delivery of the renewable generation to a time when an otherwise congested grid has the available capacity to deliver the renewable energy to load.

4.5.16 Renewables capacity firming

Renewables capacity firming applies to circumstances involving renewable energy-fueled generation whose output is intermittent. The objective is to use ESSs to “fill in” so that the combined output from renewable energy generation plus storage is somewhat to very constant and is dispatchable.

4.5.17 Emergency backup

A type of uninterruptable power supply (UPS) with longer duration energy storage capacities, the ESS must be able to provide power while generation is cut altogether. Power ratings of 1 MW for durations up to one day are most common. This functional capability can also be applied for provision of black start service application for post-outage recovery of power systems.

5. Power systems interoperability (the PS-IAP)

5.1 Introduction

IEEE Std 2030-2011 provides interoperability guidelines for the total power system. This clause presents the SGIRM from a power systems interoperability architecture perspective (PS-IAP), which provides a view of the EPS that “emphasizes the production, delivery, and consumption of electrical energy.” The PS-IAP does not specify the conduits or paths where energy will flow in the EPS. These are addressed in other standards. Rather, the PS-IAP addresses the logical flow of power information between defined domains and entities through interfaces that enable intelligent control and optimization of interoperable power system components.

Each power system interface will have SGIRM data characteristics. These data characteristics will need to be determined for each identified interface. See Table 3 for typical interface parameters for each PS-IAP customer interface.

ESS devices are identified in the PS-IAP as being located in the following entities shown in Figure 2: Bulk Storage (bulk generation and transmission system storage devices), Distribution Distributed Energy Resources, and Customer Distributed Energy Resources.

Relevant PS-IAP interfaces for ESSs include the following:

- For customer-based ESSs:
 - PS19 – to Distribution Distributed Energy Resources
 - PS61 – to Customer Substation (Large Customers)
 - PS62 – to Customer Point of Interface
 - PS63 – to AC Loads
 - PS64 – to DC Loads
 - PS69 – to other Customer Distributed Energy Resources (ESSs and energy producers)
- For distribution-system-based ESSs:
 - PS11 – to Markets
 - PS12 – to Customer Point(s) of Interface
 - PS14 – to Distribution Operation and Control
 - PS15 – to Distribution Substation
 - PS16 – to Distribution Sensors and Measurement Devices
 - PS17 – to Distribution Protection and Control Devices
 - PS19 – to Customer Distributed Energy Resources
 - PS31 – to other Distributed Energy Resources (ESSs and energy producers)
 - PS70 – to Transmission Operation and Control
 - PS71 – to Generation Operation and Control
 - PS79 – to Electric Service Providers
- For transmission-system-based (Bulk Storage) ESSs:
 - PS27 – to Transmission Substation
 - PS35 – to Transmission Sensor and Measurement Devices
 - PS42 – to Bulk Generation
 - PS43 – to Transmission Operation and Control
 - PS44 – to Generation Substation
 - PS51 – to Markets
 - PS55 – to Generation Operation and Control
 - PS73 – to Electric Service Provider

A modified version of the IEEE 2030 PS-IAP is shown in Figure 2 with energy-storage-specific entities highlighted for emphasis. All interfaces emanating from the energy storage entities (Bulk Storage, Transmission Substation, Distribution Distributed Energy Resources, and Customer Distributed Energy Resources) are relevant to the SGIRM process. This represents a subset of the total interfaces included in the original PS-IAP. The PS-IAP shown does not represent the physical flow of power, but rather represents the entities and interfaces involved in the control of power, as IEEE Std 2030-2011 addresses the interoperability of the ESSs with the EPS.

In applying the SGIRM process, the user must distinguish between control interactions internal to an ESS and the interactions that are dependent on factors outside of the system. The SGIRM process does not address the internal controls of the ESS. Rather, it addresses the interactions of the ESS with the EPS.

One example of a SGIRM-relevant factor is the ESS location relevant to generation, substations, and customers. From a power systems perspective, the physical location will have significant influence on the interfaces, even for similar applications. For example, location will influence the domains and entities

identified in the SGIRM process and the resulting interfaces for an application. This can be the case for ESS projects performing the same application, for example, renewable energy integration, but installed on different parts of the EPS.

The upper arrows in Figure 3 illustrate the traditional physical flow of power between domains. In this model, power flows from Bulk Generation, goes through the Transmission Grid, steps down to the Distribution System, and finally is distributed to the Customer. The lower double arrows show the SGIRM with bidirectional power flow enabled by ESSs, smart inverters, and community generation.

5.2 Unique aspects of ESSs and the Smart Grid

The interaction of ESSs with the EPS introduces aspects that are unique to the application. Depending on the application, ESSs are required to both provide and absorb power from the EPS. They can act as a source or sink for both power (short term) and energy (longer duration). They can act as a source or sink for both real power (e.g., frequency regulation) and reactive power (e.g., voltage support).

ESS aspects relevant to the Smart Grid include the following:

- Energy capacity available (ECA): Relevant for system operators in determining availability of assets/resources.
- Operational state: Charge, discharge, trickle charge, standby, error condition, shut down.
- Real-time discharge power limits available: Depending on the technology and manufacturer, power rating may decrease as a function of SOC, temperature, or other variables.
- Real-time charge power limits available: Similar to discharge limits defined above.
- Power flow direction (real and reactive power): ESSs introduce bidirectional power flow as a data point. Compared to variable energy resources such as wind and solar, this data point can be considered unique as the process of charging and discharging, and thus the resulting power flow direction, is an intentional and planned action. Variable energy resources often introduce bidirectional power flows simply due to the resource's variability and inability to perfectly forecast.
- Ramping capability: Represents time in which an ESS can be ramped up or down, given in kilowatts or kVAR per unit of time (seconds, minutes, hours).

Using the SGIRM process does simplify the description of the total ESS and may result in more efficient execution of a system design. The use of domains is a powerful tool to organize critical project information. The set of interfaces in IEEE Std 2030-2011 does not include all interfaces needed for ESS projects. There are also additional data unique to ESSs that will be exchanged between entities (e.g., SOC, equivalent cycles). One challenge for characterizing an ESS using the SGIRM process is that there is no common framework for the industry data that will be used to characterize the IAP requirements. For example, each utility or independent system operator/regional transmission organization (ISO/RTO) may present and organize its information and communications technology (ICT) requirements data differently.

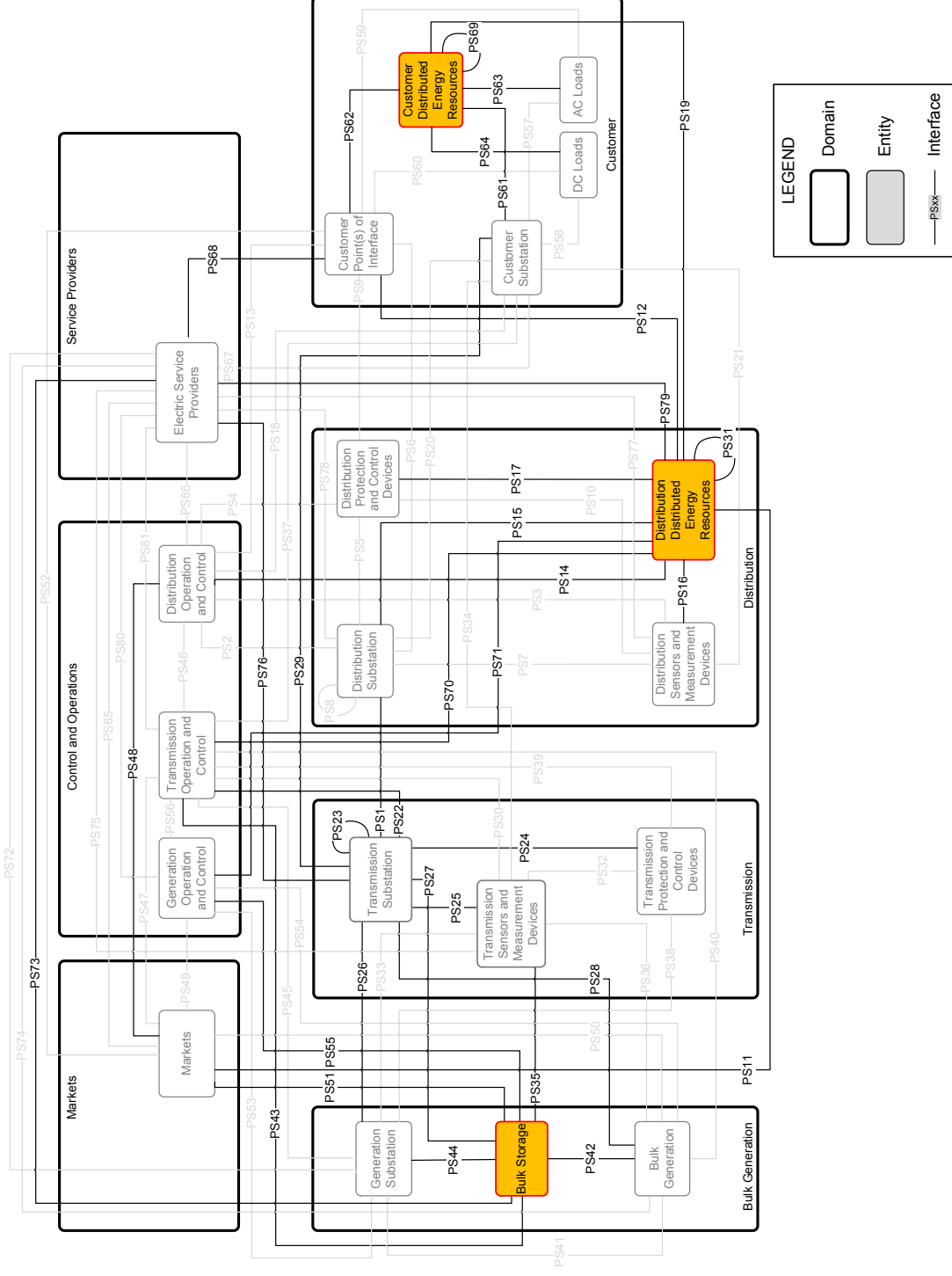


Figure 2—PS-IAP modified to highlight pertinent ESS entities and interfaces

Power Flow Between Domains: Traditional / Distributed Generation

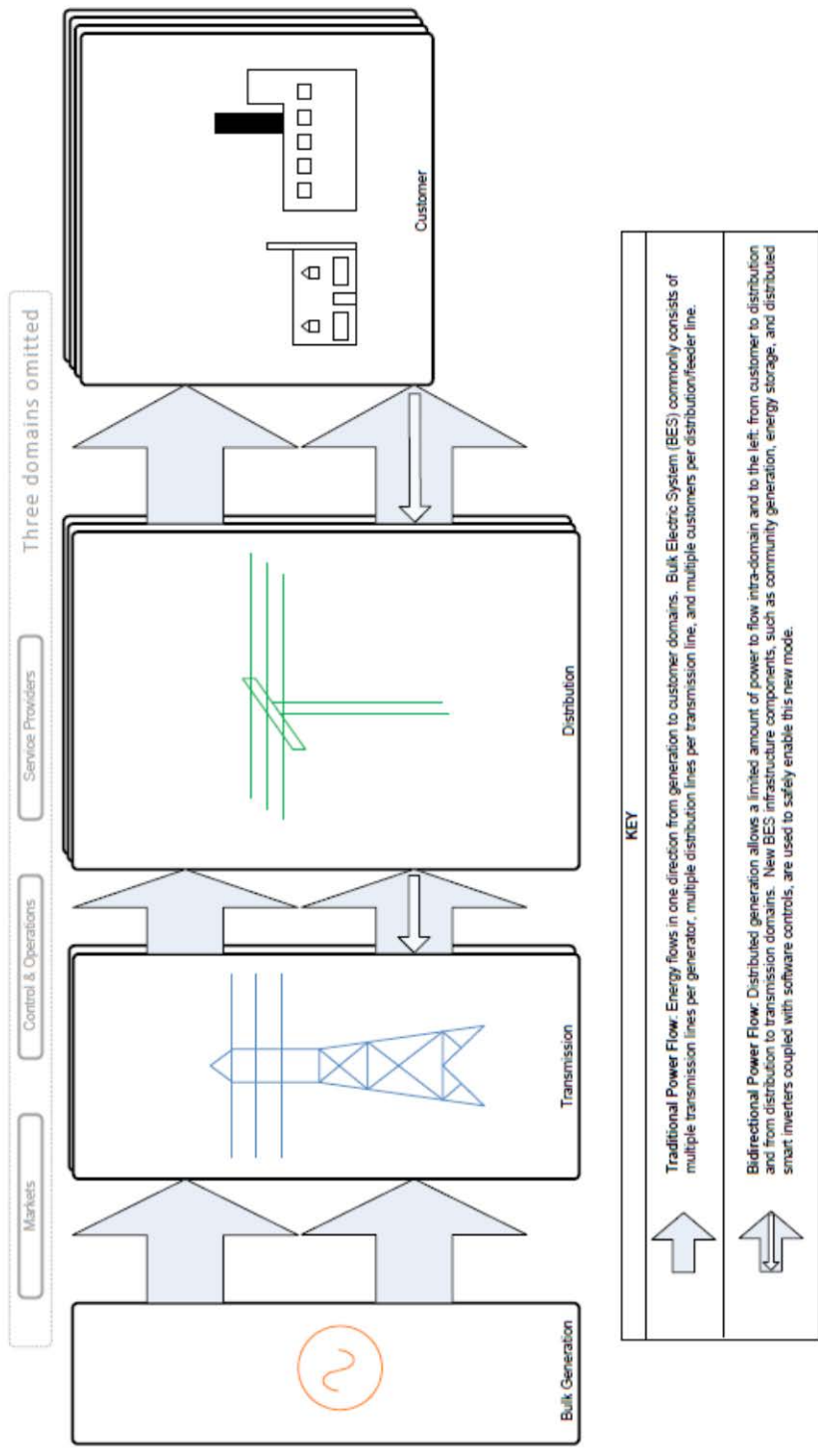


Figure 3—Representation of traditional and bidirectional power flow between bulk generation, transmission, distribution, and customers domains

5.3 Technology aspects

5.3.1 Reliability and availability

ESSs introduce a new measurable metric related to reliability and availability through the energy capacity available (ECA). In many applications, ESSs must be able to provide a metric that identifies the amount of power that can be provided and the duration it can be provided.

5.3.2 Capacity factor

The capacity factor of an ESS is dependent largely on its application. For example, a frequency regulation application will have a different capacity factor than a peak shaving or load shifting application. An energy-intensive application will vary greatly from a power-intensive application. In addition, when used for renewable energy integration, the ESS can greatly increase the capacity factor of a wind or solar plant, in which case the capacity factor applies more to the integrated project rather than the ESS as a standalone entity.

5.3.3 Inverters and VAR support

Power electronics such as bidirectional power converters interface a DC system to the AC grid. Depending on the application, a majority of the pertinent data for an ESS can be provided by the power inverter. The inverters also present a control interface for active and reactive power control, which is a critical component to ESS integration with the EPS. VAR support and controllability are common utility requirements for voltage control.

5.3.4 Evolving technology

New technologies may present new methods of providing or absorbing power from the EPS. As new technologies emerge and existing technologies evolve, it will be critical to understand the data that are relevant to the control of power flow.

5.3.5 Evolving interconnection standards

Interconnection standards will define the physical requirements for an ESS to interconnect to a utility. This may include the requirements for a lockable disconnect switch, generator step-up transformer configuration, effective grounding, and relay protection.

5.4 ESS integration

Table 3 provides an example of the data characteristics used for fast-acting and slow-acting classifications of storage technologies. Fast-acting technologies can be thought of as technologies that can provide fast changes to the electrical power system due to changes in state of the storage facilities. Examples of fast-acting technologies include battery, supercapacitors, flywheel, and SMES. Examples of slow-acting technologies include pumped hydro, compressed air, and thermal. The speed of operation for the slow-acting storage technologies is not quite as critical for the general functionality of the storage technology.

Table 3 displays the data use categories that should be considered when integrating the ESS with the IAPs. This table is based on Table 5-1 in IEEE Std 2030-2011. The table displays example data use categories for monitoring, control, and protection. The data use categories are just a few of the many data use categories that may be encountered in an actual application.

Table 3—Example data categories for ESSs

Data use category		Example classification/value range			
		Monitoring	Control fast	Control slow	Protection
Reach		Miles	Miles	Miles	Miles
Information transfer time		Between 3 ms and 10 s	Between 3 ms and 10 s	Between 10 s and minutes	<3 ms
	Data occurrence interval	Seconds	Minutes to hours	Minutes to hours	Minutes to hours
	Method of broadcast	Unicast	Unicast	Unicast	Unicast
	Priority	Low	High	High	High
Latency		High (≥ 160 ms)	Low (< 16 ms)	High (≥ 160 ms)	Low-Low (< 3 ms)
Synchronicity		No	No	No	No
Information reliability		Informative	Critical	Critical	Critical
	Availability (information reliability)	Low (limited impact)	Medium (serious impact)	Medium (serious impact)	Medium (serious impact) to high (severe or catastrophic impact)
	Level of assurance	Low	Medium	Medium	High
	High-altitude electromagnetic pulse (HEMP); Intentional electromagnetic interference (IEMI)	Hardened, No	Hardened, No	Hardened, No	Hardened, No
Data volume		Kilobytes	Bytes	Bytes	Bytes
Security		Medium (serious impact)	Medium (serious impact)	Medium (serious impact)	Medium (serious impact) to high (severe or catastrophic impact)
	Confidentiality	Medium (serious impact)	Low (limited impact)	Low (limited impact)	Low (limited impact)
	Integrity	Medium (serious impact)	Medium (serious impact)	Medium (serious impact)	Medium (serious impact) to high (severe or catastrophic impact)
	Availability (security)	Medium (serious impact)	Medium (serious impact)	Medium (serious impact)	Medium (serious impact) to high (severe or catastrophic impact)

The three data use categories shown in this example are monitoring, control, and protection. Each of these categories has its own overall characteristics that are important in determining the correct entries for the rest of the table.

Monitoring is typically done with an update rate in the seconds. Only in special cases would a faster update rate be needed. Monitoring information has a history of not always being available due to the remote

locations of monitoring devices. This has led to communication problems and delays in replacing failed sensors. However, the confidentiality of the data is important for monitoring ESSs because this data can be operational and competitive.

Control typically needs to be done quickly and with high reliability. For slow-acting ESS technologies, control that reacts in seconds is typically good enough. For fast-acting ESS technologies, faster controls may be needed for some applications. The actions resulting from control data (or lack of appropriate control data) can have serious impacts depending on the actual application and implementation of the ESSs. The results of a control signal not communicating properly in a timely manner can have a serious impact and cause equipment damage and power system problems.

Protection always needs to be communicated as close to instantaneously with as close to 100% reliability and availability as possible. This is due to the large amount of electrical energy available from the ESSs and EPS that can have a large effect on the EPS and associated equipment. Damage to equipment, loss of portions of the EPS, and the potential for personnel injury or death can result from the protection system misoperating by not communicating protection data in a timely and accurate way.

Based on these data use categories, the classification/value range for each of the data characteristics can be determined.

The reach or distance that the ESS needs to communicate is typically in the range of miles for most ESS applications in a DER setting. There may be some applications where the distances required for communications are shorter (facility application) or longer (transmission application).

The information transfer characteristic has sub-characteristics that are important for determining the information transfer characteristic. These sub-characteristics are the data occurrence interval, method of broadcast, and priority of the information transfer.

The information transfer time for most monitoring activities and control of fast-acting ESSs is typically somewhere between 3 ms and 10 s. The information transfer time is typical of central control centers of EPSs. The information transfer time for control of slow-acting ESSs can be longer than that of fast-acting ESSs. Protection of all ESS technologies always requires the fastest transfer time available. Less than 3 ms is a typical value that is used.

Data occurrence varies widely by the data use category. Monitoring occurs on a regular basis usually with intervals expressed in seconds or fractions of seconds. Data occurrence for control and protection of ESSs usually happens on an infrequent basis usually ranging from minutes to a large number of hours.

Method of broadcast is almost always unicast for communications with ESSs under any data use category.

The priority of information transfer is typically low for ESS monitoring and high for ESS control and protection.

Latency is only critical for the protection data use category. Low-Low latency (<3 ms) is required for best protection by the protection systems. High latency is sufficient for the other data use categories for all classifications of ESSs.

Synchronicity is not typically required for any ESS at this time.

Information reliability characteristics include sub-characteristics of availability, level of assurance, and HEMP/IEMI hardening requirements. Information reliability is critical for ESS control and protection due to the often serious to critical effect ESSs can have on the operation of the EPS if they are not controlled or protected appropriately. Information reliability for monitoring is usually less critical.

The availability (information reliability) is low for monitoring because the impact of not receiving that data is limited. However, for control, the impact of not receiving data can be serious as it may cause equipment damage and potential for personnel safety issues. Information must be highly available for ESS protection because the failure of a protection system to work at the desired timing can be serious to catastrophic and result in equipment damage, electrical system failure, and personnel injury or loss of life.

The level of assurance should match up with availability for the ESS data use categories identified. Therefore, the ratings are low for monitoring, medium for control, and high for protection for all data use categories.

Only in the most critical applications would the ESS equipment and ICT equipment be hardened for HEMP and IEMI.

Security characteristics have sub-characteristics of confidentiality, integrity, and availability (security). From an overall standpoint, a lapse of security may result in a serious impact and in some cases a severe or catastrophic impact. This will always be the case because even some of the smallest ESSs can affect the EPS in such a way to cause damage to equipment. The integrity and availability sub-characteristics reflect this need for medium to high security characteristics.

The confidentiality of the monitoring data is medium. The exposure of this data can provide operational and competitive data that should be exposed only to a limited set of viewers. However, the confidentiality of the control and protection data is not that critical (but should not be purposely exposed to the public) since the value of the information is relatively limited as it is just bytes of information.

The monitoring, control, and protection data use categories used in this example are a limited set of the many types of data use categories that should be considered in the application of ESSs. For example, protection systems often have archival information and the ability to change the characteristics of the protection system through data transfer. These data use categories would have different data characteristics from those displayed under protection in the example.

6. Communications technology interoperability (the CT-IAP)

6.1 Introduction

This clause presents the SGIRM from a communications technology interoperability architecture perspective (CT-IAP), which provides more details about the communications technologies associated with the particular aspects of energy storage. In the application subclauses following this introduction, the SGIRM is applied, and the requirements for individual communication paths are outlined. This subclause describes how these requirements should be evaluated for the purposes of selecting a specific communications technology for a specific communication path. Telecommunications technology evolves quickly, and at this juncture several different technologies are available and can satisfy the requirements of the chosen applications. In the future, those technologies will be further enhanced and will allow for even more applications and better performance.

These requirements take into account the specific applications defined in the subsequent subclauses. As different applications may have different requirements for the same communications path, the most stringent requirement for that path shall be the selected one. The intent of this approach is to make sure that a single telecommunications infrastructure can be used by several different applications.

The CT-IAP for the power system interfaces are shown in Figure 4 and described in the subsequent subclauses.

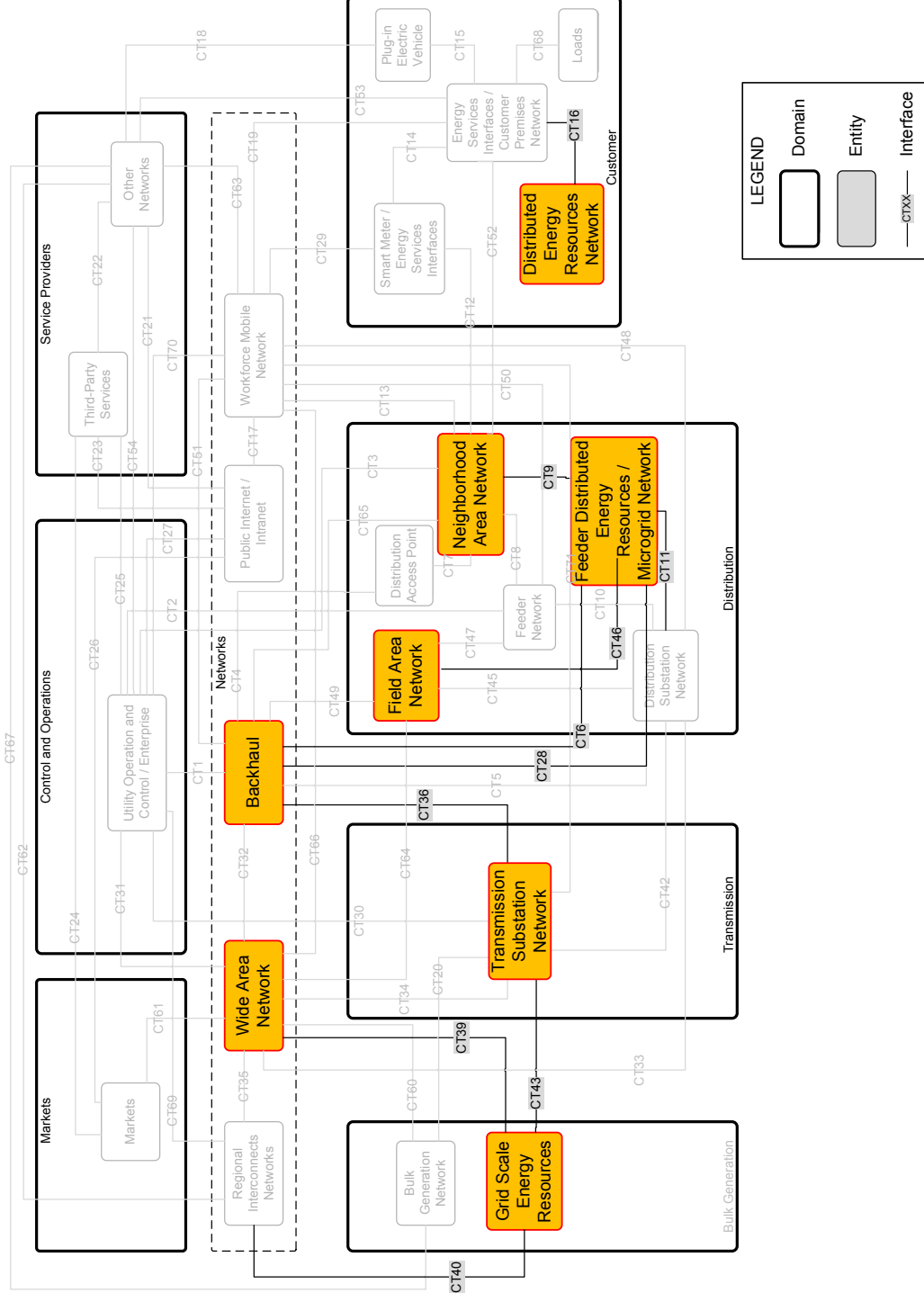


Figure 4—CT-IAP modified to highlight pertinent ESS entities and interfaces