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Information technology — Sensor networks: Sensor network and its interfaces for smart grid system

Technologies de l'information — Réseaux de capteurs: Réseau de capteurs et ses interfaces pour un réseau électrique intelligent

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword — Supplementary information.

The committee responsible for this document is ISO/IEC JTC 1, *Information technology*.

Introduction

Transitioning the existing Power Grid to Smart Grid is a challenging task over a lengthy period, and all power needs should be satisfied during the period that this transition takes place. This transition will likely affect a broad set of stakeholders, e.g., individuals and businesses, and the stakeholders should properly be informed of the changes taking place and to come. Smart Grid is a large, complex system which operates at various operation modes ranging from fully automated to handle time critical and instantaneous responses (sensing and actuation) to human-in-the-loop for response and interaction (command and control). The transition to Smart Grid will be a gradual migration with the coexistence of diverse technologies, systems, and equipment from the past, today, and the future. To ensure the interoperability of the diverse technologies, systems, and equipment without compromising the performance (e.g., reliability, safety, cyber security, etc.), Smart Grid will require effective standards. These standards should not be static, but evolve over the transitional time period. These standards should maintain their integrity to support all technologies, systems, and equipment that are and will be involved during the transition.

This International Standard does not address standards for Smart Grid (e.g., electrical power system). This International Standard addresses sensor network and its interfaces to Smart Grid, e.g., various applications of the sensor network to Smart Grid. The sensor network and its processing algorithms provide intelligent services to the user, e.g., operators in various domains of Smart Grid including power utilities and consumers.

The sensor network plays many critical roles in all areas of Smart Grid because: (1) sensors with processing capability are smart devices and sensor nodes can include actuators, (2) sensor data/information are transmitted via wired/wireless communication systems and data links, and sensor nodes typically include communication devices that formulate protocols for the data/information streams, and (3) sensors monitor and measure their designated environments, collect data from the environments, analyse the data if they have processing capability, formats the data, and stores them at their local memory devices; thus, within sensor network, some level of data management is necessary.

Sensor data from Smart Grid in many cases should be secured and cyber security should be in place to prevent from unauthorized access of sensors and related devices on the sensor network. Certain types of sensor data, e.g., customer data and information, should be protected from the information security and privacy point of view.

The sensor network can provide various applications and services during the transitional road to Smart Grid. The sensor network is expected to become one of the essential and critical players in migrating the legacy power grid system to Smart Grid. This includes adding and integrating sensor-related and network-related technologies with power systems and devices from the past, today, and the future. From the sensor network point of view, the information technology (IT) network is considered as the information highway or IT backbone providing the pathways for Smart Grid data and information. Therefore, a study of existing sensor network and power system related standards is necessary to leverage these standards for the sensor network standard development unique for Smart Grid, smart grid services and applications during the transitional period and afterward.

Information technology — Sensor networks: Sensor network and its interfaces for smart grid system

1 Scope

This International Standard is for sensor networks in order to support smart grid technologies for power generation, distribution, networks, energy storage, load efficiency, control and communications, and associated environmental challenges. This International Standard characterizes the requirements for sensor networks to support the aforementioned applications and challenges. Data from sensors in smart grid systems is collected, transmitted, published, and acted upon to ensure efficient coordination of the various systems and subsystems. The intelligence derived through the sensor networks supports synchronization, monitoring and responding, command and control, data/information processing, security, information routing, and human-grid display/graphical interfaces.

This International standard specifies

— interfaces between the sensor networks and other networks for smart grid system applications,

— sensor network architecture to support smart grid systems,

— interface between sensor networks with smart grid systems, and

— sensor network based emerging applications and services to support smart grid systems.

2 Normative References

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 29182-1, *Information technology — Sensor networks: Sensor Network Reference Architecture (SNRA) — Part 1: General overview and requirements*

ISO/IEC 29182-2, *Information technology — Sensor networks: Sensor Network Reference Architecture (SNRA) — Part 2: Vocabulary and terminology*

ISO/IEC 29182-3, *Information technology — Sensor networks: Sensor Network Reference Architecture (SNRA) — Part 3: Reference architecture views*

ISO/IEC 29182-4, *Information technology — Sensor networks: Sensor Network Reference Architecture (SNRA) — Part 4: Entity models*

ISO/IEC 29182-5, *Information technology — Sensor networks: Sensor Network Reference Architecture (SNRA) — Part 5: Interface definitions*

IEEE 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*

3 Terms and Definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 29182-2 apply.

4 Symbols (and abbreviated terms)

AMI	Advanced Metering Infrastructure
BAN	Business area Network
CB	Circuit Breaker
CMOS	Complementary Metal–Oxide–Semiconductor
CNT	Carbon Nanotube
CPN	Customer premises network
CT-IAP	Communication Technology Interoperability Architecture Perspective
DSM	Demand-Side Management
DER	Distributed Energy Resource
EPS	Electric Power System
ESI	Energy Services Interfaces
FAN	Field area networks
GIS	Gas Insulated Switchgear
GPS	Global Positioning System
HAN	Home Area Network
HV	High Voltage
IAN	Industrial Area Network
IAP	Interoperability Architecture Perspective
IED	Intelligent Electric Device
IEEE	Institute of Electrical and Electronics Engineers
IS	International Standards
ISP	Internet Service Providers
IT-IAP	Information Technology Interoperability Architecture Perspective
LAN	Local Area Network
LTC	On-Load Tap-Changer
LV	Low Voltage
MV	Medium Voltage
OHTL	Overhead Transmission Line
PD	Partial Discharge
PEV	Plug-in Electric Vehicle

PMU	Phase Measurement Unit
PS#	Power System # (Interface Designation in PS-IAP)
PS-IAP	Power System Interoperability Architecture Perspective
RH	Relative Humidity
RF	Radio Frequency
RTO	Regional Transmission Organization
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
SDOs	Standard Developing Organizations
SG	Smart Grid
SGRM	Smart Grid Reference Model
SGRA	Smart Grid Reference Architecture
SN&I	Sensor Network and its Interface
SNRA	Sensor Network Reference Architecture
UGC	Underground Cables
UHF	Ultra High Frequency
UTP	Unshielded Twisted Pair
UV	Ultraviolet
WAN	Wide Area Network

5 Smart Grid Reference Models and Architectures

5.1 General

Smart Grid (SG) reference models and architectures are being developed by various standard developing organizations (SDOs) and industrial consortia/organizations. Sensor network and its interfaces standard for SG need to be consistent with the reference model and architecture to be useful and realizable. The sensor network and its interfaces for smart grid system standards should be applicable, adoptable, and adaptable to varying architectural differences among smart grid architectures to be effective. For this reason, a number of available SG Reference Models and Architectures (SGRMs and SGRAs) are referenced, and these SG reference models and architectures are included in Annex A of this standard document. Understanding and leveraging the existing SGRMs and SGRAs is crucial for developing the sensor network and its interfaces for smart grid system for compatibility and acceptance.

5.2 Smart Grid Architectures Adopted for Developing Sensor Network & its Interfaces for Smart Grid System

For developing the sensor network and its interfaces for smart grid system, IEEE 2030 Power System Interoperability Architecture Perspective (PS-IAP) is adopted because this architecture perspective provides the entities/devices that are physical or logical in the power system for a typical implementation. Additionally, from the sensor network point of view, the sensors in sensor networks interface with the power systems in the seven SG domains, namely, Operations, Service Providers, Customer, Distribution, Transmission, Bulk Generation, and Market domains (See Annex A.2, NIST Smart Grid Conceptual Model).

Networking and communication allowing sensors and sensor networks within in each domain and also between the domains is described in IEEE 2030 Communication Technology Interoperability Architecture Perspective (CT-IAP), and this architecture perspective is adopted for any discussion of sensor networks and data/information communication routing.

From the data/information contents perspective, IEEE 2030 Information Technology Interoperability Architecture Perspective (IT-IAP) is adopted for this standard work to describe the data/information that will be passed between the entities in the same domain and also between the domains.

IEEE 2030 PS-IAP is mainly used for developing this standard because sensors are physically attached to power systems (e.g., physical interfaces), and these sensor nodes form a sensor network or sensor networks in a domain communicating data/information from one domain to another domain. The communication perspective is described in the CT-IAP. From data/information stand point, the IT-IAP is utilized to describe the data/information contents and context mapping to the physical interfaces in the PS-IAP.

5.3 IEEE 2030 Smart Grid Interoperability Guideline Standard

IEEE 2030 developed Smart Grid Interoperability Guideline Standards. In this standard, smart grid's interoperability is categorized by Power System Technology, Communications Technology, and Information Technology. In each technology, top-level reference architecture is developed, which is called Interoperability Architecture Perspective (IAP).

IEEE 2030 Power System IAP (PS-IAP) represents a view of the Electric Power System (EPS) that not only represents Smart Grid but also emphasizes the production, delivery, and consumption of electrical energy. The CT-IAP emphasizes the communication connectivity among systems, devices, and applications in the smart grid. The IT-IAP emphasizes the control of processes and data management flow in the smart grid.

The domains in IEEE 2030 are the same as those in the NIST Conceptual Model. The description of each domain in IEEE 2030 is comprehensive. Table 1 shows the description of each domain in the IEEE 2030 Interoperability Guideline standard document.

Table 1 — IEEE 2030 descriptions of the SG domains

Domain	Descriptions
Bulk Generation	The bulk generation domain contains any generation and storage that is connected directly to the transmission system (with no distribution system interface). The generation and storage can be any size such as large power generation stations, small peaking generation, and small storage connected to the electrical transmission system. These facilities may be owned by electric utilities or by independent entities. The bulk generation domain's primary interfaces are with transmission domain entities, generation and transmission operations control entity, and markets domain. The interface to the markets domain is focused on the operation of the generation and storage in order to provide economic operation. The rest of the interfaces displayed in Figure 1 (PS-IAP) are focused on efficient and reliable operation.
Transmission	The transmission domain includes entities that represent equipment associated with the electrical transmission system. This equipment is represented by three entities. The transmission substation entity represents many pieces of equipment in substations that cannot be classified as transmission protection and control devices nor sensors and measurement devices. The transmission domain's primary interfaces are with the bulk generation domain and operations/control domain. The interfaces with the bulk generation domain are focused on reliable operation. The interconnection with the transmission operation/control entity in the operations/control domain is the focal point of the centralized control of the transmission system. This is often under the control of an independent system operator, Regional Transmission Organization (RTO), or local utility. In addition, there may be interfaces with the customer domain where the customer may have a transmission-level connection to the power system, as may be the case with IPP's, large industrial facilities, or large commercial facilities.
Distribution	The distribution system domain includes entities located throughout the electrical distribution system. The distribution substation entity represents many components that cannot be assigned to the distribution protection and control devices entity nor the sensors and measurement devices entity. In addition, the distributed energy resource (DER) entity represents generation and storage of all kinds that are connected to the electric distribution system except those at customers' facilities. The distribution domain's primary interface is with the distribution operation and control entity in the control and operations domain. This interface reflects the centralized control of the distribution system from the distribution control centre. The distribution domain may also have an interface to the transmission substation entity in the transmission domain. This interface usually reflects only protection and control systems. The distribution domain may also have an interface with the generation operation and control entity in the control domain in order to provide direct dispatch of distribution connected DER.

Table 1 *(continued)*

Domain	Descriptions
Customer	The customer domain includes many types of customers that are connected to the electrical distribution system or electrical transmission system. These customers could be residential, commercial, or industrial. The customer domain may include customers with only loads and customers with any combination of loads, generation, and storage. The customer domain includes all loads whether they are connected at the transmission or distribution level, but it does not consider generation and storage connected at the transmission level. If generation and storage is connected at the transmission level, that generation or storage is considered part of the bulk generation domain. Each type of customer may have several different entities employed in its application. These entities are dependent on the size and type of customer as well as its connections to the EPS. The DER entity includes all distribution system-connected generation and storage and may require an interface with the market domain. A plug-in electric vehicle may have the characteristics of a load or customer DER. The customer domain can have interfaces to the distribution domain, markets domain, and the distribution operations/control entity of the operations/control domain. These interfaces handle the customer requirements with the exception of facilities that have a substation connected to the electrical transmission system. In this case, the substation has interfaces to the transmission domain and to the transmission operations/control entity of the operations/control domain. Transmission operations will often have control over customer substations since customer substations may have direct influence on operations of the transmission system. In some instances, customer DER will be directly dispatched by the generation or transmission operation and control entities.
Control and Operations	The control and operations domain includes three distinctive operation and control entities. These entities are control generation, transmission, and distribution. They are the controlling mechanisms that, from an EPS viewpoint, keep the grid up and running. The primary interface of each entity in the control and operations domain is to its appropriate domain in the electrical power system. These primary interfaces include the distribution operation and control entity to the distribution domain, the transmission operation and control entity to the transmission domain, and the generation operation and control entity to the bulk generation domain. In addition, the distribution operation/control entity has some interface to the customer domain for applications where the customer has controllable loads, generation, and/or storage. The transmission operation and control entity has an interface with the customer substation entity in the customer domain for those circumstances where a customer connects directly to the transmission system instead of through the distribution system. In some instances, customer DER will be directly dispatched by the generation or transmission operation and control entities.

Table 1 *(continued)*

Domain	Descriptions
Market	The markets domain reflects market operations associated with electric utilities and regional entities. The markets domain is logically connected with any of the generation, load control, and storage entities. Control by markets can be done directly at generation, load control, and storage, but it can also be done via the operations/control domain. Additionally, as new markets emerge, the customer may seek to interact directly with the marketplace.
Service Provider	The service provider domain contains third-parties and utilities that provide electrical power-related services. The service provider domain is the connection between the electric energy markets and the end users. There are many models for potential electric service providers, but the most common model in use today is that of the electric utility as service provider. Some locations have third-party service providers who aggregate electric power for consumption by end users. Electric service providers may also provide additional electric power-related services. These services may include additional power supply options, such as discounts for less consumption during peak hours. They may also include demand-side management and services such as protection against lightning and voltage excursions. Some electric service providers may also provide services such as monitoring electrical equipment for maintenance and troubleshooting purposes. The equipment monitored could include generation, storage, substation equipment, and equipment located on electric distribution or transmission lines.

5.3.1 Power System Interoperability Architecture Perspective (PS-IAP)

The Power System Interoperability Architecture Perspective (PS-IAP) shown in Figure 1 is a logical representation of the major entities that describe the functions of the EPS. Figure 1 displays domains, entities, and interfaces from the power system perspective. The PS-IAP domains (common to all perspectives) provide a division of efforts close to those of existing electric utilities.

These PS-IAP domains are:

— Bulk generation

— Transmission

— Distribution

— Customer

— Service providers

— Control and operations

— Markets

The PS-IAP entities (unique to all perspectives) reflect equipment or functions of the EPS. Interfaces between entities in the power system perspective may represent multiple data flows over multiple data links. For example, communication between a distribution substation and an operation centre may have SCADA, voice, and video signals on the same interface. Only the interfaces are displayed in this diagram. Because many alternatives of power flow options exist, the power flows are ignored in order to keep the diagram less complicated. This standard document does not address the power flow.

Smart Grid implementation covers a geographical area implementation, a utility system implementation, a control area implementation, or a nationwide implementation. For a given implementation, each entity may represent any number of physical or logical devices. The entities and interfaces in Figure 1 (PS-IAP) are described in Table B.2 and in Table B.3, respectively, and these tables are found in Annex B.

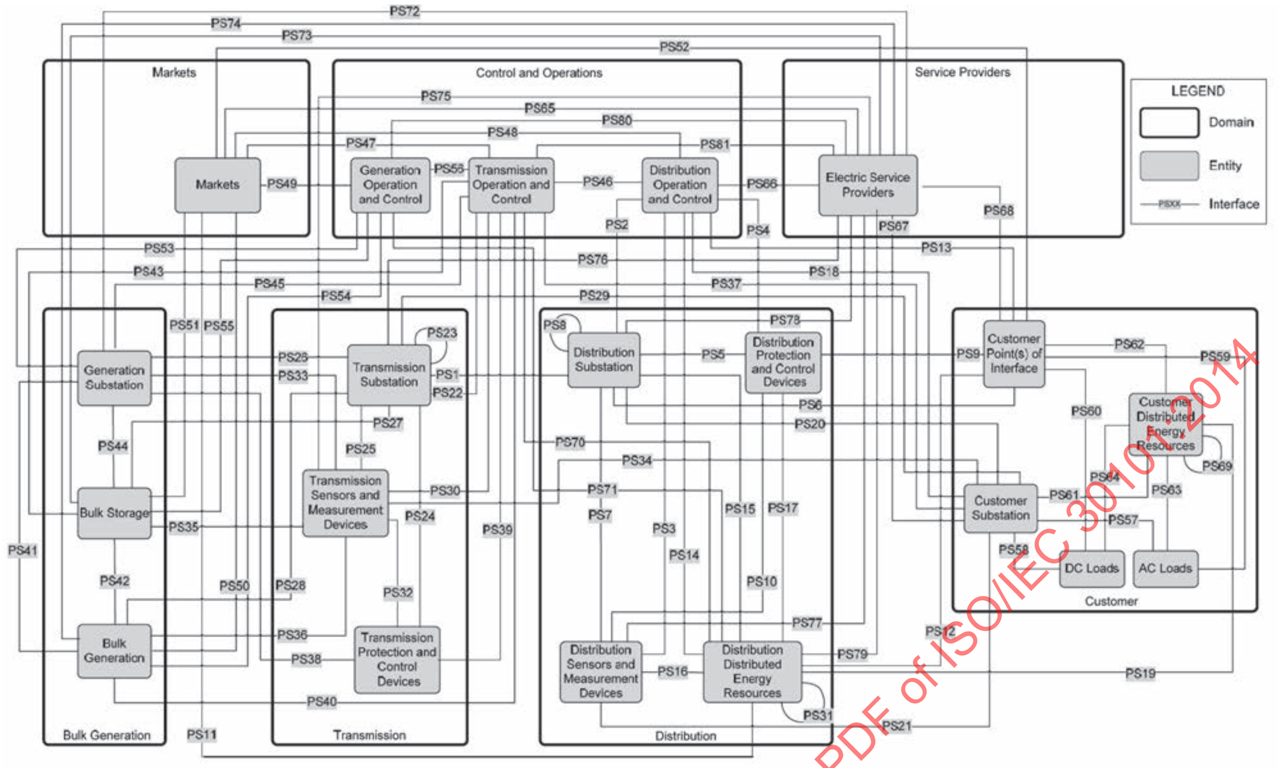


Figure 1 — Power system interoperability architecture perspectives (from IEEE 2030)

5.3.2 Communication Technology Interoperability Architecture Perspective (CT-IAP)

The Communication Technology Interoperability Architecture Perspective (CT-IAP) shown in Figure 2 displays domains, entities, and interfaces from the communications technology perspective. The CT-IAP domains (common to all architecture perspectives) provide a view of the EPS close to that of existing electric utilities' view that emphasizes the production, delivery, and consumption of electrical energy. The seven CT-IAP domains are the same as those domains in the PS-IAP:

— Bulk generation

— Transmission

— Distribution

— Customer

— Service providers

— Control and operations

— Markets

Within each domain (intra-domain) or between domains (inter-domain), the entities are connected to each other through one or more interfaces. The number of interfaces connecting one or more entities represents the available (and future) and most relevant interconnection alternatives. If new entities or interfaces are required in the near future, they can be added later following this approach.

The communications entities are either wireline or wireless network systems or relevant communications system elements that stand out as important in the context of the whole system architecture. The interfaces are further defined as generic interconnections that establish the minimum level of interoperability requirements between two or more entities. The interfaces are then further specified in terms of performance requirement, security level, protocol layer, and other more specific needs that will be identified in the future.

The entities are connected with communication links represented by lines between two entities; thus, this line represents interface or connectivity between the two entities. It should be noted that the single line between the two entities does not mean that there is only one or a single interface. The line represents an aggregation of interfaces between the two entities. This approach is used to simplify the diagram and improve readability. The entities in Figure 2 (CT-IAP) are described in Table B.4, and the interfaces are described in Table B.5, and both tables are found in Annex B.

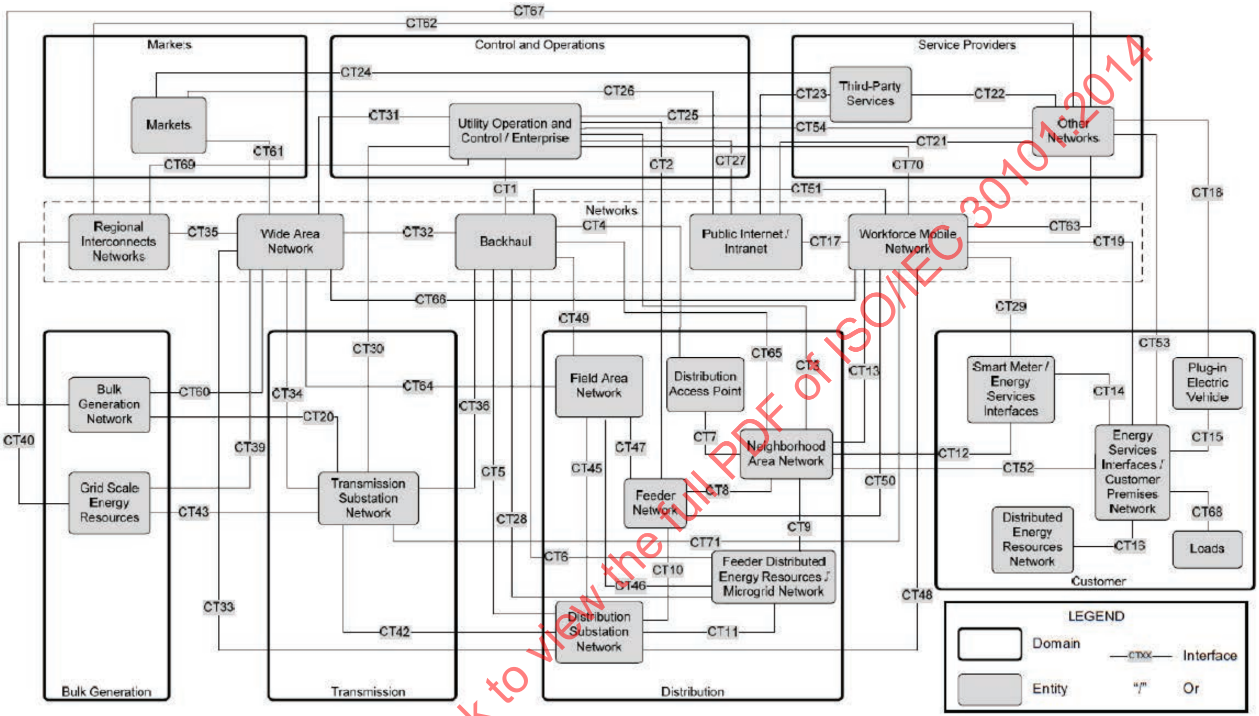


Figure 2 — Communication system interoperability architecture perspectives (from IEEE 2030)

5.3.3 Information Technology Interoperability Architecture Perspective (IT-IAP)

The Information Technology Interoperability Architecture Perspective (IT-IAP) views the Smart Grid from the perspective of the IT applications and the data flows associated with those applications. The IT application and the data flows are used to operate and manage the power system with the main goal of allowing interoperability of independently developed systems. The IT-IAP shown in Figure 3 (IT-IAP) is defined in terms of the functionality and the interoperability of the seven domains as mentioned in earlier in this document.

The objective of the IT technology represented by IT-IAP is not to define new information exchange architecture, but rather to work with the current best practices and technologies and to identify and fill the gaps for information exchange between the seven domains as necessary. Some of the gaps may be non-functional rather than functional. Functional requirements describe the functions that the software is to execute; for example, formatting some text or modulating a signal. They are sometimes known as capabilities. Nonfunctional requirements are the ones that act to constrain the solution. Nonfunctional requirements are sometimes known as constraints or quality requirements.

Explicit efforts have been made to adopt the terminology used in IEEE 2030 in order to ensure a consistent architectural framework for the Smart Grid among the organizations seeking to further their understanding, cohesive adoption, and future-proofing.

Some entities represented in the IT-IAP are aggregations of protocols or databases, other entities may be distributed potentially over multiple domains, but are located where most appropriately discussed.

The labelled lines that connect the entities represent data flows. In this guide, data flow is defined as application-level communications from a producer of data to a consumer of the data.

Table B.5 and Table B.6 describe the entities of the IT-IAP and the data flows that exist from one entity to another, respectively, and these tables are found in Annex B.

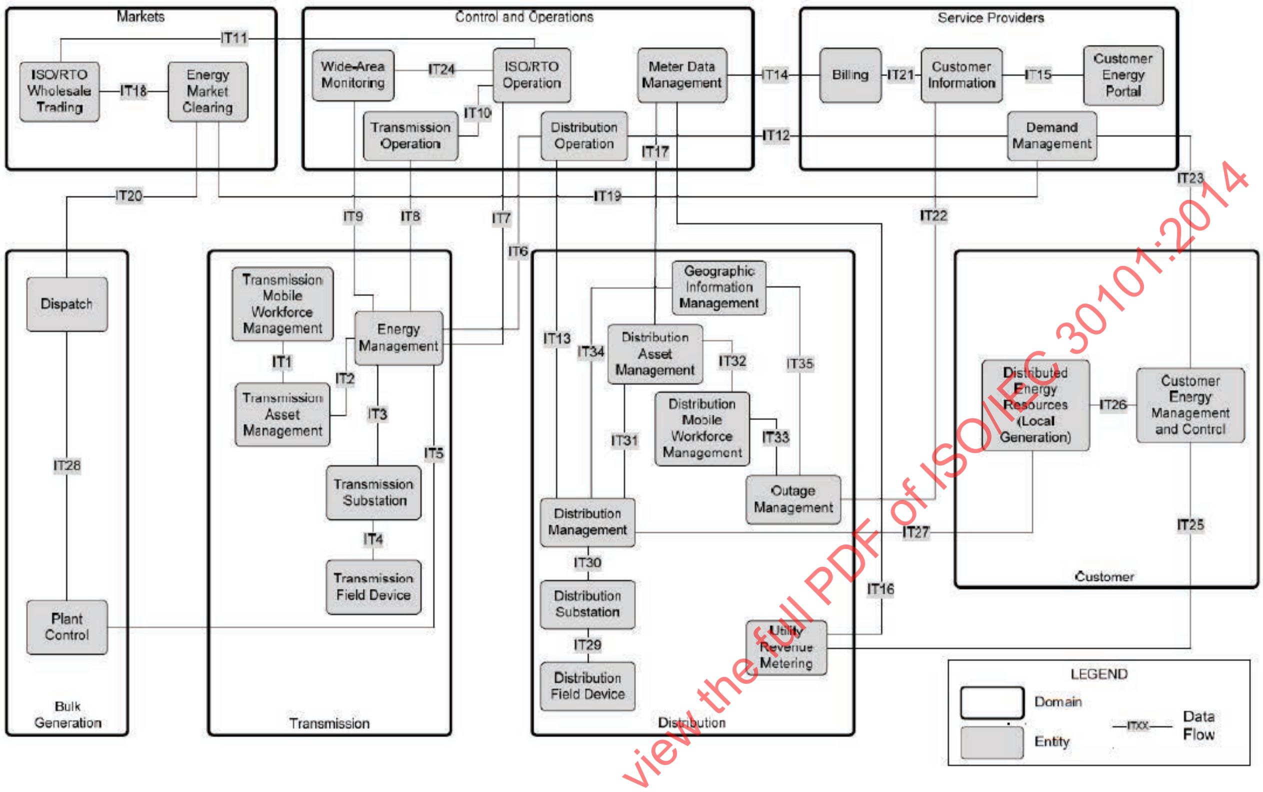


Figure 3 — Information technology interoperability architecture perspectives (from IEEE 2030)

6 Sensor Network Interface with SG Entities

From the IEEE 2030 PS-IAP's interface descriptions in Table B.2 in Annex B, all the possible locations of sensors in Electric Power Systems (EPS) can be identified. Sensors are physical entities that are attached to the physical EPS of Smart Grid. Thus, reviewing the PS-IAP's interface descriptions will allow identifying power system entities having with sensors. Therefore, Table B.2 is reproduced in Table 2 below with an additional column called "Type.". Whether sensor is involved or not involved per interface is indicated in the "Type" column of Table 2. The notations in "Type" column "SI" and "DO" represent:

— SI — Sensor(s) Involved either in Entity 1 or Entity 2; and

— DO — Data Only, typically processed data, no sensor involved.

Table 2 — Identification of PS-IAP interfaces for sensor locations

Type	IF No.	Entity 1	Entity 2	Comments
DO	PS1	Distribution Substation	Transmission Substation	Substations may be co-located or located some distance from each other. Provides for coordination between electrically connected substations. Interfaces include those for control, protection, monitoring, SCADA, and telephony.
DO	PS2	Distribution Substation	Distribution Operation and Control	Provides substation data and for direct control of distribution substations. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
SI	PS3	Distribution Sensors and Measurement Devices	Distribution Operation and Control	Provides distribution system data. Interfaces include those for monitoring, reporting, and SCADA.
SI	PS4	Distribution Protection and Control Devices	Distribution Operation and Control	Provides for monitoring of devices, controlling devices, and updating settings to devices. Interfaces include those for control, monitoring, SCADA, and reporting.
SI	PS5	Distribution Substation	Distribution Protection and Control Devices	Provides for monitoring of devices, controlling devices, and updating settings to devices as well as coordination between substation and field devices. Interfaces include those for protection, control, monitoring, reporting, and SCADA.
DO	PS6	Distribution Substation	Customer Point(s) of Interface	Provides for protection coordination and customer information that is desired at the substation. Interfaces include those for protection, control, and monitoring.
SI	PS7	Distribution Substation	Distribution Sensors and Measurement Devices	Provides for distribution system information to be provided at distribution substations. Interfaces include those for monitoring, reporting, and SCADA.
DO	PS8	Distribution Substation	Distribution Substation	Interfaces between two or more distribution substations. Interfaces include those for protection, control, monitoring, reporting, SCADA, and telephony.
SI	PS9	Distribution Protection and Control Devices	Customer Point(s) of Interface	Provides customer information to protection and control devices and certain protection and control information to customer devices. Interfaces include those for protection, control, and monitoring.
SI	PS10	Distribution Protection and Control Devices	Distribution Sensors and Measurement Devices	Provides sensor information to protection and control devices. Interfaces include those for monitoring and SCADA.
DO	PS11	Distribution Distributed Energy Resources	Markets	Provide DER information to markets and capabilities for market control of DER. Interfaces include those for control and monitoring.
DO	PS12	Distribution Distributed Energy Resources	Customer Point(s) of Interface	Provides for aggregated customer information and distribution system DER control directly to customer. Provides a means to locally balance generation and loads. Interfaces include those for control and monitoring.
DO	PS13	Distribution Operation and Control	Customer Point(s) of Interface	Provides information exchange and control of customer equipment by distribution operations and control. Interfaces include those for control and monitoring.
DO	PS14	Distribution Distributed Energy Resources	Distribution Operation and Control	Provides information exchange and control of distribution DER by distribution operations and control. Interfaces include those for control and monitoring.

Table 2 *(continued)*

Type	IF No.	Entity 1	Entity 2	Comments
DO	PS15	Distribution Substation	Distribution Distributed Energy Resources	Provides for distribution system DER information and distribution system DER control directly from the sub-station. Provides a means to locally balance generation and loads. Interfaces include those for protection, con-trol, and monitoring.
SI	PS16	Distribution Distributed Energy Resources	Distribution Sensors and Measurement Devices	Provides distribution system information for use by distribution system DER. Interfaces include those for monitoring, reporting, and SCADA.
SI	PS17	Distribution Protection and Control Devices	Distribution Distributed	Provides for coordination between distribution system protection and control devices and DER. Interfaces include those for protection and control.
DO	PS18	Distribution Operation and Control	Customer Substation	Provides for monitoring and control of customer owned stations by distribution operations and control. Inter-faces include those for control, monitoring, and SCADA.
DO	PS19	Distribution Distributed Energy Resources	Customer Distributed Energy Resources	Provides for coordination between distribution system DER and customer DER. Interfaces include those for monitoring and control.
DO	PS20	Distribution Substation	Customer Sub-station	Provides for coordination between distribution substa-tions and customer substations. Interfaces include those for protection and monitoring.
SI	PS21	Distribution Sensors and Measurement Devices	Customer Substation	Provides for distribution line information to be pro-vided at customer substations. Interfaces include those for monitoring, reporting, and SCADA.
DO	PS22	Transmission Substation	Transmission Operation and Control	Provides for transmission operations monitoring and control of substations. This would include typical SCADA data, phasor data, special protection systems, telephone, and wide area monitoring, protection and control (WAMPAC). Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
DO	PS23	Transmission Substation	Transmission Substation	Provides for coordination between two or more transmission substations, Interfaces include those for protection, control, monitoring, reporting, SCADA, and telephony.
SI	PS24	Transmission Substation	Transmission Protection and Control Devices	Provides for coordination, control, and monitoring between remote protection and control devices with transmission substations. This would include protec-tion, switching commands (open/close switches), and control device monitoring. Interfaces include those for protection, control, monitoring, reporting, and SCADA
SI	PS25	Transmission Substation	Transmission Sensors and Measurement Devices	Provides for capability to monitor information not in transmission substation. This would include informa-tion for dynamic line rating, transmission line main-tenance information, etc. Interfaces include those for monitoring, reporting, and SCADA.
DO	PS26	Transmission	Generation Substation	Provides coordination between transmission and generation substations. This would include protection systems, special protection systems, telephone, etc. Interfaces include those for protection, control, moni-toring, SCADA, and telephony.

Table 2 *(continued)*

Type	IF No.	Entity 1	Entity 2	Comments
DO	PS27	Transmission Substation	Bulk Storage	Provides for coordination between the transmission substation and bulk storage as well as monitoring of information at both entities. This would include protection systems, special protection systems, telephone, etc. Interfaces include those for protection, control, monitoring, and SCADA.
DO	PS28	Transmission Substation	Bulk Generation	Provides for coordination between the transmission substation and generation as well as monitoring of information at both locations. This would include special protection systems. Interfaces include those for protection, control, monitoring, and SCADA.
DO	PS29	Transmission Substation	Customer Substation	Provides for coordination between transmission and customer substations. This would include protection systems, special protections systems, telephone. Interfaces include those for protection, control, monitoring, and SCADA.
SI	PS30	Transmission Sensors and Measurement Devices	Transmission Operation and Control	Provides information from the transmission line to the transmission operators. This would include information for dynamic line rating, transmission line maintenance information, etc. Interfaces include those for monitoring, reporting, and SCADA.
DO	PS31	Distribution Distributed Energy Resources	Distribution Distributed Energy Resources	Interfaces between two or more distribution DERs. Interfaces include those for protection, control, monitoring, reporting, and SCADA.
SI	PS32	Transmission Sensors and Measurement Devices	Transmission Protection and Control Devices	Provides information to protection and control devices. This could include information for dynamic line rating and control of line impedance. Interfaces include those for monitoring.
SI	PS33	Transmission Sensors and Measurement Devices	Generation Substation	Provides information to generation substation. This would include information for dynamic line rating, transmission line maintenance information, etc. Interfaces include those for monitoring.
SI	PS34	Transmission Sensors and Measurement Devices	Customer Substation	Provides information to customer substation. This would include information for dynamic line rating, transmission line maintenance information, etc. Interfaces include those for monitoring.
SI	PS35	Transmission Sensors and Measurement Devices	Bulk Storage	Provides information to bulk storage. This would include information for dynamic line rating, transmission line maintenance information, etc. Interfaces include those for monitoring.
SI	PS36	Transmission Sensors and Measurement Devices	Bulk Generation	Provides information to bulk generation. This would include information for dynamic line rating. Interfaces include those for monitoring.
DO	PS37	Transmission Operation and Control	Customer Substation	Provides for transmission operators to monitor and control customer substations. Interfaces include those for control, monitoring, SCADA, reporting, and telephony
SI	PS38	Transmission Protection and Control Devices	Generation Substation	Provides coordination between remote protection and control devices with the generation substation. This would include protection and special protection systems. Interfaces include those for protection, control, monitoring, and SCADA.

Table 2 *(continued)*

Type	IF No.	Entity 1	Entity 2	Comments
SI	PS39	Transmission Protection and Control Devices	Transmission Operation and Control	Provides control of transmission system and ability to change settings on protective and control equipment. This would include typical SCADA data, phasor data, special protection systems, telephone, and wide area monitoring, protection and control. Interfaces include those for control, monitoring, SCADA, and reporting.
DO	PS40	Bulk Generation	Transmission Operation and Control	Provides for information exchange between generation and transmission operations. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
DO	PS41	Bulk Generation	Generation Substation	Provides for information exchange and coordination between generation and generation substation. Interfaces include those for protection, control, monitoring, SCADA, and telephony.
DO	PS42	Bulk Generation	Bulk Storage	Provides for information exchange and coordination between generation and storage. Interfaces include those for protection, control, monitoring, SCADA, and telephony.
DO	PS43	Bulk Storage	Transmission Operation and Control	Provides for information exchange. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
DO	PS44	Bulk Storage	Generation Substation	Provides for information exchange and coordination between storage and generation substation. Interfaces include those for protection, control, monitoring, SCADA, and telephony.
DO	PS45	Generation Substation	Transmission Operation and Control	Provides for information exchange and control of generation substation. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
DO	PS46	Transmission Operation and Control	Distribution Operation and Control	Provides for coordination between distribution operations and transmission operations. Interfaces include those for monitoring, reporting, SCADA, and telephony.
DO	PS47	Markets	Transmission Operation and Control	Wholesale market operations control to optimize portfolio of sources. Interfaces include those for monitoring, reporting, and telephony
DO	PS48	Markets	Distribution Operation and Control	Demand-side management (DSM) signals to reduce demand. Interfaces include those for monitoring, reporting, and telephony.
DO	PS49	Markets	Generation Operation and Control	Wholesale market operations control to optimize portfolio of sources. Interfaces include those for monitoring, reporting, and telephony.
DO	PS50	Markets	Bulk Generation	Wholesale market operations control to optimize portfolio of sources. Interfaces include those for control, monitoring, reporting, and telephony.
DO	PS51	Markets	Bulk Storage	Wholesale market operations control to optimize portfolio of sources. Interfaces include those for control, monitoring, reporting, and telephony.
DO	PS52	Markets	Customer Point(s) of Interface	Provides for optimization of distributed generation, storage, and load control (i.e. demand response) on the customer domain. Interfaces include those for control, monitoring, and reporting.
DO	PS53	Generation Operation and Control	Generation Substation	Provides substation information and control of substation equipment. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.

Table 2 *(continued)*

Type	IF No.	Entity 1	Entity 2	Comments
DO	PS54	Generation Operation and Control	Bulk Generation	Provides generation information and control of bulk generation. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
DO	PS55	Generation Operation and Control	Bulk Storage	Provides storage data and control of bulk storage. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
DO	PS56	Generation Operation and Control	Transmission Operation and Control	Provides for coordination between generation operations and transmission operations. Interfaces include those for monitoring, reporting, SCADA, and telephony.
DO	PS57	Customer Substation	AC Loads	Provides for intra-facility monitoring and control of AC loads. Interfaces include those for protection, control, and monitoring.
DO	PS58	Customer Substation	DC Loads	Provides for intra-facility monitoring and control of DC loads. Interfaces include those for protection, control, and monitoring.
DO	PS59	Customer Point(s) of Interface	AC Loads	Provides for information exchange and control of AC loads by entities external to customer. Interfaces include those for protection, control, and monitoring.
DO	PS60	Customer Point(s) of Interface	DC Loads	Provides for information exchange and control of DC loads by entities external to customer. Interfaces include those for protection, control, and monitoring.
DO	PS61	Customer Substation	Customer Distributed Energy Resources	Provides for information exchange and control of DERs by substation control. Interfaces include those for protection, control, and monitoring.
DO	PS62	Customer Point(s) of Interface	Customer Distributed Energy Resources	Provides for information exchange and control of DERs by entities external to customer. Interfaces include those for protection, control, and monitoring.
DO	PS63	Customer Distributed Energy Resources	AC Loads	Provides for information exchange and control of DERs and AC loads internally at the customer. Interfaces include those for protection, control, and monitoring.
DO	PS64	Customer Distributed Energy Resources	DC Loads	Provides for information exchange and control of DERs and DC loads internally at the customer. Interfaces include those for protection, control, and monitoring.
DO	PS65	Electric Service Providers	Markets	Provides for information exchange of market information and expected loading. Interfaces include those for monitoring and control.
DO	PS66	Electric Service Providers	Distribution Operation and Control	Provides for information exchange of expected loading and aggregate control mechanisms. Interfaces include those for monitoring.
DO	PS67	Electric Service Providers	Customer Substation	Provides for monitoring information and control of customer generation, storage, and loads. Interfaces include those for monitoring and control.
DO	PS68	Electric Service Provider	Customer Point(s) of Interface	Provides for monitoring information and control of customer generation, storage, and loads. Interfaces include those for monitoring and control.
DO	PS69	Customer Distributed Energy Resources	Customer Distributed Energy Resources	Interfaces between two or more customer DERs. Interfaces include those for protection, control, monitoring, reporting, and SCADA.

Table 2 *(continued)*

Type	IF No.	Entity 1	Entity 2	Comments
DO	PS70	Transmission Operation and Control	Distribution Distributed Energy Resources	Provides for monitoring information and control of customer generation, storage, and loads for direct dispatch of distribution connected DER. Interfaces include those for monitoring and control.
DO	PS71	Generation Operation and Control	Distribution Distributed Energy Resources	Provides for monitoring information and control of customer generation, storage, and loads for direct dispatch of distribution connected DER. Interfaces include those for monitoring and control.
DO	PS72	Electric Service Providers	Generation Substation	Provides for monitoring information of generation substation equipment. Interfaces include those for monitoring.
DO	PS73	Electric Service Providers	Bulk Storage	Provides for monitoring information of bulk storage equipment. Interfaces include those for monitoring.
DO	PS74	Electric Service Providers	Bulk Generation	Provides for monitoring information of bulk generation equipment. Interfaces include those for monitoring.
SI	PS75	Electric Service Providers	Transmission Sensors and Measurement Devices	Provides for monitoring information of sensors and measurements associated with transmission line equipment. Interfaces include those for monitoring.
DO	PS76	Electric Service Provider	Transmission Substation	Provides for monitoring information of transmission substation equipment. Interfaces include those for monitoring.
SI	PS77	Electric Service Providers	Distribution Sensors and Measurement Devices	Provides for monitoring information of sensors and measurement devices associated with distribution line equipment. Interfaces include those for monitoring.
DO	PS78	Electric Service Provider	Distribution Substation	Provides for monitoring information of distribution substation equipment. Interfaces include those for monitoring
DO	PS79	Electric Service Provider	Distribution Distributed Energy Resources	Provides for monitoring information of distribution distributed energy resource equipment. Interfaces include those for monitoring.
DO	PS80	Electric Service Provider	Generation Operation and Control	Provides for monitoring information provided to asset management provides from the generation operation and control centre. Interfaces include those for monitoring.
DO	PS81	Electric Service Provider	Transmission Operation and Control	Provides for monitoring information provided to asset management provides from the transmission operation and control centre. Interfaces include those for monitoring.

7 Sensors in Smart Grid System

7.1 Introduction

The data and information from sensors and their associated processing capability, either internal to sensors (e.g., smart or intelligent sensors) or external to sensors (e.g., gateway or operation centres), provides intended smart/intelligent to smart grid system. Ability to pass sensor data/information via wired and/or wireless network is another key element of sensor networks interfaced with the smart grid system. The following are some of the application/service areas that the Smart Grid Sensor Networks can support:

— Safety

— Workforce deployment

— Condition based maintenance

— Asset management

— Increased asset utilization

— Forensics and diagnostic analysis

— Probabilistic risk assessment for operations

— Automated command and control

The basic and typical measurements that are needed for smart grid sensing fall into the categories of:

— Voltage sensing,

— Current sensing,

— Temperature sensing,

— Moisture sensing,

— Continuity sensing, and

— Phase measurements.

Many sensors implemented in the past are not economical when they are integrated into the smart grid because the electromechanical sensors from the past have to be combined with discrete communications elements to communicate sensor data to gateways or command centres. Cost reductions, technological improvements in computing power, fabrication and miniaturization (e.g., CMOS technology), and reductions in power requirements in sensing and communications technologies allow system-on-a-chip levels of integration. Such chip level integration provides integrated sensors with wired or wireless connections to communicate data to decision makers at a cost that allows for economical pervasive sensor network deployment in the smart grid system.

Some of the smart sensor and sensor network applications and services that will emerge due to smart grid implementation are concisely described below. Additional sensor network applications and services can be found in Annex D of this document.

Wireless sensor networks for AMI: The AMI represents the first two-way communication between the delivery infrastructure and the end consumer. The AMI will allow the central distribution system to monitor in real time the use of each individual node on the grid and allow information about outages to be transported back to the central command structure. The AMI represents a real opportunity for the emergence of wireless smart sensor networks within the home or small business space as well as sensor opportunities for utility outage detection.

Smart voltage sensors: Smart voltage sensors will be one of many evolving smart sensor components. While traditional regulators at the substation and on main distribution lines are part of the current electromechanical net, voltage sensors along spurs and near the end of the line that report back on current conditions are currently rare but will become pervasive as part of the emerging smart-grid sensor network. Currently, without end-of-line sensors, long distribution lines use inefficient high voltages at the feeder distribution point to ensure that the voltage at the end of the line is never below quoted specification. The addition of smart sensors at the end of the line can report real-time voltage data back to the feeder line so it can distribute the current at a lower voltage than it otherwise could without the sensor information, thus allowing more efficient use of the available electricity in the distribution network. This will be especially useful in rural areas with long radial lines.

Smart capacitor control: Currently, large capacitors are used on the grid to maintain voltage and power factor. While the capacitors are able to react to changing voltage, current or power factor, they are not monitored or controlled remotely. The addition of smart sensors that can monitor and control capacitor banks remotely will increase the overall efficiency of the distribution network.

Smart sensors for outage detection: In addition to smart meters, smart continuity grid sensors that can communicate with the central distribution points will improve outage detection.

Smart sensors for transformer monitoring: Transformers represent one of the more expensive assets of local utility companies, but monitoring in general is limited to once a year manual dissolved gas analysis and periodic temperature observation with IR cameras. On-line sensors for dissolved gas analysis and temperature monitoring with two-way communications back to the substation represent a significant opportunity.

High-voltage line temperature and weather condition sensors: Sensors will provide real-time temperature and weather conditions for to improve the efficiency of high voltage distribution lines and allow more accurate dispatch of current in times of significant demand with reduced chance of outages due to line sag.

Distributed generation: For distributed generation to be viable in the emerging smart grid, sensors for load balancing between the greater grid and the distributed generating sources will be crucial. Power factor is a measure of the real power delivered to a circuit divided by apparent power; lower power factor requires more generating capacity to deliver a specific amount of power to a circuit.

Smart grid storage: Sensor opportunities are twofold for smart grid storage. There will be opportunities both in monitoring the status of all battery cells in storage banks and in load monitoring and dispatch of energy from the battery bank to the greater grid.

In the following sections, sensors in each Smart Grid domain are introduced. The additional details of each sensor and its description can be found in Annex C.

Each sensor identified in the following sections is either connected via wireline or wirelessly to transmit its measured data either to a gateway or a central processing unit as power system health condition status monitoring and diagnostics become automated and on-line monitoring rather than manual data collection by maintenance crews. Furthermore, some of these sensors may also be connected to an actuator or actuators for controlling power systems and/or subsystems. Thus, each sensor introduced in the following sections is or will be a sensor node.

7.2 Sensors in Bulk Generation Domain

7.2.1 Sensors in Bulk Generation

Sensors are installed on equipment in the bulk generation entities, and they are listed below per equipment, e.g., hydro generation, thermal generation, wind turbines, solar cells etc. Where possible, a brief description of each sensor is provided.

7.2.1.1 Sensors on Hydro Generation

Hydro generation is produced by the force of falling water. The capacity to produce this energy is dependent on both the available flow and the height from which it falls. Building up behind a high dam, water accumulates potential energy. This is transformed into mechanical energy when the water rushes down the sluice and strikes the rotary blades of turbine. The turbine's rotation spins electromagnets which generate current in stationary coils of wire. Finally, the current is put through a transformer where the voltage is increased for long distance transmission over power lines. Figure 4 describe this paragraph pictorially.

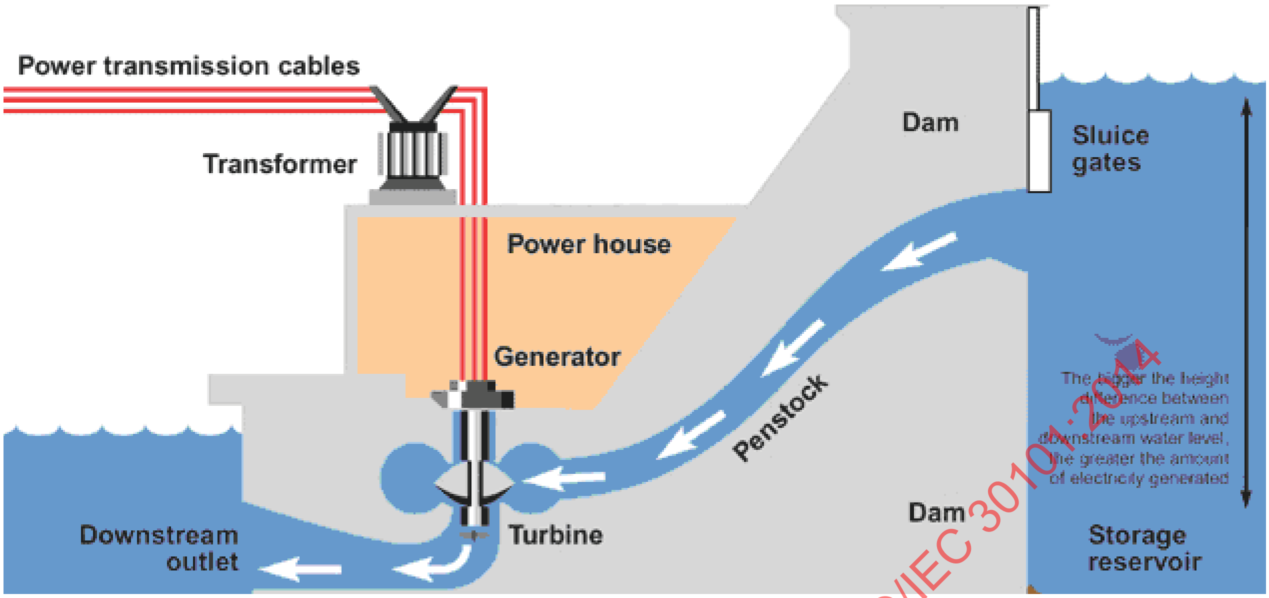


Figure 4 — Configuration of hydro generation

Monitoring of thermal power plants is primarily intended to prevent fire of turbine and overflowing. Sensors for monitoring of the external environment are applied, as shown in Table 3.

Table 3 — Sensors required for hydro generation

Sensor Types	Roles Description
Sensors for monitoring external environment	
Temperature Sensor	Measure the external temperature.
Humidity Sensor	Measure the external humidity
IP Camera	Provide real-time video
Water gauge	Measure the water level
Sensors for monitoring operation property	
Current Sensor	Measure the operating current.
Voltage Sensor	Measure the operating voltage
Accelerometers	Measure the rotational speed (RPM) of turbine

7.2.1.2 Sensors on Thermal Generation

Thermal Generation system uses the energy of heat to make electricity, as shown in Figure 5. Water is heated in a boiler until it becomes high-temperature steam. This steam is then channeled through a turbine, which has many fan-blades attached to a shaft. As the steam moves over the blades, it causes the shaft to spin. This spinning shaft is connected to the rotor of a generator, and the generator produces electricity.

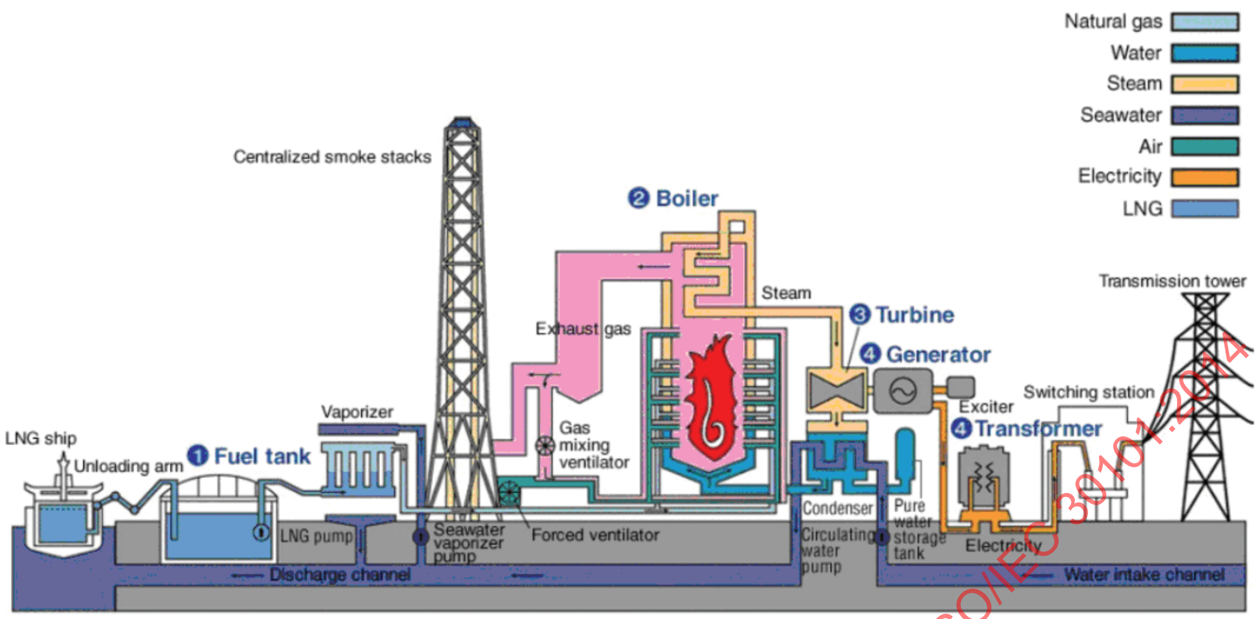


Figure 5 — Configuration of thermal generation

Monitoring of thermal power plants is primarily intended to prevent fire of turbine. Sensors for monitoring of the external environment are applied, as shown in Table 4.

Table 4 — Sensors required for thermal generation

Sensor Types	Roles Description
Sensors for monitoring external environment	
Temperature Sensor	Measure the external temperature.
Humidity Sensor	Measure the external humidity
IP Camera	Provide real-time video
Sensors for monitoring operation property	
Current Sensor	Measure the operating current.
Voltage Sensor	Measure the operating voltage
Accelerometers	Measure the rotational speed (RPM) of turbine

7.2.1.3 Sensors on Wind Turbine in Wind Generation

Wind turbines are separated into two major types depending on the type of generator.

a) PMSG(Permanent Magnet Synchronous Generator): Gearless type

b) DFIG(Doubly Fed Induction Generator): Gear type

The PMSG system is directly connected to the rotor and the generator (direct-drive type) without overdrive gear. The PMSG system is based on a major facility is divided into 19, as shown in Figure 6.

1 Spinner	6 Service Crane	11 Cooling System	16 Yaw Drive
2 Blade	7 Anemometer	12 Generator Cantilever	17 Main Frame
3 Rotor Lock	8 Aviation Light	13 Generator	18 Hub
4 Gearbox	9 Nacelle Cover	14 Nacelle Cabinet	19 Pitch Bearing
5 Torque Arm	10 Cooling Fan	15 Yaw Bearing	

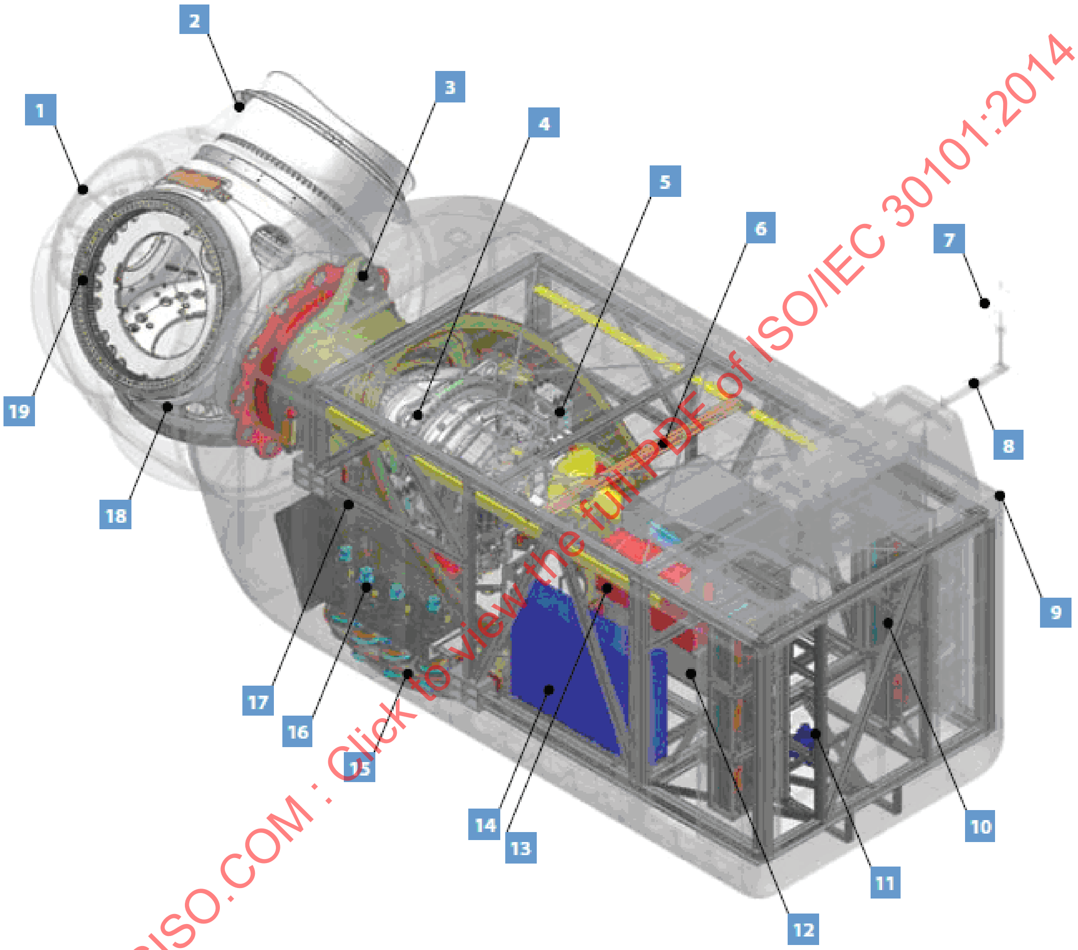


Figure 6 — Configuration of a PMSG system

The DFIG system uses a wound rotor induction machine so that the magnetizing current of the generator can be fed from both the stator and the rotor. The DFIG system is based on a major facility is divided into 11, as shown in Figure 7.

1 Main Frame	4 Generator	7 Cooling System	10 Gearbox
2 Service Crane	5 Anemometer	8 Nacelle Cabinet	11 Yaw System
3 Flexible Coupling	6 Aviation Light	9 Slipring	

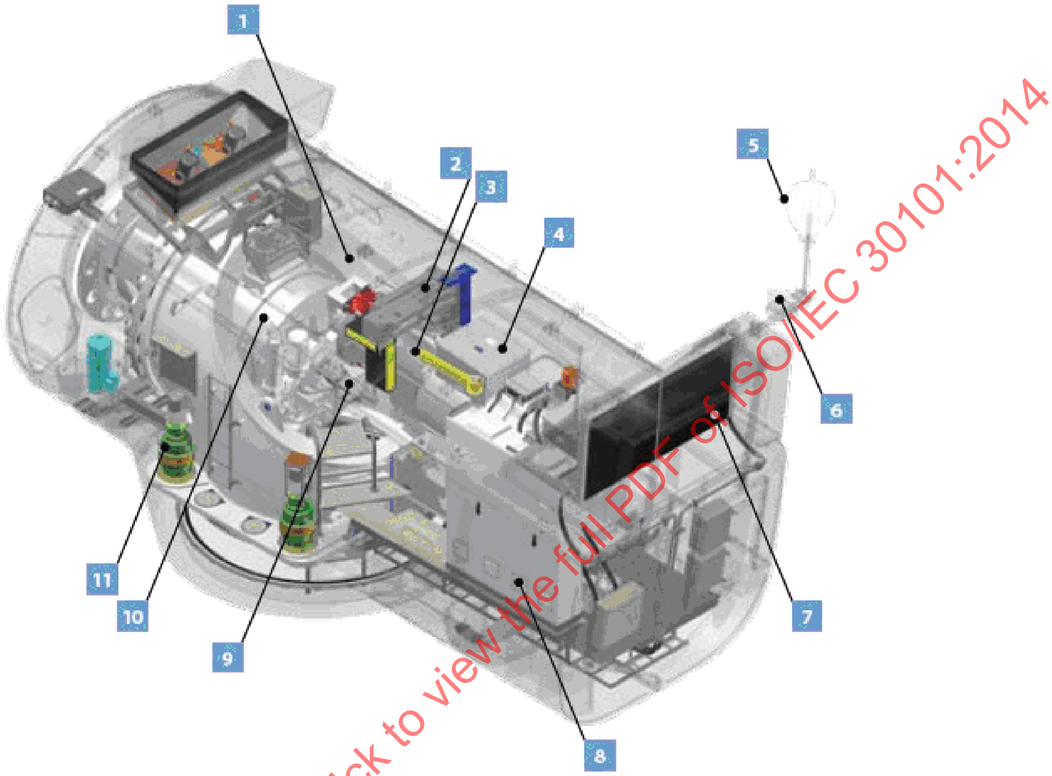


Figure 7 — Configuration of a DFIG system

Wind power systems are standardized by using a common model referring IEC 61400-25-2, as shown in Figure 8. Various Sensors to monitor main part (generators, gears, shafts etc.) are installed in wind power system.

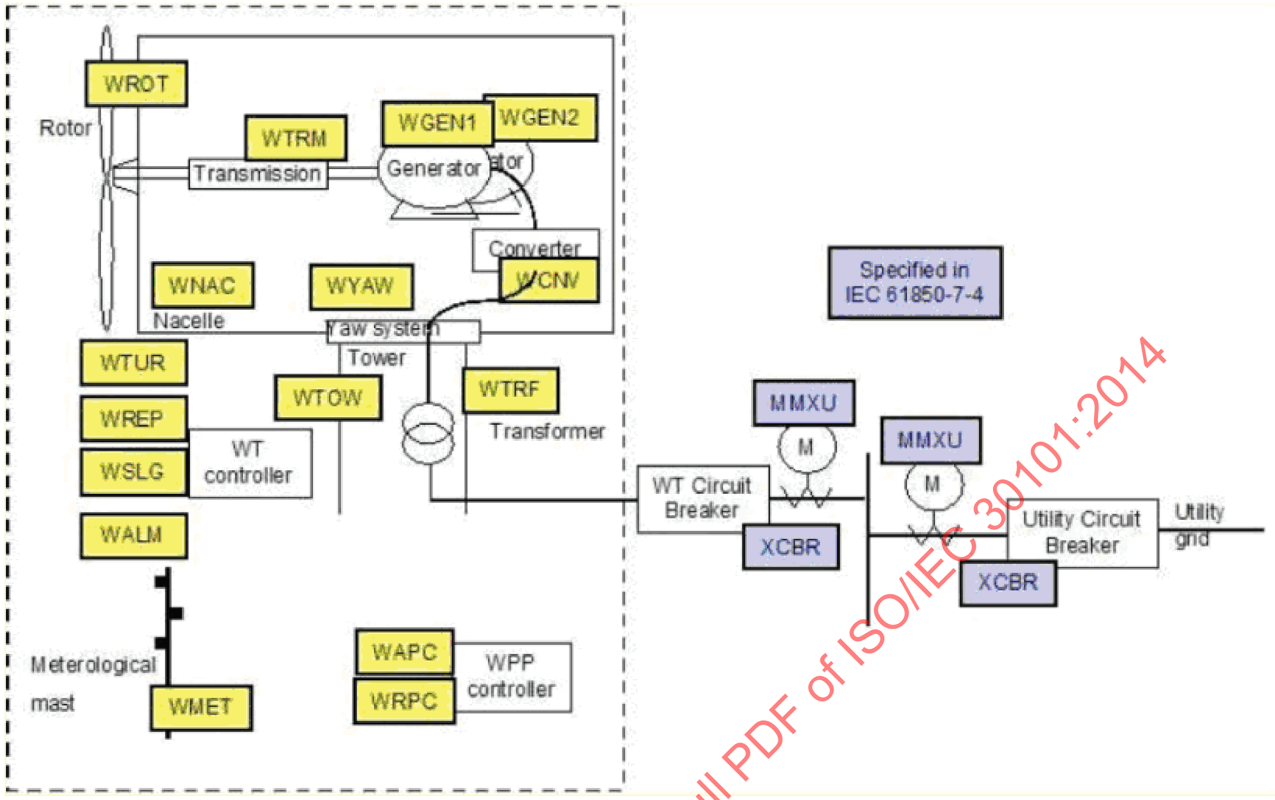


Figure 8 — Wind power systems common model referring IEC 61400-25-2

The information models for wind power plant are defined as follows:

Information Models	Description
WTUR	Wind turbine general information
WALM	Wind power plant alarm information
WMET	Wind power plant meteorological information
MAPC	Wind power plant active power control information
WROT	Wind turbine rotor information
WTRM	Wind turbine transmission information
WGEN	Wind turbine generator information
WCNV	Wind turbine converter information
WTRF	Wind turbine Transformer information
WNAC	Wind turbine nacelle information
WYAW	Wind turbine yawing information
WTOW	Wind turbine tower information
WSLG	Wind turbine state log information
WALG	Wind turbine analogue log information
WREP	Wind turbine report information

In order to perform the wind turbine condition monitoring, appropriate sensors are required as shown in Table 5. The sensors required to monitor the health of the wind power generation system.

Table 5 — Sensors required for wind turbine condition monitoring

Sensor Types	Sensor Location	Roles Description
Temperature sensor	WROT	In the rotor hub
	WRTM	Measured temperature of shaft bearing
		Measured temperature of shaft bearing2
		Measured temperature of Gearbox oil
		Measured temperature of shaft bearing
	WGEN	Temperature measurements for generator stator
		Temperature measurements for generator rotor
		Temperature measurements for inlet air/water temperature at generator
	WCNV	Temperature inside the converter
		Converter — Generator side temperature
		Converter — Grid side temperature
	WTRF	Transformer temperature on turbine side
		Transformer temperature on grid side
	WNAC	Temperature outside nacelle
		Temperature inside nacelle
	WYAW	Yawing motor/gear temperature
	WMET	Meteorological altitude 1 — Temperature
Humidity Sensor	WNAC	Humidity inside nacelle
	WTOW	Humidity inside tower
	WMET	Meteorological altitude 1 — Humidity
Pressure sensor	WROT	Pressure of hydraulic pitch system for blade 1(reference)
		Pressure of hydraulic pitch system for blade 2
		Pressure of hydraulic pitch system for blade 3
	WTRM	Gear oil pressure
		Hydraulic pressure for shaft brake
	WYAW	Yaw brake pressure
	WMET	Meteorological altitude 1 — Pressure
Vibration sensor	WTRM	Measured gearbox vibration of gearbox 1
		Measured gearbox vibration of gearbox 2

Table 5 *(continued)*

Sensor Types	Sensor Location	Roles Description
Voltage sensor	WGEN	Generator stator 3 phase phase-to-phase voltage
		Generator stator 3 phase phase-to-ground voltage
		Generator rotor 3 phase phase-to-phase voltage
		Generator rotor 3 phase-to-ground voltage
	WCNV	Generator side 3 phase phase-to-phase voltage
		Generator side 3 phase-to-ground voltage
		Grid side 3 phase phase-to-phase voltage
		Grid side 3 phase-to-ground voltage
	WTRF	Transformer turbine side 3 phase phase-to-phase voltage
		Transformer turbine side 3 phase-to-ground voltage
		Transformer grid side 3 phase phase-to-phase voltage
		Transformer grid side 3 phase-to-ground voltage
Current sensor	WGEN	Generator stator 3 phase current
		Generator rotor 3 phase current
	WCNV	Generator side 3 phase current
		Grid side 3 phase current
	WTRF	Transformer turbine side 3 phase current
		Transformer grid side 3 phase current
Wind direction sensor	External	Monitor external environment
Wind speed sensor	External	Monitor external environment

7.2.1.4 Sensors on Solar Cells for Solar Generation

Solar generation system consists of PV array, inverter, and meter, as shown in Figure 9. Sensors are applied to the solar generation system for using measurement operating current/voltage and increase efficiency as shown in Table 6.

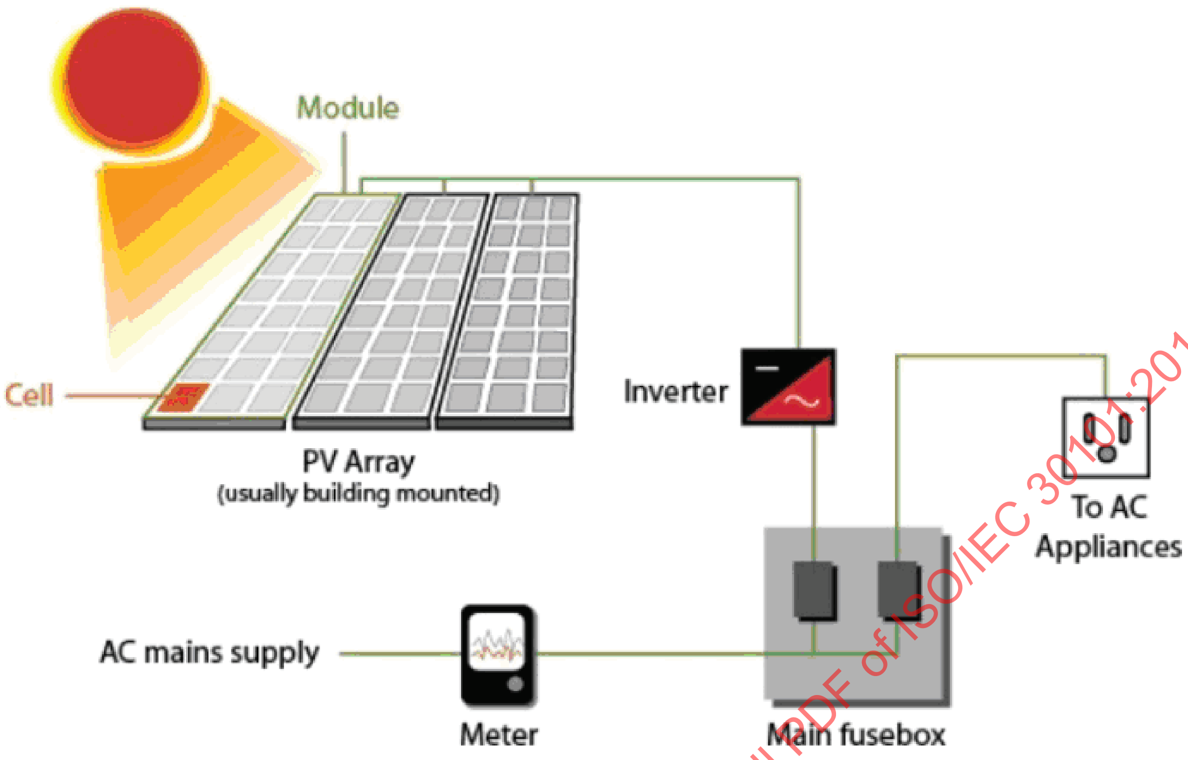


Figure 9 — Configuration of solar generation system

Table 6 — Sensors required for solar cell operation

Sensor Types	Roles Description
Sensors for monitoring operation property	
Current Sensor	Measure the operating current
Voltage Sensor	Measure the operating voltage
Sensors for increase the energy efficiency	
Azimuth Tracking Sensor	Tracking the azimuth of solar cell
Elevation Tracking Sensor	Tracking the elevation of a solar cell

7.3 Sensors in Transmission Domain

7.3.1 Sensors in Transmission

Sensors are installed on equipment in the transmission entities, and they are listed below per equipment, e.g., underground line, overhead line, steel tower, etc. Where possible, a brief description of each sensor is provided.

7.3.1.1 Sensors on Underground Lines

There are two major types of under-ground lines (or cables). Cross-linked polyethylene insulated (XLPE) Cable has two major parts, core and jacket. Core is usually made of metal to carry electricity. On the other hand, jacket is made of XLPE to insulate the core from surroundings electrically. Several methodologies have been applied to construct a cable terminal. A prefabrication method is one of the most popular ways to construct a cable terminal. It provides easy construction as well as superior insulation. Oil immersion method is another one that used to be applied for high voltage cables. It is superior in terms of insulation. Other methods include taping method, plugging-in method and semi-prefabrication method. Cables are connected using the same methods as for terminal. Oil Filled (OF) Cable have oil that is filled between core wire and jacket in this type of cables. This means that supervision of OF cable is same as or similar to that for oil in power transformer.

Sensors to monitor for underground cables (UGCs) are shown in Figure 10 along with the oil filled cable, providing the sensor data to a monitoring system in substations.

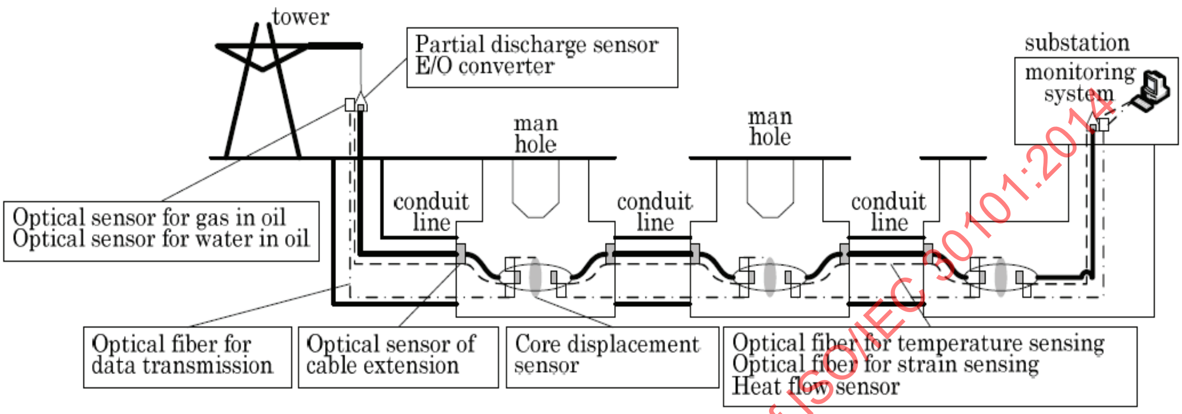


Figure 10 — An online system monitoring Oil Filled (OF) cable conditions.

The following monitoring are required for the underground cable health monitoring::

— Thermal aging monitoring;

— Cable parts cracking monitoring;

— Insulation aging monitoring;

— Water-tree monitoring;

— Earth fault without circuit breaker trip monitoring;

— Oil aging monitoring; and

— Oil leak monitoring.

In order to perform the underground cable health condition monitoring, appropriate sensors are required as shown in Table 7.

Table 7 — Sensors required to monitor the health of the underground cable.

Sensor Types	**Roles Description**
Sensors for monitoring thermal aging	
Temperature sensor	Measure temperature on cable surface. It could measure temperature at one point, or multiple points.
Sensor for monitoring cable parts cracking	
Position sensor	Measure how long a cable is displaced from a reference point.
Sensor for monitoring insulation aging	
Partial discharge sensor	Measure partial discharge from a cable.
Voltage sensor	Measure voltage applied to a conductor.
Current sensor	Measure current applied to a conductor.
Sensor for monitoring water-tree	

Table 7 *(continued)*

Sensor Types	Roles Description
Current sensor	Measure harmonic current on cable surface.
Sensor for monitoring earth fault without circuit breaker trip	
Current sensor	Measure zero-phase-sequence current
Voltage sensor	Measure zero-phase-sequence voltage
Sensor for monitoring oil aging	
Gas sensor	Measure density of a particular gas.
Sensor for monitoring oil leak	
Oil pressure sensor	Measure pressure of oil injected into a cable.
Oil level sensor	Measure oil level in a tank.

7.3.1.2 Sensors on Overhead Lines

Transmission line (TL) condition monitoring leading to preventive diagnostics requires sensors. The sensors can be clustered as shown in Figure 11. This figure depicts the general TL Condition Monitoring & Diagnosis (CMD) functionalities in hierarchy. The overhead transmission line (OHTL) condition information can be grouped as line condition information, tower condition information, insulator condition information, meteorological information, and other material information for line and tower.

The line condition information is line current and direction, line temperature, line slope, and location information.

The tower condition information includes the tension, the amount of earth rod corrosion, the inclination, the vibration, meteorological condition at the time, and tower material information. The insulator condition information is the corona, the insulator leakage current and acoustic properties.

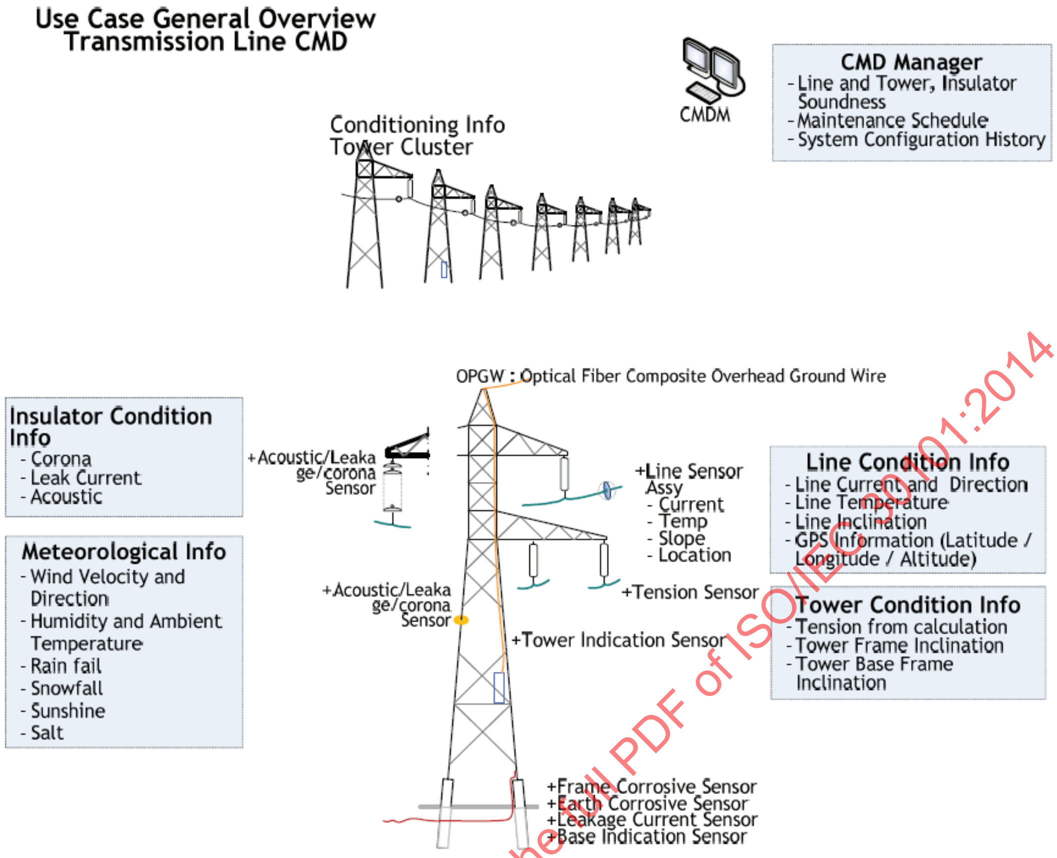


Figure 11 — Example configuration of overhead transmission line (OHTL) tower cluster.

The TL sensor unit collects the line current and direction, line temperature, inner ambient temperature, direction and velocity of the wind, line slope, and GPS information. Figure 12 shows the component of the line sensor unit.

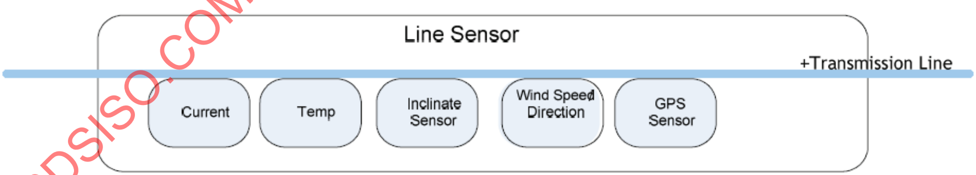


Figure 12 — Line sensor unit.

The health condition monitoring of the overhead transmission line requires sensors. These sensors and their role in condition monitoring are listed in Table 8.

Table 8 — Sensors required for the overhead transmission line health condition monitoring.

Sensor Types	Roles Description
Sensors for monitoring line condition	
Line Sensor	Measure line current, current direction, temperature, and slope and send them to the line condition server.
Meteorological Sensor	Measure wind velocity/direction, humidity, ambient temperature, snowfall, and insolation.

Table 8 *(continued)*

Sensor Types	Roles Description
Phasor Measurement Sensors (PMUs)	PMUs measure voltage, current and frequency and time stamp these readings using GPS before sending them to control centres.
Sensors for monitoring tower conditions	
Meteorological Sensor	Provide wind velocity/direction, rainfall, and snowfall.
Tension Sensor	Provide tension from load cell between transmission line and tower.
inclination Sensor	Provide slope data of inclination sensor.
GPS sensor	Provide the predefined setting value for tower. The predefined data are length between tower, tower type, tower metal quality, tower weight, etc.
Sensors for monitoring insulator condition	
Meteorological Sensor	Provide wind velocity/direction, humidity, ambient temperature, rainfall, snowfall, and salt.
Partial Discharge Sensor	Provide PD data (acoustic, UHF)
Temperature sensor	Provide insulator temperature
Current leakage sensor	Provide current leakage data
Sensors for monitoring surround areas of the tower	
Fire Sensor	Detect fire around tower.
Image Sensor	Capture surrounding area image

7.3.1.3 Sensors on Steel Tower

The tower condition information includes tension, amount of earth rod corrosion, inclination, vibration, meteorological conditions, and tower material information. The insulator condition information includes corona, insulator leakage current and acoustic properties. To provide this condition information, many types of sensors on the steel tower as shown below, but not limited to:

— Wind direction and speed sensor

— Solar irradiance sensor

— External temperature and humidity sensor

— Still image sensor

— Rain detector sensor

— UV sensor

— Line tension sensor

— Current/temperature/gradient sensor

— Tower slope measurement sensor

— Current transformer for leakage current

— CDS (optic) sensor

7.3.2 Sensors in Substation

Sensors are installed on equipment in the substation entity, and they are listed below per equipment, e.g., gas insulated switchgear, main transformer, power transformer, on-load tap changer. Where possible, the brief description of the sensors is provided.

7.3.2.1 Sensors on Gas Insulated Switchgear

A Gas Insulated Switchgear (GIS) is power equipment for disconnecting the power lines from the power grid when occurs the fault or maintenance of power lines. The GIS consists of several components such as circuit breakers (CB), disconnector switches (DS), earthing switches (ES) and instrument transformers. All high voltage parts are encapsulated in separate compartments that contain an insulating medium. Typically this insulating medium is SF_6 or gas mixture.

A condition monitoring system for GIS acquires condition data from sensors that are installed at the different GIS components. Figure 13 shows the typical GIS. Table 9 lists the sensors associated with monitoring the insulating medium, e.g.,SF6 or other gas mixture, in GIS.

Figure 13 — Typical gas insulated switchgear.

Table 9 — Sensors attached to gas insulated switchgear.

Sensor Type	Role Description
Sensors for monitoring insulating gas, e.g., SF6 or other gas mixture	
Gas Sensor	Measure the pressure and temperature inside a gas compartment of the GIS. Density calculation is performed by the sensor itself or by the IED's.
Partial Discharge (PD) Sensor including Ultra High Frequency (UHF) Sensor and Ultrasound Sensor	Include UHF Sensor and Ultrasound Sensor, and the PD Sensor measures the phi-q-N for partial discharge inside a gas compartment of the GIS. UHF Sensor measures the PD activity using the UHF signal treatment. As the UHF Sensor is fitted on a compartment, the UHF signal localization is not directly associated with compartment. UHF Sensor is used for noise background measurement. Ultrasound Sensor is for the Partial Discharge localization
Other sensors	Depending on the technology additional sensors can be used Measures the moisture / SO2, etc.
Sensors for monitoring circuit breakers for abrasion	
Primary current sensor	Measure the primary current flow through main contacts of the circuit breaker
Travel sensor	Measure the movement of the main contact of the circuit breaker
Other sensors	Depending on the technology additional sensors can be used.

Table 9 *(continued)*

Sensor Type	Role Description
Sensors for monitoring switches	
Switch	Signalize the switch position to the monitoring system
Travel sensor	Measure the movement of the switch
Other sensors	Depending on the technology additional sensors can be used.
Sensors monitoring the operating mechanism of GIS	
Energy sensor	Measure the remaining energy in the operating mechanism. Typical operating mechanisms today use spring- or hydraulics- (gas-) based energy storage.
Hydraulic Level sensor	Measure the hydraulic level inside the operating mechanism. Hydraulics can be used either to transfer energy from energy storage to the main contact or to realize the energy storage itself
Hydraulic Temperature Sensor	Measure the temperature of the hydraulic
Motor Current Sensor	Measure the current of: (a) the charging motor for the energy storage or (b) the drive motor
Humidity Sensor	Measure the humidity
Switch Position	Indicate the position of the connected switch
Sensors for monitoring POW switching controller	
Coil Voltage Sensor	Measure the voltage of the CB coil
Hydraulic Pressure Sensor	Measure the hydraulic pressure inside the operating mechanism
Drive Temperature Sensor	Measure the temperature of the drive
Switch Position Sensor	Indicate the time of the last position of the connected switch

7.3.2.2 Sensors on Power Transformer

A power transformer is in fact a complex system, and a typical power transformer is shown in Figure 14. Special conductors isolated with special paper are used for the windings; the core is laminated to reduce losses: a cooling system is necessary to maintain operation on high loads and high temperature; and oil is normally used as insulation means as well as a cooling means. Fans and pumps are also used to cool and circulate the oil. Bushings are used to provide external connections to the various voltage levels.

Many different types of sensors are installed for protection and monitoring of the transformer. These sensors monitor the power transformer's condition states. The types of monitoring of the power transformer include:

— Monitoring of dissolved gas and moisture in oil;

— Partial discharge (PD) monitoring;

— Temperature monitoring;

— Solid insulation monitoring;

— Bubbling temperature monitoring;

— Busing monitoring;

— Cooling monitoring; and

— Ancillary sensor monitoring.

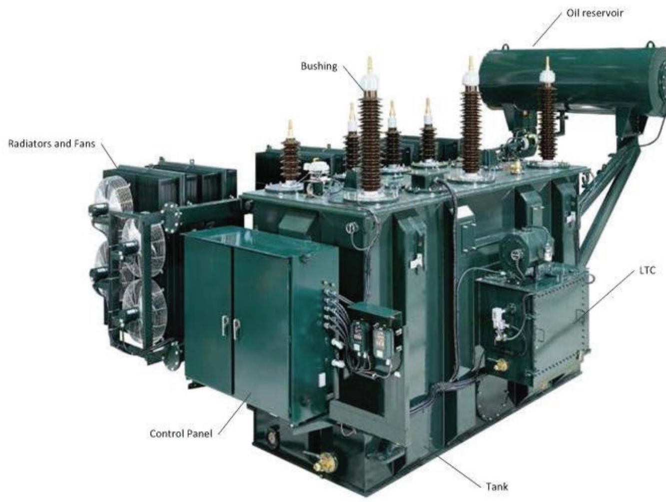


Figure 14 — Typical power transformer.

Dissolved Gas Analysis (DGA) is considered by most transformer experts as the single most important technique for condition monitoring and diagnostics in transformers. It detects problems mainly in the core and coil components of the transformer. Online DGA is now very popular and adopted worldwide for transformers ranging from large generator step-up (GSU) to smaller distribution. Several manufacturers offer products that measure from a single key gas to all combustible gases. A good percentage of online DGA analysers available also measure relative humidity. Change rate of gas concentrations is considered a very important indicator for the health of power transformer. Table 10 shows the sensors associated with the power transformers health condition monitoring and diagnostics.

Table 10 — Sensors attached to power transformer.

Sensor Types	**Roles Description**
Dissolved gas sensor	Measure dissolved gas concentration (ranges from one to multiple gases)
Relative humidity (RH) sensor	Measure relative humidity in oil
Oil Temp Sensor	Measure temp of the oil at the location of the humidity sensor
Sensor for monitoring partial discharge	
Partial discharge sensor (PD) Sensor including Ultra High Frequency (UHF) Sensor and Ultrasound Sensor	Include UHF Sensor and Ultrasound Sensor, and the PD Sensor, and measure partial discharge in the transformer UHF Sensor measures the PD activity using the UHF signal treatment. As the UHF Sensor is fitted on a compartment, the UHF signal localization is not directly associated with compartment. UHF Sensor is used for noise background measurement. Ultrasound Sensor is for the Partial Discharge localization
Sensors for monitoring power transformer temperatures	
Direct winding temp sensor	Measure winding temperature directly (Fibre Optic temp sensors)
Load current sensor	Measure the transformer load current
Top oil temp sensor	Measure the transformer oil temperature at the top of the tank
Bottom oil temp sensor	Measure the transformer oil temperature at the bottom of the tank
Sensors for monitoring solid insulation aging	
Bottom oil temp	Measure the oil temperature at the bottom of the tank
Relative humidity (RH) sensor	Measure relative humidity in oil
Oil temp sensor	Measure temp of the oil at the location of the humidity sensor
Winding hot spot temp	Measured or calculated, it is the temperature of the hottest point of the transformer winding (see Temperature supervision use case)

Table 10 *(continued)*

Sensor Types	Roles Description
Sensors for monitoring bubbling temperature	
Relative humidity (RH) sensor	Measure relative humidity in oil
Oil temp sensor	Measure temp of the oil at the location of the humidity sensor
Winding hot spot temp	Measured or calculated, it is the temperature of the hottest point of the transformer winding (see Temperature supervision use case)
Sensors for monitoring bushing	
Current sensor	Measure bushing leakage current
Voltage sensor	Measure bushing voltage from capacitive coupler
DDF and PD sensor	Measure insulation degradation
Sensors for monitoring cooling	
Load current sensor	Measure the transformer load current
Ambient temp sensor	Measure ambient temperature
Top oil temp sensor	Measure the transformer oil temperature at the top of the tank
Cooling bank status sensor	Digital sensor that detects if a cooling bank is in operation
Pump/fan current sensor	Measure the pump/fan current
Other sensors for monitoring power transformers	
Buchholz relay	Relay that detects sudden pressure and gas accumulation. It is not a predictive sensor
Oil level sensor	Measure the level of the oil to monitor oil leaks
Pressure sensor	Measure pressure to detect leaks or expansion of gases
Conservator membrane rupture detector	Detect a rupture in the membrane of the conservator

7.3.2.3 Sensors on On-Load Tap Changer (LTC)

A tap-changer is frequently used in generation and transmission transformers to vary the ratio of turns from primary to secondary with the aim of voltage regulation. There are different types of tap-changers, some internal to the transformer and some external. Thus, the tap-changer (LTC) is a device for changing the tap of a winding, suitable for operation while the transformer is energized or on load. The structure of load tap changer is shown in Figure 15 and described below:

— Diverter switch: Switching device used in conjunction with a tap selector to carry, make or break currents in circuits which have already been selected.

— Tap selector: Device designed to carry, but not to make or break, current, used in conjunction with a diverter switch to select tap connections.

— Change-over selector: Device designed to carry, but not to make or break, current, used in conjunction with the tap selector or selector switch to enable its contacts and the connection taps to be used more than once when moving from one extreme position to the other.

— Motor drive mechanism: Driving mechanism which incorporates an electric motor and a control circuit.

— Oil filter unit: Device purifying insulated oil.

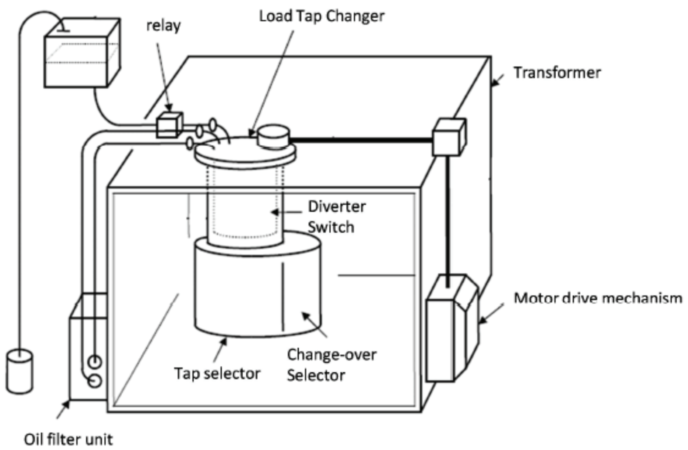


Figure 15 — Structure of load tap changer.

The following types of monitoring are needed for Load Tap Changer (LTC) health condition status and monitoring:

— Operation property monitoring;

— Operational count monitoring;

— Contact abrasion monitoring;

— LTC oil temperature monitoring; and

— Operation of oil filter unit monitoring.

Table 11 shows the sensors associated with the LTC health status and condition monitoring.

Table 11 — Sensors attached to Load Tap Changer.

Sensor Types	Roles Description
Sensors for monitoring operation property	
Motor-driving current sensor	Measure the motor driving current.
Torque sensor	Measure the drive torque.
Dial switch	Indicate tap position of LTC.
LTC operation signal Sensor	Detect start/end time of LTC operation.
Sensors for monitoring operational count	
LTC operation signal Sensor	Detect start/end time of LTC operation.
Sensors for monitoring contact abrasion	
Load Current Sensor CT embedded in bushing)	Measure load current.
LTC operation signal sensor	Detect start/end time of LTC operation.
Sensors for monitoring LTC oil temperature	
LTC oil temperature sensor	Measure temperature of LTC oil.
Transformer oil temperature sensor	Measure temperature of Transformer oil.
Sensors for monitoring operation of oil filter unit	
Oil Filter Unit OFU) operation signal sensor	Detect start/end time of OFU operation.

7.4 Sensors in Distribution Domain

Sensors are installed on equipment in the distribution entities, and they are listed below per equipment, e.g., Power Transformer, Insulated Load Break Switch, distribution line, etc. Where possible, a brief description of each sensor is provided.

7.4.1 Sensors on Distribution Transformer

Distribution Transformer is two types of single-phase and three-phase. The primary voltage (High Voltage 22.9kv) of transformer supplied from the substation is converted into the secondary voltage (Middle Voltage 110v ~ 380v) used by the customer. Capacity is divided into 2 ~ 133kVA. Structure is the box that is made of steel sheet and put the equipment which is consist of the core and windings in the box. The core and windings is in the oil tank to withstand a high voltage.

Materials and structures are as follows:

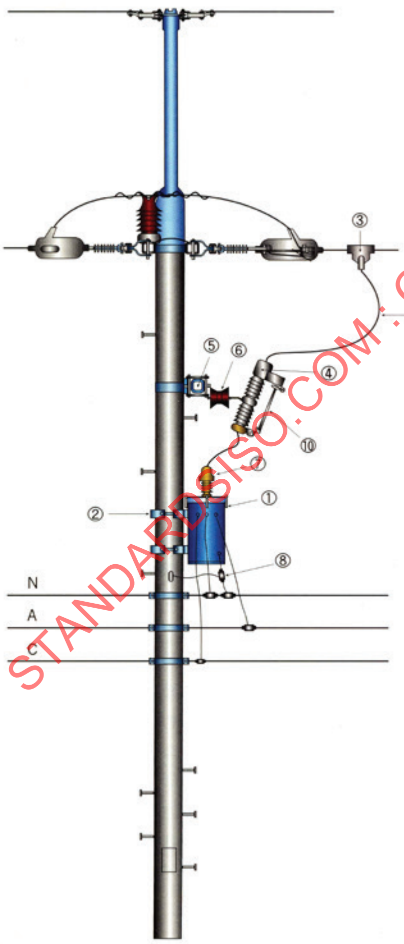
— Iron Core : Silicon steel sheets(Silicon content : 3~4%, Thick : 0.35mm)

— Conductor : Cotton yarn and using paper tape and glass fibre is composed of cooper

— Insulators : Insulation between the core and windings, Insulation between the windings and windings,

Insulation between the windings and the layer

The structure of Distribution Transformer is shown in Figure 16 and described below:



①Distribution Transformer
- Normal Pole mounts Type Transformer
- Low-loss Pole mounts Type Transformer
- Amorphous Pole mounts Type Transformer
- Self -Diagnosis Pole mounts Type Transformer
- Built-in protection Pole mounts Type Transformer
- High Voltage Pole mounts Type Transformer

②Pole Transformer Hanger Band

③Chain branching + Online Clamp/Cover

④High Voltage Cut -out Switch(25㎸ COS)

⑤Bracket

⑥Insulators

⑦Busing Terminal Cover

⑧Earth Line Service Connector

⑨High Voltage Insulated Wire

⑩Cut-Out Fuse Link

Figure 16 — Structure of pole mounts type distribution transformer & pole.

The following types of monitoring are needed for Distribution Transformer health condition status and monitoring:

— Operation Voltage monitoring

— Operation Current monitoring

— Operation oil Temperature monitoring

— Oil Status monitoring(Carbon Nanotube)

— Operation property monitoring: Voltage Range (AC 0 ~ 300V), Current Range (AC 0 ~ 1,000A), Accuracy(±1%)

— Transformer oil temperature monitoring: Temp Range(0° ~ 150°), Accuracy(±3°C)

— Operation of oil Degradation monitoring: Insulation oil deterioration degree measured by an electrochemical method(The adsorption properties of CNT(Carbon Nano Tube) using ion conductance is measured)

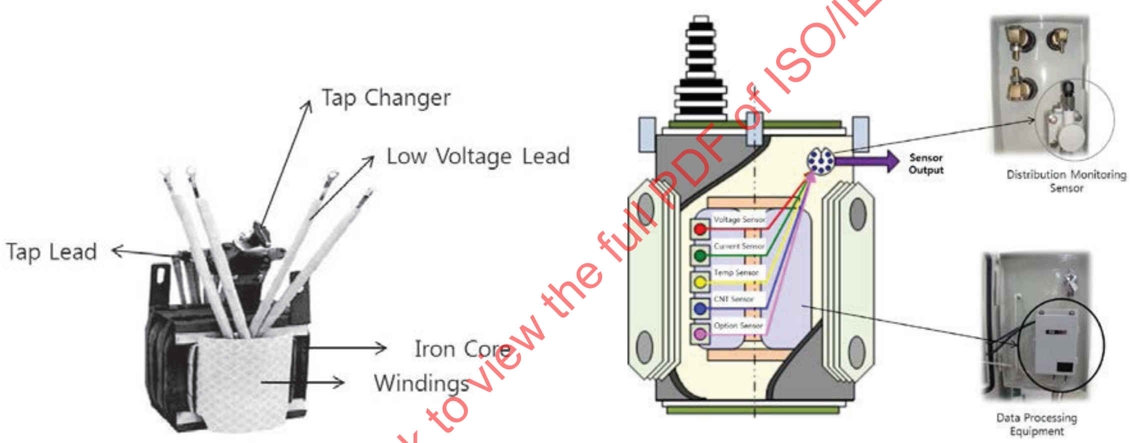
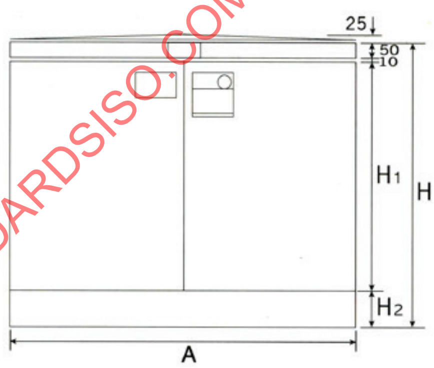


Figure 17 — Structure of pole mounts type distribution transformer.



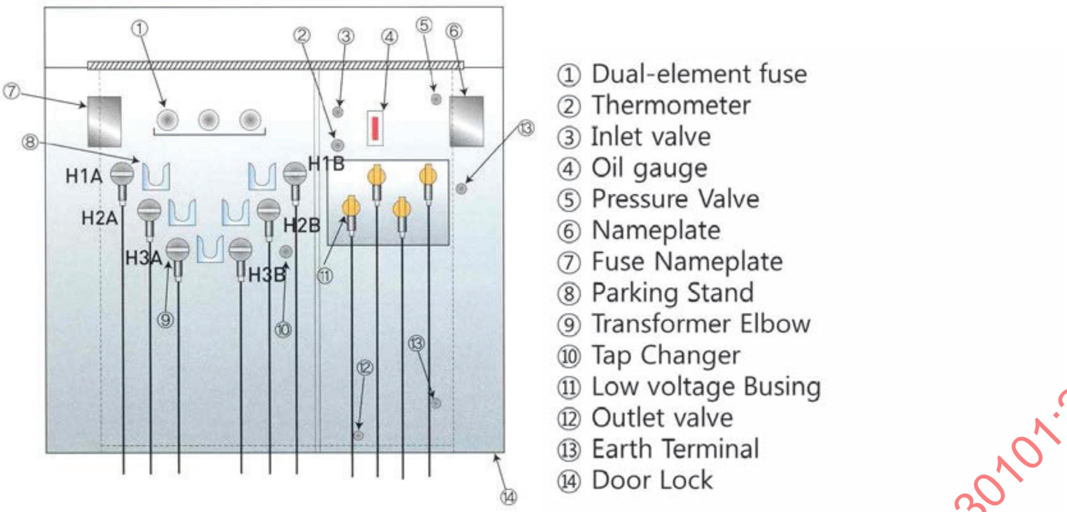


Figure 18 — Structure of ground mounts type distribution transformer.

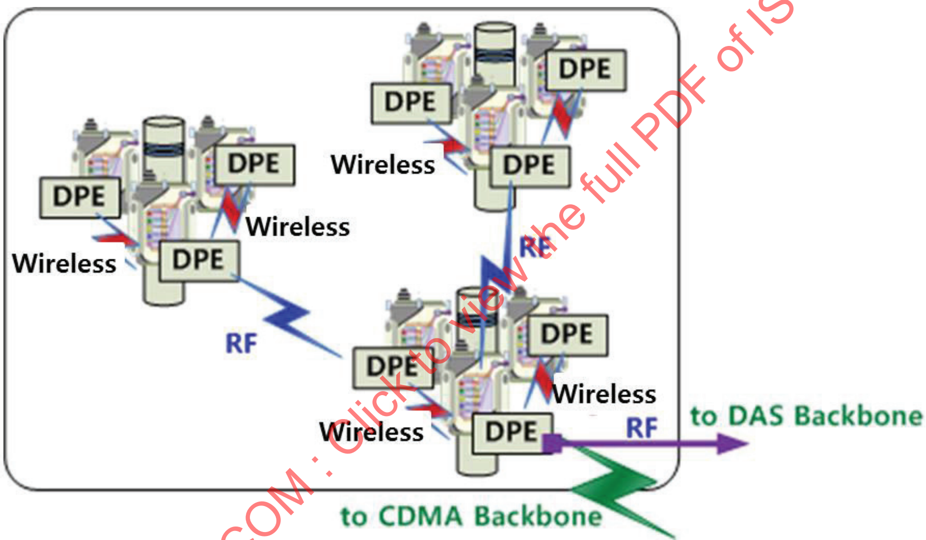


Figure 19 — Sensor and monitoring system of distribution transformer — Distribution Automation System (DAS) and Data Processing Equipment (DPE)

Table 12 shows the sensors associated with the distribution Transformer health status and condition monitoring.

Table 12 — Sensors attached to distribution Transformer.

Sensor Types	Roles Description
Sensors for monitoring operation property	
Current Sensor	Measure the distribution Transformer current.
Voltage Sensor	Measure the distribution Transformer Voltage
Sensors for monitoring Transformer oil temperature	
Transformer oil temperature sensor	Measure temperature of Transformer oil.
Sensors for monitoring operation of oil Degradation	
Oil Degradation sensor	Detect Oil Degradation of Transformer

7.4.2 Sensors on Insulated Load Break Switch

Load break switch is installed on distribution lines. Load break switch is two types of load switch that be operated (on-off) remotely though the communication network in case of the fault recovery, the suspension of power, load shedding etc and reclosing switch that remove the fault on the distribution lines. Load break switch is divided into SF6 gas type and polymer type for isolation strength and is divided into overhead type and underground type by installation location.

Main part of the device is as follows:

— Manual Operating mechanism : Operating of High Voltage COS Operating rod

— Switch Lock : Protection erroneous operation

— Operation Status Indicator : Indication of Pole/Underground Switch status

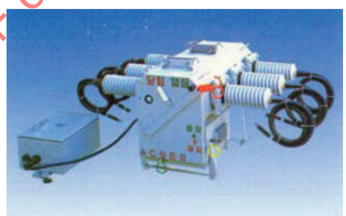
— Pressure Low Indicator : Switch to prevent accidents caused by GAS pressure low

— GAS discharge device : Prevent explosion caused by gas pressure rise

— Bushing : The lead wire connection structure of a manner preventing moisture penetration

The structure of Distribution Transformer is shown in Figure 20 and described below:

Polymer Insulated Load Break Switch (2way)



SF6 Gas Insulated Load Break Switch (2way)

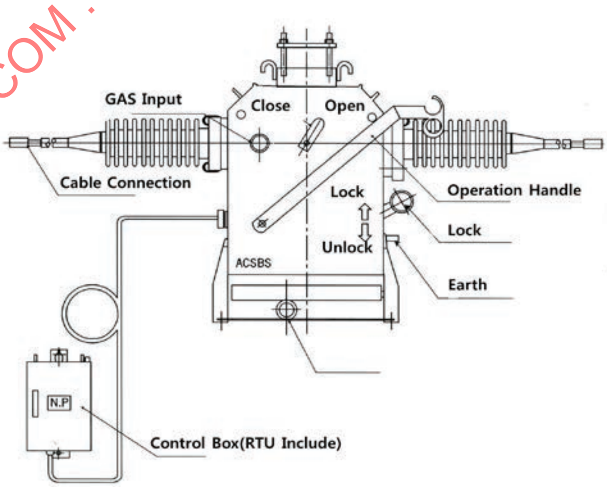


Figure 20 — Structure of insulated load break 2-way switch (overhead type).

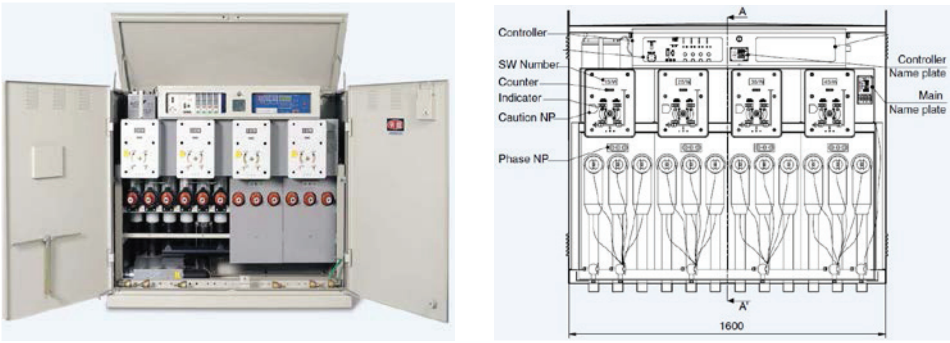


Figure 21 — Epoxy insulated load break 4-way switch (Underground type).

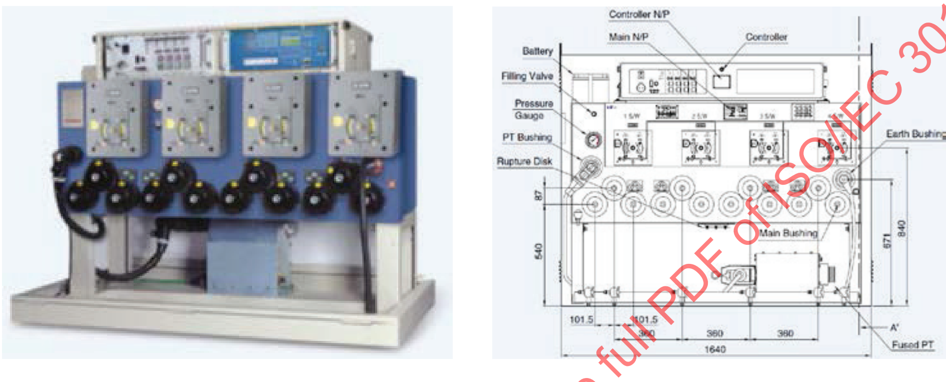


Figure 22 — SF6 gas insulated load break 4-way switch (underground type).

The following types of monitoring are needed for Insulated Load Break Switch health condition status and monitoring:

— Operation Voltage & Current monitoring;

— Operation Temperature monitoring;

— Operation Ultra Sound monitoring

— Operation Thermal Imaging monitoring

— Operation Gas Pressure/Pressure Wave monitoring

— GAS Status monitoring.(Carbon Nano Tube)

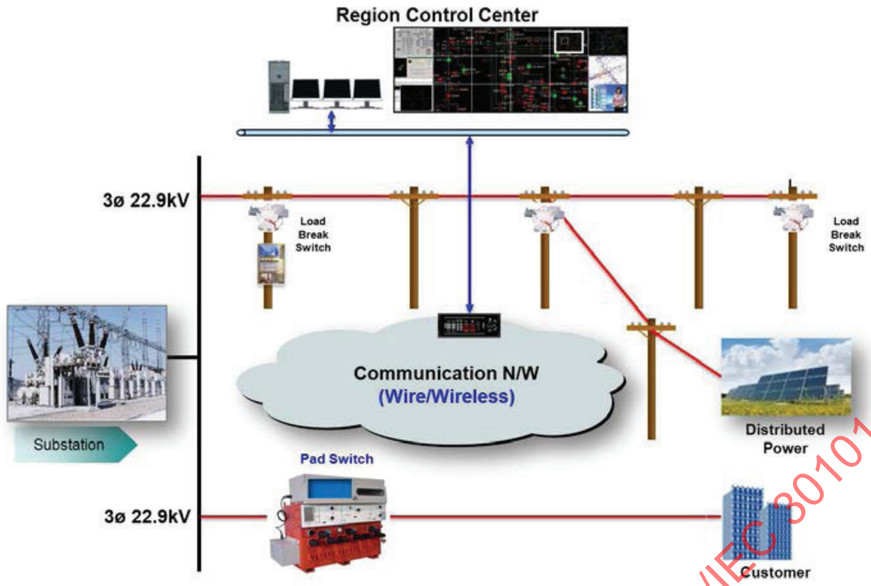


Figure 23 — Monitoring and control system of distribution management system.

Table 13 shows the sensors associated with the Insulated Lord Break Switch health status and condition monitoring.

Table 13 — Sensors attached to distribution Transformer.

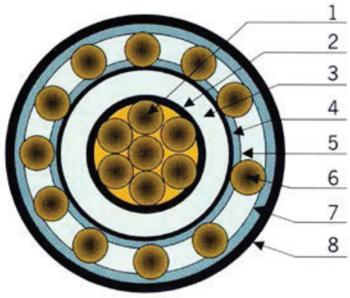
Sensor Types	**Roles Description**
Sensors for monitoring bushing	
Current sensor	Measure bushing leakage current
Voltage sensor	Measure bushing voltage from capacitive coupler
Sensors for monitoring Insulated Lord Break Switch temperature	
Temperature sensor	Measure temperature of Switch Surface
Sensors for monitoring Insulated Lord Break Switch Health	
GAS Pressure/Pressure Wave	Measure Insulation Strength of Switch and Internal Arc
Thermal Imaging Sensor(IR)	Measure Distribution Temperature of Switch (Breakdown)
Sensors for monitoring operation of SF6 GAS Degradation	
SF6 GAS Degradation sensor	Detect SF6 GAS Degradation of Switch

7.4.3 Sensors on Distribution Power Line

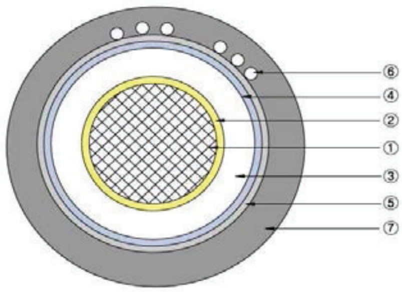
Distribution line supply power which is supplied from the substation to distribution grid and distributed to the low-voltage grid. Distribution line is divided into overhead type and underground type by installation location. Structure of distribution lined is developed such as the step 1: CNCV-W (watertight conductor), step 2: FR-CNCO-W (flame retardant), step 3: TR CNCV-W (suppressed water tree type), step 4 TR CNCE-W/AL (aluminium).

The main configuration and the materials are as follows:

The structure of Distribution Transformer is shown in Figure 15 and described below:



CNCV-W



TR CNCE-W

Figure 24 — Structure of distribution cable.

Table 14 — Structure and material distribution cable

NO	Item	CNCV-W	TR CNCE-W
1	Conductor	Filled circles watertight compression type cooper wire compound	Filled Circular compressed mixture watertight cooper wire
2	Internal semi conductive layer	Semiconducting compound	Black semi-conductive thermoplastic compound
3	Insulating layer	Cross-linked polyethylene compound	Suppressed Water tree Cross-linked polyethylene compound
4	External semi conductive layer	Semiconducting compound	Black semi-conductive thermoplastic compound
5	Neutral watertight layer	Semi-conductive swelling tape	Semi-conductive swelling tape
6	Neutral	Cooper wire	Cooper wire
7	Neutral watertight layer	swelling tape	swelling tape
8	Covering	Black vinyl	Black polyethylene

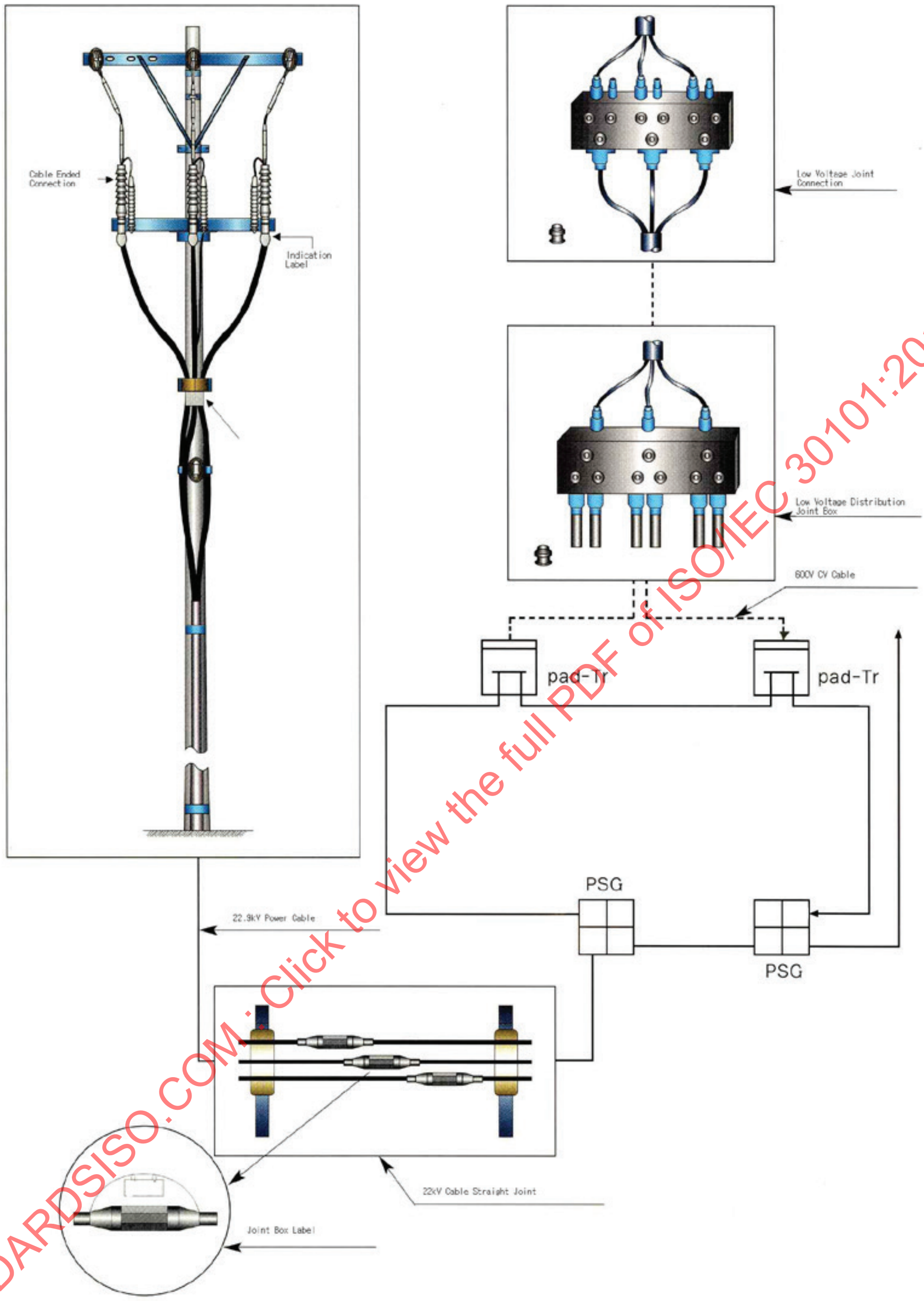


Figure 25 — Structure of distribution cable system (Pole).

Monitoring and diagnosis methods for distribution line are as follows:

a) Insulator that is support the distribution cables occurs coating eliminated, breakdown cause by the potential difference between the bind and the air gap, leakage current increase and partial discharge by micro-cracks. Crack of LP insulator and wire erosion are detected by the ultrasound diagnosis and poor insulation and heat of suspension Insulator are detected by ultrasonic equipment (Sensor) and utilizes thermal imaging diagnosis.

b) Leakage current increase in surface of the body on lightning arrester by water penetration and damage can be detected by the thermal imaging diagnosis.

The following types of monitoring are needed for Distribution Cable System health condition status and preventive inspection

— Operation Voltage & Current monitoring;

— Operation Temperature monitoring;

— Operation Ultra Sound monitoring

— Operation Thermal Imaging monitoring

— Operation Gas Pressure/Pressure Wave monitoring

— GAS Status monitoring.(Carbon Nanotube)

— Partial discharge (PD) monitoring;

— Busing monitoring;

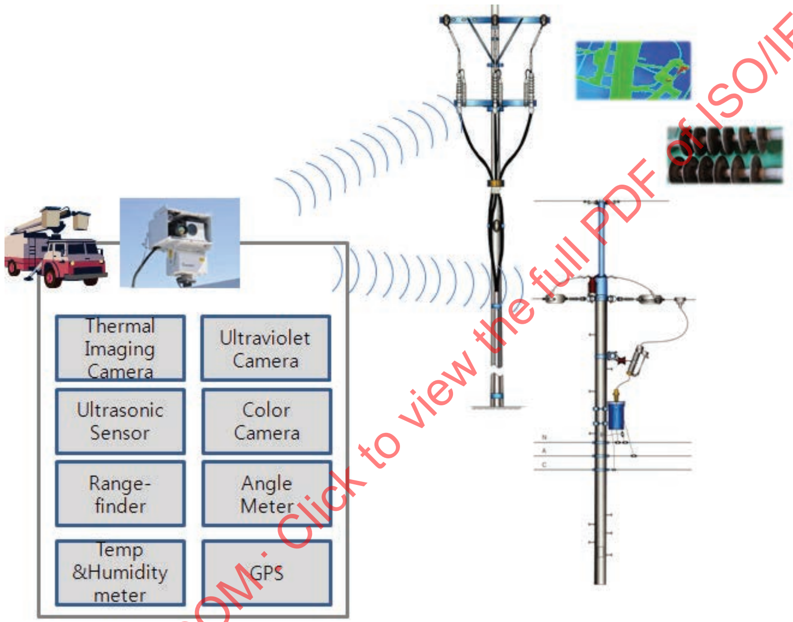


Figure 26 — Status monitoring system of pole type distribution power line.

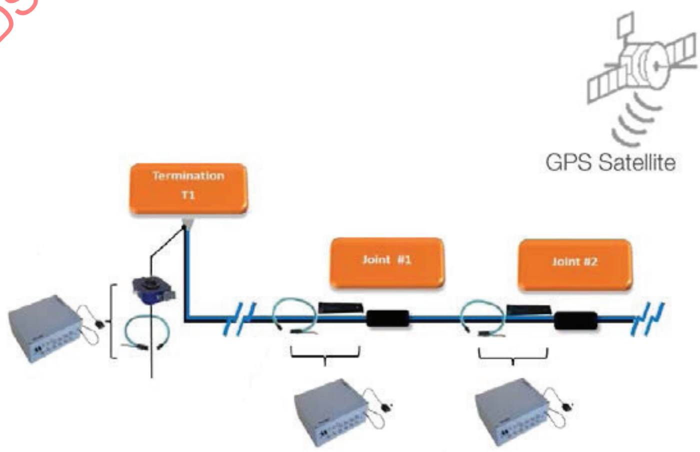


Figure 27 — Partial discharge monitoring system of underground distribution power line.

Table 15 shows the sensors associated with the Distribution Power Line health status and condition monitoring.

Table 15 — Sensors attached to distribution power line.

Sensor Types	Roles Description
Sensors for monitoring operation property	
Ultrasound sensor	COS and insulators for damage such as cracks and is measured
Thermal Imaging sensor	COS, switchgear, such as bushings, and the connection point of the connection failure, and deterioration caused by overheating of the corona is measured
Ultraviolet rays sensor	Bushings and connection point, and cracks due to poor connection with corona are measured
Sensor for monitoring partial discharge	
Partial discharge sensor (PD) Sensor including Ultra High Frequency (UHF) Sensor and Ultrasound Sensor	Include PD Sensor, Ultrasound Sensor and measure partial discharge in the power line joint part. UHF Sensor measures the PD activity using the UHF signal treatment. As the UHF Sensor is fitted on a compartment, the UHF signal localization is not directly associated with compartment. UHF Sensor is used for noise background measurement. Ultrasound Sensor is for the Partial Discharge localization
Sensors for monitoring distribution line temperatures& humidity	
Distribution temp sensor	Measure cable conductor temperature directly (Fibre Optic temp sensors)
Relative humidity (RH) sensor	Measure relative humidity in environment
Sensors for monitoring distribution line	
Current sensor	Measure bushing leakage current
Voltage sensor	Measure bushing voltage from capacitive coupler

7.5 Sensors in Customer Domain

Sensors in the customer domains are the sensors attached to Advanced Metering Infrastructure (AMI) including smart meters. Additionally, sensor node may be installed on electricity appliances, outlets, and switches. Users can retrieve data and control appliances through sensor network. Smart meters may act as sensor network gateways.

8 Networks in Smart Grid Domains

In IEEE 2030's communications technology perspective, the Communication Technology Interoperability Architecture Perspective (CT-IAP) shows a broad set of networks. At a top level view, as in Figure 28 (End-to-end SG Communications Model), a graphical view of the relationship of various networks to the Smart Grid bulk generation, transmission, distribution, and customer domains are provided.

In some cases, multiple names may be used for the same functional subnetwork. For example customer premises networks vary in size and number of connected devices but are typically classified as home-area network (HAN), business-area network (BAN) or Industrial-area network (IAN), and there is a demarcation of these networks from networks used in the distribution domain. Some communication paths are between end-points within the same domain and other communication paths are between domains, and may include a series of subnetworks.

The public internet provides communication capabilities that spans all four of the illustrated domains. However, the implementer (e.g., utility or RTO) may not want to use the public internet or regulators may choose to not allow its use. The use of the public internet remains an architectural alternative. Even though the public internet may not be commonly used, the IEEE 2030 architecture model allows use of the public internet. Use or non-use of the public internet in certain communication paths is left to the implementer.

Figure 28 (End-to-end SG Communications Model) also shows the end-to-end communications security and management layers, cutting across each Smart Grid communication domain. Although the communications security and management architectures are not within the scope of this standard, these architectures shall be developed to support the sensor network for Smart Grid.

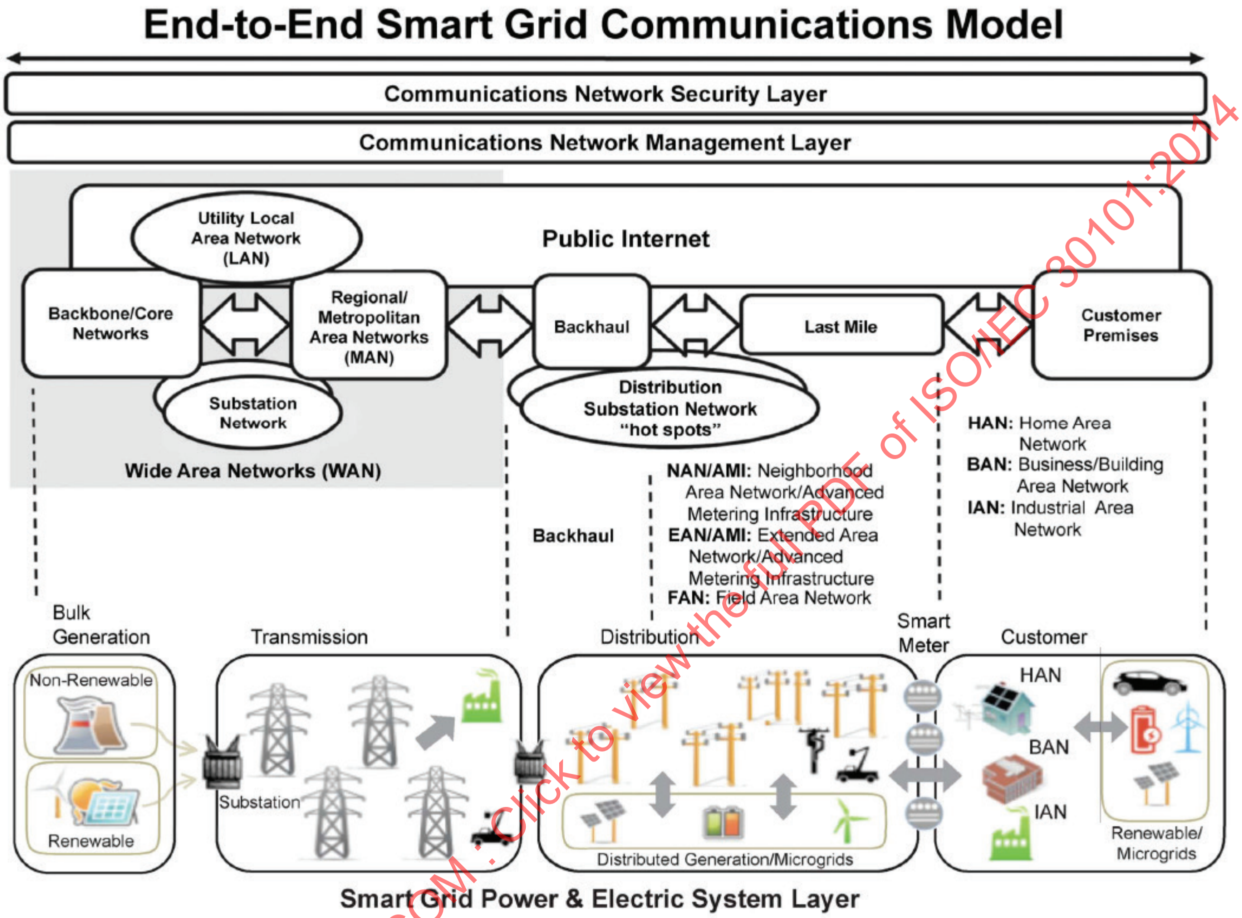


Figure 28 — End-to-end Smart Grid communication model. [from IEEE 2030].

In the CT-IAP depicted in Figure 2 (CT-IAP), numerous networks are identified. The networks found in Figure 2 (CT-IAP) and their descriptions are provided in Table 16.

Table 16 — The description of the networks in Smart Grid.

Backhaul network	Backhaul network connects the utility control/operations, including the AMI enterprise, with the WAN, distribution substation networks, DERs, FAN, NAN distribution access points, etc.
Bulk generation network	A network used within a bulk generation facility that connects to various networks.
Distributed energy resource network	Customer generation and storage systems are connected to customer premises network (HAN, BAN, IAN) through ESIs and/or electric sub-meters, using either wireline and/or wireless networks.

Table 16 *(continued)*

Distribution substation network	Distribution substation network interconnects devices within a distribution substation (e.g., comprised of local area networks that contain SCADA, IEDs, remote terminal units (RTUs), PMUs, and other field devices that needs to be controlled and monitored via the backhaul network). IEC 61850 and /IEEE 1815 (DNP3) [B13] are the protocols of choice for this network.
Energy services interfaces/ Customer premises network	Energy services interfaces (ESI) are a special class of device. It is network-centric and can also be thought of as logical gateways. Customer premises network (CPN) represents HAN, BAN, or IAN.
Feeder Distributed Energy Resources/Microgrid network	Feeder distributed energy resources (DER) network is comprised of all renewable and non-renewable sources (e.g., wind, solar, diesel, etc.), not part of the centralized energy generation. These energy resources could be interconnected through a LAN. Access communications gateways can then connect these DERs and storage LAN networks to the main grid, creating grid-connected energy sources. Utility scale storage energy systems connected at the distribution substation are also considered.
Feeder network	Feeder or distribution network is the communications network overlaid on the electrical grid. It comprises wireless or wireline communications technologies.
Field area network	Field area networks (FAN) connect the distribution substations, the distributed/ feeder (field devices), and distributed energy resources/microgrids, including the utility scale electric storage, to the utility control and operation centre.
Public Internet/Intranet	Internet service providers (ISPs) provide Internet access to the customer premises network. Public internet may be the primary communication path between utility enterprise data centres, market, and third-party energy providers.
Neighbourhood area network	Field area networks (FAN) connect the distribution substations, the distributed/ feeder (field devices), and distributed energy resources/microgrids, including the utility scale electric storage, to the utility control and operation centre.
Other networks	Optical or electronic wireline or wireless networks will play a role in AMI/ NAN networks, DA, substation automation, backhaul, workforce automation, and also on PEV mobile/roaming schemes. Wireless networks can use a variety of radio technologies paging, point-to-point and point-to-multipoint networks, multiple-address radio networks, or satellite links.

9 Sensor Network Architecture Supporting Smart Grid System

9.1 Architecture of Sensor Network and its Interfaces for Smart Grid System

Figure 29 shows the architecture of sensor network and its interfaces supporting Smart Grid, and it illustrates a set of functional entities that realizes various sensor network services for Smart Grid. In the sensor network functional architecture shown in Figure 29, Sensing Domain transports data/information to Service Domain through Local Area Networks, Wide Area Network, and/or other types of networks.

As shown in the figure, there are two main groups responsible for data and information generation: Data, Information, & Communications Group and Control & Management Group within Sensing Domain. Data, Information & Communication Group provides functions such as data acquisition, data storage, data processing (e.g., collaborative processing, data aggregation, feature extraction, data fusion, etc.), data communication (e.g., communication protocol, communication support function, etc.). Control & Management provides functions such as sensing device management, service management, network management, security management. Once data/information is passed to Service Domain, the data/information is processed by the functions such as data mining, information extraction, data fusion and other relevant functions not shown in the figure. Additionally, the data/information can be stored, communicated, and provisioned in Service Domain.

In Annex E, a different representation or view of the architecture in Figure 29 is depicted. The purpose of the architecture representation in Annex E is to map the sensor networks and its interfaces for smart grid system to the Sensor Network Reference Architecture developed in ISO/IEC 29182-5 (Part 5

Interface) showing the interfaces defined in ISO/IEC 29182-5. Although the architecture representation in Annex E does not fully describe the entirety of the sensor network and its interfaces for smart grid systems, it is a useful depiction of the architecture because ISO/IEC 29182-5 provides the reference architectural descriptions and understanding of the interfaces. ISO/IEC 29192-3 (Architecture Views) and ISO/IEC 29182-4 (Entity Models} along with ISO/IEC 29182-5 will provide the complete picture of the sensor network reference architecture developed in the ISO/IEC 29182 International Standard series. Additionally, ISO/IEC 29182-1 (General Overview and Requirements) will provide the general requirement for the sensor networks.

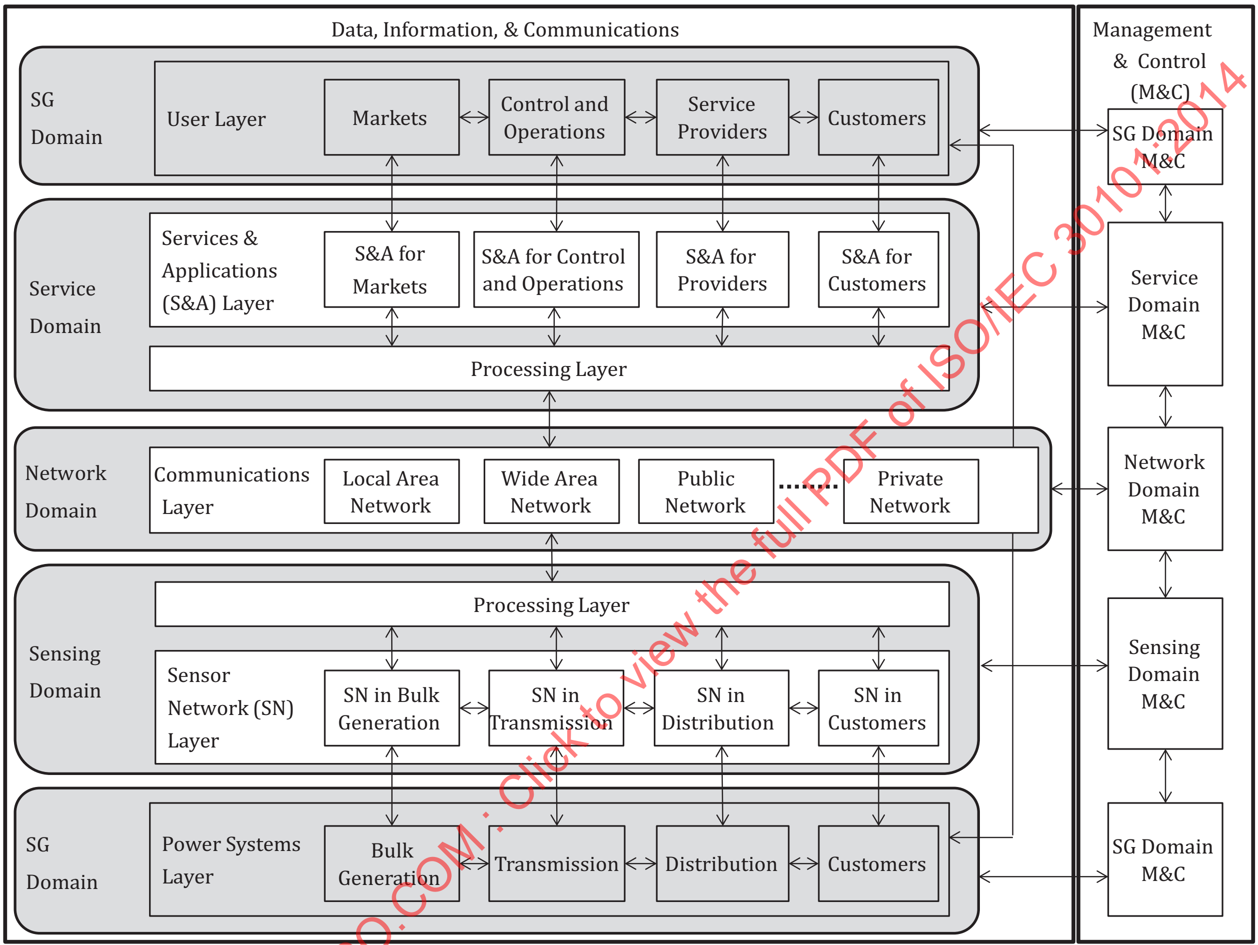


Figure 29 — Architecture showing sensor network and its interfaces supporting Smart Grid System.

9.2 SG Domain

SG Domain is shown on the top and bottom of the architectural diagram in Figure 29. The physical power systems are categorized and reside in Power Systems Layer – Bulk Generation, Transmission, and Distribution. Systems (e.g., machines and human) are not associated with the physical power systems in the SG Domain are shown as User Layer – Markets, Operations, and Service Providers. However, Customers appears both User Layer and Power Systems Layer because customers are not only the user of the electricity but also have sensors and sensor networks in and premise of their properties, e.g., houses, buildings, factory, etc.

9.3 Sensing Domain

Sensing Domain consists of Sensor Network (SN) Layer and Processing Layer, and this figure shows the three sensor networks in Sensing Domain – Sensor networks for Bulk Generation, Transmission and Distribution. In each sensor network, various functions are maintained, and Table 17 describes the typical functional entities within each sensor networks.

Table 17 — Function model and descriptions for Sensing Domain.

Functional Entities	Descriptions
Data acquisition	Sense and capture data from the environment for applications.
Data storage	Store sensor data, control instructions, and management data.
Data processing	Use data/signal processing algorithms to extract requested or useful information from sensor data and metadata. The information extraction algorithms include collaborative information processing (e.g., data fusion, feature extraction, data aggregation and data presentation).
Data communication	Transmit and receive data among sensor nodes and sensor network gateway through a communication protocol stack and communication support functions. Examples of data transmitted and received are temperature, humidity, time synchronization and location data.
Device management	Manage devices in Sensing Domain, including power, system parameter, identification, and embedded software/firmware programs in the device.
Service management	Manage the service(s) provided by sensor nodes and sensor network gateways, including service registration, service discovery, service description, service analysis, and service processing queue.
Security and Privacy management	Manage the security of communication and data, including authentication, authorization, encryption, and key management. Manage the protection of personal information, including data minimization, anonymization, pseudonymization and so on. Privacy management typically begins with a privacy risk/impact assessment, including the identification of safeguards required to mitigate the identified risks.
Network management	Manage the network topology, routing table, configuration information, performance and reconfigure network information.
Application Management	Manages the parameter changes or application updates in sensor nodes or in a sensor network or sensor networks
Feedback & control	Trigger control instruction on actuators according to user's feedback depending on the application requirement. Whether feedback control is needed or not depends on the application requirement.
Feature extraction	There are different levels of feature[a] extraction. Feature extraction methods can vary depending on sensor type and the data the sensor generates. In general, features can be extracted from raw data from a sensor or from processed data. The feature extraction is performed typically by an algorithm or algorithms.
Data Aggregation	Data aggregation assembles the similar data from multiple sources (e.g., sensors, processors, databases). It also may assemble the data chronologically when needed.
Data Fusion	Data fusion is the use of techniques that combine data from multiple, disparate data/information sources and translates that information into discrete, actionable items through inferencing. Data fusion processes are often categorized as low, intermediate or high, depending on the processing stage at which fusion takes place. For example, low level fusion, data fusion algorithm/software combines several sources of raw data to produce new raw data. The fused data is likely provides more complete pictures of the physical world, especially for objects of interest in the physical world compared to individual data from the multiple sources that have not been fused.
Collaborative Information Processing (CIP)	Collaborative information processing is similar to Data Fusion in many respects. The emphasis is given to network level data fusion where there are multiple networks involved. The fundamental ideas of combining data from multiple sources to produce actionable items are the same as Data Fusion.

[a] In OpenGiS® Implementation Standard for Geographic Information – Simple feature access – Part 1: Common Architecture (Open Geospatial Consortium OGC 06-103r4, 28 May 2011), "feature" is defined as "abstraction of real world phenomena"; however, in this standard, feature is used in a general sense including such definition in the OGC document.

Table 17 *(continued)*

Functional Entities	Descriptions
Information Extraction	A type of information retrieval whose goal is to automatically extract structured information from unstructured and/or semi-structured data.
Data Mining	Data mining is a process of discovering new patterns from large data sets involving methods from statistics and artificial intelligence but also database management. In contrast to for example machine learning, the emphasis lies on the discovery of previously unknown patterns as opposed to generalizing *known* patterns to new data.

[a] In OpenGiS® Implementation Standard for Geographic Information – Simple feature access – Part 1: Common Architecture (Open Geospatial Consortium OGC 06-103r4, 28 May 2011), "feature" is defined as "abstraction of real world phenomena"; however, in this standard, feature is used in a general sense including such definition in the OGC document.

9.4 Network Domain

In the Network Domain, only functions concerning sensor network are shown in the sensor network functional architecture. Many types of communication networks can be used to support Smart Grid communication (e.g., data, information, command & control, etc.). The typical networks are local area network (LAN), wide area networks (WAN), public networks, and private networks, etc. Under the network domain, dada communication, device management, security management, and other functions can reside to support Smart Grid communications. Table 18 describes the functional entities in the network activities domain in Figure 29. Network Domain can be realized by Local Area Network and/or by Wide Area Network. A Local Area Network can be used when Sensing Domain and Service Domain are within the same network while Wide Area Network can be used when Sensing Domain and Service Domain reside in different networks. There will also be cases where (1) one Sensing Domain serves multiple Service Domains; (2) multiple Sensing Domains serving one Service Domain; or (3) more than one Sensing Domain serve more than one Service Domain.

Table 18 — Function model and descriptions for Network Domain.

Functional Entities	Descriptions
Data communication	Transmit and receive data among devices using existing or emerging data transmission technologies.
Device management	Manage information about the devices in a Wide Area Network, including power, system parameter, identification, and embedded software/firmware programs in the device.
Security management	Manage the security of transporting data, including access control, authentication, authorization, encryption, and key management.

9.5 Service Domain

In Service Domain, additional data/information processing is performed. And various services and applications that support SG Domain's User Layer are shown in Figure 29. These are typically business management and user management related entities that support Smart Grid. The use of these two management entities is dependent upon the requirements of the services and applications of the sensor network being designed and developed. Table 19 describes the functional entities in Service Domain. Service Domain has functions such as data storage, data process, information communication and provision, device management, service management, and so on.

Table 19 — Function model and descriptions for Service Domain.

Functional Entities	Descriptions
Data storage	Store data, including sensor data from Sensing Domain, and control instructions from user.
Data process	Use data/signal processing algorithms to extract requested or useful information from sensor data and metadata. The information extraction algorithms include collaborative information processing or data fusion, feature extraction, and data aggregation, for example.
Information communication	Transmit and receive data among the devices in Service Domain using data transmission technology of legacy network.
Information provision	Provide useful information to users through user interface.
Device management	Manage information about application end devices, including the power, system parameter, identification, and programs of the device.
Service management	Manage the service provided by application service to the users, including service registration, service discovery, service description, service analysis, and service processing queue.
Security management	Manage the security of data and communication in service domain, including access control, authentication, authorization, encryption, and key management.
Business management	Manage the business procedure, business rules, business operations and statistical analysis of business data. Whether business management is necessary depends on application requirement. Dynamic pricing activities may be included in this function.
User management	Manage information about users, including user identification, application requirement, and authorization of users. Whether user management is necessary depends on application requirement.

9.6 Tasks and Activities in Sensor Networks Enabled by the Domain Functions

Figure 30 describes the representative tasks and activities, operational elements, and information exchanges required to accomplish the processes associated with sensor network supporting smart grid systems. This physical operational activity diagram depicted in Figure 30 contains graphical and textual products that identify the operational nodes and elements, assigned tasks and activities, and information flows required between operational nodes. This activity diagram in Figure 30 can further define and detail the types of information exchanged, the frequency of exchange, which tasks and activities are supported by the information exchanges, and the nature of the information exchanges. In Figure 30, a generalized sequence of a sensor network's operational activities required to achieve its any given task is illustrated. Each operational activity shown in Figure 30 is described below:

— Monitor – the inputs to this activity is typically a sensor operational planning and programming and any feedback data/information from any other activities in the activity sequence, and the output from this activity is typically an observation information of the physical world under monitoring;

— Detect – the input to this activity is the observation information, and the output from this activity is typically the data/information about a detected object or objects in the monitoring area. The data/information can include the object(s)' features;

— Assess – the inputs to this activity is the data/information about the detected object(s) and also location data which is the data about the location or area where the object(s) is/are detected, and the output from this activity tells about what this or these objects potentially is/are (e.g., type, identification, etc.);

— Decide – the inputs to this activity is the data/information about the object(s) and any other data available from other sources (e.g., data level) if available, and the output of this activity is accurate parameters about the detected object(s);

— Response – the inputs to this activity is the parameters about the detected object(s) and any other data/information from other sources (through data fusion or collaborative processing – decision level), and the output from this activity is an action or reaction plan which is assigned to actuators linked to a sensor network or to a human operator; and

— Confirm – the inputs to this activity is the observation data from Monitor activity to determine the action or reaction execution has been performed and its effectiveness and the output is the confirmation of the execution and effectiveness. If the execution is ineffective or the action/reaction cannot be confirmed, this activity may reissue the execution plan.

Each of these tasks describes the individual responsibilities along with the systems that are being utilized.

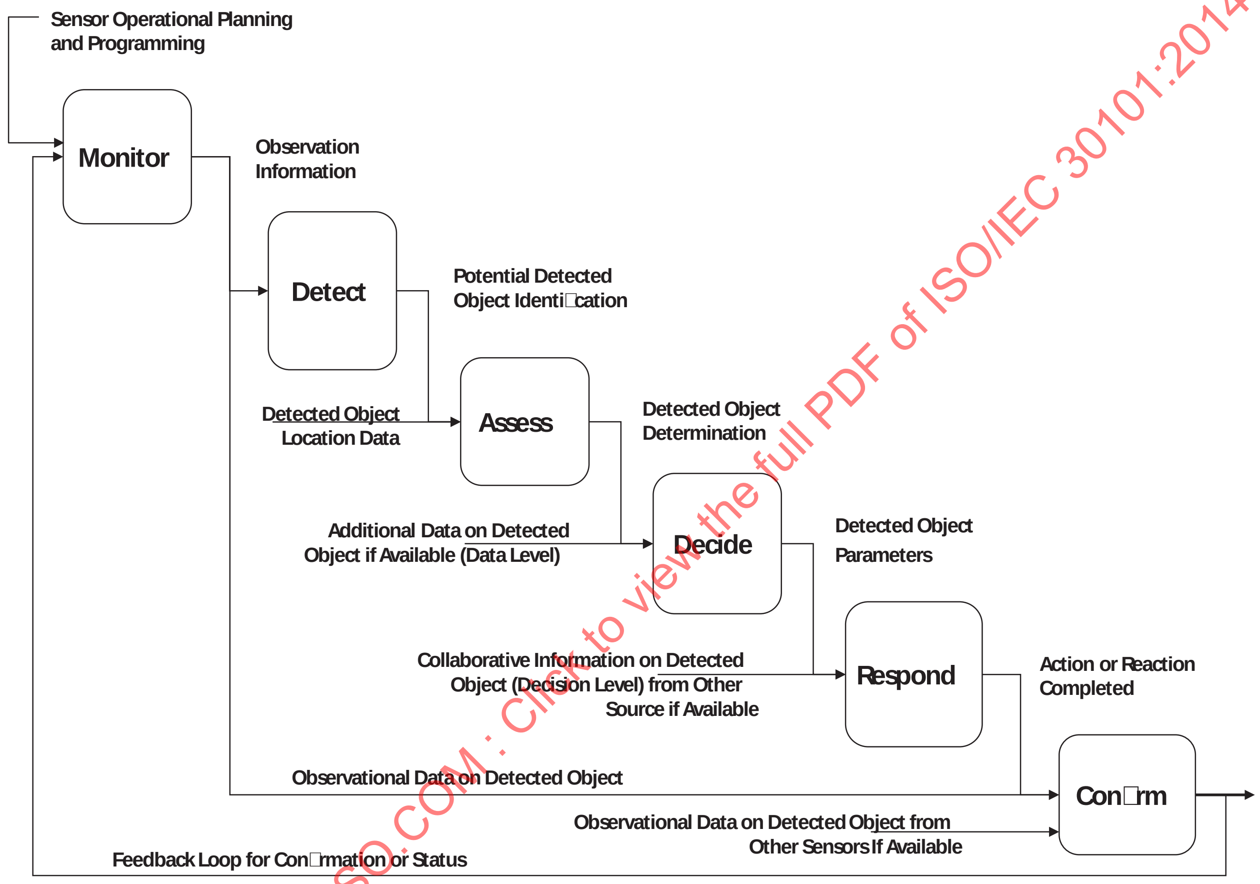


Figure 30 — Sensor network physical operational activity model.

Annex A
(informative)

Other Smart Grid Reference Models and Architectures

A.1 IEC SMB Smart Grid Strategic Group 3 (SG3)

In the IEC SMB's Smart Grid Standardization Roadmap document (see [1] in Bibliography of this document), it introduced the IEC 62357 Reference Architecture shown in Figure A.1 (TC57 Reference Architecture). This architecture addresses the communication requirements of the application in the power utility domain. Its scope is the convergence of data models, services and protocols for efficient and future-proof system integration for all applications. This architectural framework comprises communication standards including semantic data models, services and protocols for intersystem and subsystem communications.

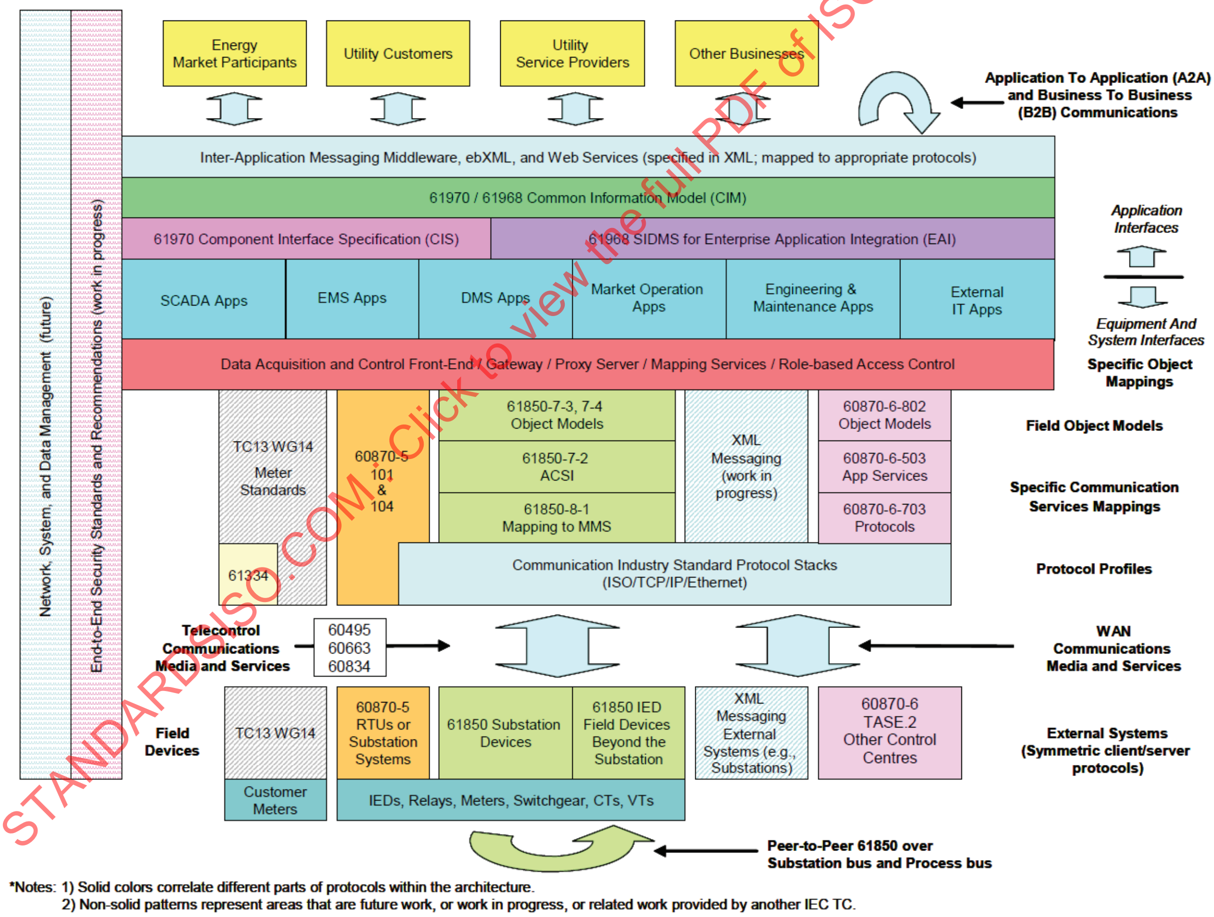


Figure A.1 — TC 57 Reference architecture.

The IEC roadmap also provides the following top level requirements:

— From the viewpoint of Smart Grid, highly interoperable communication between all components is the major goal of smart grid communication. This means that the communication shall be based on a common semantic (data model), common syntax (protocol) and a common network concept. Therefore a convergence and a harmonization of subsystem communication shall be pursued.

— General requirements are that the communication concept shall be future-proof. That means that it shall be open for future extensions regarding application fields as well as communication technologies.

— The concept shall be open regarding an efficient integration of state-of-the-art components, but also open for integration of legacy communication components.

— As an essential part of a critical infrastructure, the communication concept shall be deterministic, transparent and fully comprehensible at any time.

— Real-time applications require system-wide time synchronization with high accuracy. In case of important and critical applications, the communication concept shall provide a high quality of service. Therefore enhanced redundancy concepts are essential.

A.2 National Institute of Standards and Technology (NIST)

In the National Institute of Standards and Technology (NIST)'s Framework and Roadmap for Smart Grid Interoperability Standards document (see [2] in Bibliography of this document), the NIST's Smart Grid conceptual model is introduced as shown in Figure A.2. This conceptual model supports planning and organization of the diverse, expanding collection of interconnected networks that compose the Smart Grid. This NIST's Smart Grid conceptual model was also introduced in the IEC's Smart Grid Standardization Roadmap. As shown in Figure A.2, NIST identified the Smart Grid into seven domains:

— Customers

— Markets

— Service Providers

— Operations

— Bulk Generation

— Transmission

— Distribution

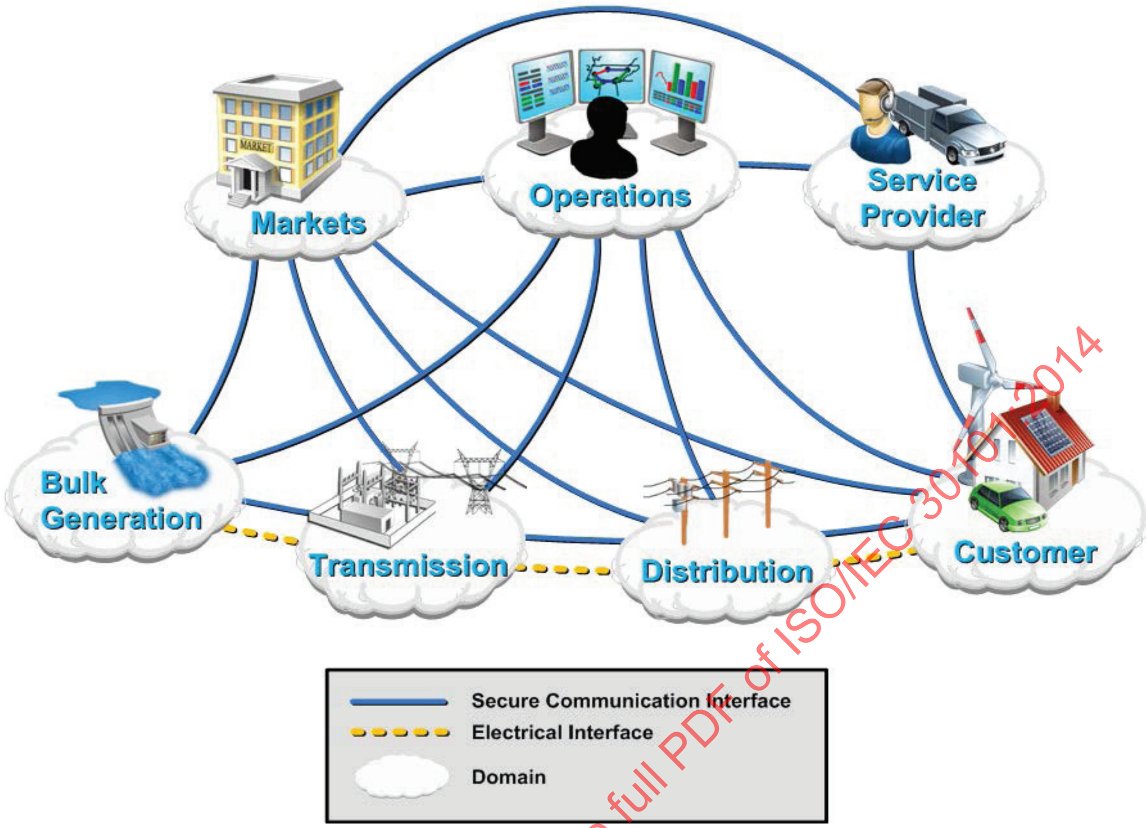


Figure A.2 — NIST Smart Grid conceptual model [from the NIST Smart Grid Roadmap Document].

NIST's description of each smart grid domain is provided in Table A.1.

Table A.1 — NIST description of the SG domains.

Domain	Description
Customers	The end users of electricity. May also generate, store, and manage the use of energy. Traditionally, three customer types are discussed, each with its own domain: residential, commercial, and industrial.
Markets	The operators and participants in electricity markets.
Service Providers	The organizations providing services to electrical customers and utilities.
Operations	The managers of the movement of electricity.
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. May also store and generate electricity.
Distribution	The distributors of electricity to and from customers. May also store and generate electricity.

Each domain and its sub-domains encompass smart grid actors and applications. Actors (or entities) include devices, systems, or programs that make decisions and exchange information necessary for performing applications: smart meters, solar generators, and control systems represent examples of devices and systems. Applications, on the other hand, are tasks performed by one or more actors within a domain. For example, corresponding applications may be home automation, solar energy generation and energy storage, and energy management. Figure A.3 is a composite "box" diagram that combines attributes of the seven domain-specific diagrams.

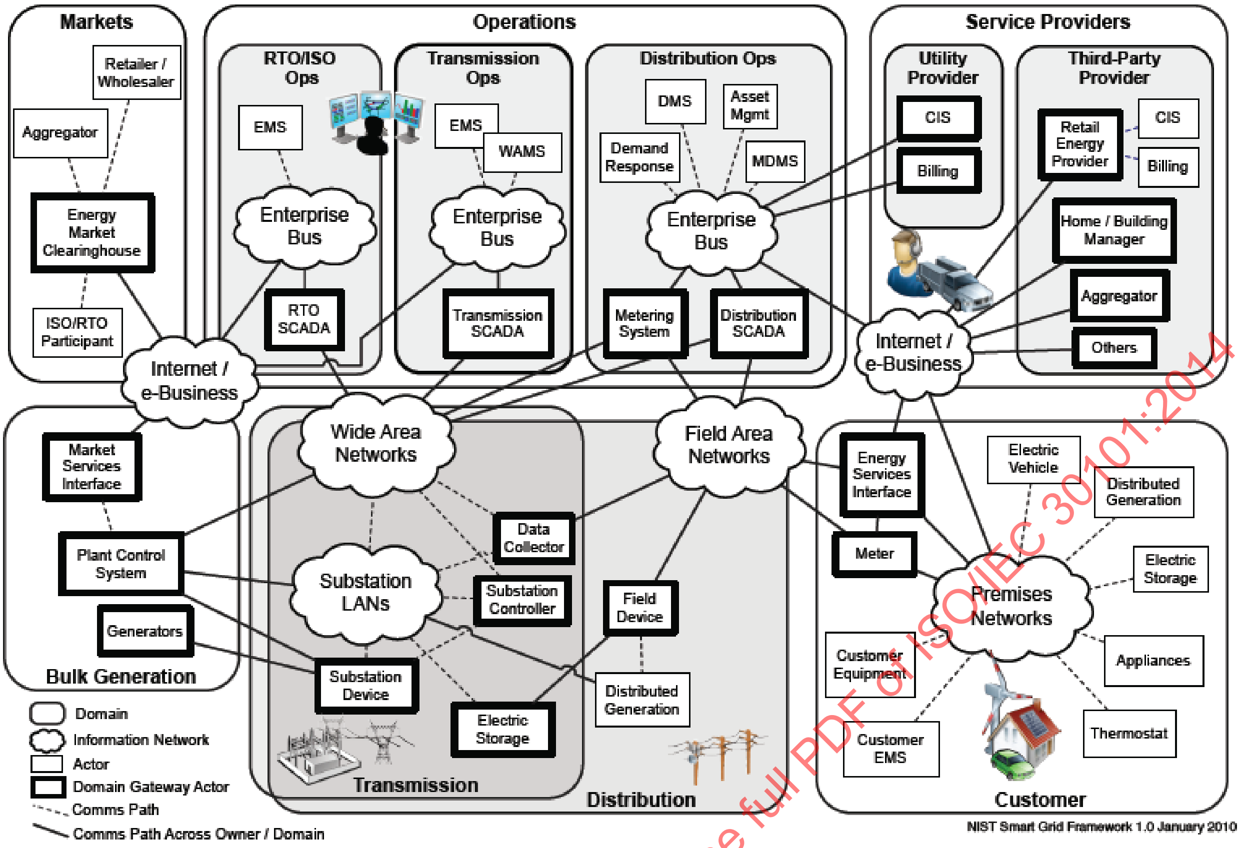


Figure A.3 — NIST Conceptual reference diagram for Smart Grid information network [from NIST Smart Grid Roadmap].

A.3 CEN/CENELEC/ETSI Smart Grid Reference Architecture

The Smart Grid Reference Architecture (Version 3.0) document published by CEN-CENELEC-ETSI Smart Grid Coordination Group (SG-CG), addresses the technical reference architecture part of mandate M/490 and has defined the context for the development of the Smart Grids Reference Architecture (SGRA) including main categories as below.

— **European Conceptual Model:** An evolution of the NIST model in order to take into account some specific requirements of the EU context that the NIST model did not address.

— **Architecture Viewpoints:** A limited set of ways to represent abstractions of different stakeholders' views of a Smart Grid system.

— **Smart Grids Architecture Model (SGAM) Framework:** The architecture framework takes into account already identified relevant aspects like interoperability (e.g. the GridWise Architecture Council (GWAC) Stack), multi-viewpoints (SGAM Layers).

A.3.1 EU Smart Grid Conceptual Model

The EU Conceptual Model for Smart Grid was introduced as shown in Figure A.4.

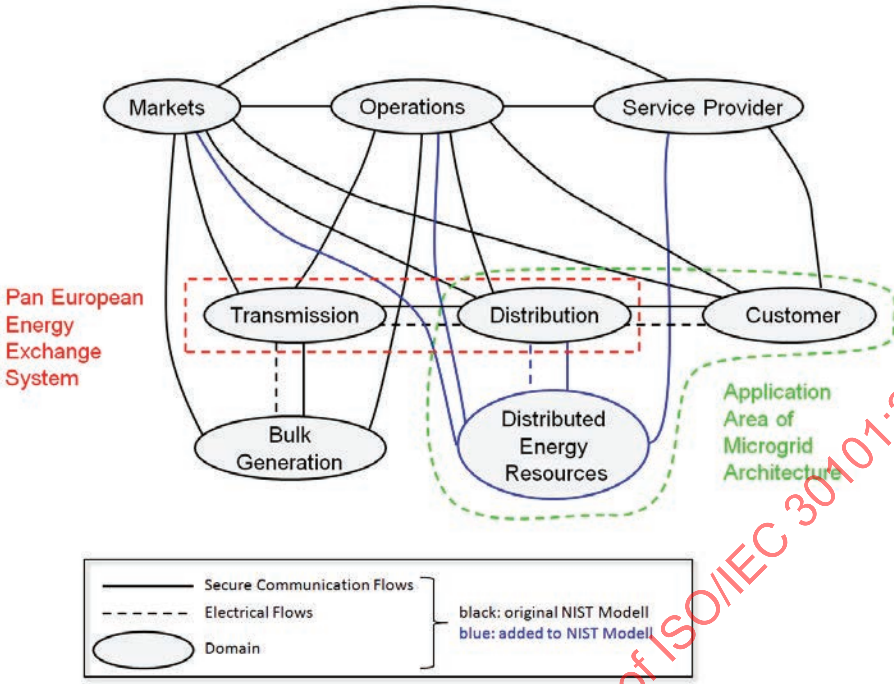


Figure A.4 — EU extension of the NIST model.

This EU Conceptual Model is an overall high-level model that describes the main actors of the Smart Grid and their main interactions, and also acts as a bridge between the underlying models in the different viewpoints of the Reference Architecture. It corresponds for the most part with the NIST Model and extends it with a new DER (Distributed Energy Resources) Domain to fulfill the specific European requirements. It is a future-oriented model for European Smart Grid System and describes a totally centralized grid, a totally decentralized grid and a mixture between both extreme points on a defined level.

A.3.2 Reference Architecture Viewpoints

Architecture viewpoints represent a limited set of ways to represent abstractions of different stakeholders' views of a Smart Grid system. The report of the CEN/CENELEC/ETSI Joint Working Group (JWG) for Standards for the Smart Grids had outlined some of the potential viewpoints that the work of M/490 might have to deal with Conceptual/Communication/Information Architecture. Considering the JWG recommendations and the Reference Architecture requirements, the following viewpoints have been selected as the most appropriate to represent the different aspects of Smart Grids systems: Four viewpoints have been selected by the SG-CG/RA: Business, Functional, Information and Communication, with associated architectures:

— The **Business Architecture** is addressed from a methodology point of view, in order to ensure that whatever market or business models are selected, the correct business services and underlying architectures are developed in a consistent and coherent way.

— The **Functional Architecture** provides a meta-model to describe functional architectures and gives an architectural overview of typical functional groups of Smart Grids.

— The **Information Architecture** addresses the notions of data modeling and interfaces and how they are applicable in the SGAM model. Furthermore, it introduces the concept of "logical interfaces" which is aimed at simplifying the development of interface specifications especially in case of multiple actors with relationships across domains.

— The **Communication Architecture** deals with communication aspects of the Smart Grid, considering generic Smart Grid use cases to derive requirements and to consider their adequacy to existing communications standards in order to identify communication standards gaps. It provides a set of recommendations for standardization work as well as a view of how profiling and interoperability specifications could be done.

A.3.3 Smart Grids Architecture Model (SGAM) Framework

The SGAM Framework aims at offering a support for the design of smart grids use cases with an architectural approach allowing for a representation of interoperability viewpoints in a technology neutral manner, both for current implementation of the electrical grid and future implementations of the smart grid.

It is established by merging the concept of the interoperability layers with the smart grid plane (domains and zones). So it has a three dimensional model that is merging the dimension of five interoperability layers (Business, Function, Information, Communication and Component) with the two dimensions of the Smart Grid Plane, i.e. zones (representing the hierarchical levels of power system management: Process, Field, Station, Operation, Enterprise and Market) and domains (covering the complete electrical energy conversion chain: Bulk Generation, Transmission, Distribution, DER and Customers Premises). The SGAM Framework is shown in Figure A.5.

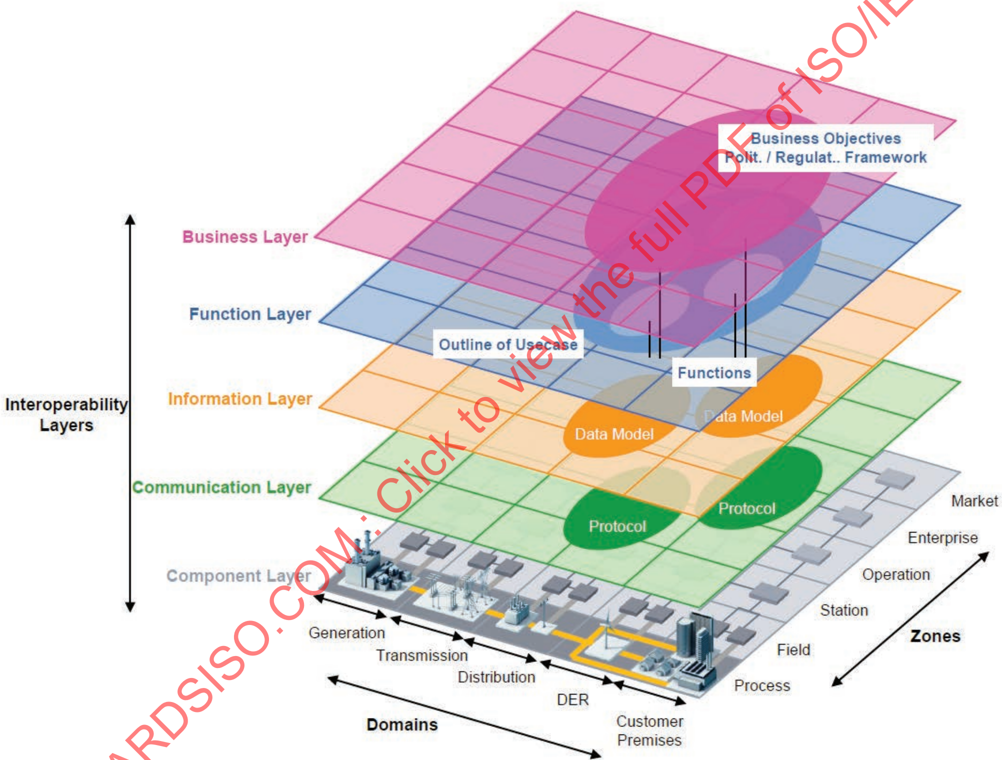


Figure A.5 — SGAM framework.

A.3.3.1 SGAM Interoperability Layers

In order to allow a clear presentation and simple handling of the architecture model, the interoperability categories described in the GridWise Architecture model are aggregated in SGAM into five abstract interoperability layers: Business, Function, Information, Communication and Component, as illustrated in Figure A.6.

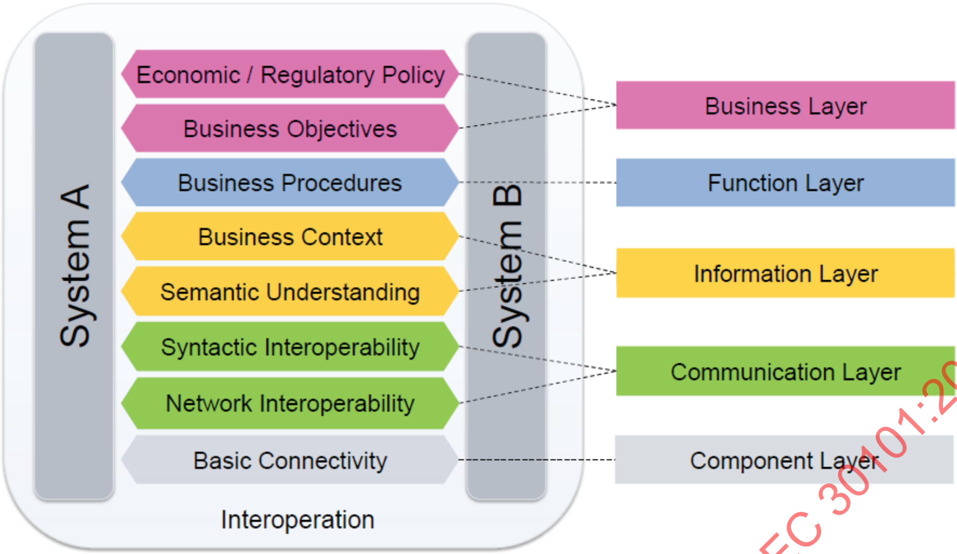


Figure A.6 — Grouping into interoperability layers.

— The **Business Layer** represents the business view on the information exchange related to smart grids; regulatory and economic (market) structures and policies, business models, business portfolios (products & services).

— The **Function Layer** describes functions and services including their relationships from an architectural viewpoint. The functions are represented independent from actors and physical implementations in applications, systems and components.

— The **Information Layer** describes the information that is being used and exchanged between functions, services and components. It contains information objects and the underlying canonical data models.

— The **Communication Layer** describes protocols and mechanisms for the interoperable exchange of information between components in the context of the underlying use case, function or service and related information objects or data models.

— The **Component Layer** describes the physical distribution of system actors, applications, power system equipment (typically located at process and field level), protection and tele-control devices, network infrastructure (wired/wireless communication connections, routers, switches, servers) and any kind of computers.

A.3.3.2 SGAM — Smart Grid Plane

In general power system management distinguishes between electrical process and information management viewpoints. The Smart Grid Plane, as shown in Figure A.7 is defined from the application to the Smart Grid Conceptual Model of the principle of separating the Electrical Process viewpoint (partitioning into the physical domains of the electrical energy conversion chain) and the Information Management viewpoint (partitioning into the hierarchical zones (or levels) for the management of the electrical process.

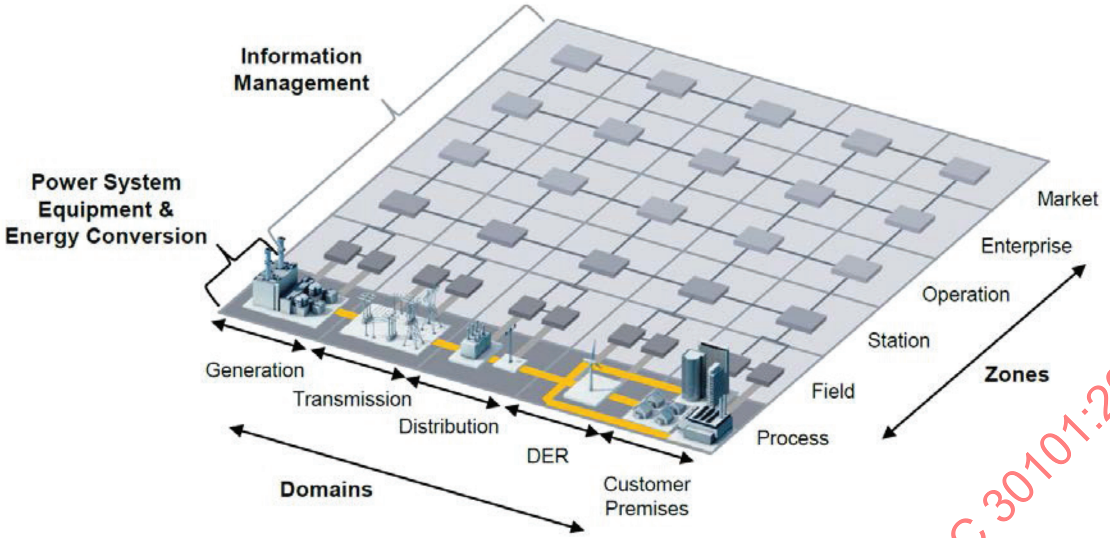


Figure A.7 — Smart Grid plane – Domains and hierarchical zones.

A.3.3.3 SGAM Domains

The Smart Grid Plane includes the domains listed in Table A.2. One dimension of the Smart Grid Plane covers the complete electrical energy conversion chain, partitioned into five domains: Bulk Generation, Transmission, Distribution, DER and Customers Premises.

Table A.2 — SGAM Domains.

Domain	Description
Bulk Generation	Representing generation of electrical energy in bulk quantities, such as by fossil, nuclear and hydro power plants, off-shore wind farms, large scale solar power plant (i.e. PV, CSP) — typically connected to the transmission system
Transmission	Representing the infrastructure and organization which transports electricity over long distances
Distribution	Representing the infrastructure and organization which distributes electricity to customers
DER	Representing distributed electrical resources directly connected to the public distribution grid, applying small-scale power generation technologies (typically in the range of 3 kW to 10 000 kW). These distributed electrical resources may be directly controlled by DSO
Customer Premises	Hosting both end-users of electricity, also producers of electricity. The premises include industrial, commercial and home facilities (e.g. chemical plants, airports, harbours, shopping centres, homes). Also generation in form of e.g. photovoltaic generation, electric vehicles storage, batteries, micro turbines... are hosted

A.3.3.4 SGAM Zones

The SGAM zones represent the hierarchical levels of power system management [IEC 62357]. These zones reflect a hierarchical model which considers the concept of aggregation and functional separation in power system management. The SGAM zones are described in Table A.3.

Table A.3 — SGAM Zones.

Zone	Description
Process	Including the physical, chemical or spatial transformations of energy (electricity, solar, heat, water, wind …) and the physical equipment directly involved. (e.g. generators, transformers, circuit breakers, overhead lines, cables, electrical loads any kind of sensors and actuators which are part or directly connected to the process,…).
Field	Including equipment to protect, control and monitor the process of the power system, e.g. protection relays, bay controller, any kind of intelligent electronic devices which acquire and use process data from the power system.
Station	Representing the areal aggregation level for field level, e.g. for data concentration, functional aggregation, substation automation, local SCADA systems, plant supervision…
Operation	Hosting power system control operation in the respective domain, e.g. distribution management systems (DMS), energy management systems (EMS) in generation and transmission systems, microgrid management systems, virtual power plant management systems (aggregating several DER), electric vehicle (EV) fleet charging management systems.
Enterprise	Includes commercial and organizational processes, services and infrastructures for enterprises (utilities, service providers, energy traders …), e.g. asset management, logistics, work force management, staff training, customer relation management, billing and procurement…
Market	Reflecting the market operations possible along the energy conversion chain, e.g. energy trading, mass market, retail market…

Annex B
(normative)

IEEE 2030 Descriptions of Entities and Interfaces

B.1 Power System Interoperability Architecture Perspective (PS-IAP) Description of Entities and Interfaces

Table B.1 provides the description and associated comment of each entity found in the Power System Interoperability Architecture Perspective (PS-IAP) shown in Figure 1.

Table B.1 — PS-IAP entities and descriptions.

Entity	Description	Comments
AC Loads	Loads on customer site using AC electric power.	—
Bulk Generation	Conventional or renewable generation source that is connected to the electrical transmission system.	Typical generation types include nuclear, fossil fuels, hydro, and various renewable resources.
Bulk Storage	Electric storage that is connected to the electrical transmission system.	Bulk storage technologies include pumped hydro, compressed air, geothermal, superconducting magnetic energy storage, and batteries.
Customer Distributed Energy Resource	Customer DER includes demand response, generation, and energy storage located on and connected to the customer electrical system.	Customer generation or storage that is connected to the transmission system is considered in the Bulk Generation domain. Customer DER may include PEVs.
Customer Point(s) of Interface	The customer point(s) of interface is a common point for the on-premises devices that may communicate with the entities outside of the customer domain.	Can be a physical interface box, meter, EMS, generator controller, controllable load devices, or directly connected. A single customer may have more than one point of interface.
Customer Substation	Electrical transmission or distribution substation located at customer facility that converts power to distribution voltage levels, which are then distributed within the customer site. Contains infrastructure necessary to control, monitor, and protect the electrical distribution system. Facility may include transformers, bus work, circuit breakers, capacitor banks, etc.	Customer substations can be at transmission or distribution voltage levels, depending on the size of the facility.
DC Loads	Loads on customer site using DC electric power.	—
Distribution Sensors and Measurement Devices	Distribution sensors and measurement devices located on the distribution system but not within a distribution substation.	Distribution sensors and measurement devices are typically a device associated with conversion equipment such as current transducers or voltage transducers. Examples of these items include meters, oscillographs, temperature sensors, etc.
Distribution Distributed Energy Resources	Distribution DERs include demand response, generation, and energy storage located on and connected to the distribution system.	Generation or storage connected to the transmission system is considered in the bulk generation domain.

Table B.1 *(continued)*

Entity	Description	Comments
Distribution Operation and Control	Facility/function that may include real-time control and monitoring.	May include oscillography, event records, equipment diagnostics, etc.
Distribution Protection and Control Devices	Devices on a distribution circuit external to a distribution substation that control and protect the electrical distribution system.	Examples include capacitors, sectionalizers, circuit interrupters, voltage regulators, surge protective devices, etc.
Distribution Substation	Centralized facility that contains infrastructure necessary to control, monitor, and protect the electrical distribution system.	Facility may include transformers, voltage regulating transformers, circuit breakers, capacitor banks, etc. Distribution substations may be located at the same facility as a transmission substation. May include distribution switching stations.
Electric Service Providers	An organization that contracts to provide electric power-related services.	Service providers can be electric utilities or other parties. They may provide market-oriented services, equipment management, or troubleshooting services, etc.
Generation Operation and Control	Provides for dispatch of generation based on reliability usually incorporated with economic dispatch.	—
Generation Substation	Centralized facility that converts voltage to transmission levels and contains infrastructure necessary to control, monitor, and protect the generation interconnection equipment	The generator substation is usually located adjacent to the generation facility. The generator substation provides the interface between the generator and the electrical transmission system.
Markets	Markets are entities that signal changes in the operation of the system based on market economic variables.	Markets discussed are wholesale market, retail market, and ancillary services. Wholesale electricity markets can have extremely high price volatility at times of peak demand and supply shortages. The particular characteristics of this price risk are highly dependent on the generation supply portfolio to the market such as the mix of types of generation plants and relationship between demand and weather patterns. Retail electricity pricing varies based on time of day but follows fairly regular daily and seasonal cycles. Retail prices are generally segmented by customer type: residential, commercial, and industrial. Ancillary services are used to provide spinning reserve, frequency control, and other functions not directly related to the amount of energy consumed by the customer. This could include the aggregation of DER into larger blocks for marketing purposes. Includes capacity markets.
Transmission Sensors and Measurement Devices	Sensors and monitoring equipment installed on the transmission lines external to the transmission substations.	This equipment may include transmission line sag monitor, tower monitoring equipment, insulation detection monitoring, etc.
Transmission Operation and Control	Facility/function that may include real-time control and monitoring.	May include oscillography, event records, equipment diagnostics, etc.

Table B.1 *(continued)*

Entity	Description	Comments
Transmission Protection and Control Devices	Devices on a transmission line external to a transmission substation that control and protect the electrical transmission system.	Examples can include flexible AC transmissions (FACTs) devices, remote transmission switches, series capacitors, surge protective devices, etc.
Transmission Substation	Centralized facility that allows the exchange of power between the bulk generation and the distribution system. Contains infrastructure necessary to control, monitor, and protect the electrical transmission system, stations, etc.	Transmission substations include facilities that convert voltages from transmission voltages to another transmission voltage or distribution voltages as well as transmission voltage- level switching stations. Facilities may include transformers, bus, circuit breakers, capacitor banks, static or synchronous reactors, FACTs devices, AC to DC converters, and DC to AC converters.

Table B.2 provides all the interfaces (the lines with the numbers, e.g., PS1) found in the PS-IAP (Figure 1) including the two entities (e.g., Entity 1 and Entity 2) connected by the interface line.

Table B.2 — PS-IAP interfaces.

IF No.	Entity 1	Entity 2	Comments
PS1	Distribution Substation	Transmission Substation	Substations may be co-located or located some distance from each other. Provides for coordination between electrically connected substations. Interfaces include those for control, protection, monitoring, SCADA, and telephony.
PS2	Distribution Substation	Distribution Operation and Control	Provides substation data and for direct control of distribution substations. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
PS3	Distribution Sensors and Measurement Devices	Distribution Operation and Control	Provides distribution system data. Interfaces include those for monitoring, reporting, and SCADA.
PS4	Distribution Protection and Control Devices	Distribution Operation and Control	Provides for monitoring of devices, controlling devices, and updating settings to devices. Interfaces include those for control, monitoring, SCADA, and reporting.
PS5	Distribution Substation	Distribution Protection and Control Devices	Provides for monitoring of devices, controlling devices, and updating settings to devices as well as coordination between substation and field devices. Interfaces include those for protection, control, monitoring, reporting, and SCADA.
PS6	Distribution Substation	Customer Point(s) of Interface	Provides for protection coordination and customer information that is desired at the substation. Interfaces include those for protection, control, and monitoring.
PS7	Distribution Substation	Distribution Sensors and Measurement Devices	Provides for distribution system information to be provided at distribution substations. Interfaces include those for monitoring, reporting, and SCADA.
PS8	Distribution Substation	Distribution Substation	Interfaces between two or more distribution substations. Interfaces include those for protection, control, monitoring, reporting, SCADA, and telephony.
PS9	Distribution Protection and Control Devices	Customer Point(s) of Interface	Provides customer information to protection and control devices and certain protection and control information to customer devices. Interfaces include those for protection, control, and monitoring.

Table B.2 *(continued)*

IF No.	Entity 1	Entity 2	Comments
PS10	Distribution Protection and Control Devices	Distribution Sensors and Measurement Devices	Provides sensor information to protection and control devices. Interfaces include those for monitoring and SCADA.
PS11	Distribution Distributed Energy Resources	Markets	Provide DER information to markets and capabilities for market control of DER. Interfaces include those for control and monitoring.
PS12	Distribution Distributed Energy Resources	Customer Point(s) of Interface	Provides for aggregated customer information and distribution system DER control directly to customer. Provides a means to locally balance generation and loads. Interfaces include those for control and monitoring.
PS13	Distribution Operation and Control	Customer Point(s) of Interface	Provides information exchange and control of customer equipment by distribution operations and control. Interfaces include those for control and monitoring.
PS14	Distribution Distributed Energy Resources	Distribution Operation and Control	Provides information exchange and control of distribution DER by distribution operations and control. Interfaces include those for control and monitoring.
PS15	Distribution Substation	Distribution Distributed Energy Resources	Provides for distribution system DER information and distribution system DER control directly from the substation. Provides a means to locally balance generation and loads. Interfaces include those for protection, control, and monitoring.
PS16	Distribution Distributed Energy Resources	Distribution Sensors and Measurement Devices	Provides distribution system information for use by distribution system DER. Interfaces include those for monitoring, reporting, and SCADA.
PS17	Distribution Protection and Control Devices	Distribution Distributed	Provides for coordination between distribution system protection and control devices and DER. Interfaces include those for protection and control.
PS18	Distribution Operation and Control	Customer Substation	Provides for monitoring and control of customer owned stations by distribution operations and control. Interfaces include those for control, monitoring, and SCADA.
PS19	Distribution Distributed Energy Resources	Customer Distributed Energy Resources	Provides for coordination between distribution system DER and customer DER. Interfaces include those for monitoring and control.
PS20	Distribution Substation	Customer Substation	Provides for coordination between distribution substations and customer substations. Interfaces include those for protection and monitoring.
PS21	Distribution Sensors and Measurement Devices	Customer Substation	Provides for distribution line information to be provided at customer substations. Interfaces include those for monitoring, reporting, and SCADA.
PS22	Transmission Substation	Transmission Operation and Control	Provides for transmission operations monitoring and control of substations. This would include typical SCADA data, phasor data, special protection systems, telephone, and wide area monitoring, protection and control (WAMPAC). Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
PS23	Transmission Substation	Transmission Substation	Provides for coordination between two or more transmission substations, Interfaces include those for protection, control, monitoring, reporting, SCADA, and telephony.

Table B.2 *(continued)*

IF No.	Entity 1	Entity 2	Comments
PS24	Transmission Substation	Transmission Protection and Control Devices	Provides for coordination, control, and monitoring between remote protection and control devices with transmission substations. This would include protection, switching commands (open/close switches), and control device monitoring. Interfaces include those for protection, control, monitoring, reporting, and SCADA
PS25	Transmission Substation	Transmission Sensors and Measurement Devices	Provides for capability to monitor information not in transmission substation. This would include information for dynamic line rating, transmission line maintenance information, etc. Interfaces include those for monitoring, reporting, and SCADA.
PS26	Transmission	Generation Substation	Provides coordination between transmission and generation substations. This would include protection systems, special protection systems, telephone, etc. Interfaces include those for protection, control, monitoring, SCADA, and telephony.
PS27	Transmission Substation	Bulk Storage	Provides for coordination between the transmission substation and bulk storage as well as monitoring of information at both entities. This would include protection systems, special protection systems, telephone, etc. Interfaces include those for protection, control, monitoring, and SCADA.
PS28	Transmission Substation	Bulk Generation	Provides for coordination between the transmission substation and generation as well as monitoring of information at both locations. This would include special protection systems. Interfaces include those for protection, control, monitoring, and SCADA.
PS29	Transmission Substation	Customer Substation	Provides for coordination between transmission and customer substations. This would include protection systems, special protections systems, telephone. Interfaces include those for protection, control, monitoring, and SCADA.
PS30	Transmission Sensors and Measurement Devices	Transmission Operation and Control	Provides information from the transmission line to the transmission operators. This would include information for dynamic line rating, transmission line maintenance information, etc. Interfaces include those for monitoring, reporting, and SCADA.
PS31	Distribution Distributed Energy Resources	Distribution Distributed Energy Resources	Interfaces between two or more distribution DERs. Interfaces include those for protection, control, monitoring, reporting, and SCADA.
PS32	Transmission Sensors and Measurement Devices	Transmission Protection and Control Devices	Provides information to protection and control devices. This could include information for dynamic line rating and control of line impedance. Interfaces include those for monitoring.
PS33	Transmission Sensors and Measurement Devices	Generation Substation	Provides information to generation substation. This would include information for dynamic line rating, transmission line maintenance information, etc. Interfaces include those for monitoring.
PS34	Transmission Sensors and Measurement Devices	Customer Substation	Provides information to customer substation. This would include information for dynamic line rating, transmission line maintenance information, etc. Interfaces include those for monitoring.
PS35	Transmission Sensors and Measurement Devices	Bulk Storage	Provides information to bulk storage. This would include information for dynamic line rating, transmission line maintenance information, etc. Interfaces include those for monitoring.

Table B.2 *(continued)*

IF No.	Entity 1	Entity 2	Comments
PS36	Transmission Sensors and Measurement Devices	Bulk Generation	Provides information to bulk generation. This would include information for dynamic line rating. Interfaces include those for monitoring.
PS37	Transmission Operation and Control	Customer Substation	Provides for transmission operators to monitor and control customer substations. Interfaces include those for control, monitoring, SCADA, reporting, and telephony
PS38	Transmission Protection and Control Devices	Generation Substation	Provides coordination between remote protection and control devices with the generation substation. This would include protection and special protection systems. Interfaces include those for protection, control, monitoring, and SCADA.
PS39	Transmission Protection and Control Devices	Transmission Operation and Control	Provides control of transmission system and ability to change settings on protective and control equipment. This would include typical SCADA data, phasor data, special protection systems, telephone, and wide area monitoring, protection and control. Interfaces include those for control, monitoring, SCADA, and reporting.
PS40	Bulk Generation	Transmission Operation and Control	Provides for information exchange between generation and transmission operations. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
PS41	Bulk Generation	Generation Substation	Provides for information exchange and coordination between generation and generation substation. Interfaces include those for protection, control, monitoring, SCADA, and telephony.
PS42	Bulk Generation	Bulk Storage	Provides for information exchange and coordination between generation and storage. Interfaces include those for protection, control, monitoring, SCADA, and telephony.
PS43	Bulk Storage	Transmission Operation and Control	Provides for information exchange. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
PS44	Bulk Storage	Generation Substation	Provides for information exchange and coordination between storage and generation substation. Interfaces include those for protection, control, monitoring, SCADA, and telephony.
PS45	Generation Substation	Transmission Operation and Control	Provides for information exchange and control of generation substation. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
PS46	Transmission Operation and Control	Distribution Operation and Control	Provides for coordination between distribution operations and transmission operations. Interfaces include those for monitoring, reporting, SCADA, and telephony.
PS47	Markets	Transmission Operation and Control	Wholesale market operations control to optimize portfolio of sources. Interfaces include those for monitoring, reporting, and telephony
PS48	Markets	Distribution Operation and Control	Demand-side management (DSM) signals to reduce demand. Interfaces include those for monitoring, reporting, and telephony.
PS49	Markets	Generation Operation and Control	Wholesale market operations control to optimize portfolio of sources. Interfaces include those for monitoring, reporting, and telephony.
PS50	Markets	Bulk Generation	Wholesale market operations control to optimize portfolio of sources. . Interfaces include those for control, monitoring, reporting, and telephony.
PS51	Markets	Bulk Storage	Wholesale market operations control to optimize portfolio of sources. Interfaces include those for control, monitoring, reporting, and telephony.

Table B.2 *(continued)*

IF No.	Entity 1	Entity 2	Comments
PS52	Markets	Customer Point(s) of Interface	Provides for optimization of distributed generation, storage, and load control (i.e. demand response) on the customer domain. Interfaces include those for control, monitoring, and reporting.
PS53	Generation Operation and Control	Generation Substation	Provides substation information and control of substation equipment. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
PS54	Generation Operation and Control	Bulk Generation	Provides generation information and control of bulk generation. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
PS55	Generation Operation and Control	Bulk Storage	Provides storage data and control of bulk storage. Interfaces include those for control, monitoring, SCADA, reporting, and telephony.
PS56	Generation Operation and Control	Transmission Operation and Control	Provides for coordination between generation operations and transmission operations. Interfaces include those for monitoring, reporting, SCADA, and telephony.
PS57	Customer Substation	AC Loads	Provides for intra-facility monitoring and control of AC loads. Interfaces include those for protection, control, and monitoring.
PS58	Customer Substation	DC Loads	Provides for intra-facility monitoring and control of DC loads. Interfaces include those for protection, control, and monitoring.
PS59	Customer Point(s) of Interface	AC Loads	Provides for information exchange and control of AC loads by entities external to customer. Interfaces include those for protection, control, and monitoring.
PS60	Customer Point(s) of Interface	DC Loads	Provides for information exchange and control of DC loads by entities external to customer. Interfaces include those for protection, control, and monitoring.
PS61	Customer Substation	Customer Distributed Energy Resources	Provides for information exchange and control of DERs by substation control. Interfaces include those for protection, control, and monitoring.
PS62	Customer Point(s) of Interface	Customer Distributed Energy Resources	Provides for information exchange and control of DERs by entities external to customer. Interfaces include those for protection, control, and monitoring.
PS63	Customer Distributed Energy Resources	AC Loads	Provides for information exchange and control of DERs and AC loads internally at the customer. Interfaces include those for protection, control, and monitoring.
PS64	Customer Distributed Energy Resources	DC Loads	Provides for information exchange and control of DERs and DC loads internally at the customer. Interfaces include those for protection, control, and monitoring.
PS65	Electric Service Providers	Markets	Provides for information exchange of market information and expected loading. Interfaces include those for monitoring and control.
PS66	Electric Service Providers	Distribution Operation and Control	Provides for information exchange of expected loading and aggregate control mechanisms. Interfaces include those for monitoring.
PS67	Electric Service Providers	Customer Substation	Provides for monitoring information and control of customer generation, storage, and loads. Interfaces include those for monitoring and control.
PS68	Electric Service Provider	Customer Point(s) of Interface	Provides for monitoring information and control of customer generation, storage, and loads. Interfaces include those for monitoring and control.

Table B.2 *(continued)*

IF No.	Entity 1	Entity 2	Comments
PS69	Customer Distributed Energy Resources	Customer Distributed Energy Resources	Interfaces between two or more customer DERs. Interfaces include those for protection, control, monitoring, reporting, and SCADA.
PS70	Transmission Operation and Control	Distribution Distributed Energy Resources	Provides for monitoring information and control of customer generation, storage, and loads for direct dispatch of distribution connected DER. Interfaces include those for monitoring and control.
PS71	Generation Operation and Control	Distribution Distributed Energy Resources	Provides for monitoring information and control of customer generation, storage, and loads for direct dispatch of distribution connected DER. Interfaces include those for monitoring and control.
PS72	Electric Service Providers	Generation Substation	Provides for monitoring information of generation substation equipment. Interfaces include those for monitoring.
PS73	Electric Service Providers	Bulk Storage	Provides for monitoring information of bulk storage equipment. Interfaces include those for monitoring.
PS74	Electric Service Providers	Bulk Generation	Provides for monitoring information of bulk generation equipment. Interfaces include those for monitoring.
PS75	Electric Service Providers	Transmission Sensors and Measurement Devices	Provides for monitoring information of sensors and measurements associated with transmission line equipment. Interfaces include those for monitoring.
PS76	Electric Service Provider	Transmission Substation	Provides for monitoring information of transmission substation equipment. Interfaces include those for monitoring.
PS77	Electric Service Providers	Distribution Sensors and Measurement Devices	Provides for monitoring information of sensors and measurement devices associated with distribution line equipment. Interfaces include those for monitoring.
PS78	Electric Service Provider	Distribution Substation	Provides for monitoring information of distribution substation equipment. Interfaces include those for monitoring
PS79	Electric Service Provider	Distribution Distributed Energy Resources	Provides for monitoring information of distribution distributed energy resource equipment. Interfaces include those for monitoring.
PS80	Electric Service Provider	Generation Operation and Control	Provides for monitoring information provided to asset management provides from the generation operation and control centre. Interfaces include those for monitoring.
PS81	Electric Service Provider	Transmission Operation and Control	Provides for monitoring information provided to asset management provides from the transmission operation and control centre. Interfaces include those for monitoring.

B.2 Communication Technology Interoperability Architecture Perspective (CT-IAP) Description of Entities and Interfaces

Table B.3 provides the description and associated comment of each entity found in the Communication System Interoperability Architecture Perspective (CT-IAP) shown in Figure 2.

Table B.3 — CT-IAP entities and descriptions.

Entity	Description	Comments
Backhaul	The backhaul network connects the utility control/operations, including the AMI enterprise, with the wide area network (WAN), distribution substation networks, DERs, field area network (FAN), NAN distribution access points, etc.	The backhaul network can be owned by the utility and/or managed by a public telecommunications/cable service provider. It can be wireline (dial-up, T1, twisted pair, cable, fibre optic, etc.) or wireless (3G, WiMAX™, point-to-point, pagers, radios, etc.). A typical NAN/FAN usually has more than one backhaul/access point connected to the WAN. In some cases, the backhaul is not used when centralized utility operation manages the networks directly from their back office.
Bulk Generation Network	A network used within a bulk generation facility that connects to various networks.	These networks facilitate large-scale power generation connected at the grid generation transmission side.
Distributed Energy Resources Network	Customer generation and storage systems are connected to CPN (HAN, BAN, IAN) through energy services interfaces (ESIs) and/or electric submeters, using either wireline and/or wireless networks.	Customer energy resources can be used to balance the utility's electricity load. Energy can be supplied by customers back to the grid. It is expected that customers will have a balanced portfolio of energy generated locally (in their premises) and supplied by the utility, with an energy supply ratio that can be dynamically changed during outages or peak energy periods.
Distribution Access Point	Distribution access point (DAP) is the device that collects and aggregates data coming from/to end devices/users through the NANs. It also interfaces with the backhaul.	DAPs can be considered part of the NAN. These devices have routing and traffic handling capabilities to prioritize multiple data flows. More than one DAP might be used to collect data (e.g., smart meter reading). They interface with the backhaul transport network.
Distribution Substation Network	Distribution substation network interconnects devices within a distribution substation (e.g., comprised of LANs that contain SCADA, IEDs, remote terminal units [RTUs], PMUs, and other field devices that needs to be controlled and monitored via the backhaul network). IEC 61850 and IEEE Std 1815™ (DNP3) are the protocols of choice for this network.	The distribution substation is controlled and supervised remotely via the utility's backhaul and interconnects to DERs/microgrids, NAN/FAN networks, and connects to the feeder/distribution electricity grid.
Energy Services Interfaces/ Customer Premises Network	ESIs are a special class of device. It is network centric and can also be thought of as logical gateways. CPN represents HAN, BAN, or IAN.	It permits applications such as remote load control, monitoring and control of DER, in home display of customer usage, reading of non-energy meters, and integration with building management systems. It also provides auditing/logging functions that record transactions to and from HAN devices.
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Table B.3 *(continued)*

Entity	Description	Comments
Feeder Distributed Energy Resources/ Microgrid Network	Feeder DER network is comprised of all renewable and non-renewable sources (e.g., wind, solar, diesel), not part of the centralized energy generation. These energy resources could be interconnected through a LAN. Access communications gateways can then connect these DERs and storage LAN networks to the main grid, creating grid connected energy sources. Utility scale storage energy systems connected at the distribution substation are also considered.	Feeder DERs/microgrid networks are used for low-medium (kilowatt) distributed energy generation and storage energy resources that are connected to substations and/or feeder networks. In most cases, the generation sources are located in campuses, industrial parks, etc. (e.g., microgrids).
Feeder Network	Feeder or distribution network is the communications network overlaid on the electrical grid. It comprises wireline or wireless communications technologies.	In some cases, the feeder communications network consists of wireless or cabled connections to exchange information with field devices (reclosers, switches, cap banks, etc.). It also controls volt/var optimization, power quality, and other advanced DA applications.
Field Area Network	FANs connect the distribution substations, the distributed/ feeder (field devices), and DERs/microgrids, including the utility scale electric storage, to the utility control and operation centre.	The FAN connects critical utility assets and transport operations control data.
Grid Scale Energy Resources	These are large-scale energy resources (wind solar, storage, etc.) that are connected to the transmission/generation side of the grid and can handle several hundreds of megawatts.	Utility-scale renewables are remotely located from the energy consumption centres and require new transmission lines and communications links to be built (if not available) to control these remote assets.
Loads	Loads can communicate through local networks using a variety of technologies. These networks provide functionality to exchange information for load management.	Loads can be appliances, pump controls, HVAC, PEVs, etc. Loads can be located in industrial facilities, commercial facilities, or homes.
Markets	Markets will provide energy information services with variable energy/electricity pricing information to allow dynamic exchange of energy services to/from consumers and utilities, establishing a buyer's or seller's energy market.	Markets will communicate to third-party providers and utilities through secure public Internet connections.
Neighbourhood Area Network	NANs connect smart meters, distributed/ feeder (field devices), DERs/microgrids, including the utility scale electric storage, to the utility control and operation centre.	The NAN supports several applications and can either use wireless or cabled (power line, fibre, twisted pair, etc.) networks.
Other Networks	Optical or electronic wireline or wireless networks will play a role in AMI/NAN networks, DA, substation automation, backhaul, workforce automation, and also on PEV mobile/roaming schemes. Wireless networks can use a variety of radio technologies such as paging, point-to-point and point-to-multipoint networks, multiple-address radio networks, or satellite links.	In some circumstance, inter-grid communications shall be provided through the wireless networks so drivers can access information (such as location of the nearest charging station, pricing schemes, etc.) on the road through their mobile phones or on-board EMSs.
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Table B.3 *(continued)*

Entity	Description	Comments
Plug-in Electric Vehicle	PEVs or plug-in hybrid electric vehicles are considered both “load” and “source/storage” to provide power back to the grid to balance energy supply.	PEVs are considered a load when the vehicle is stationary and energy is drawn from the grid to charge their batteries. Proper dimensioning of the utilities distribution networks with PEV adoption forecast is important to avoid unexpected peaks of energy consumption when charging PEVs. The mobile/roaming case is also considered when PEVs need to access charging, billing, and positioning information.
Public Internet/ Intranet	Public Internet may be the primary communication path between utility enterprise data centres, market, and third-party energy providers.	Energy management services may be offered to customers by third-parties, utilities, or Internet service providers (ISPs) via the Internet. A certain level of protocol security shall be provided to all levels of energy management services through the Internet. ISPs provide Internet access to the CPN.
Regional Interconnects Networks	Regional interconnects connect the utilities communications networks to other utilities networks. This could be done through their own proprietary networks or through public carrier backbones.	These are core network interconnections using synchronous optical network/synchronous digital hierarchy and/or dense wavelength division multiplexing and internet protocol fibre rings. In some new constructed utility owned networks, fibre optical power ground wire cables is the technology medium of choice.
Smart Meter/ Energy Services Interfaces	The smart meter/ESIs entity performs a variety of intelligent metering tasks. The smart meter is typically part of the AMI. The ESI function (optionally located within the smart meter) acts as the communication gateway between the NAN and CPN, which includes the HBES, loads, PEVs, and customer DER network.	The NAN, CPN, HBES, and DER networks may each be associated with different physical transmission mediums, and consequently, in order to maximize interoperability, standards involving communication with the smart meter should not be restrictive to a particular transmission medium (e.g., only RF or only power line). Standards allow a variety of physical transmission mediums (e.g., twisted pair, power line, and RF) and, in general, any standardized protocol and interface.
Third-Party Services	Third-party value-added energy services can offer managed energy services (home and building), demand response, and other emerging services to end consumers and utilities.	Third-party energy management services require data access from devices connected to the CPN. Communications paths may be via a utility network infrastructure or the public Internet. Third-party services may include monitoring of specific customer devices, support for control, scheduling, or shaving of loads to accommodate customer energy usage policies.
Transmission Substation Network	Transmission substation network interconnects devices within a transmission substation (e.g., the substation may contain Ethernet networks that connect SCADA, IEDs, RTUs, PMUs, and other field devices that need to be controlled and monitored via the backhaul network).	The transmission substation is controlled and supervised remotely via the utility’s WAN/backhaul network.
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Table B.3 *(continued)*

Entity	Description	Comments
Utility Operation and Control/ Enterprise	Utility control and/or SCADA operation (substation automation, distribution sub-station, etc.) and AMI enterprise centre control, supervise, manage, and monitor all utilities' assets, processes, and custom-ers.	The utility control/operation network, also called back-office, and AMI enterprise control, monitor, supervise, and manage processes, data flows from meters, SCADA, substations, and all critical and non-critical information flow. The control/operations centre can be a single integrated entity that manages transmission and distribution and customers or one control entity (DMS/EMS and others) for each transmission and distribution grid segment, depending on the type of utility or energy service provided model.
Wide Area Net-work	A communication network entity that connects other networks including bulk generation, substation, backhaul, and last mile networks to/from utility control/ operations/enterprise centre.	A WAN covers a large geographic area commu-nications requirements and may utilize wireless or cabled (e.g., fibre optic) communications technologies.
Workforce Mobile Network	Workforce mobile network (WAN) is used by the utility's workforce to provide dis-patch, maintenance, and normal day-to-day operations.	It can use either AMI-NAN/FAN utility-owned networks or public 3G/WiMAX services provided by wireless service providers (WSPs). The sub-station hot spots can be used in conjunction with this network to download/access broadband data to/from the utility control centre.
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Table B.4 provides all the interfaces (the lines with the numbers, e.g., CT1) found in the CT-IAP (Figure 2) including the two entities (e.g., Entity 1 and Entity 2) connected by the interface line.

Table B.4 — CT-IAP interfaces.

Interface	Entity 1	Entity 2	Comments
CT1	Utility Operation and Control/ Enterprise	Backhaul	Either owned by the utility or managed by a telecommu-nications service provider through a secure connection.
CT2	Utility Operation and Control/ Enterprise	Feeder Network	This is a centrally based network where the commu-nications to/from the utility centre does not require backhaul. It is usually owned by the utilities.
CT3	Utility Operation and Control/ Enterprise	Neighbourhood Area Network	This is a communications network that connects directly to the utility centre. It is usually owned by the utility.
CT4	Backhaul	Distribution Access Point	The access point is the demarcation point between the NAN/FAN-AMI and the backhaul. It can also be called collector, aggregation point, cell relay, or gateway. It usually contains dual-radio communications inter-faces—one facing the backhaul (e.g., 3G or WiMAX) and one facing the last mile network (e.g., RF mesh radio). It can be a mesh RF collector, a point-to-multipoint RF radio (e.g., 3G or WiMAX), or a wireline access node (e.g., BPL/PLC).
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Table B.4 *(continued)*

Interface	Entity 1	Entity 2	Comments
CT5	Backhaul	Distribution Substation Network	This is the connectivity between the distribution substation networks and the utility control/operation/SCADA network via the backhaul WAN network. Typical connections are usually a secure wireline (e.g., T1 line, dial-up) or wireless point-to-point microwave radio links. In some cases, the substation networks are connected together.
CT6	Backhaul	Feeder Distributed Energy Resources/ Microgrid Network	It provides the DER communication integration to the grid (connecting utility scale solar/wind and other nonrenewable DERs)/microgrids to/from the backhaul/ WAN network to/from the utility control operations and/or enterprise centre. It also interconnects utility scale energy storage networks and systems.
CT7	Distribution Access Point	Neighbourhood Area Network	The access point can also be considered as an element of the NAN, or just an interface between the NAN and the backhaul.
CT8	Feeder Network	Neighbourhood Area Network	It interconnects the NAN to the distribution network, also called the feeder network, which contains intelligent field devices that go on poles, such as cap banks, reclosers, switches, smart transformers, field sensors, etc. Some elements of the distribution network are also found within the distribution substations.
CT9	Feeder Distributed Energy Resources/ Microgrid Network	Neighbourhood Area Network	This is an alternative to CT6 where the connectivity to the utility scale DERs, located within the utility's distribution network, is done through the NAN/AMI network.
CT10	Distribution Substation Network	Feeder Network	It provides the connectivity between the distribution substation networks and the distribution network field devices. It can use radio or wireline (BPL/PLC) hubs (e.g., towers) within the distribution substation to connect to distribution network field devices.
CT11	Distribution Substation Network	Feeder Distributed Energy Resources/ Microgrid Network	It interconnects the utility scale DERs/microgrids to/ from the utility control/operations/enterprise centre through the distribution substations.
CT12	Smart Meter/ Energy Services Interfaces	Neighbourhood Area Network	Connects the smart meters through wireline or wireless NAN. Smart meters could be residential (including building/business) or industrial-grade.
CT13	Workforce Mobile Network	Neighbourhood Area Network	The NAN can be used as a conduit between a workforce mobile network and the utility control centre. The NAN can provide redundancy in cases where a primary workforce mobile network is out of range or unavailable. Access to the NAN by workforce mobile worker devices will be used to diagnose and repair problems in the NAN and with NAN devices.
CT14	Smart Meter/ Energy Services Interfaces	Energy Services Interfaces/ Customer Premises Network	In general, the ESI is the gateway between the smart meter and the end-use devices and loads. By definition, the physical communication links between the ESI and the loads are part of the CPN (see CT68, CT15, CT16). In many cases, the ESI is physically located within the smart meter (i.e., the meter and ESI are one in the same). However, this may not always be the case. CT14 describes the properties of the link in this latter case.
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Table B.4 *(continued)*

Interface	Entity 1	Entity 2	Comments
CT15	Energy Services Interfaces/ Customer Premises Network	Plug-in Electric Vehicle	This provides connectivity between the ESI (which may be a stand-alone device or could be integrated into the smart meter itself) and the electric vehicle service equipment (EVSE) and/or electric vehicle (EV) in order to support functions such as charging, billing, load shedding and storage, and positioning information. It is assumed that the EVSE (also known as the charging station) is a part of the CPN, and likely connected to the EMS or similar system on the customer premises. Here (CT15), we only consider the case where the EV is physically located at a premise with an EVSE and is capable of communication with the ESI. Note that the ESI/CPN may communicate with the vehicle not only when it is located on the customer premises (e.g., parked or plugged into an on-site charging station) but also when the vehicle is mobile (e.g., to support services like mobile charging, billing, diagnostics, and positioning information). There are other links/paths in the reference architecture that deal with the case of communicating with the vehicle while it is mobile (e.g., CT53–CT18).
CT16	Energy Services Interfaces/ Customer Premises Network	Distributed Energy Resources Network	This provides connectivity between the ESI (which may be a stand-alone device or could be integrated into the smart meter itself) and the DER network via the CPN to the DER in order to support functions such as charging, billing, load shedding, generation, and storage. Here (CT16), we only consider the case where the DER is capable of communication with the ESI.
CT17	Workforce Mobile Network	Public Internet/ Intranet	The public Internet may provide access for workforce mobile networks to third-party information such as maps, news, or weather.
CT18	Other Networks	Plug-in Electric Vehicle	This connectivity is used as a direct communications path to the EV and can be used when the vehicle is stationary, mobile, and/or roaming. This can replace and/or supplant CT15 as another means to reach the head-end software. This connectivity can provide complete communications to the EV to support functions such as charging, billing, uploading rate/tariffs, load shedding and storage, and positioning using on-board energy information systems. For those EVs employing on-board smart chargers, complete EV charging control and vehicle information can be accessed. This connectivity is typically described as telematics and is widely utilized by several vehicle equipment manufacturers OEMs. The connection is established typically by wireless connectivity to the telematics provider head-end system wherein specific applications can provide connectivity to utilities and/or supplier head-end system. The WSP could use 3G/GSM, 4G/LTE™/WiMAX, or satellite transponder technology inside the vehicle as the means to communicate.
CT19	Workforce Mobile Network	Energy Services Interfaces/ Customer Premises Network	Workforce mobile networks can access the ESI via the HAN, IAN, or BAN to retrieve ESI logging data to be able to perform maintenance and repair work.
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Table B.4 *(continued)*

Interface	Entity 1	Entity 2	Comments
CT20	Bulk Generation	Transmission Substation Network	—
CT21	Public Internet/ Intranet	Other Networks	It connects the ISPs to the other networks (e.g., WSPs).
CT22	Other Networks	Third-Party Services	It connects other networks (e.g., WSPs) to the third-party network (value-added service provider).
CT23	Public Internet/ Intranet	Third-Party Services	It connects the third-party network (value-added service provider) to the public Internet.
CT24	Markets	Third-Party Services	It connects the third-party network (value-added service provider) to the markets for energy/electricity price signalling information.
CT25	Utility Operation and Control/ Enterprise	Third-Party Services	It connects the third-party network (value-added service provider) to the utility control/operation/enterprise centre. It is usually part of an open ADE data exchange arrangement where the third-party network accesses customer metering/billing and energy consumption information through the utility's data repositories. Other schemes involve third-party demand response and other services.
CT26	Markets	Public Internet/ Intranet	It connects the market with utilities and other third-party providers through the public Internet.
CT27	Utility Operation and Control/ Enterprise	Public Internet/ Intranet	It connects the utility control/operation/enterprise centre to the third-party service provider, ISP, WSP, and other providers through the public Internet.
CT28	Backhaul	Feeder Distributed Energy Resources/ Microgrid Network	It connects the backhaul to/from field devices (reclosers, cap banks, switches, etc.).
CT29	Workforce Mobile Network	Smart Meter/ Energy Services Interfaces	Workforce mobile networks can access smart meters and the ESI to retrieve ESI logging data to be able to perform maintenance and repair work.
CT30	Transmission Substation Network	Utility Operation and Control/ Enterprise	This provides direct connectivity between devices on the transmission substation network and the utility control/operations/enterprise LAN. This interface consists of legacy services, (PSTN, serial, satellite) (i.e., not WAN-based).
CT31	Wide Area Network	Utility Operation and Control/ Enterprise	This provides data flow between the utility's control/ operations centre and the WAN. This interface maintains isolation between the WAN services (e.g., regional interconnections, WAN last mile (backhaul/ WAN), and the transmission substation networks).
CT32	Wide Area Network	Backhaul	This is the connection between the WAN and the WAN last mile (backhaul/WAN). The WAN last mile serves as the extension of the WAN to connect primarily the distribution networks.
CT33	Wide Area Network	Distribution Substation Network	This securely interconnects devices within a utility's distribution substation network and the WAN of the utility. This connection is common to utilities with combined transmission and distribution substations.

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Table B.4 *(continued)*

Interface	Entity 1	Entity 2	Comments
CT34	Transmission Substation Network	Wide Area Network	This provides data flow between the transmission substation network of the utility and the WAN. This interface normally carries all IT and OT traffic including EMS and RAS traffic from the substation to the control centre.
CT35	Regional Interconnects Networks	Wide Area Network	This provides data flow between other utilities and a utility's WAN to facilitate regional interconnections. The interface is primarily used for monitoring RTUs of another utility to enable RAS applications, as well as PMU data for inter-utility wide-area situational awareness.
CT36	Transmission Substation Network	Backhaul	This provides data flow between the transmission substation network of the utility and the WAN last mile. This interface maybe used as an alternative for direct WAN (CT34) connectivity or where there is inadequate capacity on legacy services (CT30).
CT37	Not Used	Not Used	Not Used
CT38	Not Used	Not Used	Not Used
CT39	Grid Scale Energy Resources	Wide Area Network	This connects grid scale energy resources in the generation domain of a utility including hydro, geothermal, wind, and photovoltaic plants with the WAN of the utility. The connectivity can be provided via wireline (fibre, dial-up, xDSL, T1) or wireless (WiMAX, UMTS™, GPRS, 3G, etc.).
CT40	Regional Interconnects Networks	Grid Scale Energy Resources	This provides data flow between the grid scale energy resources in the generation domain of a utility and other utilities' communication networks. The connectivity can be provided via wireline (fibre, dial-up, xDSL, T1) or wireless (WiMAX, UMTS, GPRS, 3G, etc.).
CT41	Workforce Mobile Network	Feeder Distributed Energy Resources/ MicroGrid Network	This provides data flow between DERs and the workforce mobile network. It may be wireless to support mobility of the workforce.
CT42	Transmission Substation Network	Distribution Substation Network	This interconnects directly devices within a utility's transmission substation network to the devices within the utility's distribution substation including SCADA, IEDs, RTUs, PMUs, and other field devices. Data flow between these two entities is latency critical.
CT43	Grid Scale Energy Resources	Transmission Substation Network	This connects grid scale energy resources in the generation domain of a utility including hydro, geothermal, wind, and photovoltaic plants with devices in the transmission substation network of the utility.
CT44	Not Used	Not Used	Not Used
CT45	Field Area Network	Distribution Substation Network	This provides data flow between a FAN of a utility and the distribution substation network of the utility. Thus, information can be carried between SCADA, PMUs, RTUs, and IEDs in the distribution substation network and the utility's control/operations centre over the FAN.

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Table B.4 *(continued)*

Interface	Entity 1	Entity 2	Comments
CT46	Field Area Network	Feeder Distributed Energy Resources/ Microgrid Network	This provides data flow between a FAN of a utility and the DERs/microgrid network. Thus, information can be carried between SCADA, RTUs, and IEDs in the distribution substation network and the utility's control/operations centre over the FAN.
CT47	Field Area Network	Feeder Network	—
CT48	Workforce Mobile Network	Distribution Substation Network	Wireless hotspots or wired connections into the distribution substation network will be used to provide additional information to the workforce mobile network devices for diagnosis and repair work.
CT49	Backhaul	Field Area Network	—
CT50	Workforce Mobile Network	Feeder Network	An interface between feeder networks to workforce mobile network devices will allow for faster and more accurate diagnosis, isolation, and repair of feeder network problems.
CT51	Workforce Mobile Network	Backhaul	In addition to AMI communications, a backhaul/WAN can provide communications links to mobile workers.
CT52	Energy Services Interfaces/ Customer Premises Network	Neighbourhood Area Network	The ESI is the interface between NAN and HAN. Through ESI, NAN and HAN can communicate to each other even though they might use different communication technology.
CT53	Other Networks	Energy Services Interfaces/ Customer Premises Network	This provides connectivity between the ESI (which may be a stand-alone device or could be integrated into the smart meter itself) and WANs (e.g., GSM, EDGE, UMTS, GPRS, LTE, WiMAX, WCDMA, CDMA, microwave, satellite, etc.) in order to enable wide-area connectivity into the CPN (typically the ESI/EMS is the entry point) from a variety of other end-points (e.g., the utility distribution control/operations centre, mobile PEV, and many others). This link could be associated with the following applications: AMI/NAN, DA, workforce automation, outage management, PEV (mobile charging, billing, localization, etc.), DER management/control, and various other applications.
CT54	Utility Operation and Control/ Enterprise	Other Networks	—
CT55	Not used	Not used	Not used
CT56	Not used	Not used	Not used
CT57	Not used	Not used	Not used
CT58	Not used	Not used	Not used
CT59	Not used	Not used	Not used
CT60	Bulk Generation	Wide Area Network	—
CT61	Markets	Wide Area Network	—
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Table B.4 *(continued)*

Interface	Entity 1	Entity 2	Comments
CT62	Regional Intercon-nects Networks	Other Networks	—
CT63	Workforce Mobile Network	Other Networks	Other networks not called out specifically can also be used for workforce mobile networks. These other net-works can be either the primary network or a redundant backup network for mobile networks.
CT64	Wide Area Net-work	Field Area Net-work	—
CT65	Backhaul	Neighbourhood Area Network	The meter information goes through NAN and is col-lected by DAP and then publishes to backhaul through WAN. The information from backhaul goes through WAN to DAP and then distributes to meters through NAN.
CT66	Workforce Mobile Network	Wide Area Net-work	A WAN is one of the alternative networks that can carry data to/from workforce mobile network access points and base stations. The WAN itself can be used as a net-work for dispatch communications.
CT67	Bulk Generation	Other Networks	—
CT68	Energy Services Interfaces/ Cus-tomer Premises Network	Loads	This provides connectivity between the ESI (which could be physically located on the smart meter itself) and the various loads (possibly thousands) within the customer premises in order to support functions such as energy management, lighting control, solar protection, HVAC control, security/access control, control of audio/video services. The physical links associated with CT68 are generally considered a part of the HAN/BAN/IAN. Also, note that some of the key customer premises systems and controls such as HBES, BACS (building automation and control system), and EMS could physically reside in the ESI, or in a separate device connected directly to the ESI via CT68.
CT69	Regional Intercon-nects Networks	Utility Operation and Control/ Enterprise	—
CT70	Workforce Mobile Network	Utility Operation and Control/ Enterprise	Dispatch, maintenance, and restoration work will be managed over the workforce mobile network between the utility control centre and the mobile workers. A variety of communications solutions ranging from public carrier networks to dedicated private voice and data networks are used.
CT71	Workforce Mobile Network	Transmission Sub-station Network	Wireless hotspots or wired connections into the trans-mission substation network will be used to provide additional information to the workforce mobile network devices for diagnosis and repair work.
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B.3 Information Technology Interoperability Architecture Perspective (IT-IAP) Description of Entities and Interfaces

Table B.5 provides the description and associated comment of each entity found in the Information System Interoperability Architecture Perspective (IT-IAP) shown in Figure 3.

Table B.5 — IT-IAP entities and descriptions.

Entity	Description	Comments
Billing	Customer billing	Utilizes meter data and applicable tariff for customer billing and back-office financial functions.
Customer Energy Portal	Supports customer interaction with the service provider	May be accessed via the Internet, telephone support, or other means. Includes energy usage, billing data, and customer authorizations.
Customer Energy Management and Control	—	Typically called home EMS (HEMS), business EMS (BEMS), or industrial EMS (IEMS). The energy management function may be distributed (e.g., between smart meter and HEMS) or may be provided by a service provider.
Customer Information	Utility customer database	Includes history, location, contact, credit and other usage, and PII of the customer.
Demand Management	Provides load control based on the state of the power system.	Utilizes usage data and pricing to encourage load control by the customer. Load control may be achieved via customer action, controlled outages, etc.
Distributed Energy Resources (Local Generation)	DERs at the customer site	Includes generation and storage. May or may not be dispatchable.
Dispatch	Plans generation needs	Utilizes market data to schedule generation and to provide availability data to the markets.
Distribution Asset Management	Identify and manage equipment and future investments in the distribution domain	A broad set of functions that integrate for the distribution domain: planning, preventative maintenance, spare inventory control, financial reporting, etc.
Distribution Field Device	The aggregator of distribution system data	Provides monitoring, information exchange, and control data for operations/control. Typically provided via SCADA.
Distribution Management	Integrates all distribution system operations	Manages distribution system operations including load management, reliability, and assets. Utilizes data from the distribution system, customer, and control/operations.
Distribution Mobile Workforce Management	Automation of field service resources	Optimizes matching of personnel and equipment to maintenance, construction, and repair.
Distribution Operation	SCADA, asset management, and similar operations related to the distribution system	Maintains reliability and safe operation of the distribution system.
Distribution Substation	The aggregator of distribution system data	Provides monitoring, information exchange, and control data for operations/control. Typically provided via SCADA.
Energy Management	Integrates all transmission system operations	Manages transmission operations including power flows, reliability, and assets. Utilizes data from the transmission system and data provided from control/operations.
Energy Market Clearing	Financial processes related to energy trading	—
Geographic Information Management	Provides spatial data and analysis	—
ISO/RTO Operation	System stability across utilities including load balancing and switching.	Integrates markets with transmission system operation for bulk power.

