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TECHNICAL REPORT

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Power systems management and associated information exchange – Part 1: Reference architecture

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Power systems management and associated information exchange – Part 1: Reference architecture

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

POWER SYSTEMS MANAGEMENT AND ASSOCIATED INFORMATION EXCHANGE –

Part 1: Reference architecture

FOREWORD

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IEC 62357-1, which is a technical report, has been prepared by IEC technical committee 57: Power systems management and associated information exchange.

This first edition cancels and replaces the first edition of IEC 62357 published in 2003 and constitutes a technical revision. This edition includes the following significant technical changes with respect to the previous edition:

a) update of the description of the various standards activities within TC 57 and the way they individually and collectively contribute to meeting the objectives of TC 57;

b) update of the areas where harmonization of existing standards within TC 57 is needed and provision of detailed recommendations regarding harmonization of the CIM IEC 61968/61970 and IEC 61850 standards;

c) definition of a new layered architecture to help direct longer term goals and activities to ensure compatibility of all new standards developed in TC 57;

d) alignment of the architecture on other internationally recognized architecture standards, such as the UN/CEFACT Core Components Technical Specification;

e) incorporation of lessons learned during development of the current standards and their application on actual utility projects;

f) provision of new guidance on the role of TC 57 standards in the Smart Grid.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
57/1184/DTR	57/1255/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62357 series, published under the general title *Power systems management and associated information exchange*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

0.1 General

The objectives of IEC/TR 62357-1 are to

- provide a framework to show how the various standardisation activities within IEC Technical Committee 57 relate to each other and how they individually and collectively contribute to meeting the objectives of IEC Technical Committee 57, and
- develop a strategy to combine and harmonize the work of these various activities to help facilitate a single, comprehensive plan for deployment of these standards in product development and system implementations.

IEC/TR 62357-1 provides updates and defines a layered reference architecture to help direct longer term goals and activities, specifically to ensure compatibility of all new standards developed in TC 57 by benefitting from lessons learned during development of the current standards and their application on actual utility projects as well as through application of other internationally recognized architecture standards, such as the UN/CEFACT Core Components Technical Specification.

The second edition of IEC 62357-1 currently being prepared will reflect the progress recently achieved from the international Smart Grid (SG) initiatives and the CIGRE D2.24 large system architecture vision. This second edition will also reflect the most recent editions of the TC 57 standards including IEC 61850 series and IEC 61968 series, IEC 61970 series, and IEC 62325 series.

0.2 Objectives and overview of this technical report

0.2.1 Overview

IEC TC 57 is chartered with developing standards for electric power system management and associated information exchange in the areas of generation, transmission and distribution real-time operations and planning as well as information exchange to support wholesale energy market operations. This technical report has three objectives with respect to TC 57's current and future work. It also has a fourth objective regarding the role of TC 57 standards in development and implementation of the Smart Grid.

0.2.2 Existing TC 57 standards and architecture

The first objective of this technical report is to provide a reference architecture to show how the various existing standards activities within IEC TC 57 relate to each other today and how they individually and collectively contribute to meeting the objectives of TC 57. Clause 3 describes each of the working groups and their current scope of work, while Clause 4 shows how all the standards developed to date fit into an overall architecture

0.2.3 Areas for harmonization

The second objective is to identify areas where harmonization between TC 57 standards is needed and to suggest possible approaches to achieve it in order to facilitate a single, comprehensive, optimal plan for deployment of these standards in product development and system implementations. Clause 5 describes the data modelling and service definition approaches currently used in TC 57. Clause 6 describes way these modelling standards and services are mapped to concrete technologies, while Clause 7 discusses the harmonization needed to ensure that these existing modelling and technology mapping standards are compatible, if not totally integrated.

0.2.4 Future vision for TC 57 standards architecture

The third objective is to define a vision for the future reference architecture that will help direct longer term goals and activities. More specifically the goal is to ensure compatibility of all new standards developed in TC 57 by benefitting from lessons learned during development of the current standards and their application on actual utility projects as well as through application of other internationally recognized architecture standards, such as the UN/CEFACT Core Components Technical Specification.

Clause 8 defines the fundamental architecture principles established to guide the structure of new standards work, specifically proposing a layered architecture that recognizes internationally accepted concepts for a layered architecture including an abstract information model, a business context layer, message assembly layer, and an implementation or technology mapping layer. Clause 9 discusses the conclusions.

0.2.5 Role of TC 57 standards in the smart grid

The fourth objective is to provide an overview of the TC 57 standards and their role in the Smart Grid. Now that the TC 57 standards, such as the IEC 61968 series, IEC 61970 series and IEC 61850 series, have been recognized as pillars for realization of the Smart Grid objectives of interoperability and device management, it is imperative that a correct understanding of these standards and their application be made available to the key stakeholders and all other interested parties involved in implementing the Smart Grid.

0.3 Rationale

The need for this technical report was motivated by three major factors:

a) there are multiple independent standards initiatives that need to be coordinated and harmonized to facilitate information exchange between systems using these various standards;

b) there is a need to have a comprehensive vision of how to deploy these standards for actual system implementations and integration efforts;

c) there needs to be a vision of the future so that additional work can take into account the evolving communications and modelling technologies, and can be incorporated within a clearly defined architectural framework.

There are several different initiatives within TC 57, each dealing with a selected part of real-time operations and planning. Each has a specific objective and may have sufficient breadth of scope to provide the bulk of the relevant standards needed for product vendors to develop products based on those standards.

0.4 Trend toward model driven architectures and integration

In today's utility enterprise, where information exchange between the various generation, distributed resource, transmission, and distribution management systems, as well as customer systems and other IT systems is not only desirable but necessary, each system plays the role of either the supplier or consumer of information, or more typically both. That means that both data semantics and syntax need to be preserved across system boundaries, where system boundaries in this context are interfaces where data is made publicly accessible to other systems or where requests for data residing in other systems are initiated. In other words, the "*what"* of the information exchange is actually much more important for system integration purposes than "*how"* the data is transported between systems.

Most previous efforts to define system architectures have dealt primarily with the *how* (i.e., definition of protocols for transporting the data), with a focus on utilizing as many existing ISO or TCP/IP standards as possible to provide the various layers in the ISO OSI seven-layer reference model for protocol profiles.[1] However, the increasing use of object modelling techniques to define the data for information exchange within the different standards initiatives has properly shifted the focus away from the *how* to the *what.* Of even more importance, this trend has resulted in the separation of the data from the protocol standards, creating a new layer of abstraction for the data model as well as the data exchange methods that is independent of the underlying infrastructure. The consequence of this is that a common data model and a few generic data-driven interface patterns can be used for all information exchange independent of the underlying protocols selected for a given system implementation. This new architecture is known as a Model-Driven Architecture (MDA), or when applied to integration of systems and applications, as Model-Driven Integration (MDI). Actual implementations can then take advantage of the current industry architectural trends, such as Service Oriented Architectures (SOA) and the use of Web services.

Standardization efforts within TC 57 began several years prior to development of the MDA/MDI architectural concepts. As a result, there was little or no collaboration between working groups. Each working group chose its own modelling language/notation and more importantly generated their own object and service model definitions. This was not done intentionally, and in fact each initiative had perfectly good reasons for their choices given the limited scope of their domain of application. But the consequence is that instead of one object model for each physical entity in the generation, transmission and distribution operations domains being standardized, at least two or more object models exist in most cases with different definitions for classes, attributes, data types, and relationships between classes. Furthermore, in most cases different modelling languages have been used as well.

0.5 Purpose of the reference architecture

To achieve the first objective of this technical report, a reference architecture for power system information exchange is defined to describe all the existing object models, services, and protocols within TC 57 and how they relate to each other. Then, to meet the second objective, a strategy is developed to show where harmonization is needed, and if possible, to recommend how to achieve a common model. Where changes cannot be made due to maturity of standards, then recommendations for adapters to make the necessary transformations between models are made. The third objective of this technical report is achieved by defining a new future reference architecture that recognizes the importance of a single, internally consistent semantic layer to avoid unnecessary seams (i.e., the concept of a seamless architecture), while facilitating information exchange over a variety of industry-standard transport infrastructures. This new reference architecture provides a framework for growth and incorporation of new, evolving technologies without invalidating the existing standards developed by TC 57.

0.6 Scope of reference architecture

0.6.1 General

Originally the charter and title of TC 57 was "Power system control and associated telecommunications". The focus was on developing different protocol standards to address the data communications requirements of different parts of power system control, such as data communications over low-speed serial lines, distribution line carrier protocols, and inter-control center communications protocols.

Later as the scope of the TC 57 work broadened to include data exchange between applications within an energy management system as well as inter-computer system data exchange between distribution management systems and deregulated energy market communications, the charter was changed to "Power system management and associated information exchange", so that the focus shifted from lower lever protocol development to

1 The original EPRI UCA project, for example, had the focus of settling on the use of MMS and a few standard profiles for transporting data rather than on the semantics of information transfer between systems.

development of more abstract data models and generic interfaces at higher levels in the architecture. This shift resulted in the creation of new working groups to address the new business functions embraced by the new TC 57 charter, which includes:

- energy management,
- SCADA and network operation,
- substation protection, monitoring, and control,
- distribution automation,
- distributed energy resources (DER),
- demand response and load control,
- meter reading and control,
- customers,
- work,
- network expansion planning,
- operational planning and optimization,
- maintenance and construction,
- records and asset management,
- market operations,
- reservations,
- financial,
- energy scheduling.

0.6.2 IEC standards included in reference architecture

The scope of the reference architecture for power system information exchange embraces all these areas from both the abstract information modelling perspective (i.e., platform independent models) as well as the technology mappings for implementation (i.e., platform specific models).

Figure 1 shows where some of these standards are used in the utility operations environment. Not all standards listed above are shown and not all end field devices/systems are shown. More detailed descriptions and illustrations are provided in Clause 3.

The reference architecture for power system information exchange includes the following IEC TC 57 standards (responsible working groups are shown in parentheses):

IEC 60495, *Single sideband power-line carrier terminals (WG20)*

IEC 60663, *Planning of (single-sideband) power line carrier systems (WG20)*

IEC 60870-5 (all parts), *Telecontrol equipment and systems – Part 5: Transmission protocols (WG3)*

NOTE 1 IEC 60870-5 series covers reliable data acquisition and control on narrow-band serial data links or over TCP/IP networks between SCADA masters and substations.

IEC 60870-6 (all parts), *Telecontrol equipment and systems – Part 6: Telecontrol protocols compatible with ISO standards and ITU-T recommendations (WG7)*

NOTE 2 IEC 60870-6 series covers the exchange of real-time operational data between control centres over Wide Area Networks (WANs). This series is known officially as TASE-2 and unofficially as ICCP.

IEC 61334 (all parts), *Distribution automation using distribution line carrier systems (WG9)*

NOTE 3 IEC 61334 series covers data communications over distribution line carrier systems.

IEC 61400-25 (all parts), *Wind turbines – Part 25-1: Communications for monitoring and control of wind power plants*

NOTE 4 IEC 61400-25 series covers monitoring and control of wind power plants and associated communication. The standards developed by JWG 25 are based on IEC 61850 series.

IEC 61850 (all parts), *Communication networks and systems for power utility automation (WG10, WG17, WG18)*

NOTE 5 IEC 61850 series covers communication networks and systems in substations. These standards are known unofficially as the UCA2 protocol standards. They also include standards for hydroelectric power plant communication, monitoring, and control of distributed energy resources and hydroelectric power plants.

IEC 61968 (all parts), *Application integration at electric utilities – System interfaces for distribution management (WG14)*

NOTE 6 IEC 61968 series covers Distribution Management System (DMS) interfaces for information exchange with other IT systems. These include the distribution management parts of the CIM and extensible Markup Language (XML) message standards for information exchange between a variety of business systems, such as meter data management, asset management, work order management, Geographical Information Systems (GIS), etc.

IEC 61970 (all parts), *Energy management system application program interface (EMS-API) (WG13)*

NOTE 7 IEC 61970 series facilitate integration of applications within a control centre, exchange of network power system models with other control centres, and interactions with external operations in distribution as well as other external sources/sinks of information needed for real-time operations. These standards include the generation and transmission parts of the Common Information Model (CIM), profiles for power system model exchange and other information exchanges, and XML file format standards for information exchange.

IEC 62325 (all parts), *Power systems management and associated information exchange – Data and communications security (WG16)*

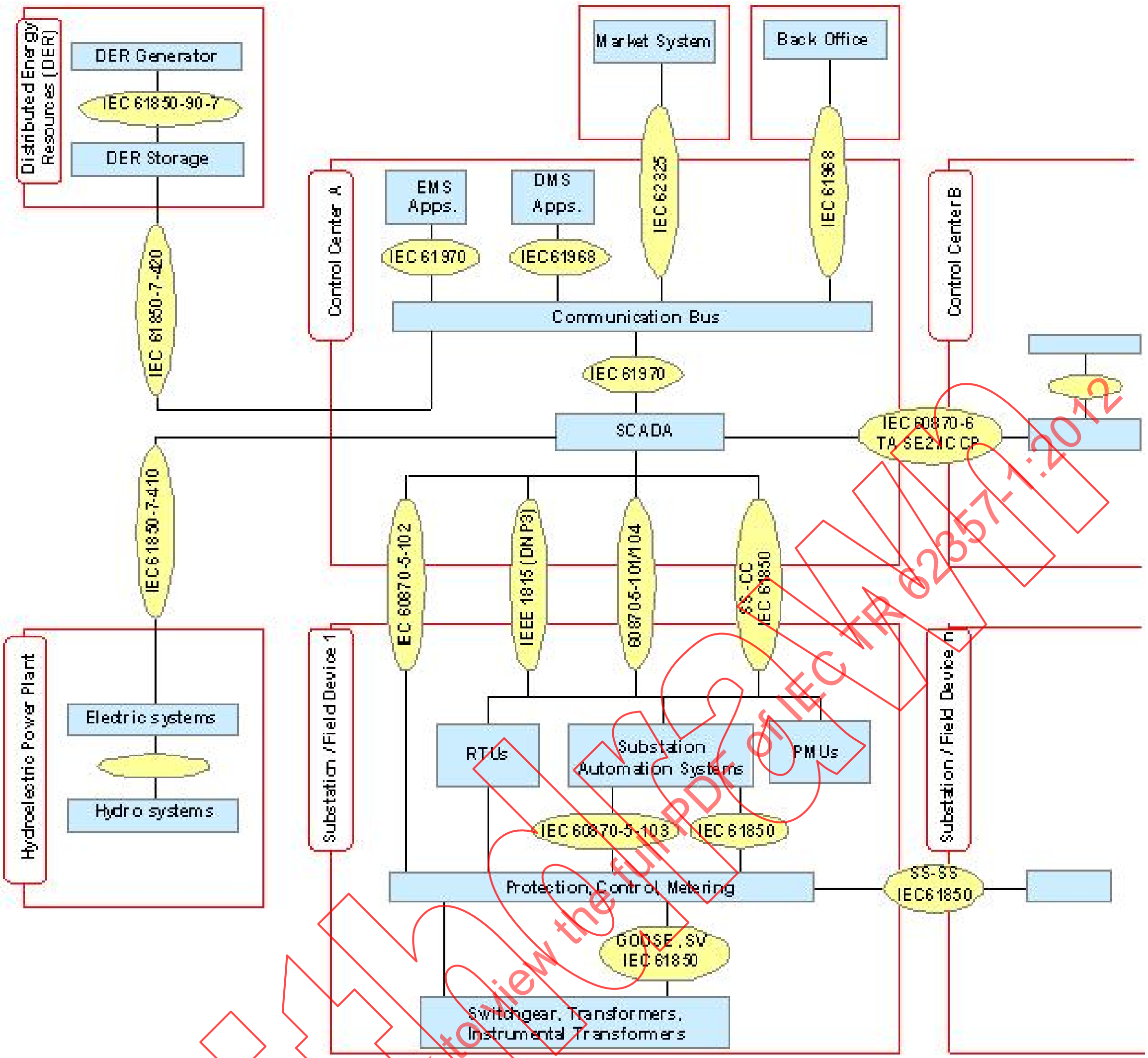
NOTE 8 IEC 62325 series covers deregulated energy market communications.

IEC 62351 (all parts), *Power systems management and associated information exchange – Data and communications security (WG15)*

NOTE 9 IEC 62351 series covers data and communication security.

IEC 62488 (all parts), *Power line communication systems for power utility applications (WG20)*

NOTE 10 IEC 62488 series covers data power line communication systems for power utility applications.



IEC 2049/12

Figure 1 – Application of TC 57 standards to a power system

0.6.3 TC 57 organization and formal liaisons

Figure 2 shows the organization of the IEC TC 57 working groups that are responsible for producing these standards. The formal TC 57 liaisons with external organizations and industry consortiums are also shown and listed below with additional detail:

- **CIGRE**: Category A
  - SC D2-24 Information systems and telecommunications – EMS architectures for the 21st century
  - SC B5-38: Protection and automation
- **ITU-T** (International Telecommunication Union) – Telecommunications sector which is responsible the efficient and timely production of standards covering all fields of telecommunications on a worldwide basis, as well as defining tariff and accounting principles for international telecommunication services. Category A with TC57.
- **UCAIug** (UCA International User Groups), including CIM, OpenSG, and 61850: Category D with WG10, WG13 and WG14
- **ebIX** (European forum for energy business information exchange): Category D with WG16
- **ENTSO-E** (European Network of Transmission System Operators for Electricity), responsible for Europe-wide planning and operations for all cross-border exchanges of electricity: Category D with WG13 and WG16

- **IEEE** (Institute of Electrical and Electronic Engineers) **PES** (Power Engineering Society) **PSCC** (Power Systems Communications Committee) **Security Subcommittee**: Category D with WG15
- **UN/CEFACT** (United Nations/Center for Trade Facilitations and Electronic Business), a United Nations body that is in charge of trade facilitations and have launched an initiative for e-commerce known as ebXML, a suite of specifications to enable enterprises to conduct business over the Internet. Included is a mechanism for enterprises to register core components in XML meta-language, so that other enterprises can determine what information is available, and can then establish dynamic interactions automatically: MoU (Memo of Understanding) between IEC and UN/CEFACT

Later in the introduction the activities of each of the IEC TC 57 working groups is described. As shown the activities are coordinated by the Convener's Advisory Group (CAG) and WG19, which functions as an architecture board to ensure standards developed fit a common architectural framework and are compatible with existing standards.

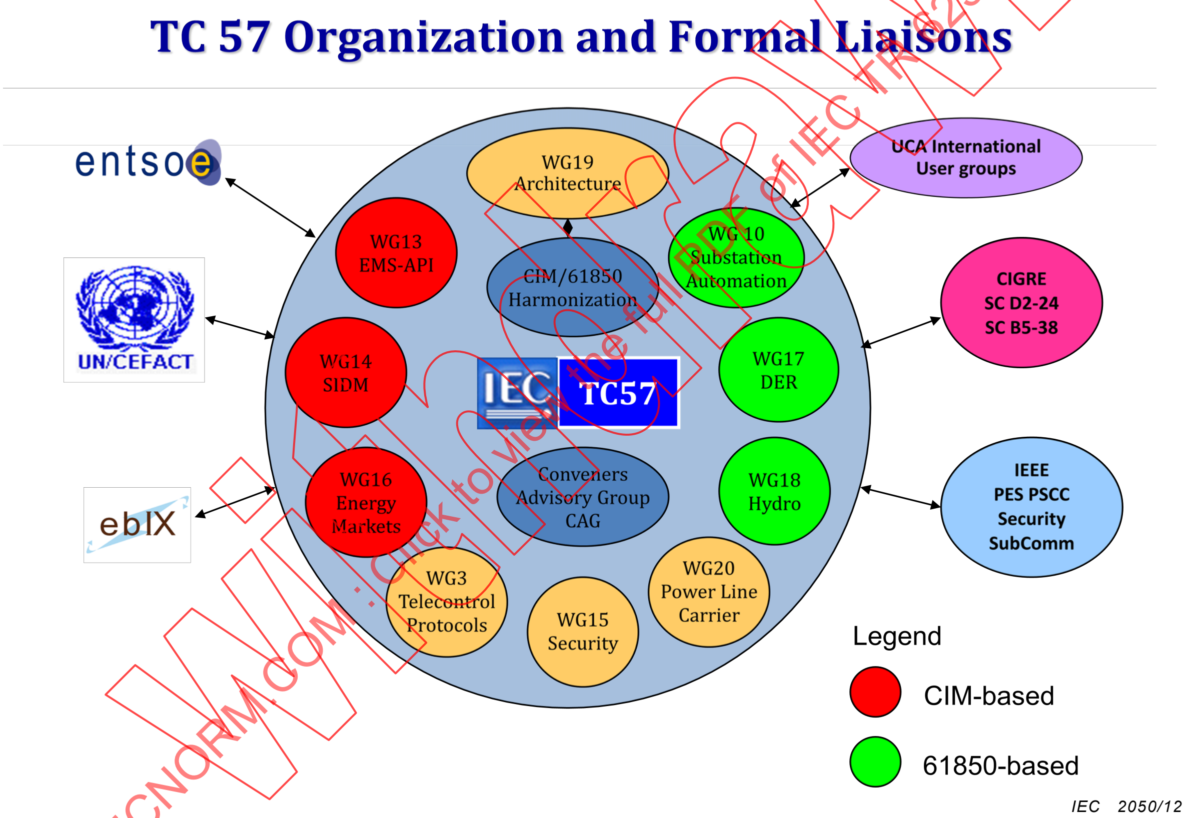


Figure 2 – TC 57 organization and formal liaisons

0.6.4 IEC internal liaisons

Current IEC internal liaisons include:

- IEC TC 4 Hydraulic turbines
- IEC TC 8 Systems aspects for electrical energy supply
- IEC TC 13 Electrical energy measurement, tariff- and load control
- IEC SC 17C High-voltage switchgear and controlgear assemblies
- IEC TC 38 Instrument transformers
- IEC TC 65 Industrial-process measurement, control and automation
- IEC TC 88 Wind turbines (IEC 61400-25-1 to -6)

- IEC TC 95 Measuring relays and protection equipment

0.6.5 Related standards activities

In addition to the formal liaisons, there are other standards-related activities that are relevant to TC 57 and are the source of either existing or planned standards that can be adopted (perhaps with some tailoring to meet utility-specific needs) for use within TC 57. Figure 2 graphically depicts these activities and domains of application. Of particular interest are the following:

National Institute of Standards and Technology (NIST), the non-regulatory federal agency within the U.S. Department of Commerce responsible for generating the Smart Grid Roadmap and defining standards for the Smart Grid.

North American Energy Standards Board – Electricity (NAESBE), an industry forum for the development and promotion of standards which will lead to a seamless marketplace for wholesale and retail electricity, as recognized by its customers, business community, participants, and regulatory entities.

IEEE, in particular the IEEE PES committees, including the power system relaying Committee, and the substations committee, as well as the IEEE Communications Society, IEEE SCC36, and IEEE SCC21.

OPC, an industry consortium responsible for standards related to the integration of near real time applications – primarily in the process control, manufacturing, and utility sectors. WG13 is working closely with OPC to leverage their unified architecture set of interface services for exchanging CIM-based data**.**

Open Application Group (OAG), an industry consortium responsible for Enterprise Application Integration (EAI) solutions. WG14 is working closely with the OAG to develop standard XML messages for information exchange between distribution management systems and other IT systems.

MultiSpeak, a collaboration of the National Rural Electric Cooperative Association (NRECA) in the USA. The MutiSpeak Initiative has developed and continues to expand a specification that defines standardized interfaces among software applications commonly used by electric utilities.

European Transmission System Operator (ETSO), a consortium of European TSOs that define standards for information exchange. They rely on the UN-CEFACT standardisation process.

European Federation of Energy Traders (EFET), an organization that federates the traders in Europe.

World-Wide Web Consortium (W3C), a consortium that develops interoperable technologies (specifications, guidelines, software, and tools) to lead the Web to its full potential, among these technologies are XML, RDF, OWL, Web services.

Internet Engineering Task Force (IETF) Internet Services

International Standards Organization (ISO) Security and Metadata Repository Standards

Electric Power Research Institute (EPRI), although not a standards organization as such, was a source for a number of the drafts which became standards within TC 57 via the Control Center Applications Program Interface (CCAPI) project.

0.7 Purpose of the future reference architecture for power system information exchange

The future reference architecture is built upon the current TC 57 reference architecture and the many utility requirements that went into defining that architecture. However, it also takes into account new concepts and evolving technologies in the information industry at large. In some cases these are incorporated into the future reference architecture, not necessarily because they are better than what has been developed to-date, but because the electric industry must and will follow technology trends from other industries where these are proven to be cost-beneficial. In other cases, the electric power industry is just now getting into new areas, such as market operations, where some of the needed technologies are being defined elsewhere.

POWER SYSTEMS MANAGEMENT AND ASSOCIATED INFORMATION EXCHANGE –

Part 1: Reference architecture

1 Overview

1.1 Scope

This part of IEC 62357, which is a Technical Report, specifies a reference architecture and framework for the development and application of IEC standards for the exchange of power system information.

This technical report provides an overview of these standards as well as guidelines and general principles for their application in distribution, transmission, and generation systems involved in electric utility operations and planning.

The future multi-layer reference architecture described in this technical report takes into account new concepts and evolving technologies, such as semantic modelling and canonical data models, in order to build on technology trends of other industries and standards activities to achieve the interoperability goals of the Smart Grid.

1.2 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.

IEC 61850 (all parts), *Communication networks and systems for power utility automation*

IEC 61968 (all parts), *Application integration at electric utilities – System interfaces for distribution management*

IEC 61970 (all parts), *Energy management system application program interface (EMS-API)*

2 Abbreviations

For the purposes of this document, the following abbreviations apply.

ACSI	Abstract Communication Service Interface
AHWG	Ad Hoc Working Group
API	Application Program Interface
ASCII	American Standard Code for Information Interchange
ASN	Abstract Syntax Notation
CASE	Computer Aided Software Engineering
CASM	Common Access Service Methods
CC	Control Centre
CCAPI	Control Centre Application Program Interface
CCTS	Core Component Technical Specification
CDA	Common Data Access
CES	Component Execution System
CIM	Common Information Model

CIS	Common Interface Specification
CMIP	Communication Management Information Protocol
COM	Common Object Model
CPSM	Common Power System Model
CS	Common Services
DA	Data Access
DAF	Data Access Facility
DAIS	Data Acquisition from Industrial Systems
DBMS	Database Management System
DCOM	Distributed Common Object Modelling
DER	Distributed Energy Resource
DLC	Distribution Line Carrier
DLMS	Distribution Line Messaging System
DMS	Distribution Management System
DOM	Document Object Model
DTD	Document Type Definition
DTF	Domain Task Force
EAI	Enterprise Architecture Integration
ebXML	e business XML
EDI	Electronic Data Interchange
EDIFACT	Electronic Data Interchange for Administration, Commerce and Transport
EII	Enterprise Information Integration
EJB	Enterprise Java Beans
EMS	Energy Management System
EPRI	Electric Power Research Institute
ERP	Enterprise Resource Planning
ETL	Extract, Transform, and Load
EV	Electric Vehicle
FTP	File Transfer Protocol
GDA	Generic Data Access
GES	Generic Eventing and Subscription
GIS	Geographic Information System
GOOSE	Generic Object Oriented System Event
GSSE	Generic Substation Status Event
GUI	Graphic User Interface
GUID	Globally Unique Identifier
HDAIS	Historical Data Access from Industrial Systems
HIS	Historical Information System
HMI	Human Machine Interface
HSDA	High Speed Data Access
HTML	Hypertext Markup Language
ICCP	Inter-Control Centre Protocol
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronics Engineers
IEM	Information Exchange Model
IP	Internet Protocol
IRM	Interface Reference Model
ISO	International Standards Organization or Independent System Operator
IS	International Standard
IT	Information Technology
J2EE	Java 2 Enterprise Edition
LAN	Local Area Network

LD Logical Devices
LV Low Voltage

MAC Media Access Control
MDA Model Driven Architecture
MDI Model Driven Integration
MDR Metadata Repository
MIB Management Information Base
MMS Manufacturing Messaging Specification
MRID Master Record Identification Number
MV Medium Voltage

NDR Naming and Design Rules
NERC North American Electric Reliability Corporation
NWIP New Work in Progress

OAG Open Application Group
OLE Object Linking and Embedding
OMG Object Management Group
OPC OLE for Process Control
ORB Object Request Broker
OSI Open System Interconnect
OWL Ontology Web Language

PC Personal Computer
PIM Platform Independent Model
PLC Programmable Logic Controller
PSM Platform Specific Model
PV PhotoVoltaic

RDBMS Relational Data Base Management System
RDF Resource Description Framework
RDFS RDF Schema
RFP Request for Proposal
RTO Regional Transmission Operator
RTU Remote Terminal Unit
RWO Real World Objects

SAS Substation Automation System
SCADA Supervisory Control and Data Acquisition
SCD System Configuration Description
SCL Substation Configuration Language
SCSM Specific Communication Service Mapping
SGML Standard Generalized Markup Language
SIDMS System Interfaces for Distribution Management Systems
SMV Sample Measured Value
SNMP Simple Network Management Protocol
SOA Service Oriented Architecture
SOAP Simple Object Access Protocol
SPAG Strategic Policy Advisory Group
SQL Structured Query Language
SSD Substation System Description

TASE Telecontrol Application Service Element
TC Technical Committee or Time Constant
TCP/IP Transport Control Protocol/Internet Protocol
TLS Transport Layer Security
TSDA Time Series Data Access

UCA Utility Communication Architecture
UDDI Universal Description and Discovery Information
UML Unified Modelling Language

UMM	UN/CEFACT Modelling Methodology
UMP	UML Profile
UN/CEFACT	United Nations Centre for Trade Facilitation and Electronic Business
URI	Uniform Resource Identifier
URL	Universal Resource Locator
URN	Universal Resource Name
VLPGO	Very Large Power Generation Operators
VPN	Virtual Private Network
WAN	Wide Area Network
WG	Working Group
W3C	World Wide Web Consortium
WSDL	Web Services Definition Language
XMI	Extensible Mark-Up Language Metadata Interchange
XML	Extensible Mark-up Language
XSD	XML Schema Definition
XSL	Extensible Style Sheet Language
XSLT	Extensible Style Sheet Language Template

3 IEC TC 57 standards

3.1 General

As in most standards activities, the working documents that eventually become standards from TC 57 have their genesis within the individual working groups of TC 57. These working groups were formed from the bottom up rather than from an initial vision embodied in an umbrella framework or reference architecture handed down by TC 57. That is, within the original charter of TC 57, which was "power systems control and associated telecommunications", working groups were formed whenever a member country took the initiative to propose a new work item.

The first working groups focused on protocols and services for data links from control centres to substations and distribution feeders, and to other control centres (WG3, WG7, and WG9). This work primarily provided standards for exchanging SCADA data and controlling substation/field devices.

As new working groups were subsequently formed, the emphasis shifted more to modelling and semantics of data (i.e., the of information exchange rather than the *how*, as previously mentioned) with transport mechanisms provided by world-wide, industry-independent standards provided by ISO, W3C, and others. WG10 applied these modelling techniques to substation automation and control, while WG13 and 14 focused on information exchange between transmission and distribution applications and systems, with the focus on message payload definitions and service definitions independent of the underlying transport mechanisms. WG16 extended this approach to market operations. WGs 17 and 18 further extended the application domain to DER and hydroelectric plants, respectively. WGs15 and 19 deal with security and harmonization issues, respectively, to ensure a common approach and internal consistency across all TC 57 working groups.

In parallel with this and in recognition of this shift in the subject of TC 57 standards, the charter of TC 57 was changed to "power system management and associated information exchange."

The following subclauses describe the standards developed within each of these working groups.

3.2 IEC 60870-5 telecontrol protocol standards from WG3

WG3 initially focused on providing standards for reliable communications on narrow-band serial data links traditionally used for communications between a SCADA master in a control centre and RTUs located in transmission substations in the field. The first WG3 standard, IEC 60870-5-101, resulted in a three-layer protocol stack custom designed for high reliability and high transmission efficiency for use on wires capable of only low bit rates. Later the scope of WG3 was broadened to include telecontrol protocols mapped onto data networks, such as router-based WANs. This resulted in IEC 60870-5-104, which provides network access for 60870-5-101 using standard transport profiles, primarily TCP/IP.

These standards implicitly assume an "anonymous point-oriented model" to identify the values received and devices controlled. This means that the source of a data value, such as analog measurement, status, or accumulator (i.e., counter) value, is an RTU point number or name. This is in contrast to the "device-oriented models" being developed in WG10 in the IEC 61850 series, where real world substation and field devices are represented by object models and the value of the object is identified by a structured name identifying the device that supplies it and the object it contains. In fact, the entire device is modelled to include other information, such as nameplate data.

3.3 IEC 60870-6 standards from WG7

WG7, which is no longer active, focused on providing protocols that could run over a WAN to interconnect control centres[2] with heterogeneous databases and EMS applications. The goal was to develop protocols and services compliant with the OSI 7-layer reference model using existing ISO standards to the maximum extent possible.[3]

The first standard published was TASE.1, comprising IEC 60870-6-501,-502, -504, and -701, which is based on the ELCOM-90 protocol from Norway over an OSI protocol stack. While TASE.1 includes enhanced functionality, the primary objective of TASE.1 is to provide for operation of an existing ELCOM-90 protocol over an OSI protocol stack. The application program interface for TASE.1 was maintained exactly as defined in the ELCOM-90 protocol documents to facilitate replacement of ELCOM-90 with TASE.1.

The second standard published was TASE.2, comprising IEC 60870-6-503, -505, -702, and -802. The major objectives of TASE.2 are to provide (1) increased functionality and to (2) maximize the use of existing OSI-compatible protocols, specifically the Manufacturing Messaging Standard (MMS) protocol stack. TASE.2 provides a utility-specific layer over MMS.

In addition to SCADA data and device control functionality as provided in TASE.1, the TASE.2 standards also provide for exchange of information messages (i.e., unstructured ASCII text or short binary files) and structured data objects, such as transmission schedules, transfer accounts, and periodic generation reports. This standard is also known unofficially as ICCP, from the name given by the EPRI project that sponsored the development of the draft specifications for this standard.

The TASE.2 standards make use of a client/server model, in which the client initiates transactions that are processed by the server. Object models were used to define the transactions and services for transferring this data, such as Association, Data Value, Data Set, Transfer Sets, Device Control, etc. The actual data to be transferred was separated from these services and defined as static data objects, such as Indication Points, Control Points, Transfer Account, Device Outage, etc. Thus an attempt was made to separate the data objects to be transferred from the underlying services used to transfer the data.

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2 The term control centre here also includes power plants and automated substations that contain a host computer acting as a SCADA master located within the substation itself.

3 The scope of TC 57 and WG7 was later modified to embrace the use of TCP/IP for the transport layer as well.

However, since the primary objective of TASE.2 was to support the exchange of real-time SCADA data or schedules and accounting information, the information needed was largely independent of the source of the information. That is, the knowledge of the physical device supplying measurands or status data was immaterial, as long as a power system model within the control centre could make the association of the received point data with its location in the network topology. For that reason, point-oriented models were used to represent the data values received and control commands sent to another control centre or substation host computer acting as a SCADA master for the substation. In other words, while an object model approach is used to define the data objects and services, an anonymous point-oriented model is used to identify the values received and devices controlled, as was done in WG3.

IEC 60870-6-503 defines the services and protocols, including a mapping of the abstract services and data types defined in the server objects onto MMS services and data types. IEC 60870-6-802 defines the data objects and their mapping onto MMS data types. IEC 60870-6-702 defines an application profile for the TASE.2 protocol stack in the upper 3 layers. IEC 60870-6-505 is a user guide for TASE.2.

3.4 IEC 61334 standards from WG9

3.4.1 General

These standards developed by WG9 (inactive) support distribution automation using distribution line carrier systems. These standards address protocols for accessing distribution devices in the field from distribution operations management systems over existing distribution power lines.

The scope of these standards covers communications using distribution line carrier technology on both, medium voltage (MV) and low voltage (LV) distribution networks. The distribution line communication system provides two-way communications which can be used for a large number of devices with various functions (e.g., station control units, remotely controlled feeder switches, meters, transformer station concentrators, portable input unit, light control, load management, and traffic lights).

IEC 61334-4-1 defines the reference architecture based on the client-server model. In IEC 61334-4-41, known as the Distribution Line Messaging System (DLMS), an abstract, object-oriented server model is provided. This model considers the limited resources of distribution devices. The protocol data units of the application protocol supporting the model are described in Abstract Syntax Notation.1 (ASN.1). In addition, efficient encoding-rules are provided (IEC 61334-6).

The standard series IEC 61334-5-1 to IEC 61334-5-5 define several physical and Media Access Control (MAC) layers using different modulation technologies suited for LV and MV communication. IEC 61334-4-511 and -512 specify the management framework and the management procedures, respectively, for the IEC 61334-5-1 profile. IEC 61334-3-21 and -22 define the requirements for coupling the Distribution Line Carrier (DLC) signals into the MV line considering the necessary safety requirements.

3.4.2 Relation to "external" standards

The DLMS standard IEC 61334-4-41 forms the basis for a series of standards developed by IEC TC13 WG14 for metering applications. In particular, IEC 62056 series provides a complete communication stack – including the meter device models –, which is compatible with IEC 61334-4-41.

3.5 IEC 61850 standards for power system IEC communication and associated data models from WG10

3.5.1 General

As the need for standards to address substation automation was identified, new working groups were formed (WG10-12) to develop standards for architectures and interfaces within substations and on distribution feeders. Because of similar and closely related objectives, these three working groups eventually merged into a single working group – working group 10 which produces standards for power system IED communication and associated data models. Work is underway to extend the scope of IEC 61850 to include substation-to-substation communications and substation to control centre communications

As the application use cases for IEC 61850 expanded, two new working groups were created to address these new areas:

- WG17 – Communications systems for Distributed Energy Resources (DER)
- WG18 – Hydroelectric power plants – Communication for monitoring and control

The standards produced by WG17 and WG18 which are also part of the IEC 61850 series of standards are discussed later in 3.10 and 3.11 respectively.

Unlike some other TC 57 protocols which have a flat or tag oriented data hierarchy, IEC 61850 data models are hierarchical in nature. The general IEC 61850 philosophy is to represent substation functions (e.g., metering or protection) by the use of non-distributable function atoms working together to define standardized naming, attributes, data, and methods of such function atoms, called logical nodes. A client then interacts with the resulting data object model *directly* in order to access it for purposes of reading attribute values, such as nameplate data or measured values, or to control the device, rather than indirectly through an RTU.

The common services needed by all substation devices, especially field devices, are modelled as services on objects, which are defined in IEC 61850-7-2 Abstract Communication Service Interface (ACSI). Field devices incorporate these services by specifying which objects within their models inherit the class objects defined in the ACSI. For example, if a model of a utility field device contains a measured value which needs to be read by a substation host, the object inherits the attributes and methods associated with the measurand object Basic Data Class defined in IEC 61850-7-3.

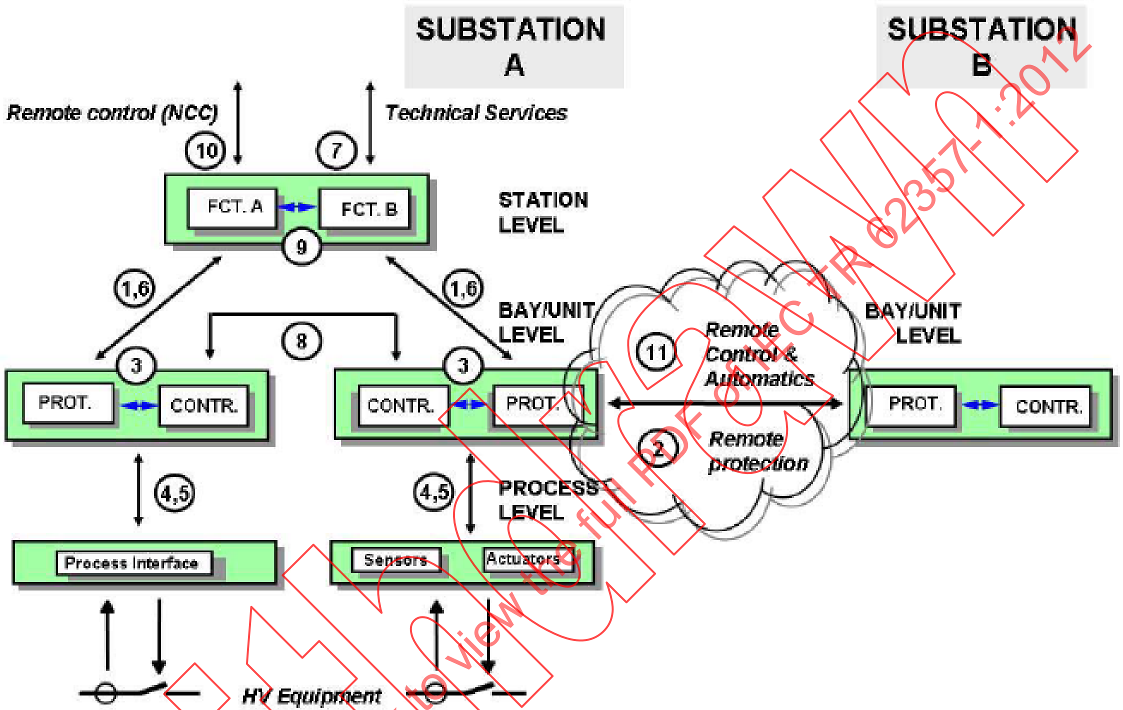
The IEC 61850 standards are based largely on object models for substation devices that originated with the EPRI-sponsored UCA2 project (now IEEE Technical Report 1550). Their general structure can be reused for other application areas by just providing the function atoms (logical nodes) with appropriate data for the new application area, thus allowing the reuse of all service definitions and configuration in the related parts of IEC 61850.

3.5.2 Substation architecture and interface specifications

The IEC 61850 standards specify three kinds of communication services:

- client/server based services, which are intended for vertical communication between system levels, typically from field level to station level to network level,
- a publish/subscribe service for exchanging real time data in the millisecond range between IEDs typically within the same LAN,
- a publish/subscribe based service to exchange analog sample values, typically used to send information from voltage and current sensors to bay level IEDs.

Figure 3 illustrates the logical data flows and interfaces between substation system levels. As may be seen, several types of communication interfaces and requirements are specified in the IEC 61850 standards. Interfaces 1, 3, 6, 8, and 9 comprise what is typically called a station bus. Specifications for these interfaces define the requirements for peer-to-peer information exchange of physical substation devices (e.g., bay controllers, protection relays, and meters). Interfaces 4 and 5 comprise what is typically called the process bus. Specifications for these interfaces define the requirements for sensor-to-device information exchange. Interface 7 enables remote engineers to communicate directly with devices on the station bus for the purposes of monitoring, configuration, and diagnostics. Interface 10 supports SCADA data exchange with a remote SCADA master. It is shown “greyed out” because, although it has similar requirements to Interface 7, it is up to now not within the scope of the IEC 61850 standards. Interface 2 is for protection-data exchange between bay level and remote protection, and Interface 11 is for control-data exchange between different substations.



IEC 2051/12

Figure 3 – Communication interface architecture for IEC 61850

Standardized mappings of these abstract services to different application layer communication protocol profiles are defined in IEC 61850-8-x (client server communication and real time communication) / IEC 61850-9-x (raw analog sample values), so that common utility functions will be performed consistently across all field devices independent of the underlying communication stacks.

As described earlier, the architecture of the “IEC 61850 bus” and its communication services enables bay/unit level devices to interact in a peer-to-peer fashion. It also supports the remote monitoring of these devices either directly (e.g., peer-to-peer) or through some type of information aggregator (e.g., sub-Scada master, RTU, or bay controller) at the station level. However, the use of aggregation coupled with protocol conversion (e.g., a sub-Scada master that attaches to the “station bus” with IEC 61850, but transfers information to the Scada master through TASE.2 or IEC 60870) will typically cause some IEC 61850 services to become un-available to the Scada master. Annex A shows which parts of IEC 61850 currently contain the mappings of the abstract services and if those services could be mapped through a TASE.2 aggregator.

3.5.3 Substation configuration description language

Another standard in the IEC 61850 series is the configuration description language for communication in electrical substations related to IEDs, known as the Substation Configuration description Language (SCL), IEC 61850-6, an XML-based configuration language for the binding of logical nodes (i.e., functional atoms within physical devices) to primary equipment, and specifying configuration and parameter data, and the structure and addressing of the communication network. The intended use is to provide an interoperable way to exchange IED and SA system configuration information between the engineering tools of different (IED) manufacturers.

3.6 IEC 61970 energy management system application program interface standards from WG13

3.6.1 General

WG13 was formed to develop EMS API standards to facilitate the integration of EMS applications developed independently by different vendors, between entire EMS systems developed independently, or between an EMS and other systems concerned with different aspects of power system operations, such as generation or distribution management. This is accomplished by defining standard interfaces to enable these applications or systems to access public data and exchange information independent of how such information is represented internally.

There are three major categories of the IEC 61970 standards:

a) Part 3XX: The Common Information Model (CIM), which provides an abstract model for a complete power system using Unified Modelling Language (UML) notation. The CIM is part of the overall EMS-API framework The CIM specifies the semantics for system interfaces (i.e., the meaning of information passed over the interface).

b) Part 4XX: The Component Interface Specifications (CIS), which specify profiles for interfaces needed in specific business contexts as identified by use cases. The profiles define a restricted subset of the CIM information model needed to support the information content exchanged over the interface. The services needed for the information exchange are provided by existing standards, such as the IEC 62541 OPC Unified Architecture series of standards.

c) Part 5XX: Message/file assembly and implementation technologies for serialization of the data passed over an interface. These standards provide the syntax for information exchanges (i.e., "how" information is passed to/from an application independent of the underlying communications infrastructure) to ensure interoperability between different vendor products.

3.6.2 Common information model (CIM)

The CIM is an abstract model that represents all the major objects in an electric utility enterprise. This model includes public classes and attributes for these objects, as well as the relationships between them.

Many aspects of the power system of concern to TC 57 are modelled only in the CIM, such as generation equipment, generation dynamics, schedules, energy schedules, financial objects, reservations, and the topology for electrically connecting equipment. Other parts of the power system are modelled in both the CIM and in the IEC 61850 standards produced by WG10, such as substation equipment including transformers, switches, breakers, etc.

The comprehensive CIM is partitioned into several packages for convenience. IEC 61970-301 defines a base set of packages which provide a logical view of the physical aspects of EMS information, including the core, topology, wires, outage, protection, SCADA, measurements, load model, generation, and domain. The IEC 61968 series of standards from WG14 (described later) extend the CIM to include many additional packages modelling different aspects of utility operations, such as assets, consumers, documentation, and distribution systems. The IEC 62325 series of standards from WG16 further extends the CIM to include market operations, reservations, financial, and energy scheduling for deregulated energy market communications.

3.6.3 Component interface specifications (CIS) for information exchange

The CIS series of standards specifies the profiles that a component (or application) should implement to exchange information with other components (or applications) and/or to access publicly available data in a standard way. The profiles describe the specific properties (i.e., a restricted subset of the CIM) that are to be included in information exchanges between applications and/or systems.

The purpose of the CIS is to specify the interfaces that an application or system is to use to facilitate integration with other independently developed applications or systems. For message-based exchanges, the CIS specifies the profile (i.e., information content of the messages exchanged between two (or more) applications). This permits new applications to be developed with knowledge beforehand as to what and how information is available for processing and expected by receiving applications. For the integration of existing systems, the CIS enables a single adapter to be built for a given infrastructure technology independent of who developed the other systems.

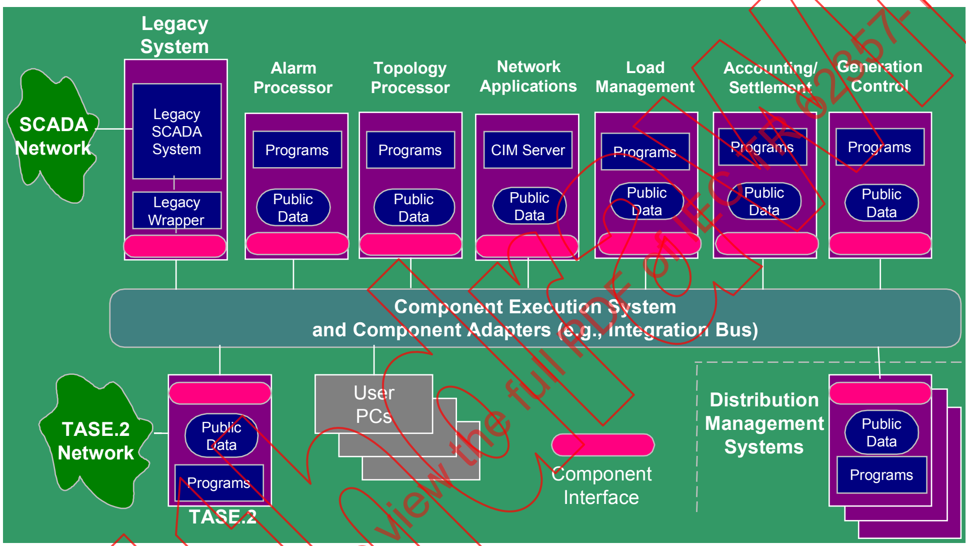
For a specific type of application, it is necessary to define what object classes and attributes are exchanged as well as what interface is used. These object classes and attributes typically consist of subsets or views of the CIM object classes. In other words the CIM is used as the basis for "what" information is exchanged between applications and the CIS is used to define "how" data is exchanged between applications as well as defining specific data content for each message (i.e., the message payload).

The CIS (or profiles) in use today are primarily used to define the data content for interactions between systems, such as network model exchange between Transmission System Operators (TSOs) or between Independent System Operators/Regional Transmission Operators (ISO/RTOs) and distribution utilities. A series of profiles are planned for additional information exchanges, such as a SCADA database or planning applications and a historical archive. Since the intent of the EMS-API standards is to define *interface standards* rather than to define *standard applications*, the scope of these CIS can best be understood by considering the list of typical application categories that will be supported by the EMS-API standards. The application categories include, but are not limited to, the following:

- SCADA,
- alarm processing,
- topology processing,
- network applications (e.g., state estimator, optimal power flow, etc.),
- load management,
- generation control,
- unit commitment,
- load forecast,
- energy/transmission scheduling,
- accounting settlements,
- maintenance scheduling,
- historical information system,
- external systems (e.g., distribution management systems (DMS), weather, wholesale power marketing, etc.),
- asset management.

3.6.4 IEC 61970 standards as an integration framework

Figure 4 illustrates the concept of an integration framework within a control centre based on the use of EMS-API standards. Application data is integrated via the component interfaces as specified in the EMS-API CIS standards. The CIS can be used to solve not only application integration, but also the data integration required for data warehousing and content management. The actual middleware technology (referred to as a Component Execution System (CES) in Figure 4) used to interconnect the applications can be chosen by the system implementer from among the best of breed and is not the subject of the EMS-API standards. As long as the public appearance of the data at the component interface to the CES conforms to the CIM and CIS standards, any application that also conforms will be able to receive and interpret the data. The CIM thus provides the “common language” for information exchange and understanding between applications possibly developed independently by different vendors, creating a model-driven approach to integration for utilities as described earlier.



IEC 2052/12

Figure 4 – EMS-API standards as an integration framework

The EMS-API standard requires that any data presented at the interface comply with the standard regarding semantics and syntax, so that any application that wants to receive data from another application should conform to the CIM standards. For SCADA data, for example, this means that a transformation shall be made from the data representation of the protocol used to acquire the data to the CIM representation and the SCADA CIS, which employs an HSDA service interface, should be used for data exchange with other applications.

3.7 IEC 61968 system interfaces for distribution management standards from WG14

WG14 was formed shortly after WG13 to address the need for standards for System Interfaces for Distribution Management Systems (SIDMS). The IEC 61968 series is intended to facilitate inter-application integration of the various distributed software application systems supporting the management of utility electrical distribution networks. These standards define requirements, integration architecture, and interfaces for the major elements of a utility’s Distribution Management System (DMS) and other associated external IT systems. Examples of DMS include asset management systems, work order management systems, geographic information systems, customer information systems, while customer resource management is an example of an external IT system interface. The message-based technology used to mesh these applications together into one consistent framework is commonly referred to as

Enterprise Application Integration (EAI); IEC 61968 series guides the utility's use of EAI. Figure 5 clarifies the scope of IEC 61968-1 graphically in terms of business functions.

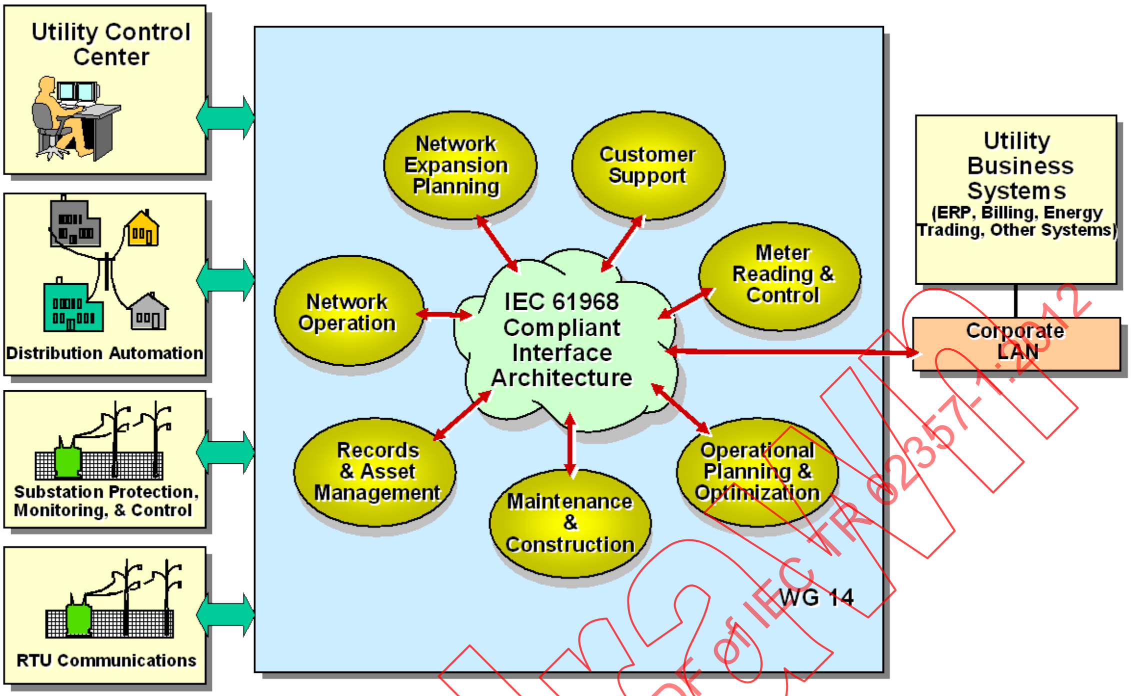


Figure 5 – Distribution management system with IEC 61968 compliant interface architecture

Standard interfaces are being defined for each class of applications identified in the IEC 61968-1 Interface Reference Model (IRM), as shown in Figure 6 below. A series of normative CIM-based XML message payloads have been and are being defined for each Part identified in the yellow boxes to ensure interoperability between the systems that provide the functionality shown in the green and magenta boxes. In addition to these Parts, the IEC 61968 CIM is also being actively deployed for achieving the Smart Grid vision of interoperability from DMS systems to edge networks and networks. For example, message payloads based on the CIM are being defined for demand response applications as well as Zigbee Smart Energy (SE) profiles for home and building automation.

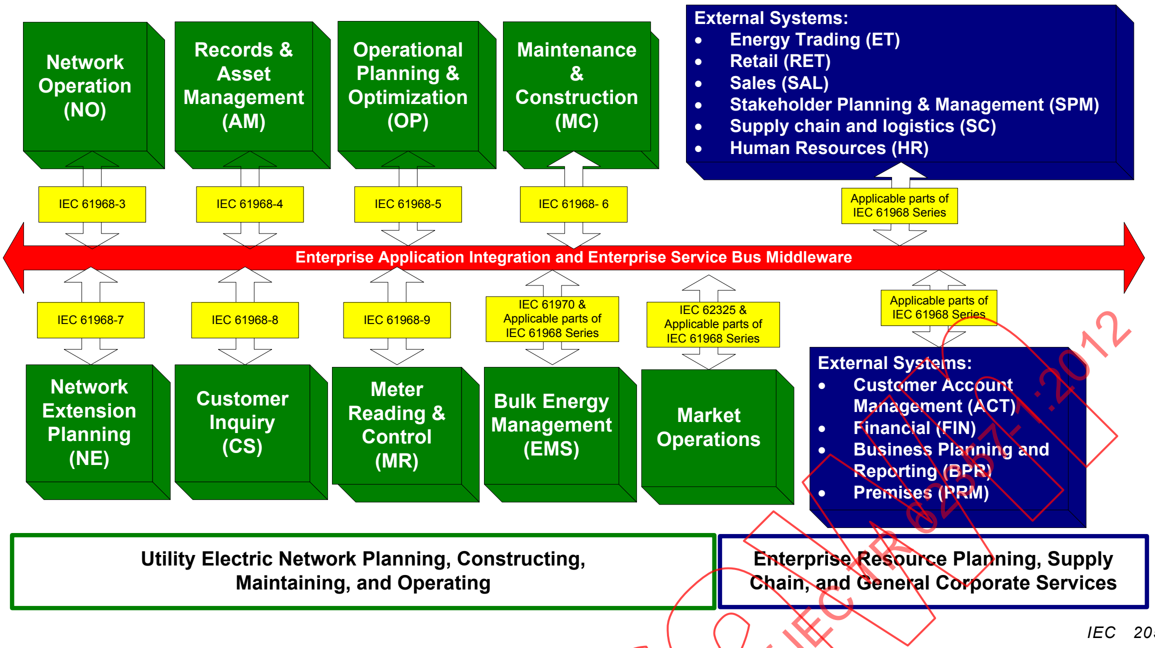


Figure 6 – IEC 61968 Interface Reference Model (IRM)

WG14 is using the Unified Modelling Language (UML) to define additional Real World Objects (RWO) classes in the CIM that are relevant to inter-application information exchange in the distribution domain. The resulting CIM classes (specified in both IEC 61970-301 and IEC 61968-11) govern the semantics used in message types being defined for the Information Exchange Model (IEM), which is to be included in IEC 61968-3 to IEC 61968-9.

XML is a data format for structured document interchange particularly on the Internet. One of its primary uses is information exchange between different and potentially incompatible computer systems. XML is thus well-suited to the domain of system interfaces for distribution management. Therefore, where applicable, IEC 61968-3 to IEC 61968-9 will define document structures in XML. In addition to close cooperation with WG13, WG14 is also working collaboratively with the OAG to improve utilities' ability to integrate between T&D applications (IEC TC 57 domain) & Enterprise Resource Planning (ERP) applications (OAG domain). OAG message exchange is defined using XML.

As described above, WG14 is basing their standards on the same CIM as WG13, with extensions specifically needed for the distribution systems addressed in WG14. Thus WG14 and WG13 are both using the CIM for inter-application information exchange and building an IEM as needed to define the specific semantics and syntax for these exchanges.

Note that the use of object modelling techniques internal to each of the applications/systems integrated with either WG13 or WG14 standards is not a requirement or an issue here. It is only relevant for describing data at the interface that is to be shared. Thus the CIM is the canonical language for semantics and syntax on the network interconnecting applications/systems.

3.8 IEC 62351 standards for data and communications security from WG15

3.8.1 General

WG15 is chartered with undertaking the development of standards for security of the communication protocols defined by IEC TC 57, specifically the IEC 60870-5 series, the IEC 60870-6 series, the IEC 61850 series, the IEC 61970 series, and the IEC 61968 series, as well as undertaking the development of standards and/or technical reports on end-to-end security issues.

The interrelationship of these security standards and the protocols are illustrated in Figure 7.

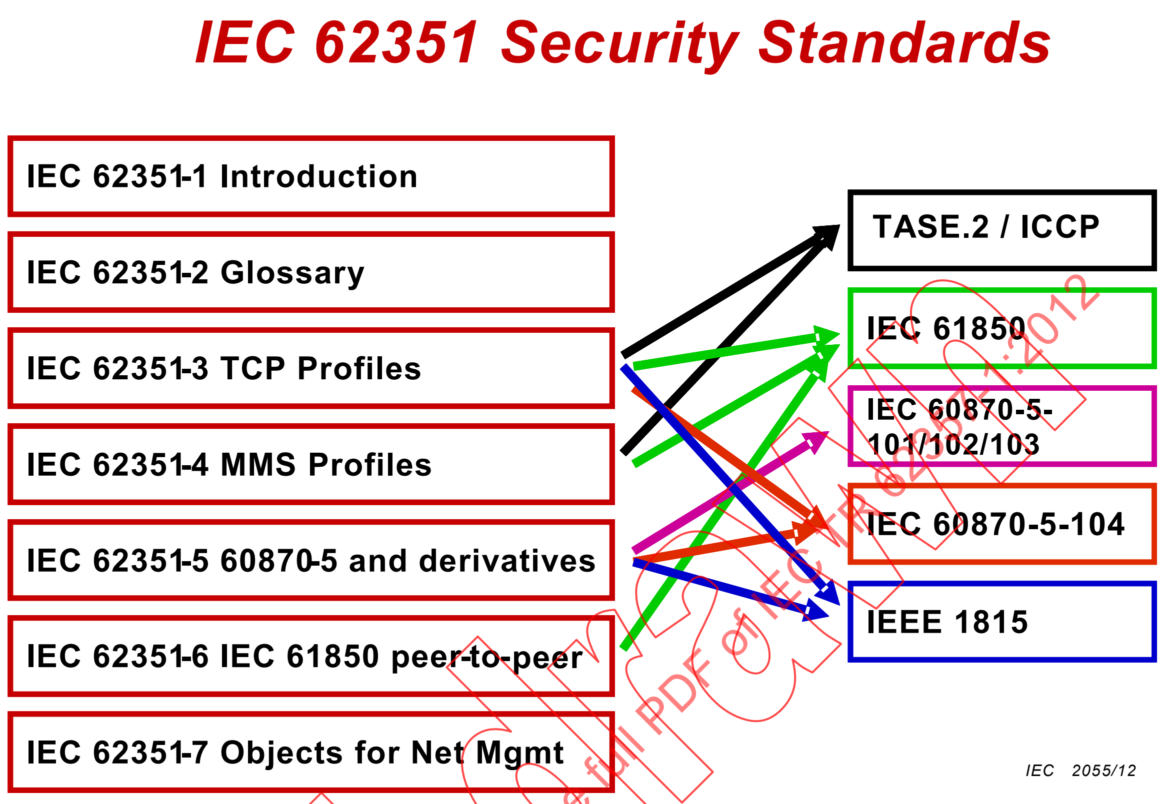


Figure 7 – Interrelationship of IEC 62351 security standards and the TC 57 protocols

3.8.2 Security for TCP/IP-based profiles

IEC 62351-3 provides security for any profile that includes TCP/IP. Rather than re-inventing the wheel, it specifies the use of TLS which is commonly used over the Internet for secure interactions, covering authentication, confidentiality, and integrity. This part describes the parameters and settings for TLS that should be used for utility operations.

Specifically, IEC 62351-3 protects against eavesdropping through TLS encryption, man-in-the-middle security risk through message authentication, spoofing through security certificates (node authentication), and replay, again through TLS encryption. However, TLS does not protect against denial of service. This security attack should be guarded against through implementation-specific measures.

3.8.3 Security for MMS ISO 9506

IEC 62351-4 provides security for profiles that include MMS, including IEC 60870-6 (TASE.2) and IEC 61850. It primarily works with TLS to configure and make use of its security measures, in particular, authentication (i.e., the two entities interacting with each other are who they say they are).

It also allows both secure and non-secure profiles to be used simultaneously, so that not all systems need to be upgraded with the security measures at the same time.

3.8.4 Security for IEC 60870-5 and derivatives

IEC 62351-5 provides different solutions for the serial version of IEC 60870-5 (i.e., IEC 60870-5-101) and for the networked versions (IEC 60870-5-104 and IEEE 1815).

Specifically, the networked versions that run over TCP/IP can utilize the security measures described in IEC 62351-3, which includes confidentiality and integrity provided by TLS encryption. Therefore, the only additional requirement is authentication.

The serial version is usually used with communications media that can only support low bit rates or with field equipment that is compute-constrained. Therefore, TLS would be too compute-intense and/or communications-intense to use in these environments. Therefore, the only security measures provided for the serial version include some authentication mechanisms which address spoofing, replay, modification, and some denial of service attacks, but do not attempt to address eavesdropping, traffic analysis, or repudiation that require encryption. These encryption-based security measures could be provided by alternate methods, such as Virtual Private Networks (VPNs) or “bump-in-the-wire” technologies, depending upon the capabilities of the communications and equipment involved.

3.8.5 Security for IEC 61850 peer-to-peer profiles

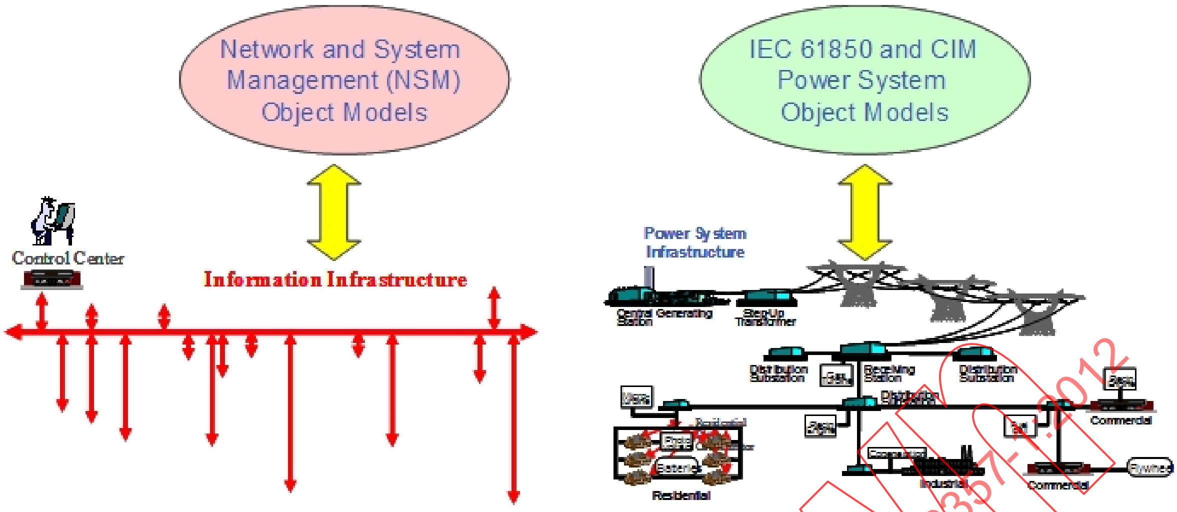
IEC 61850 contains three protocols that are peer-to-peer multicast datagrams on a substation LAN and are not routable. The messages need to be transmitted within 4 ms, so encryption or other security measures which affect transmission rates are not acceptable. Therefore, authentication is the only security measure included, so IEC 62351-6 provides a mechanism that involves minimal compute requirements for these profiles to digitally sign the messages.

The different communication profiles of IEC 61850 require security enhancements to ensure that they can be implemented and used in non-secure environments:

a) client/server, which will specify security primarily through TLS and MMS, but may include additional security measures such as VPNs,
b) GOOSE – analogue and digital multicast,
c) GSSE – digital only multicast, MMS involved,
d) GSE management,
e) SMV.

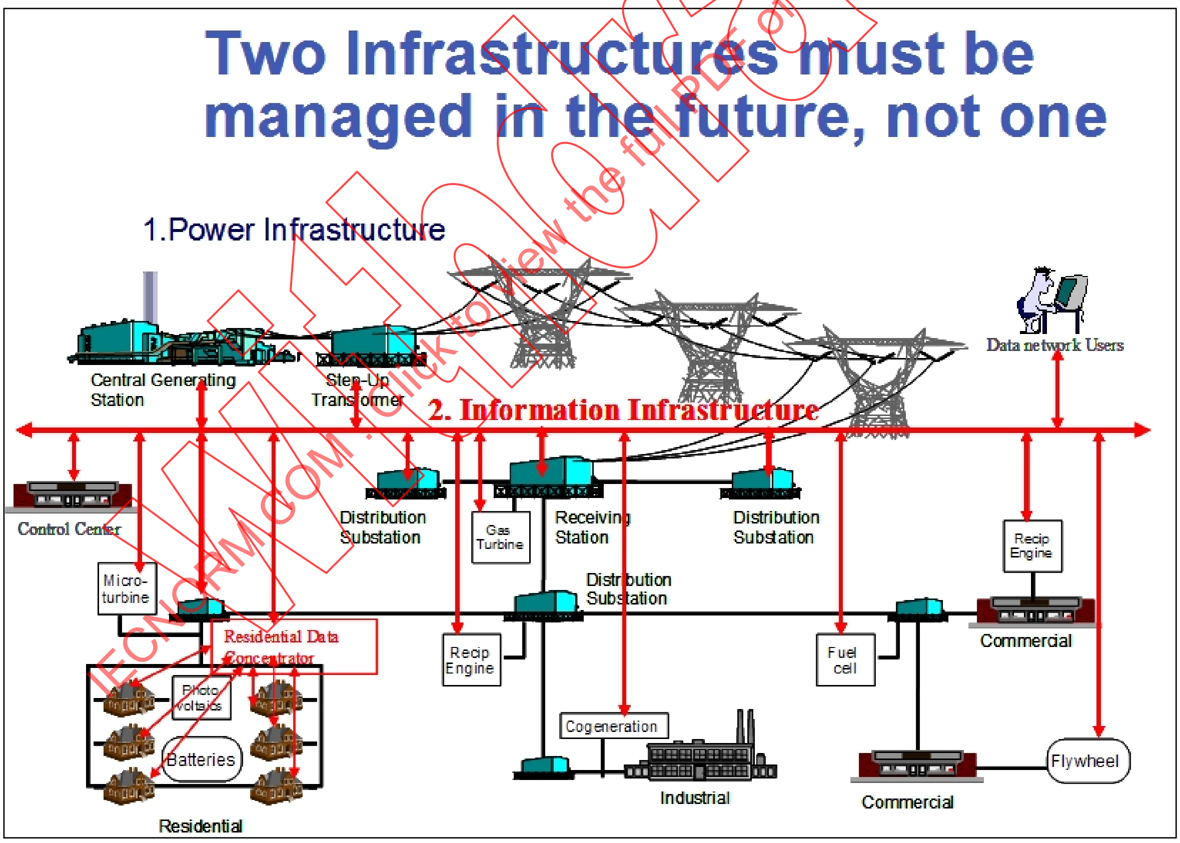
3.8.6 Management Information Base (MIB) requirements for end-to-end network management

In addition to security standards for SCADA protocols, standards are also being developed to provide end-to-end security, which involves security policies, access control mechanisms, key management, audit logs, and other critical infrastructure protection issues. To this end, the plan is to develop Management Information Base (MIBs) for the power system operational environment. These MIBs would reflect what information is needed to manage the information infrastructure as reliably as the power system infrastructure is managed. Figure 8 and Figure 9 illustrate this concept.



IEC 2056/12

Figure 8 – Management of two infrastructures



IEC 2057/12

Figure 9 – Information infrastructure underlying power infrastructure

Once the information management requirements are defined, they can be structured as abstract objects, and formatted as standardized Management Information Base (MIBs) to be compliant with information industry (i.e. IETF's Simple Network Management Protocol (SNMP)) standards. The ISO CMIP and the IETF SNMP standards for network management rely on Management Information Base (MIB) data to monitor the health of networks. MIB data, which can be mapped to IEC 61850, IEC 60870-5, or IEC 60870-6 for power system operations, should be developed to support utility networks. This uses a broader definition of security, with the concept that network management is a key component of end-to-end security.

The primary purpose of the WG15 MIB development effort is to define what information is needed to manage the power industry operations information infrastructure as reliably as the power system infrastructure is managed, and to develop standardized MIBs for power industry operations. Two types of MIBs are planned:

- MIBs for network management focused on the detection of security violations and/or intrusions in communications networks used for power system operations,
- MIBs for end devices or systems used in power system operations. These include information on the status of the systems, applications within the systems, devices, etc.

3.9 IEC 62325 standards for a framework for deregulated energy market communications from WG16

This working group is chartered with developing a framework for deregulated energy market communications with a focus on the interface between utilities and the energy market (see Figure 10).

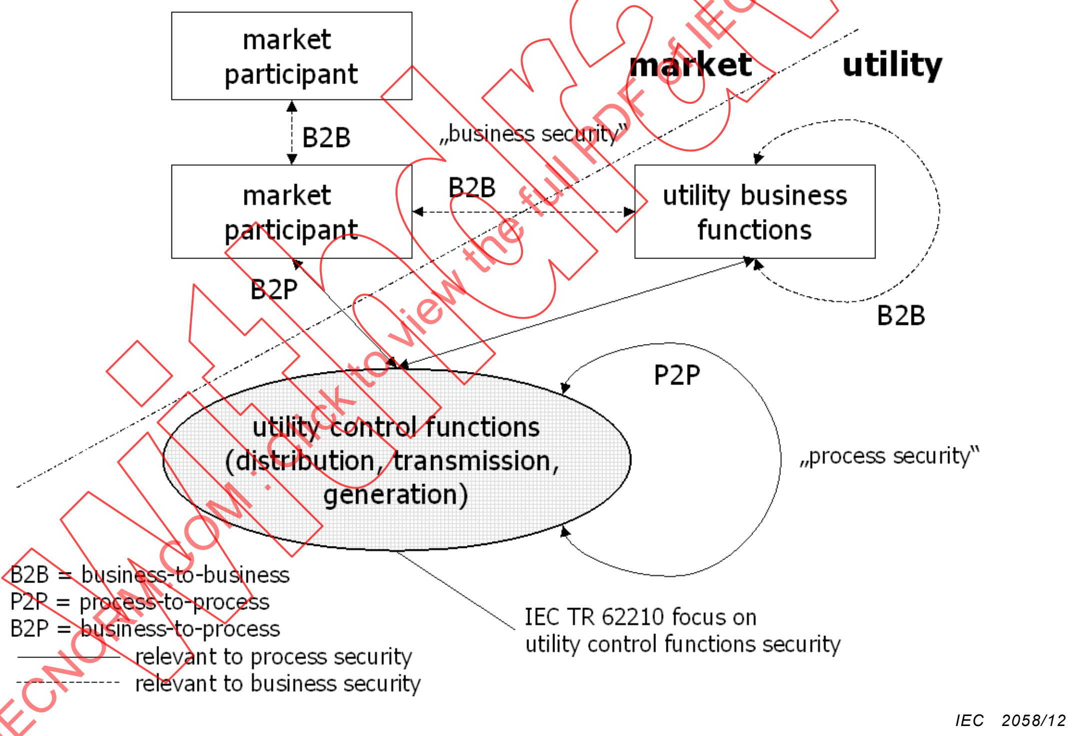


Figure 10 – Framework for deregulated energy market communications

With the transition of monopoly energy supply structures to deregulated energy markets the function of the markets depends heavily on seamless e-business communication between market participants. Compared with global e-business, e-business in the energy market is only a small niche. Today EDIFACT or X12 messages, or propriety HyperText Markup Language (HTML) and XML solutions based on Internet technologies are being used. With the advent of new e-business technologies such as ebXML by UN/CEFACT (United Nations / Centre for trade and electronic business) together with OASIS (Organization for the advancement of structured information standards), and Web services by W3C, an energy market specific profile of these standards can be used for regional energy markets. This profile allows the re-use of proven core components and communication platforms across markets, thus saving cost and implementation time. Because some of these technologies are still developing, other technologies or converged technologies are not excluded for the future.

Besides general requirements and guidelines, this framework includes the business operational view and profiles of technical e-business communication architectures together with migration scenarios. It supports the communication aspects of all e-business applications in deregulated energy markets with emphasis on system operators. The business operational view includes the market communication aspects of system operator applications with interfaces to other market participants from trading over-supply to balancing planned generation and consumption, change of supplier, market services and billing.

Many market participants need to communicate with each other in the energy market. In this framework it is assumed that e-business in energy markets makes use of the public unreliable and insecure Internet in a reliable and secure manner (see Figure 11).

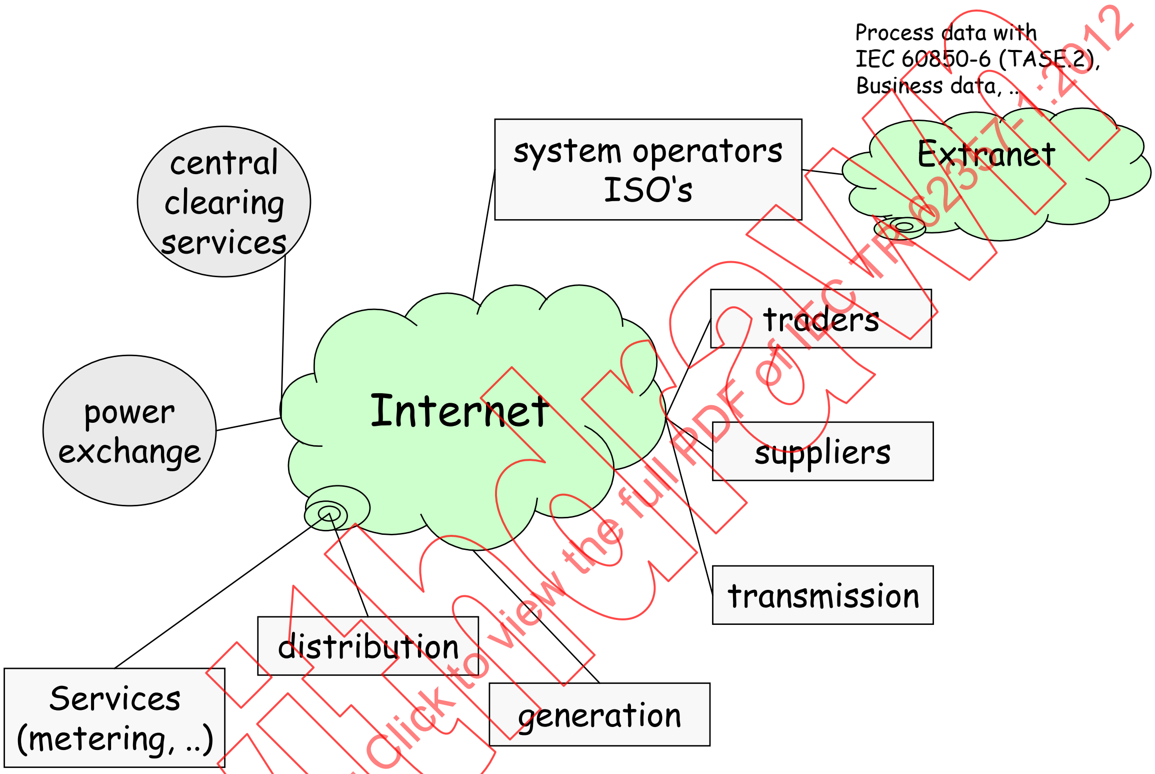


Figure 11 – Energy market communication over the Internet

IEC/TR IEC 62195 issued in April 2000 deals with deregulated energy market communications at an early stage. Its amendment 1 issued in April 2002 points out important technological advancements which make it possible to use modern internet technologies based on XML for e-business in energy markets as an alternative to traditional EDI with EDIFACT and X12. The new IEC 62325 series consisting of reports 101 (General guidelines and requirements), 102 (Energy market model example), 501 (General guidelines for use of ebXML), and specification 502 (Profile of ebXML) is intended to follow this direction and to replace IEC/TR IEC 62195 and its amendment.

Whereas the parts of the current framework edition are restricted to the use of the ebXML technology, the planned parts are intended to convert the framework into a more open framework also taking into account other e-business technologies besides ebXML, such as Web services. This will also include an abstraction service model with mapping to the various e-business technologies to hide the e-business technology actually used from the application. Further the standardization of basic business content including a market information model is planned, which could be the extension of the CIM model used in control centres.

3.10 IEC 61850 standards for communications systems for Distributed Energy Resources (DER) from WG17

3.10.1 General

This working group is chartered with developing IEC 61850 object models for providing standard communications interfaces to DER devices such as photovoltaic systems, reciprocating engines, fuel cells, and combined heat and power devices.

3.10.2 Need for communications with DER systems

The initial work of WG10, 11 and 12, as well as UCA2, was limited to substations. Since IEC 61850 provides detailed models for all field equipment, additions shall be made whenever the standard is to be used for a new field of applications. While most of the electric equipment in a power plant is already covered by the current version of IEC 61850, in order to fully support the requirements of distributed energy resources, new models (logical nodes) for (micro-)turbines and related equipment are needed.

The advent of decentralized electric power production is a reality in the majority of the power systems all over the world, driven by the need for new types of energy converters to replace the heavy reliance on oil, by the increased demand for electrical energy, by the development of new technologies of small power production, by the deregulation of the energy market, and by increasing environmental constraints. These pressures have greatly increased the demand for Distributed Energy Resources (DER) systems which are interconnected with the distribution power systems.

Distribution power systems are and will continue to be most impacted by DER, but transmission and the management of generation operations are also impacted to some degree. A number of studies on the wide-spread interconnection of DER systems have shown significant effects and impacts on operation of the entire electrical system.

As a result not only of DER systems, but also the need for greater efficiency and reliability of the power system, automation of distribution systems is becoming a major requirement. Distribution automation implies new remote control functions, modified distribution configurations, increasingly intelligent protection systems, and the use of significantly more telecommunication and information technologies.

The rapid advances of digital technologies have enabled the automation of electric power operations, providing utilities and customers with both new capabilities and new challenges. The challenge facing utilities, customers, vendors, and the electricity marketplace is: how can the information infrastructure be implemented to meet the expanded needs of the power system, while not becoming part of the problem itself.

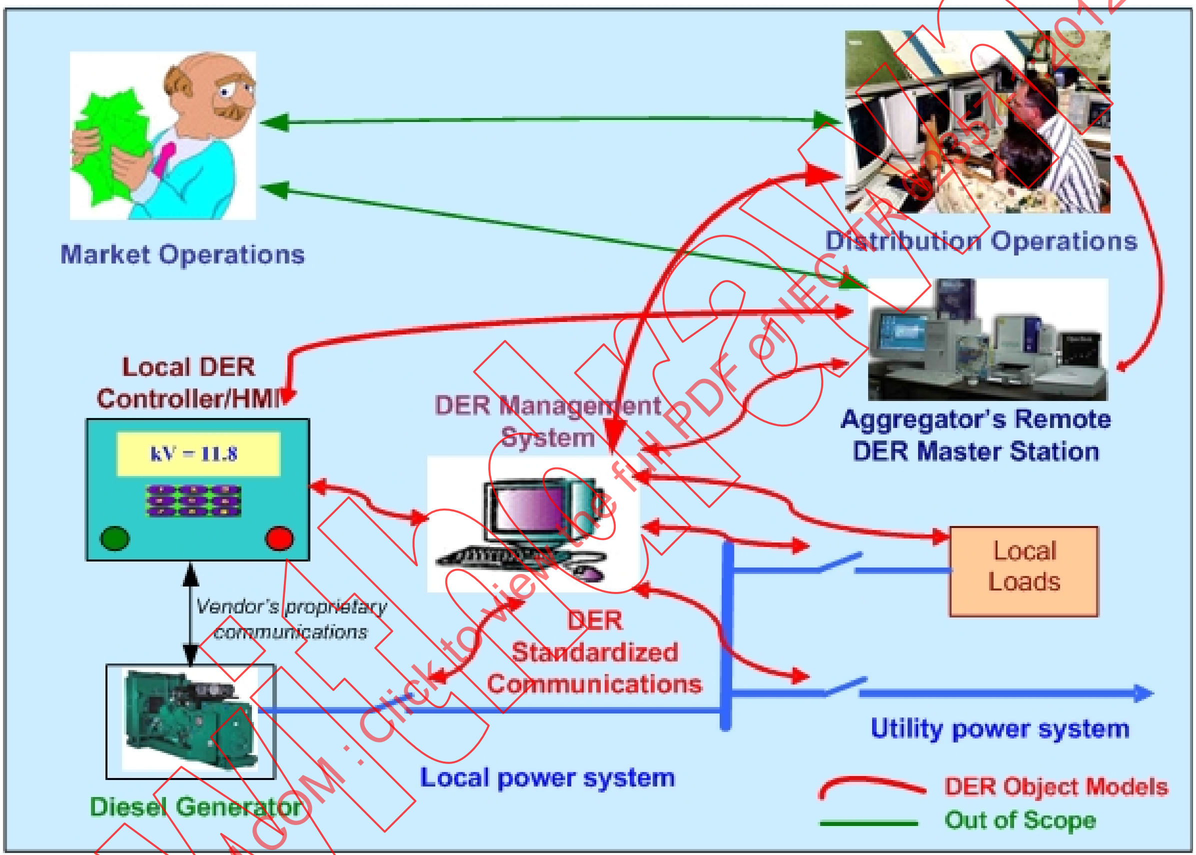
Part of that challenge can be met by IEC 61850 object models for DER, as the standardized communications interface for DER devices. Standardized communication interfaces permit the interoperability between different systems from different vendors, thus increasing the cost benefit to all owners, operators, and users of DER systems.

DER systems involve more than just turning a DER unit on and off. DER systems involve the following:

- management of the interconnection between DER units and the power systems they connect to, including local power systems, switches and circuit breakers, and protection,
- monitoring and controlling DER units as producers of electrical energy,
- monitoring and controlling individual generators, excitation systems, and inverters/converters,

- monitoring and controlling energy conversion systems, such as reciprocating engines (e.g. diesel engines), fuel cells, photovoltaic systems, and combined heat and power systems,
- monitoring and controlling auxiliary systems, such as interval meters, fuel systems, and batteries,
- monitoring physical characteristics of equipment, such as temperature, pressure, heat, vibration, flow, emissions, and meteorological information.

The information requirements for DER systems are illustrated in Figure 12 below. These IEC 61850 DER object models cover all operational aspects of DER systems, but do not address market operations.



IEC 2060/12

Figure 12 – DER interactions in electric power system operations

3.10.3 IEC 61850-7-420

IEC TC 57 WG17 is developing the communication architecture for integrating DER into the IEC 61850 body of communication standards. IEC 61850-7-420 is the first standard to be produced by WG-17. It provides standards for object models for exchanging information with DER devices. DER devices are generation and energy storage systems that are connected to a power distribution system. Object models for four specific types of DER are provided:

a) photovoltaic systems,

b) reciprocating engines,

c) fuel cells,

d) combined heat and power.

The approach taken by the working group in developing these models was to seek wide applicability of the models. Accordingly, no assumption was made as to DER ownership. Ownership could reside with a utility or an alternative party. No limitations were placed on the type of distribution system (networked or radial) or on where in the distribution system the DER might be located. The requisite distribution design engineering for DER installations shall address the distribution system electrical issues and determine where DER can safely be placed in the distribution system and what alterations to the electrical system may be needed. The focus is specifically on the ability to communicate with the DER and dispatch the services it may be intended to provide for the distribution system operator, such as emergency power and voltage support.

The object models provide the structured, standard identification and naming of the attributes that need to be included in the information exchange with the DER. These object models will become a part of the IEC 61850 body of communication standards for electric power systems. The goal is to achieve interoperability of DER with the power system, including current components and new technologies that are coming in the future. Interoperability of all intelligent electronic devices (IEDs) in the system is desired, and DER is one such IED type. IEC 61850 series is the principal body of international communication architecture standards evolving to support real-time automated operation of the power system of the future. As such, it is intended that the DER object models be a part of this communication architecture and not be used as a standalone entity. In other words, if a power system operator specifies that DER should conform to the IEC 61850 family of standards, it is because they are intending to migrate their whole automated system to IEC 61850 conformity.

3.10.4 IEC 61850-90-7 DER inverter object models

IEC 61850-90-7 is being developed as a Technical Report of IEC 61850 DER inverter object models.

DER systems challenge traditional power system management. The increasing numbers of DER systems are also leading to pockets of high penetrations of these variable and often unmanaged sources of power which impact the stability, reliability, and efficiency of the power grid. No longer can DER systems be viewed only as “negative load” and therefore insignificant in power system planning and operations. Their unplanned locations, their variable sizes and capabilities, and their fluctuating responses to both environmental and power situations make them difficult to manage, particularly as greater efficiency and reliability of the power system is being demanded.

At the same time, DER devices could become very powerful tools in managing the power system for reliability and efficiency. The majority of DER devices use inverters to convert their primary electrical form (often direct current (d.c.) or non-standard frequency) to the utility power grid standard electrical interconnection requirements of 60 Hz (or 50 Hz) and alternating current (a.c.). Not only can inverters provide these basic conversions, but inverters are also very powerful devices that can readily modify many of their electrical characteristics through software settings and commands, so long as they remain within the capabilities of the DER device that they are managing and within the standard requirements for interconnecting the DER to the power system.

DER systems are becoming quite “smart” and can perform autonomously according to pre-established settings. They can “sense” local conditions of voltage levels, frequency deviations, and temperature, and can receive broadcast emergency commands and pricing signals, which allow them to modify their power and reactive power output. They can also operate according to schedules or in response to direct control commands.

Given these ever more sophisticated capabilities, utilities and energy service providers (ESPs) are increasingly desirous (and even mandated by some regulations) to make use of these capabilities to improve both power system reliability and efficiency.

IEC 61850-90-7 covers many of the key inverter functions, including:

- immediate control functions for inverters,
- Volt-VAr management modes,

- frequency-watt management modes,
- voltage management settings for dynamic grid support during voltage dips,
- watt-power factor management modes,
- voltage-watt management modes,
- non-power-related modes,
- parameter setting and reporting.

At least three levels of information exchanges are envisioned:

- **tightly-coupled interactions** focused on direct monitoring and control of the DERs with responses expected in "real-time";
- **loosely-coupled interactions** which request actions or "modes" that are interpreted by intelligent DER systems for undertaking **autonomous reactions** to local conditions or externally provided information. Information is then sent back on what actions they actually performed;
- **broadcast/multicast** essentially one-way requests for actions or "modes", without directly communicated responses by large numbers of DERs.

These different DER management interactions are shown in Figure 13.

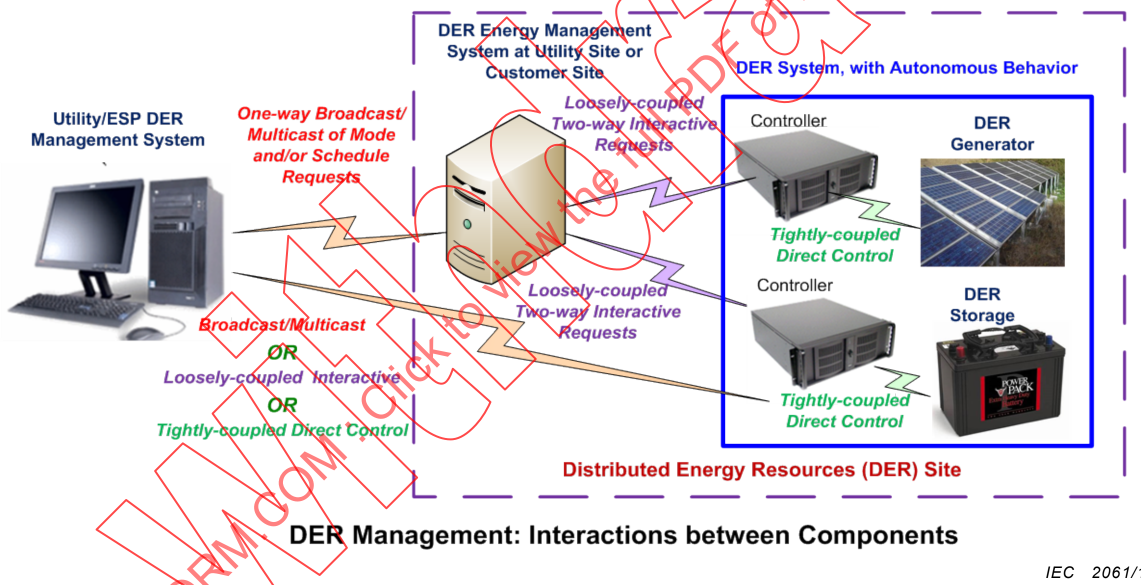


Figure 13 – DER management interactions

3.11 IEC 61850 standards for hydroelectric power plants from WG18

3.11.1 General

This working group is chartered with developing standards for hydro power plant communication, monitoring, and control. The approach is to extend the present IEC 61850 models to also cover hydroelectric power plants. The initial work of WG10 was limited to substations. Since IEC 61850 provides detailed models for all field equipment, additions shall be made whenever the standard is to be used for a new field of applications. While most of the electric equipment in a power plant is already covered by the current version of IEC 61850, in order to fully support the requirements of hydropower plants, new models (logical nodes) for turbines and related equipment, dams, gates, etc. are needed.

Most of the logical nodes defined by WG18 are not specific for hydropower plants; they can be of use in any type of plant in a power system (e.g., all sensor logical nodes). There are some conceptual deviations from the original principles of IEC 61850; one such modification relates to the specification of more or less generic logical nodes. Rather than having a number of logical nodes that are named after what they control, the working group decided to name them after the basic algorithm used, or behaviour of the function, and is proposing a prefix naming structure to define what they are controlling.

3.11.2 Basic concepts for hydropower plant control and supervision

Figure 14 below is based on the substation structure described in IEC 61850-6. A typical power plant will include a “substation” part that will be identical to what is described in the IEC 61850 series. The generating units with their related equipment are added to the basic structure.

A generating unit consists of a turbine – generator set with auxiliary equipment and supporting functions. Generator transformers can be referenced as normal substation transformers; there is not always a one-to-one connection between generating units and transformers.

The dam is a different case. There is always one dam associated with a hydropower plant. There are however reservoirs that are not related to any specific power plant as well as power plants from which more than one dam is being controlled. While all other objects can be addressed through the power plant, dams might have to be addressed directly.

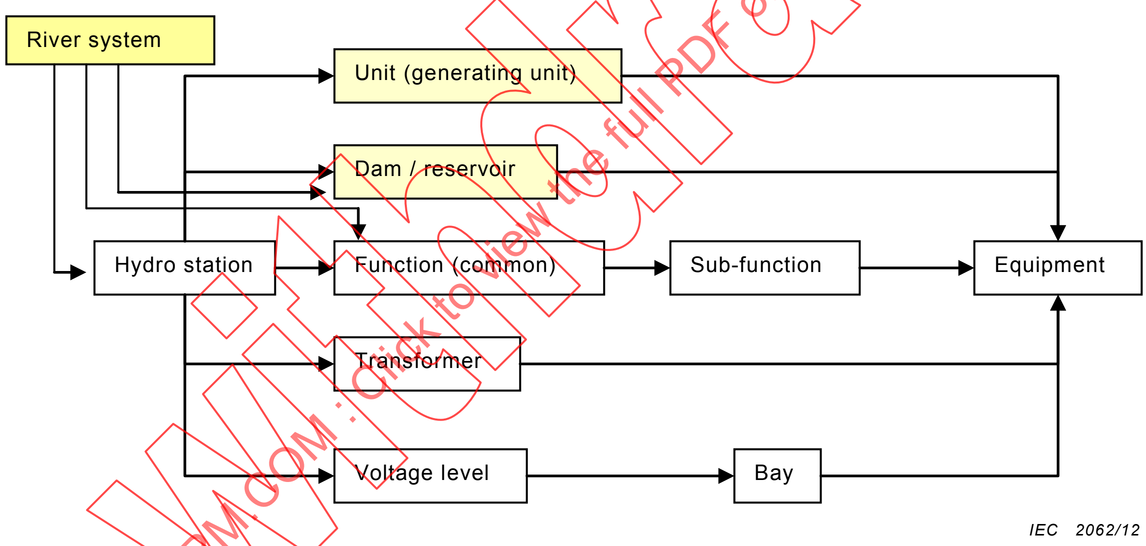


Figure 14 – Structure of a hydropower plant

There is, however, no standardised way of arranging overall control functions; the structure will depend on whether the plant is manned or remotely operated, as well as traditions within the utility that owns the plant. In order to cover most arrangements, some of the logical nodes defined in this standard are more or less overlapping. This will allow the user to arrange logical devices by selecting the most appropriate logical nodes that suits the actual design and methods of operation of the plant. Other logical nodes are very small, in order to provide simple building blocks that will allow as much freedom as possible in arranging the control system.

Some control functions work more or less autonomously after being started and stopped by the start / stop sequencer. Such functions include the cooling system for the generator and the lubrication oil system for the bearings.

3.11.3 Principles for water control in a river system

3.11.3.1 General

The water control of river systems and hydropower plants can follow different strategies, depending on the external requirements put on the operation of the system.

3.11.3.2 Water flow control

In this type of control, power production is roughly adapted to the water flow that is available at the moment. The water level is allowed to vary between high and low alarm levels in the dams. The dams are classified according to the time period over which the inflow and outflow are measured (daily, weekly, etc.).

3.11.3.3 Water level control

In some locations there are strict limits imposed on the allowed variation of the water level of the dam. This might be due to parallel shipping locks or by environmental requirements. In this case the upper water level of the dam is the overriding concern; power production is adjusted by the water level control function to provide correct flow to maintain the water level.

3.11.3.4 Cascade control

In rivers with more than one power plant, the overall water flow in the river is coordinated between plants to ensure an optimal use of the water. Each individual plant can be operated according to the water level model or the water flow model as best suited, depending on the capacity of the local dam and allowed variation in water levels. The coordination is normally done at the dispatch centre level, but power plants often have feed-forward functions that automatically will notify the next plant downstream if there is a sudden change of water flow.

Power plants with more than one generating unit and/or more than one dam gate, can be provided with a joint control function that controls the total water flow through the plant as well as the water level control.

3.11.4 Principles for electrical control of a hydropower plant

A power plant can be operated in different modes: active power production mode or voltage control. In voltage control mode, the generator can be used as a pure synchronous condenser, without any active power production and with the turbine itself spinning in air.

In a pumped storage plant there is a motor mode for the generator. A generator in a pumped storage plant can also be used for voltage control in a synchronous condenser mode, in this case normally with an empty turbine chamber.

The following operational modes are defined for the unit:

Excited, not connected – Field current is applied and a voltage is generated, the generator is however not connected to any load, and there is no significant stator current.

Synchronised – The generator is synchronised to an external network. This is the normal status of an operating generator.

Synchronised in condenser mode (- in motor mode) – The generator is synchronised. However it does not primarily produce active power. In condenser mode it will produce or consume reactive power; in motor mode (for pumped storage), it consumes active power.

PSS control – The power swing stabiliser device has detected a power swing in the grid to which the generator is connected and uses the voltage control function trying to reduce it.

Island operation mode – The external network has been separated and the power plant controls the frequency.

Local supply mode – In case of a larger disturbance of the external network, one or more generators in a power plant can be set at minimum production to provide power for local supply only. This type of operation is common in thermal power plants to shorten the start-up time once the network is restored, but can also be used in hydropower plants for practical reasons.

3.12 WG19 harmonization

The charter of WG19 is to address harmonization issues between the other TC 57 working groups and to chart a roadmap for future standards development in TC 57. As such, WG19 functions primarily as an architecture board, providing the expertise needed to deal with technical issues that cross individual working group boundaries. WG19 may also produce standards and/or technical reports that cross individual working group boundaries (e.g., XML naming and design rules).

WG19 deals with the technical strategies for TC 57 while the Chairman's Advisory Group (CAG) comprised of all the WG conveners serves as an advisory board for overall coordination of TC 57 and its relationship to other IEC technical committees.

3.13 IEC 62488 standards for power line communication systems for power utility applications from WG20

The charter of WG20 is to produce standards for power line communication systems for power utility applications. The scope includes planning of analogue and digital power line carrier systems operating over EHV/HV/MV electricity grids. A specific focus is to replace two existing IEC standards:

- IEC 60663: Planning of single sideband power line carrier systems. This standard was first published in 1980;
- IEC 60495: Single sideband power line carrier terminals. This standard was first published in 1993.

3.14 Interfaces and protocol profiles relevant to systems connected to the electrical grid from WG21

The charter of WG21 is to develop requirements and international standards for system interfaces, communication protocols and profiles in consideration of:

- Interconnecting a large number of geographically distributed systems;
- Domain specific protocols for industrial, home and building automation;
- State-of-the-art wireless and wired communication;
- Efficient installation, commissioning and maintenance.

4 Current reference architecture

4.1 General

In this section the standards described in the previous clause are organized into a framework architecture, referred to here after as the current reference architecture for power system information exchange (see Figure 15). An architecture helps visualization of where all the existing object models, services, and protocols apply in the management of a power system and how they relate to each other.

The primary purpose of this architecture is to identify the boundaries between standards where harmonization is required. While this architecture places existing standards into layers in order to define interfaces between them, this layering is not to be confused with the layered architecture for the future reference architecture described later in Clause 8.

4.2 Overview

Starting at the top, layer 1 is concerned with integration of systems/applications via inter-application messaging as provided via commercial off-the-shelf middleware. The next two layers provide for data representation as specified in the interface standards of IEC 61968 and IEC 61970. The next layer 4 represents the various transmission and distribution computer systems/applications for which integration standards are being developed in TC 57. This includes the following:

- SCADA systems,
- EMS applications, including inter-control centre data links,
- DMS applications,
- a variety of distribution systems, such as meter reading and control, customer inquiry, records and asset management, maintenance and construction, operational planning, etc.

For each layer 4 application, an application interface and an equipment and system interface is shown. For purposes of this diagram, these interfaces are defined as follows:

Equipment and system interface: the view looking ***outward*** toward the external systems/devices with which these layer 4 applications/systems communicate to acquire data and/or control devices. Such external devices include substation devices, field devices, wind power devices, hydro power devices, DER devices, and others.

In this view, some layer 4 applications/systems act as clients initiating transactions with remote servers in the field. The client and server can be connected by various types of communication networks. Communication media may have geographic and utilization constraints, such as limited bit rates, proprietary data link layers, restricted times for use, and satellite hop delays. Network topology may be hierarchical, with a few "central" sites authorising and managing the interactions with a large number of "field" sites, or it may be networked with peer-to-peer interactions. Communication media may have varying configurations, such as point-to-point, multi-drop, mesh, hierarchical, WAN-to-LAN, intermediate nodes acting as routers, as gateways, or as data concentrators.

Information exchange on the equipment and system interface is defined by the TC 57 standards developed in Working Groups 3, 7, 9, 10, 17, and 18 as shown in the reference architecture. The client/server interaction and communication protocol stacks between clients and servers are the subject of these standards. These standards are shown in the lower layers of the reference architecture.

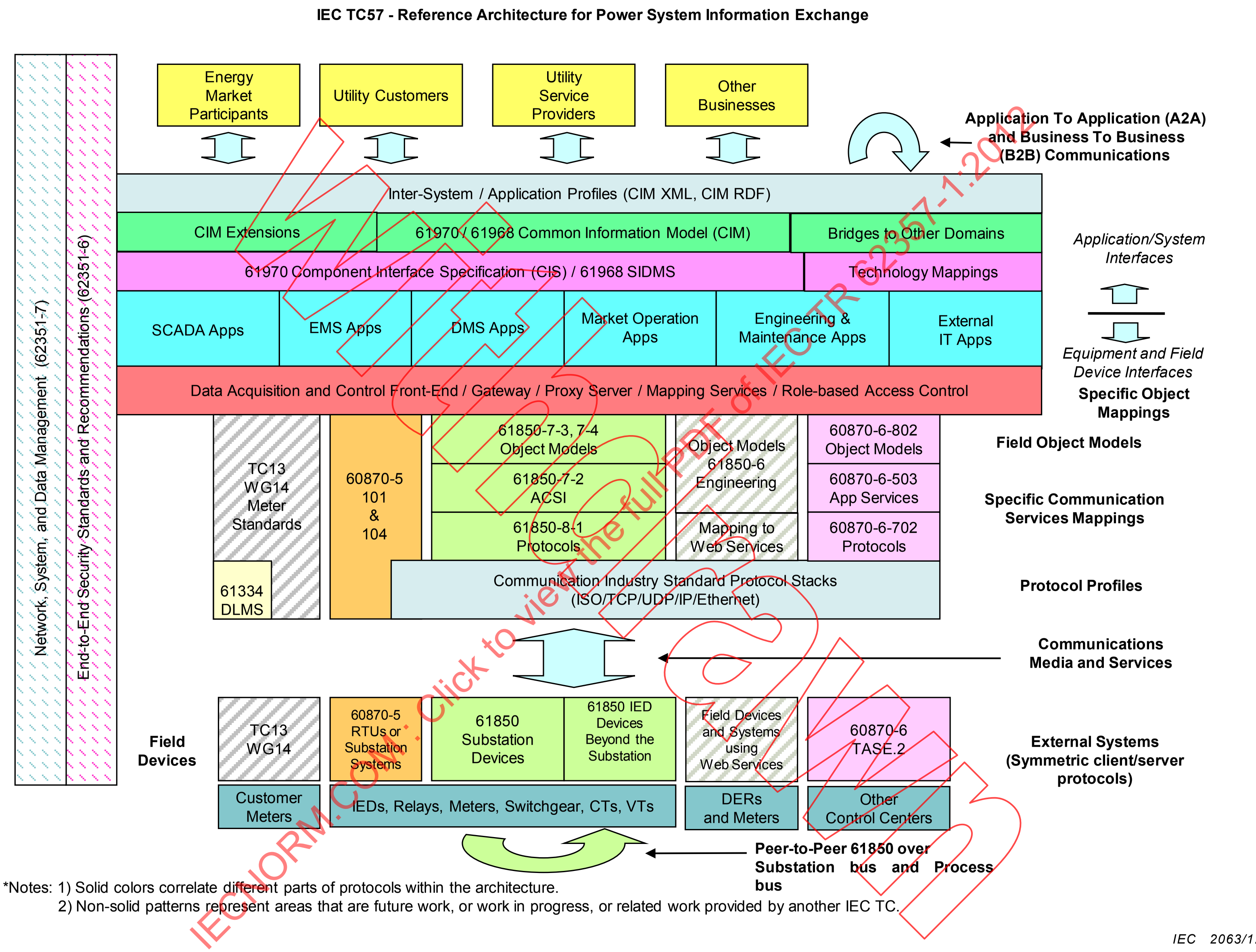


Figure 15 – Current reference architecture for power system information exchange

Application interface: the view looking ***inward*** toward other layer 4 applications/systems (e.g., back office systems) or external systems, such as energy market participants, utility customers, utility service providers, or other businesses for the purposes of exchanging information. In this view, the layer 4 applications/systems interact with each other as peers, typically using either a client/server model, where each system may function as both client and server, or an event-driven model, where an application publishes to multiple subscriber applications.

Information exchange between these applications/systems on the application interface is based on the semantics and syntax specified in the IEC 61970/ IEC 61968 CIM standards. The complete specification of the message contents and behaviour associated with these messages are specified in the IEC 61970 CIS for control centre applications and in the IEC 61968 SIDMS for DMS applications and systems being developed by Working Groups 13 and 14, respectively. These standards are shown in the upper layers of the reference model.

Some applications/systems in layer 4 have both equipment and system interfaces as well as application interfaces, such as SCADA, inter-control centre communications, or some DMS applications. In these cases, whereas the system acts as a client regarding the equipment and system interface, it acts in turn as a server on the application interface, being a source of data to other applications. For example, a SCADA system with an ACSI client which talks to ACSI servers using IEC 61850 standards to access data from substation and field devices, now may act as a server using IEC 61970 standards to exchange data with EMS applications, such as topology processor or state estimator, in a control centre environment.

4.3 SCADA interfaces

4.3.1 General

Among the applications shown is SCADA for real-time data acquisition and device control. While there are several protocol/service and interface standards in TC 57 for SCADA operations on the equipment and system interface, as shown in the reference architecture, the IEC 61970 SCADA CIS defines the standard SCADA data representation for exchanging SCADA data with other EMS/DMS applications for real-time operation and control on the application interface.

As can be seen, there are several standards defined for accessing substation and field devices. These include standards from WGs 3, 9, and 10 plus standards from other TCs. TASE.2 from WG7, while intended primarily for inter-control centre communications, can also be used to access SCADA data in a substation when a SCADA master is located at the substation itself.

The data representation and service used to expose data is different for each of these working groups as defined in their respective standards (i.e., IEC 60870-5, IEC 60870-6, and IEC 61850) as previously described. Therefore, there is a need to have the SCADA data representations from each of these SCADA services to be harmonized with the CIM representation of SCADA data. There are two approaches to accomplish this:

a) provide for data transformation processing in the SCADA system or at the interfaces to the SCADA system using the existing standards models;

b) resolve the differences in models within the developing standards before they become finalized to negate the need for real-time data transformation. In fact, work is in progress in WG19 to achieve this harmonization between IEC 61850 and the IEC 61970 CIM on an object model level.

Each of these approaches is described in more detail in the following two subclauses.

4.3.2 Data transformation via gateways and adapters

Figure 16 illustrates the relevant interfaces and the transformations required when these standards are applied today. SCADA data received via IEC 60870-6 TASE.2 links from either another control centre or from a SCADA master in a substation is transformed in the TASE.2 adapter to be compliant with the IEC 61970 CIM. More specifically, it is transformed to comply with the SCADA CIS defined as part of the EMS-API standards. This data is then exposed to the integration bus via one of the standard interfaces. In a similar fashion, SCADA data received via IEC 61850 ACSI links from either substation or field devices is transformed in the ACSI adapter to be compliant with the CIM and the same service interface. SCADA data from an existing SCADA system that uses the IEC 60870-5 standards, IEEE 1815, DNP3, or some proprietary RTU protocol is transformed by a custom SCADA system adapter to be CIM-compliant.

The effect of the use of adapters is that all SCADA data, regardless of the protocols/services and data representation used to obtain the data from the field or from other control centres, has the same representation on the integration bus. This means that any applications that operate on SCADA data, including data repositories or historical information systems, need to be designed to support only a single interface, the IEC 61970 EMS-API CIS SCADA interface, to be able to be integrated into a system framework.

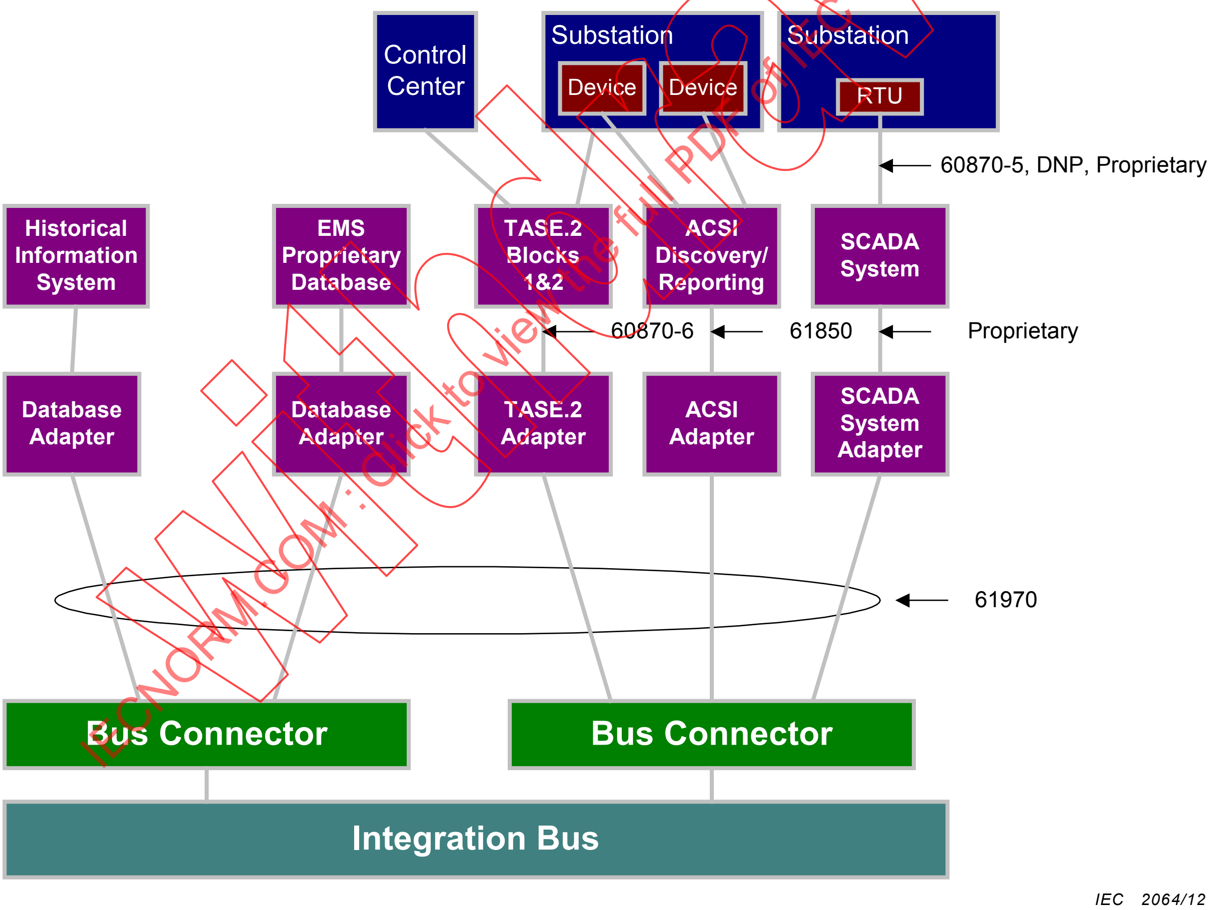


Figure 16 – SCADA data interfaces

Figure 16 also illustrates the use of database adapters to transform data from proprietary representations in an EMS database or from industry standard representations in a historical information system to the CIM representation for access via the integration bus.

4.3.3 Harmonization of the data models

Although adapters will always be required to translate proprietary data formats in legacy systems, a goal is to harmonize standards within TC 57 so that a single representation of SCADA data is used in all TC 57 standards, thus eliminating the need for translation in adapters. This would lead to a seamless architecture and is part of the vision of the future reference architecture described in Clause 7.

In the meantime, efforts have been undertaken to harmonize existing standards to the maximum extent possible. These efforts are somewhat constrained by the fact that many of these standards have been published and are extensively implemented in existing products and systems, so there is some resistance to change at this point. However, harmonization has been achieved in some key areas and more is planned. Clause 6 describes these efforts.

4.4 Inter-control centre data links

The inter-control centre data link services/protocols are provided by IEC 60870-6-503, -702, and -802. There are no other standards for this service in TC 57. These standards are now complete and extensively deployed in commercial products in the field at many utilities around the world.

The data representation in IEC 60870-6-503 and -802 is not harmonized with the CIM representation. However, since these standards are now in wide use, it seems that data transformation is the only practical answer in the near term. The mapping of TASE.2 objects to the CIM is a work in progress.

There are additional standards for exchanging metadata information between control centres that are not shown in the reference architecture. An XML version of the CIM is used to exchange power system models between control centres, where the XML tags are based on the CIM classes and attributes. Standards exist for transferring the following:

- complete models,
- partial models (i.e., add a new substation), and
- incremental updates to existing power system models (i.e., change the resistance and reactance of an a.c. line, remove a load, etc.).

Since the files transferred are XML documents, any protocol that can transport an XML document can be used, such as anonymous FTP. FTPs, and HTTPs over TCP/IP.

4.5 EMS applications

Most EMS applications rely on the SCADA application or inter-control centre data links to provide real-time operational data. As a result, there are no relevant TC 57 standards on the equipment and system interface side of these applications, so there are no data or object model harmonization issues between TC 57 standards.

However, there are issues between proprietary interfaces used in the many EMS applications currently available from EMS vendors and the CIM standards contained in the IEC 61970 standards being developed by WG13. In actual deployment of these standards, one of two possible integration scenarios is possible:

a) existing EMS applications are “wrapped” to transform the existing proprietary application interface to the interface specified in the CISs and the data representation specified in the CIM;

b) EMS applications are rewritten to provide the API specified in the IEC 61970 standards. For new applications, the standard interface would be incorporated into the original design to avoid the need for wrappers.

4.6 DMS applications and external IT applications

4.6.1 General

The distinction between application interfaces and equipment and system interfaces blurs somewhat with DMS applications/systems such as asset management, work order management, geographic information, customer information, etc., which are designed primarily as stand-alone systems. The exception is network operations, which interfaces to field devices and distribution feeders via the equipment and system interface using the IEC 61334 power line carrier, TC13 WG14 meter standards, or any of the other protocols shown. All other interfaces between these systems and with external IT systems that are not strictly utility systems, such as customer resource management, are the subject of the IEC 61968 standards. Since the CIM provides the model for information exchange between these systems, the interfaces are considered as application interfaces in Figure 15.

4.6.2 Substation/field devices

Switchgear, transformers, and other substation or field devices can be accessed indirectly via an RTU or directly through the use of substation automation and intelligent devices.

As described in 4.3, RTUs provide limited access to typical SCADA point-oriented data only via IEC 60870-5 standards. Since these standards are published and quite mature, the only practical approach to harmonization is through data transformation in the control centre.

Substation automation with the IEC 61850 standards provides more extensive access to devices using device-oriented data models. In addition to real-time operational SCADA data used by EMS applications, configuration, topological, and asset information can also be accessed and used in the power system model maintained in the CIM in the EMS. For this reason, it is important to try to harmonize object and attribute names and data types by adopting common conventions for those portions of the device models used in the EMS.

Although not shown in the diagram, IEC 61850-6 defines an XML-based configuration language for the binding of logical nodes (i.e., functional groups within physical devices) to primary equipment, configuration data, and the structure of the communication network. The intended use is to provide an interoperable IED and system configuration data exchange between engineering tools of different manufacturers.

5 Abstract modelling in TC 57

5.1 General

As can be seen from the above descriptions, there are a number of different ways that data and applications are modelled in TC 57. That is, there are different ways of representing the data that is to be transferred over data links or across interfaces as well as the services that are the subject of standards in TC 57. The way data is represented at the lower layers of a protocol stack is of concern when addressing interoperability of products from different vendors at each end of a data link or logical association. But from a harmonization point of view, the only place it really matters is at the interfaces where software implementing one standard interface to software implementing another standard (i.e., at the semantic layer).

To help in achieving the second stated objective of harmonization between different TC 57 standards, this report attempts to separate the TC 57 models into abstract models and concrete models, or to use the terminology adopted by the OMG in their Model Driven Architecture (MDA) perspective - Platform Independent Models (PIMs) and Platform Specific Models (PSMs), respectively. PIMs are abstract in nature in that they are independent of the technology used to implement them, as the name implies. That is, the specification of the information, data, and services is done with a modelling language or approach that can be mapped to a number of different technologies. PSMs are concrete mappings of the PIMs onto a specific implementation technology, such as C++, Java, or Web services.

The focus for achieving harmonization in this report, then, is on the PIM standards or models. Where these models purport to represent the same physical object, ideally it would be desirable to have only one model for that object used consistently by all standards. To understand what is involved in moving toward that goal, this section describes the abstract models (or PIMs) now in use within TC 57. There are two major models and modelling approaches used in TC 57:

a) The Common Information Model (CIM) defined using the Universal Modelling Language (UML) and Component Interface Specifications (CIS) which define interface profiles for information exchange;
b) IEC 61850 Abstract Communication Server Interface (ACSI) class definitions and the Substation Configuration Language (SCL) which describes instances of these classes on a specific IED.

These two models are each described in the following two subclauses, 5.2 and 5.3. Subclause 5.5 describes the different data modelling techniques used followed 5.6 which covers the service modelling techniques used. Subclause 5.7 addresses the harmonization work underway to facilitate interoperability between the CIM and IEC 61850 standards. Subclause 5.4 discusses the TASE.2 standards.

Additional information on these two modelling approaches is contained in Annex A, which provides a summary of the different objects modelled in each of the major TC 57 models, and Annex B, which provides a concrete example of how a circuit breaker is modelled using first the CIM and then the IEC 61850 models.

5.2 Common Information Model (CIM) and Component Interface Specifications (CIS)

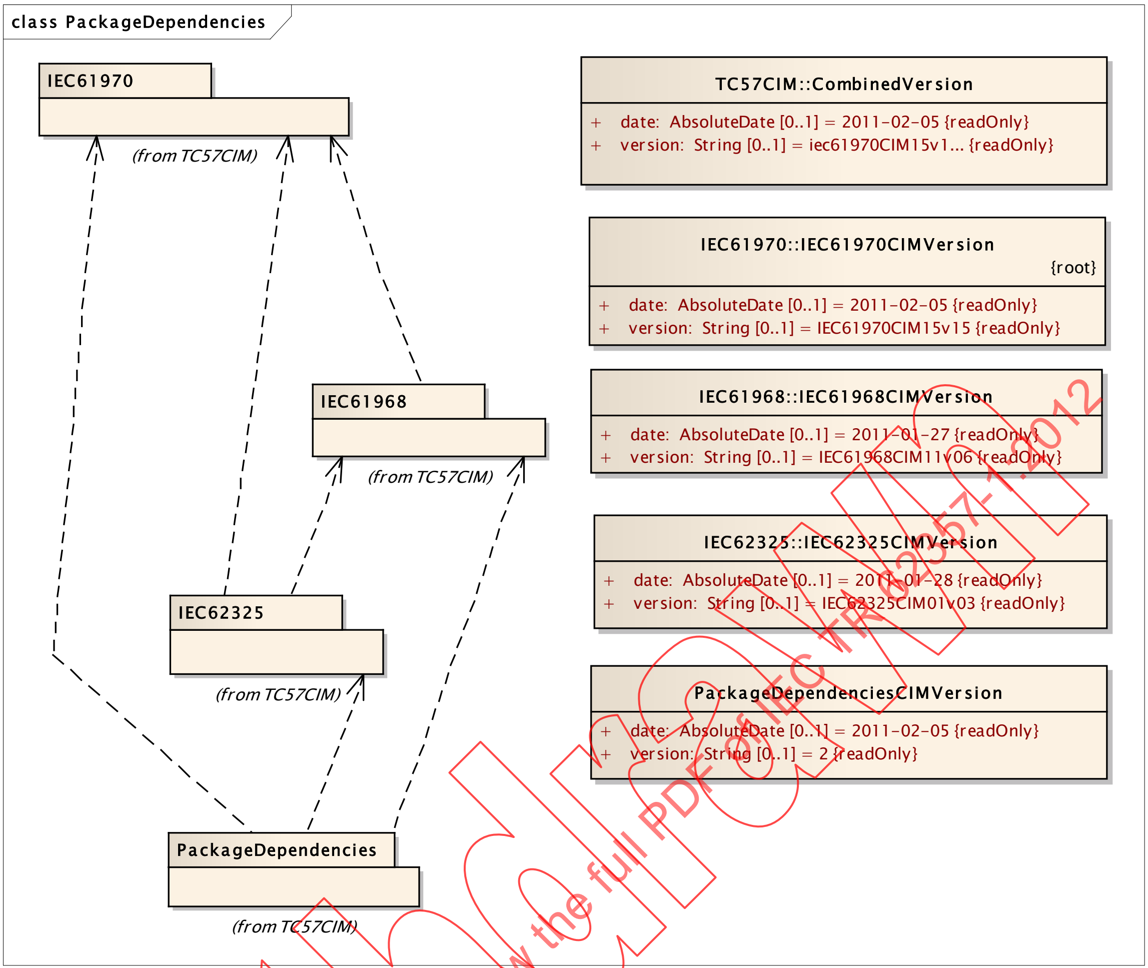
5.2.1 CIM

The CIM is perhaps a logical place to start, since it attempts to model the entire power system, both from an operational point of view and more recently from an asset management point of view, at least for those aspects of assets needed to manage real time operations. The CIM is an abstract model (or PIM) that represents all the major objects in an electric utility enterprise typically contained in an EMS information model. This model includes public classes and attributes for these objects, as well as the relationships between them. The objects represented in the CIM are abstract in nature and may be used in a wide variety of applications.

The CIM is described in class diagrams using UML notation. While the model is partitioned into several packages for convenience, as shown in the following figures, it is actually one single inter-connected class diagram. A package is a general purpose means of grouping related model elements. There is no specific semantic meaning. The packages have been chosen to make the model easier to design, understand and review. The Common Information Model consists of the complete set of packages. Entities may have associations that cross many package boundaries. Each application will use information represented in several packages.

Many aspects of the power system of concern to TC 57 are modelled only in the CIM, such as generation equipment, generation dynamics, schedules, energy schedules, financial, and reservations. Other parts of the power system are modelled in both the CIM and elsewhere (e.g., IEC 61850), such as substation equipment including transformers, switches, breakers, etc.

Figure 17 shows the top-level package structure defined for the CIM. The dashed lines indicate a dependency relationship, with the arrowhead pointing from the dependent package to the package on which it has a dependency.

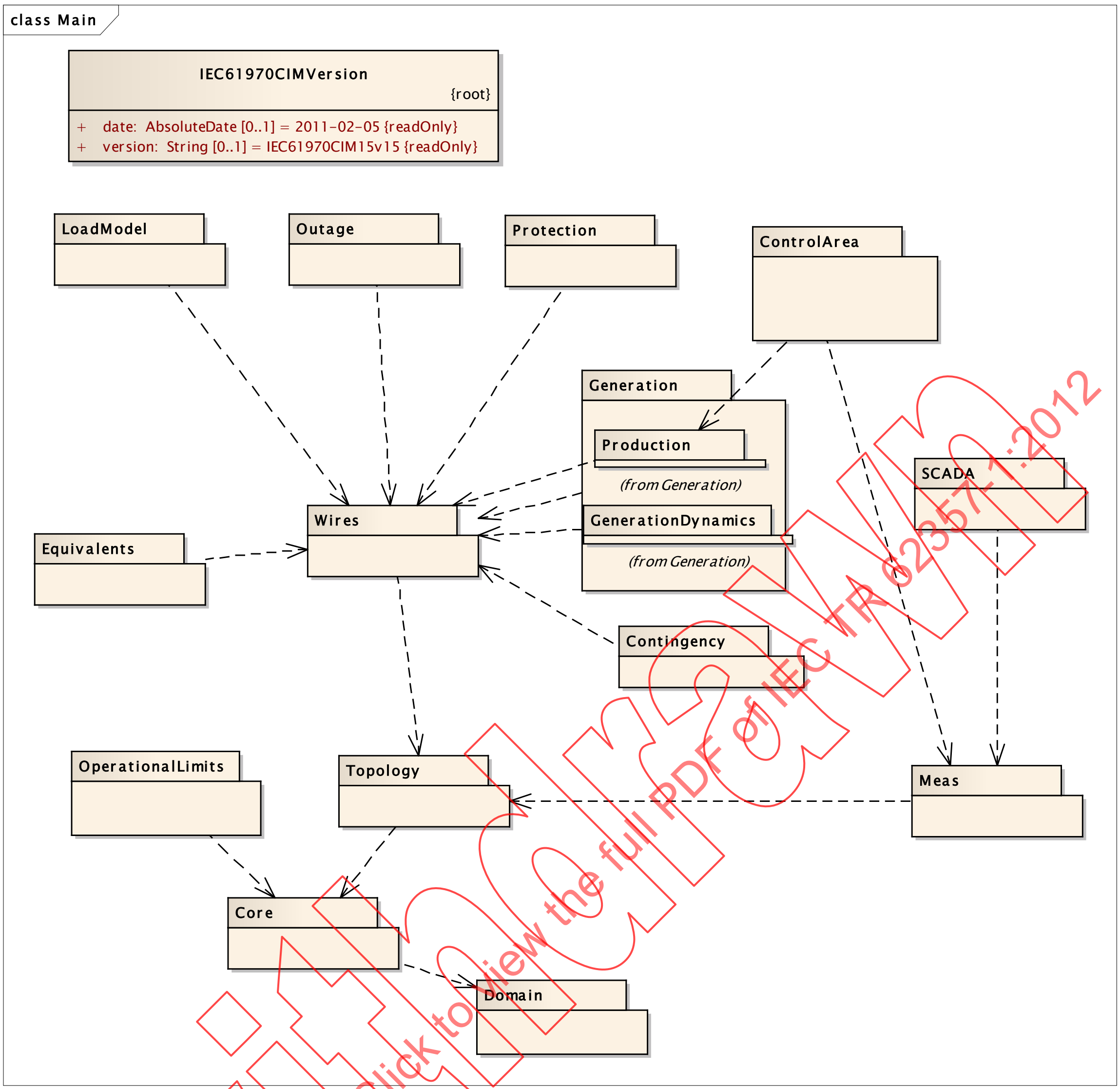


IEC 2065/12

Figure 17 – Common Information Model (CIM) top-level packages

Figure 18 shows the packages included in the IEC 61970 CIM standards.

At the time of this edition was prepared, additions to the IEC 61970 CIM are being approved to add a graphics package to support exchange of diagrams, such as one-line schematics, and to add dynamic equipment models that can be associated with the existing static models for generators and loads, for example, to enable information exchanges for dynamic system assessment and planning studies that require system simulation.



IEC 2066/12

Figure 18 – IEC 61970 CIM packages

Figure 19 shows the major packages included in the IEC 61968 CIM standards. They are organized by part number from the Interface Reference Diagram (IRD) described in 5.2.4. The packages shown are all normative, in that there are normative interface standards that reference their contents. There is also an Informative group packages that contain many additional packages that have no normative interface standards at this time which use the classes contained in these packages. As interface standards are defined, the contents of the applicable packages will be validated and moved to normative status.

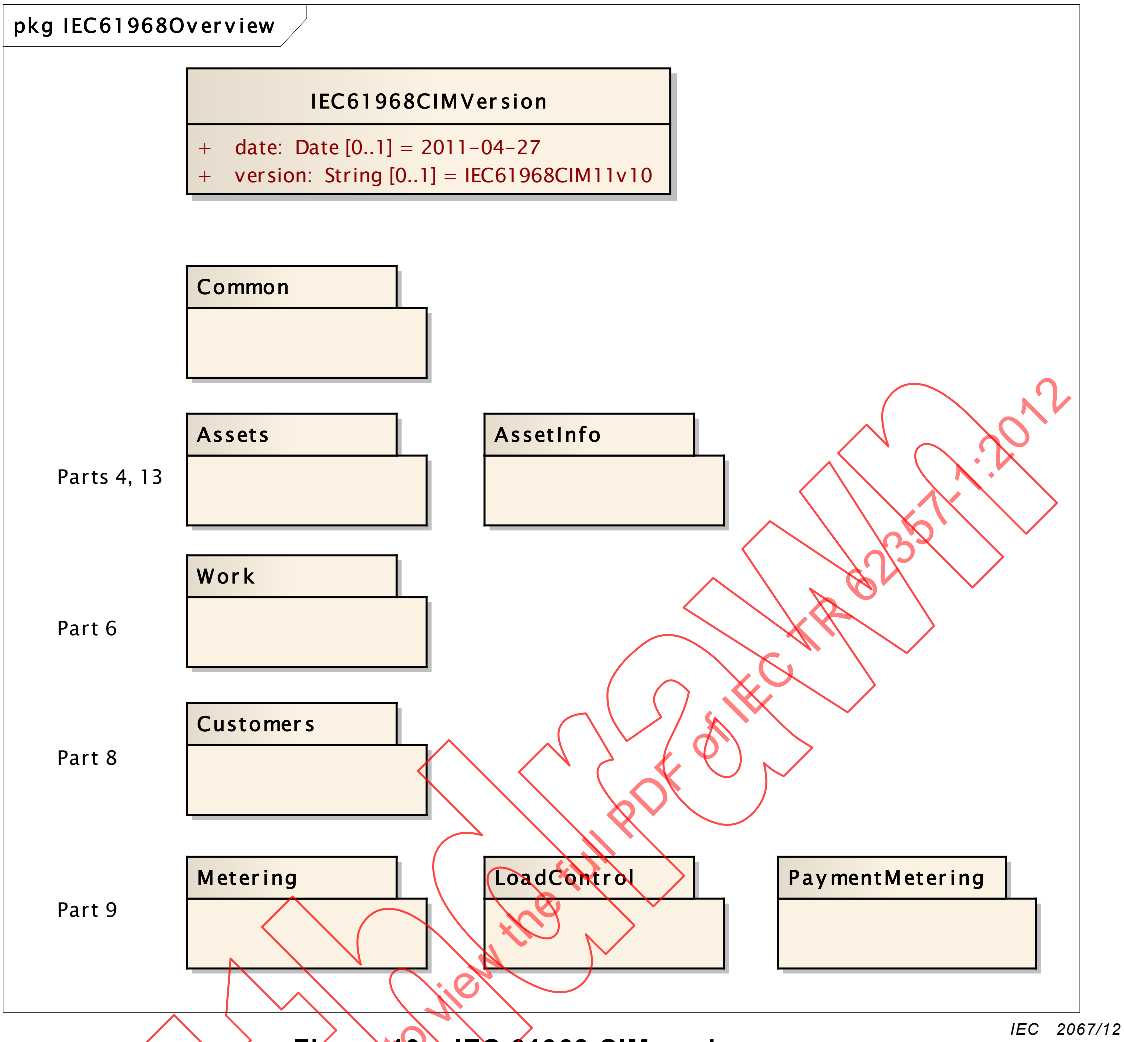


Figure 19 – IEC 61968 CIM packages

Figure 20 shows the major packages included in the IEC 62325 CIM standards which provide a framework for deregulated energy market communications. These models are grouped into four major packages: MarketOperations, Financial, Reservation, and EnergyScheduling.

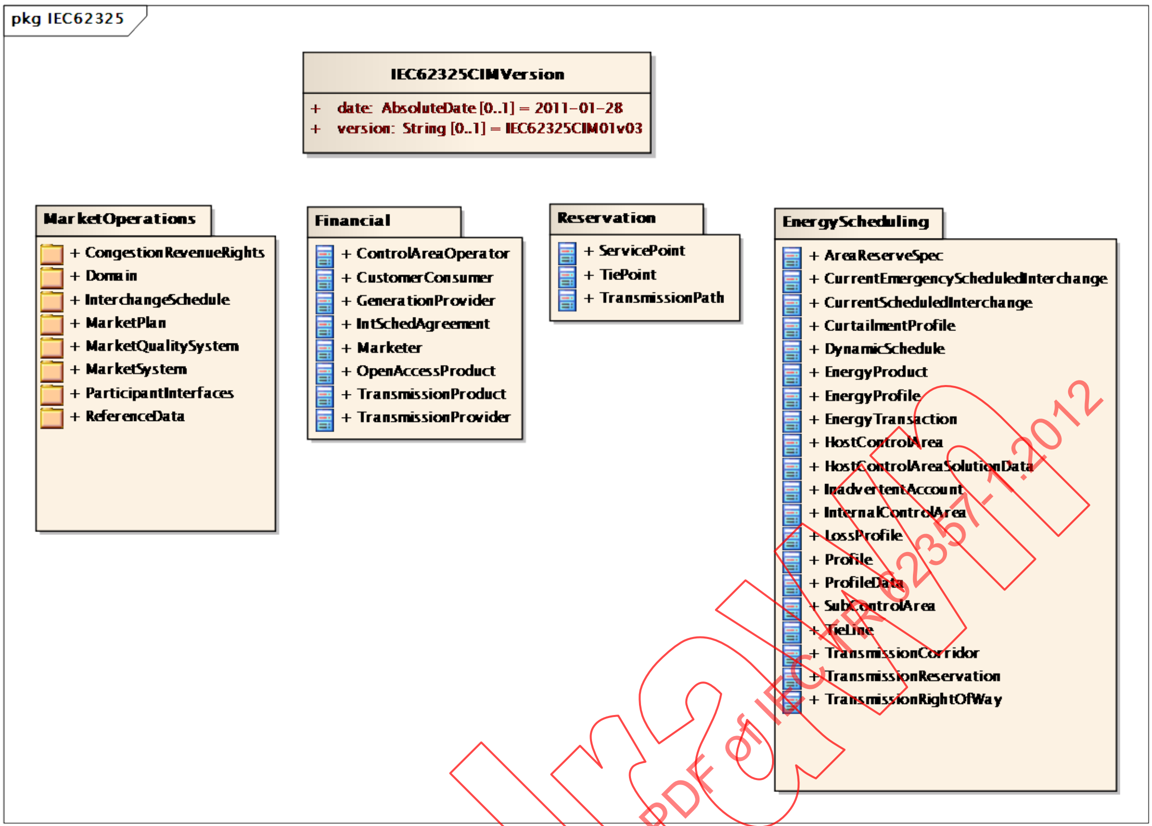


Figure 20 – IEC 62325 CIM packages

5.2.2 CIM classes and relationships

The UML class diagram(s) for each CIM package shows all the classes in the package and their relationships. Where relationships exist with classes in other packages, those classes are also shown with a note identifying the package which owns the class.

Classes and objects model what is in a power system that needs to be represented in a common way to EMS applications. A class is a description of an object found in the real world, such as a power transformer, generator, or load that needs to be represented as part of the overall power system model in an EMS. Other types of objects include things such as schedules and measurements that EMS applications also need to process, analyse, and store. Such objects need a common representation to achieve the purposes of the EMS-API standard for plug-compatibility and interoperability. A particular object in a power system with a unique identity is modelled as an instance of the class to which it belongs.

It should also be noted that the CIM is defined to facilitate data exchange. As defined in this document, CIM entities have no behaviour other than default create, delete, update and read. In order to make the CIM as generic as possible it is highly desirable to make it easy to configure for specific implementations. In general it is easier to change the value or domain of an attribute than to change a class definition. These principles imply that the CIM should avoid defining too many specific sub-types of classes. Instead the CIM defines generic classes with attributes giving the type name. Applications may then use this information to instantiate specific object types as required. Applications may need additional information to define the set of valid types and relationships.

Classes have attributes that describe the characteristics of the objects. Each class in the CIM contains the attributes that describe and identify a specific instance of the class. Only the attributes that are of public interest to EMS applications are included in the class descriptions.

Each attribute has a type, which identifies what kind of attribute it is. Typical attributes are of type integer, float, boolean, string, and enumeration, which are called primitive types. However, many additional types are defined as part of the CIM specification. For example, CapacitorBank has a MaximumActivePower, attribute of type Voltage. The definition of data types is contained in the Domain Package.

Relationships between classes reveal how they are structured in terms of each other. CIM classes are related in a variety of ways, including generalization, simple association, composite and shared aggregation.

The use of the CIM goes far beyond its application in an EMS. This standard should be understood as a tool to enable integration in any domain where a common power system model is needed to facilitate interoperability and plug compatibility between applications and systems independent of any particular implementation.

The original purpose of the CIM was to model that portion of the power system of interest to EMS applications being handled in WG13. However, the scope has since been broadened to embrace the scope of WG14, and therefore now includes models needed for DMS applications and systems. Additional extensions to support market operations are expected in the future.

Some of the important features of the CIM are:

The CIM is hierarchical. Attributes common to more than one subclass of object are inherited from a common class.

The CIM is normalized. All attributes are unique and belong to only one class, although they may be incorporated into other classes via one of the class relationships supported, which include generalization, association, and aggregation. This makes the model useable by a variety of applications, all of which may not have been foreseen when the CIM was originally constructed. The alternative is make the model de-normalized, creating new classes and duplicating attributes to optimize the structure for each application's view of the model.

The CIM is static. The CIM is an information model wherein a physical object may be represented by a number of interrelated classes. Since no specific application was in view when the model was constructed, the objects that an application may want to access through some method may not be represented by a single class. That is, the CIM comprises many "small objects", not necessarily the "big objects" that would be subject of some operation by an application. Therefore, it is not appropriate to try to add operations/methods to the actual class definitions in the CIM.

The CIM is modelled in UML. The entire CIM exists as a UML model file viewable with UML modelling tools as well as in an Internet browser using the HTML version. This unified model includes definitions of all the classes, attributes, types, and relationships as well as class diagrams created to assist viewers in understanding and referencing various parts of the model. Viewing the CIM in this fashion provides a graphical navigation interface that permits all CIM specification data to be viewed via point-and-click from the class diagram in each package.

The CIM IEC standards documents are auto-generated using the electronic UML model.

The CIM has a representation in XML. Power system models are represented in XML using the RDF schema and a simplified RDF syntax as a part of the IEC 61970 standards. An XML schema version of the CIM is used in the IEC 61968 standards to define standard message payloads for use with Web services. This permits the CIM to be viewed and deployed using off-the-shelf XML tools.

The CIM is in use in many production systems.

The CIM is meant to contain classes and attributes that will be exchanged over public interfaces between major applications. The goal is to keep, as much as possible, only the generic features from which a detailed implementation may be derived. In general, it is easier to change the value or domain of an attribute than to change a class definition. This makes the model more robust because it is able to support a broader class of requirements, and more stable because new requirements may be able to be handled without requiring changes to the model

5.2.3 CIS

Whereas the CIM is a static abstract information model, the CIS documents which are the subject of the IEC 61970-4xx and 5xx standards, define a subset of the CIM data objects for a specific system interface as well as the common services needed to exchange data. The IEC 61970 reference model is based on a component architecture, as defined in the software industry by defacto standard component models, such as Enterprise Java Beans (EJB).

The PIM component models (i.e., the Part 4XX series of standards) in the CIS define profiles which specify a restricted subset of the CIM data objects for a specific interface completely independent of the underlying infrastructure used to communicate between components. The CIS thus defines the ***syntax*** for information exchanges while the CIM provides the ***semantics*** or content of the transfer.

The PSM component models (i.e., the Part 5XX series of standards) define the technology mappings to technologies such as C++, Java, Web Services, and XML.

Of particular interest is the representation of the CIM in XML. A methodology is specified using RDF schema to create an XML representation of the CIM, or some subset of the CIM needed to support a particular use case, such as power system model transfer.

5.2.4 Interface Reference Model (IRM)

The IRM and individual system interfaces defined therein provide the framework for a series of message payload standards based on the CIM which are the subject of the IEC 61968-XX standards. These standards define the use of XML for the exchange of information between the various systems defined in the IRM. Use cases define the data content of message payloads between these various systems, and XML schemas are used to define the structure and format for each message payload. These message payload standards are intended to be defined payloads that can be loaded on to messages of various messaging transports, such as SOAP, JMS, or Web services. These IRC IEC 61968 message payload standards are intended to be leveraged by both Service Oriented Architectures (SOA) and Enterprise Service Buses (ESB). In the future, it is possible that payload formats other than XML could also be adopted.

5.3 IEC 61850 data modelling, ACSI and SCL

5.3.1 General

IEC 61850 information model is based on two main levels of modelling – explained below:

- the breakdown of a real device (physical device) into logical devices;
- the breakdown of logical device into logical nodes, data objects and attributes.

Figure 21 shows an example of how each level is included into the upper layer.

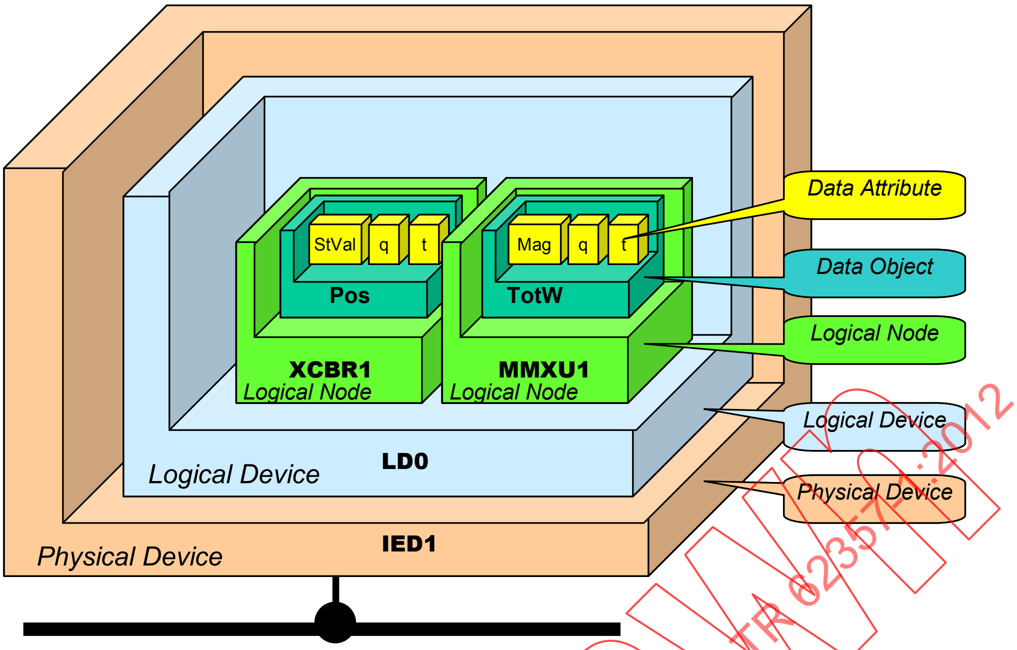


Figure 21 – IEC 61850 data modelling

The approach of this standard as defined in IEC 61850-1 is to decompose the application functions into the smallest entities which are used to exchange information. The granularity is given by a reasonable distributed allocation of these entities to dedicated devices (IED).These entities are called logical nodes (for example, a virtual representation of a circuit breaker class, with the standardised class name XCBR). Other examples may be a distance protection function, PDIS or a measurement value, MMXU. The logical nodes are first defined from the conceptual application point of view in IEC 61850-5 and then modelled in parts 7-4 and 7-4xx.

Then several logical nodes comprise a logical device as defined above (for example, a representation of a bay unit). Based on their functionality, a logical node contains a list of data (for example, position) with dedicated data attributes. The data have a structure and a well-defined semantic and are fully defined through Clause 7 of the standard.

The LN modelling is accomplished by defining standard classes built up through inheritance and aggregation from a common set of Abstract Communication Server Interface (ACSI) class definitions. The ACSI is defined in IEC 61850-7-2 and basically defines the server object classes and the allowed services that are used for communication, but not the content of the information transferred. Logical node classes, which are the subject of IEC 61850-7-4, define the basic functions of the function atom, and the content of the information available on it. The SCL language then describes the instances of these classes available on a specific IED or IED type, grouped into logical devices for function management.

Users of ACSI-based devices can access the device features through well-defined communication services operating on the objects. The ACSI data access model defines the rules for defining and organizing the communication related objects. The IEC 61850 standards incorporate the services and models from the EPRI Common Access Service Methods (CASM)[4] with some revisions based on more recent developments. The object-oriented terminology used in these standards is similar to the UML used in the CIM and includes: class, object, method, attribute, inherit, instantiate, and aggregate. However, beneath some generic UML models used to document the general concepts, IEC 61850 uses tables and text for object modelling rather than UML. The ASN.1 language is used in the protocol mapping (SCSM) for describing the abstract structure of the data present in a message. It does so by providing a notation for structured data types and referring to MMS basic data types.

4 See Annex B for a description of CASM.

The following subclauses provide more details on IEC 61850 ACSI and SCL.

5.3.2 IEC 61850 ACSI

5.3.2.1 General

In ACSI, a client/server model is assumed, in which the client initiates transactions that are processed by the server. The ACSI server hides real data and devices, using objects to represent them instead. Objects that are directly accessible by a client through a network are contained in an object from the server class. The servers, and the object instances they contain, are mapped to the communication stacks for communication with the real devices. Figure 22 illustrates this concept.

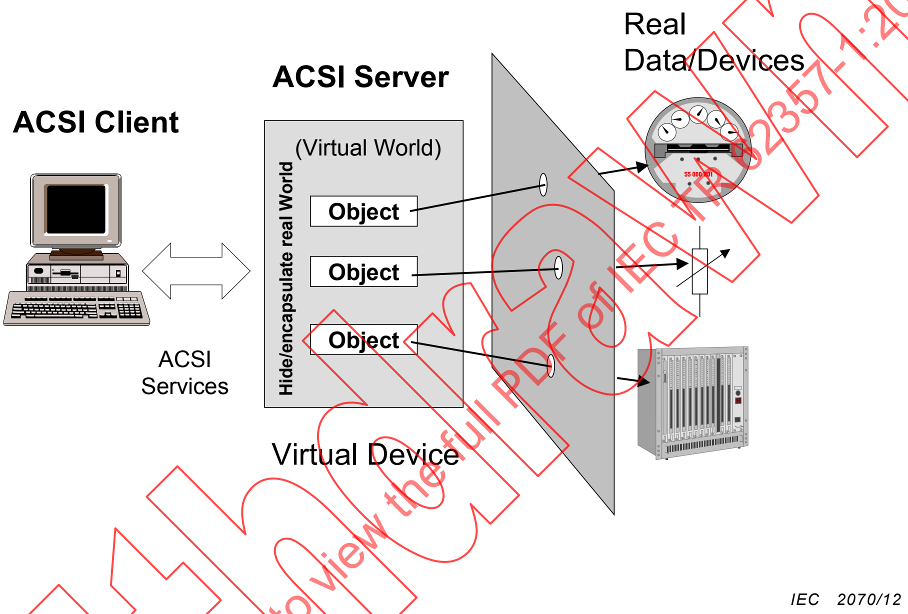


Figure 22 – ACSI client/server model

5.3.2.2 Logical devices

Logical devices are a composite of function atoms, which are represented by logical nodes, and which have to be commonly managed. The collection of these logical nodes provides the functionality of the logical device. A physical device can implement one or more logical devices. For example, a distribution relay device might include several standardized relay functions. In addition, an electronic distribution relay would likely have a capability to measure the voltages and currents in the conductors it is controlling. To represent this device in IEC 61850 series, a logical device would be created that contained a nameplate, device identity, a measurement unit logical node, and one or more standardized relay function logical nodes. Alternatively, the physical device can contain a logical device for measurement and a logical device for protection.

It should be noted that IEC 61850 allows for arbitrary assembly of logical nodes into logical devices. The composition of a logical device is left to the manufacturer and can always be determined by reading the SCL description of the physical device, or by browsing an instance of a physical device with the ACSI directory services.

With the use of SCL offline or the ACSI directory services online, the online properties of each IEC 61850 server device can be discovered and used to populate a database in the control centre. Any changes in the field (i.e., new installations, revisions to existing installations, removal of field equipment, etc.) can be discovered automatically as the changes are made, rather than requiring a separate manual data entry at the control centre.

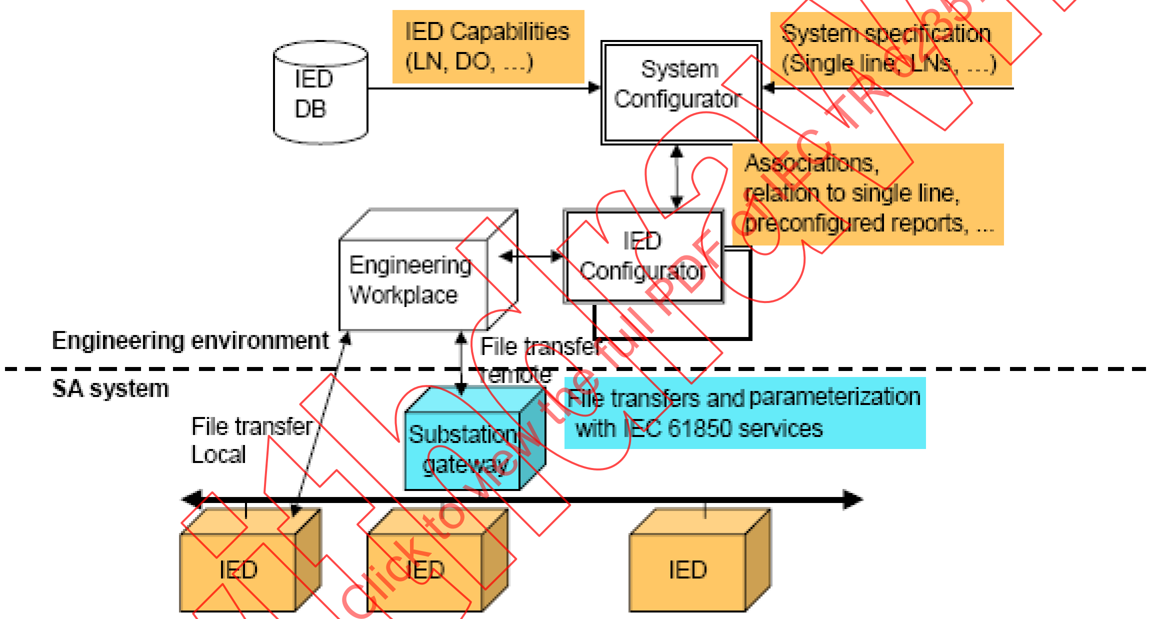
5.3.3 SCL modelling language

5.3.3.1 General

SCL is used to describe IED configurations and communications systems defined in the IEC 61850-5 and -7xx standards. The main purpose is to allow the exchange of IED and communication system configuration data between an IED configuration tool and a system configuration tool from different vendors. Files created using SCL are also used to transfer the IEC configuration data from the IED configuration tool to IEDs in the switchyard.

5.3.3.2 SCL uses and data exchanges in the engineering process

Figure 23 below illustrates the types of data exchanges where SCL is used. The text boxes describe the type of information exchanged.



IEC 2071/12

Figure 23 – Use of SCL files to exchange IED configuration data

5.3.3.2.1 System specification – SSD file

As shown in Figure 24, an SCL file may be generated by planning applications to supply the system specification to a system configuration tool (i.e., system configurator). The system specification comprises a single line diagram with an allocation of logical nodes (LNodes) to parts and equipment in the single line diagram to indicate the needed functionality. This uses the SCL file type SSD as defined in IEC 61850-6.

5.3.3.2.2 IED capability description – ICD file

An SCL file may be used to provide data on pre-configured IEDs to the system configurator. The file may originate from either (1) an IED database or may be (2) exported directly by a tool from the IED. This data consists of LNode description type definitions and may contain optional substation model information. This data exchange uses SCL file type ICD.

5.3.3.2.3 Substation automation system description – SCD file

An SCL file is used to transfer a complete system configuration from the system configurator to an IED configuration tool (i.e., IED configurator). The system configuration specifies how

IEDs are bound to process functions and primary equipment using the IED and substation parts of the SCL model (see following subclauses for a description of the SCL model). This system configuration also includes the substation communications configuration information in terms of the access point connections for each IED and possible subnetwork paths for clients to access them using the IED and communication parts of the SCL model. This data exchange uses SCL file type SCD.

5.3.3.2.4 IED configuration description – CID file

An SCL file can be used to transfer configuration data from the IED configurator to an IED. The configuration data contains a communications section (using the communications part of the SCL model) with the assigned address of the IED. If an optional substation section (using the substation part of the SCL model) is included, it will provide the name values assigned. This file is essentially the same as the SCD file stripped down to only what the targeted IED needs in the way of configuration information.

5.3.3.3 SCL model in XML

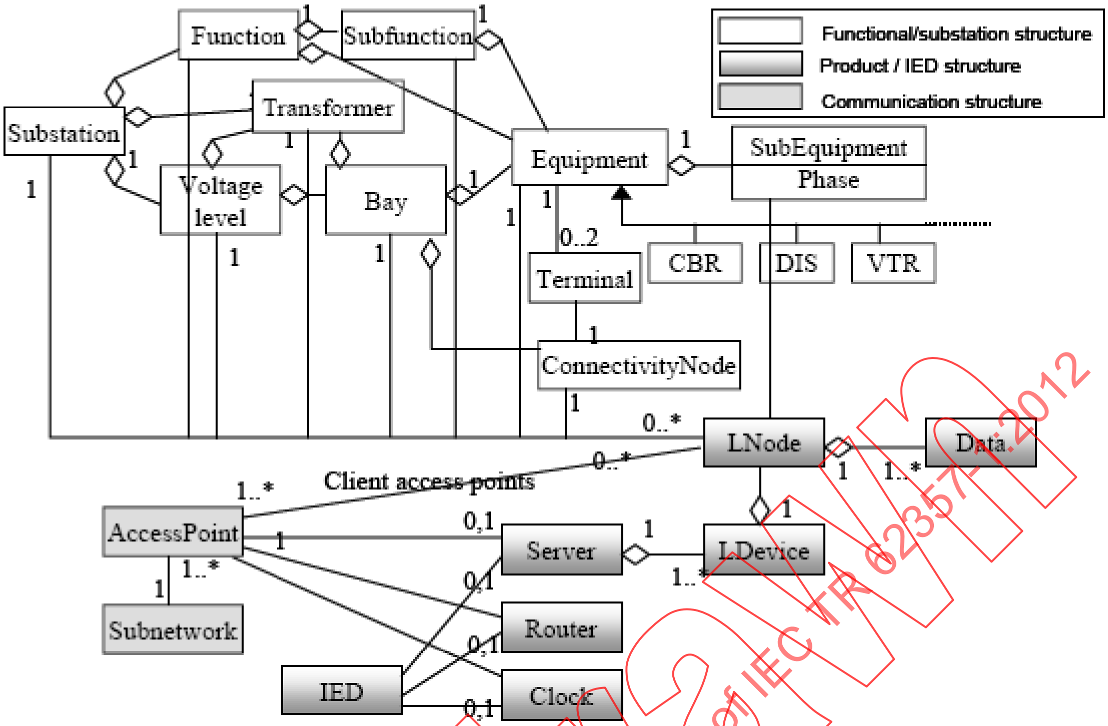
5.3.3.3.1 General

There are three parts to the SCL model (see Figure 24):

a) Substation part. This is a hierarchical model describing switchyard equipment (Substation, VoltageLevel, Bay, and Equipment) from a functional view and their interconnection via Terminal and ConnectivityNode. These classes have direct parallels in the CIM. The model also includes classes for Function, Subfunction, SubEquipmentPhase, and separate classes for individual devices, but not based on the CIM (e.g., CBR for circuit breaker)

b) Product (IED) part. This part models substation automation equipment, such as IEDs, and the application level communications between them (i.e., how data is grouped into data sets for sending, how IEDs trigger the sending and which service they choose, which input data from other IEDs is needed by an IED). To do this the model defines classes for LNode, Data, LDevice, Server, Router, Clock, and IED. These classes are not modelled in the CIM.

c) Communication part. This part models how IEDs are physically interconnected via networks and subnetworks and specifies which communications ports are used. The model comprises Subnetwork and AccessPoint classes for this purpose. The communication connections between IEDs are described in terms of logical nodes as clients and servers. This is not modelled in the CIM.



IEC 2072/12

Figure 24 – SCL object model

As can be seen from Figure 24, the logical node (LNode) is the transition object that relates the different parts of the model to each other. That means the Lnode instance has a functional aspect within the switchyard (via LNode – substation object association) and a communication aspect as a client or a server within the substation automation system (via LNode – AccessPoint associations). In other words, the SCL model shows the relations between instantiated logical nodes and their hosting IEDs on the one side and the switchyard (or function) parts on the other side.

The substation part and the product part form hierarchies, which are used for naming. This hierarchical structure and naming rules follow IEC 61346 -1 and -2.

The communication model part just contains the communication connection relations of IEDs to subnetworks, between subnetworks by means of routers at an IED, and the placement of master clocks at the subnetworks for time synchronisation.

5.3.3.3.2 Substation model

The purpose of the substation model is twofold:

a) to relate a logical node and its function to a substation function (substation part or equipment or subequipment),

b) to derive a functional designation for the logical node from the substation structure. The functional hierarchy is used as the basis for naming of each instantiated object in an SCL model.

5.3.3.3.3 Product (IED) model

The product model only covers the IEDs that form the substation automation equipment, not the primary switchyard equipment. Primary devices as products are outside the scope of SCL, only their functional side is modelled by the substation hierarchy for functional naming purposes.

5.3.3.3.4 Communication model

The purpose of this model is to model the possible logical connections between IEDs via access points and subnetworks. Client LNodes use the address attribute of the access point to build up associations to server LNodes on other IEDs.

5.4 TASE.2

The TASE.2 models represent a virtual control centre rather than an individual substation or field devices. The TASE.2 models for SCADA operations are point-oriented, as explained earlier. That is, there are no models of physical devices being monitored or controlled. Management of physical devices in the field was not within the scope of WG7, so there is no provision for configuration of devices or discovery of new devices as there is in the IEC 61850 standards.

Regarding data acquisition with TASE.2, the assumption is that the topological information associated with point data received via TASE.2 is stored locally in a power system model in the receiving control centre database. TASE.2 provides updates to measurement and status values using a unique reference number for each point that was agreed to by both sending and receiving control centres when the bilateral tables used for access control are established.

5.5 Data modelling techniques used

5.5.1 IEC 61850 series

IEC 61850 series uses UML diagrams and text to document the basic ideas behind the function, data and service models, and then describes the details by means of text and tables. SCL (which is defined in IEC 61850-6 and is based on XML) is used to describe the IED configurations and communications systems defined in the IEC 61850-5 and -7xx standards. While UML is used to show the relations between SCL model parts and elements, SCL is used to document the abstract data model in terms of XML elements and data types.

5.5.2 IEC 61968 series, IEC 61970 series

IEC 61968 and IEC 61970 series use UML to define the abstract information model in these standards. UML class diagrams are used to document the CIM in its entirety in terms of UML classes, attributes and relationships. Although UML is used, certain conventions defined in the UML standards are not strictly followed. For example, although the UML specification may state that all attributes defined for a class are mandatory, in the CIM each attribute is treated as optional. So in this sense, the CIM serves as a semantic model or common language for information exchange.

For a given application of the CIM, it is therefore important to define external to the CIM which classes, attributes, and relationships are in fact mandatory and which are optional to ensure interoperability between different users of the CIM model. These are defined as profiles in the IEC 61970 series of CIM standards. An example is the NERC minimum data requirements for a Common Power System Model (CPSM) used to exchange transmission power system models.

The IEC 61968 series of information exchange standards define message payloads instead of profiles. These standards specify which CIM classes are mandatory and optional for business transactions of various types. The standards are defined as XML schemas for messages, where the XML elements and attributes are based on the CIM class attributes.

5.6 Service model techniques used

5.6.1 IEC 61850 series

The IEC 61850 series services are task specific (i.e., device specific). Device communication is tightly coupled. In this case a client needs to be assured that it has control of a server. The services defined in ACSI include:

- Association – The services to establish an association between a client and a server. With the exception of the high-speed peer-to-peer services, all other services of IEC 61850 rely on an established client – server association.
- Get or set data – A general purpose request/reply interface for reading or writing data objects defined in the IEC 61850 run-time model.
- Controls – Several services for writing data with varying levels of reliability checking and confirmation beyond that of a simple "set" operation. Used for operating equipment within the substation.
- Data sets – The ability to group together data under a single name for reading, writing, reporting or logging. May be grouped statically at configuration time or dynamically at run-time.
- Reporting – Unsolicited reporting services used by a server to spontaneously transmit data to a single client either periodically or when the data changes. Reports may or may not be buffered at the reporting device, depending on the level of reliability required. Intended for maintaining synchronization of run-time databases.
- Logging – Services to store events locally in the server and to retrieve them as needed by the client.
- High-speed peer-to-peer – Several services that are similar to reporting except that data is multicast to many devices in a substation simultaneously using a very efficient transport profile. The Generic Object-Oriented Substation Event (GOOSE) service is intended to replace point-to-point logic connections between protection relays and typically carries information required for interlocking logic for control devices. Sampled Measured Value (SMV) service transmits waveform samples in real-time.
- Self-description – A set of services permitting a client to query the run-time model in use within a device at any given moment.
- Settings groups – A set of services used to change configurations quickly at run-time without restarting the device. Permits a new set of parameters to be "pre-loaded" by a client and then switch them all into use together with a single request.
- Substitution – A service intended to temporarily "force" data to certain values, typically during upgrades of the system, to hide the fact that the real measurements are corrupted or not available.
- File transfer – The ability to read or write files of data for purposes that may be related to configuration, logging, fault recording, or any of several other substation applications.

5.6.2 IEC 61968 series

IEC 61968-100 describes how message payloads defined by Parts 3-9 of IEC 61968 are conveyed using Web services and the JMS. Guidance is also provided with respect to the use of Enterprise Service Bus (ESB) technologies. The goal is to provide details that would be sufficient to enable implementations of IEC 61968 series to be interoperable. In addition, this technical report is intended to describe integration patterns and methodologies that can be leveraged using current and future integration technologies. Web Service Description Language (WSDL) templates are included in this technical report for both generic and strong types service interfaces.

5.6.3 IEC 61970 series

IEC 61970 series services rely on existing protocol standards for transporting power system network model files and other information exchanges defined in the IEC 61970 series of standards. These include File Transport Protocol (FTP), OPC Unified Architecture (UA) specification (see [2] in the Bibliography) has been adopted as IEC 62541, and the IEC 61968-100 Web services. These services are used to achieve loosely coupled integration where clients request a server to perform some action, but it is up to the server to decide how to respond to the request.

5.7 Reconciling CIM and IEC 61850 standards via a harmonized model

5.7.1 General

The TC 57 models developed to date have evolved as several overlapping models to suit different users. Broadly speaking, the models can be classified as:

a) the control centre and distribution management view (i.e., EMS, DMS) of a network with large numbers of simplified devices. This view also includes many non-power system objects, such as consumers, schedules, documents, assets, etc., to ensure data consistency across all information exchanges between participating systems, and

b) the substation (i.e., protection) view of a smaller number of more complex devices. The data model to support this view is designed to allow substation functions to span multiple physical devices, and to separate the function oriented model from the communication related model.

Annex A is an attempt to compare the types of models discussed above. This is not an exhaustive list, only representative of the models. As shown, there is a range of overlap in all models in the SCADA area for analog measurands, status changes, and control points. For substation and feeder device models, IEC 61970 and IEC 61850 models overlap. For yet other areas, such as contracts and generation, there is no overlap.

Annex B provides a more detailed comparison of the different modelling techniques used by providing a concrete example of how a circuit breaker is modelled with the different approaches currently used in TC 57. The model contained in the IEC 61850 standards is described first followed by the model used for the IEC 61970 standards.

An EPRI-funded project completed in 2010 proposed to harmonize the CIM and IEC 61850 standards through the creation of a harmonized information model (described as a unified information model in the report) that provides a common set of semantics for use by both the CIM and IEC 61850 standards. Utilities should be able to exchange information between systems and devices using a common language supported by both, regardless of the specific interface involved. This can be achieved by having a common semantic model from which the specific information to be exchanged can be derived, thus avoiding the proliferation of endless point-to-point links, each based on a different set of semantics. While mapping is still required from a system's native representation of data to the standards-based common language for information exchange, this approach ensures that an accurate and lossless transformation occurs at every interface to another system where the common semantic model is applied. This is, in fact, the stated vision for the National Institute of Standards and Technology (NIST) smart grid interoperability framework.

The harmonized information model expressed in UML was developed by extending the existing IEC 61968/IEC 61970 CIM UML model to incorporate extensions needed to support the IEC 61850 semantic concepts defined in IEC 61850-6 SCL, since there was no UML information model in IEC 61850. Although the goal was to minimize changes to the existing SCL standards, some changes are proposed to SCL to address differences in modelling approaches and functionality. The proposed harmonized model supports both the CIM and IEC 61850 standards for generating information exchanges expressed in either CIM/XML files/messages or IEC 61850 SCL XML.

Areas where these differences need to be reconciled occur when information is shared between a system using one set of models (e.g., an EMS/SCADA system based on the CIM) with a system using the other models (e.g., an automated substation using the IEC 61850 standards). Another example would be a fault location system or maintenance management system based on CIM network and asset models using data from a IEC 61850-based automated substation to provide fault and asset data.

Details on recommendations for harmonization can be found in the EPRI technical report recently published (see Bibliography). A summary of these recommendations is provided in the following subclauses. At the present time these recommendations represent one possible approach to achieving the desired harmonization between the CIM and IEC 61850 standards.

5.7.2 Use cases and interfaces

The following use cases were identified as high priority for harmonizing the CIM and IEC 61850 standards:

a) generate an SCL file from the harmonized UML model and new SCL profile. This validates that all the necessary elements of an SCL file can be generated from the CIM UML harmonized model as modified to include the required IEC 61850 objects in UML. This also demonstrates conformance of IEC 61850 to the TC 57 reference architecture;

b) update an EMS load flow model imported via CIM/XML with IEC 61850 configuration data. This demonstrates how field changes made by a substation engineer to an IEC 61850-configured substation can be used to automatically update a load flow model without having to re-enter the data manually. This use case validates that all the necessary harmonization has been done to permit IEC 61850 configuration data to be used to update CIM models;

c) real-time SCADA data import from IEC 61850 devices;

d) asset and Condition Based Maintenance (CBM) application import of data from IEC 61850 substation devices (future). This use case validates that the data contained within the SS fence needed by this application could be made available to applications in a CIM format.

5.7.3 Summary of harmonized model reconciliation recommendations

5.7.3.1 General

Reconciling data models is a combination of harmonizing the semantic models and creating relationships between the different representations so that it becomes possible to unequivocally map object representations in one standard to the other, permitting interoperability and information exchange with no loss or corruption of data. This subsection summarizes the recommended changes and mappings from the perspective both the CIM and IEC 61850 standards. Changes to both the existing CIM UML model and the IEC 61850 SCL are required to implement these recommendations.

5.7.3.2 UML changes

Although there are already many similarities in the CIM and IEC 61850 substation models, changes are needed to the CIM UML model to add missing classes. Figure 25 shows the inheritance hierarchy that contains the proposed class additions (shown in yellow). Besides the new classes added, an attribute was added to the conductor class. The attribute InsulationType was added to allow the expression of the type of insulation used by the conductor. A proposed enumeration was also added to support the values of this attribute (e.g. TypeOfLineInsulation).

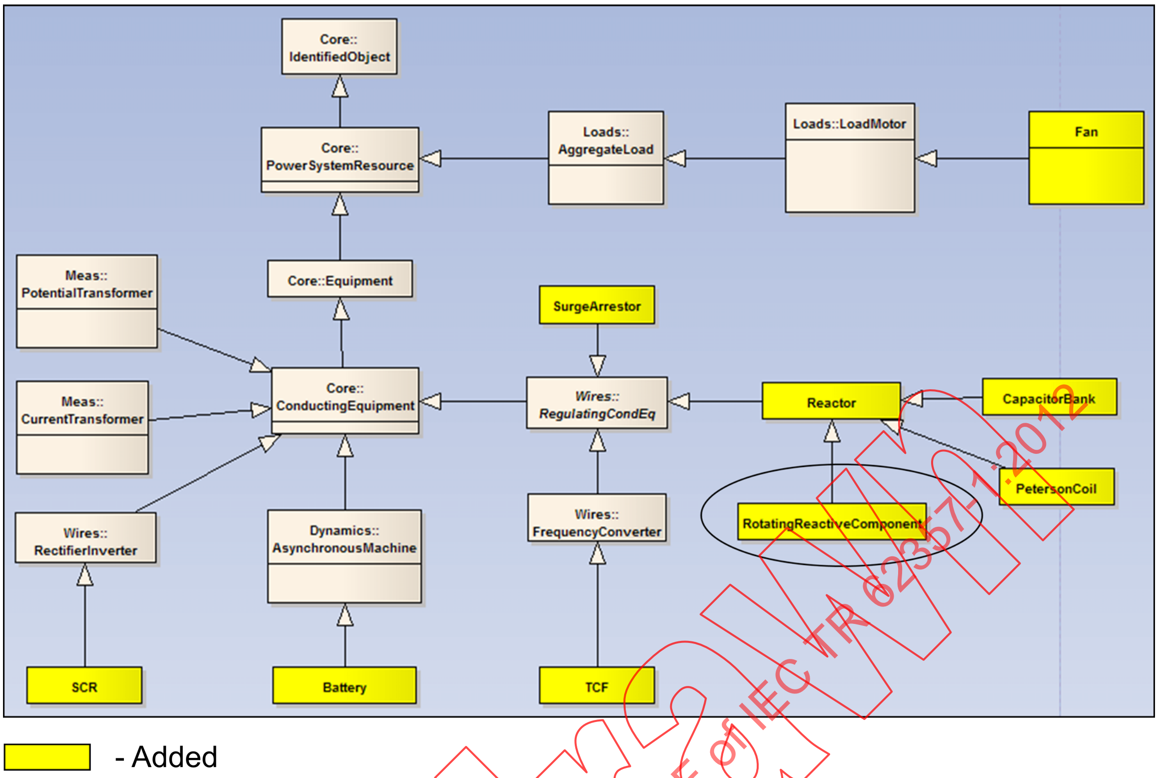


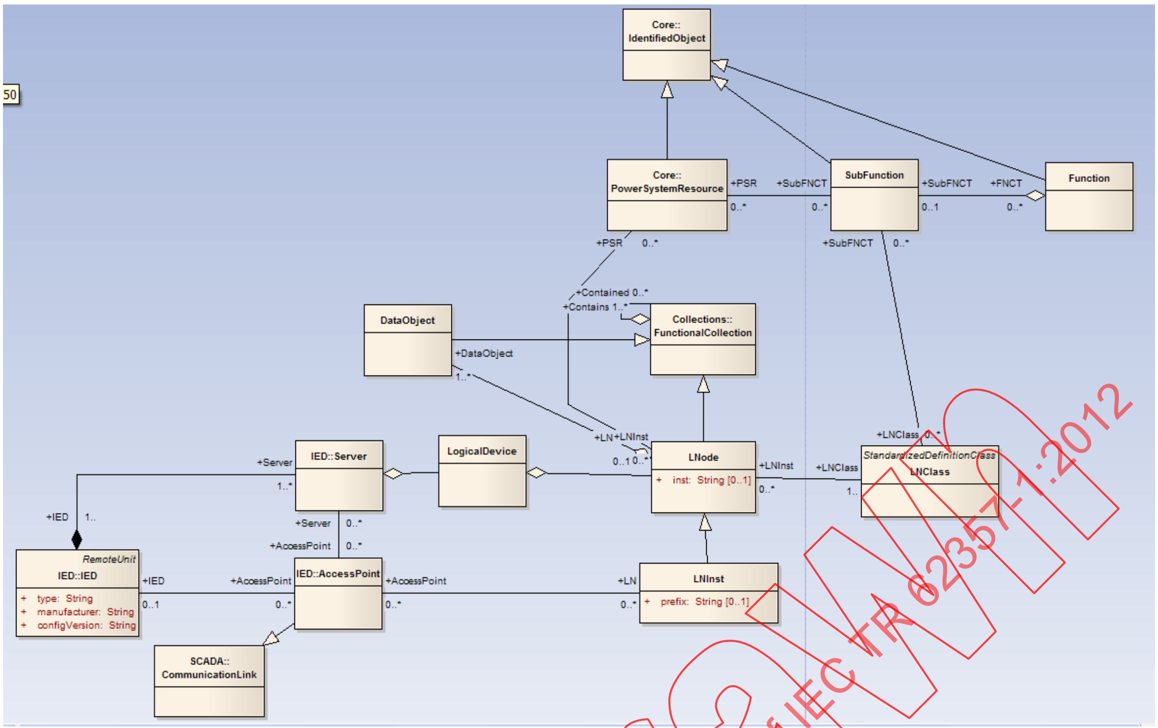
Figure 25 – Proposed changes to the substation equipment UML model

Figure 26 shows the proposed changes to link IEC 61850 classes to Power System Resources (PSRs) in the CIM UML. There are actually two uses for a relationship of substation functions (e.g. IEC 61850 logical nodes) to the CIM PowerSystemResources (PSR) (see Chapter 6, Relating Logical Nodes to PowerSystemResources in [1][5]):

a) the first use (as described in use case 1 in 5.7.1) is to allow a planning activity to specify what type of substation functions need to be associated with a PSR. Such a specification allows the abstract requested “function” to be related to the actual PSR upon which the function is requested;

b) the second use is to relate the actual instance of the function to the PSR that is providing the requested function. Additionally, this second type of relationship allows for the substation engineer to assign actual “functions” and instances to PSRs even if the planned model did not explicitly define a particular need (e.g. determined during some other process or substation commissioning). Figure 26 depicts the proposed UML to allow both the abstract function and Logical Nodes to be related to PSRs.

5 Numbers in square brackets refer to the Bibliography.



IEC 2074/12

Figure 26 – Proposed linkage of IEC 61850 classes to CIM PSR classes in UML

5.7.3.3 SCL changes

The following additions of enumerated values to the XSD Types are recommended:

- To tPredefinedCommonConductingEquipmentEnum, the following enumeration values are proposed to be added:
  - – BBS – BusBarSection
  - – CND – Conductor
  - – CON – Connector
  - – EnergyConsumer
  - – RINV – RectifierInverter
  - – SCMP – Series Compensator
- To tPredefinedGeneralEquipmentEnum, the following enumeration values are proposed to be added:
  - – GEN – GeneratingUnit
  - – PROT – Protection Equipment
- An attribute was added to tConnectivityNode to indicate if the node was grounded or not.
- A tSwitch production was added to allow a closer alignment to CIM Switches. The enumerated values proposed for this type are:
  - – DIS – Disconnector
  - – FUSE
  - – GNDDIS – Ground Disconnector
  - – JMP – Jumper
  - – GEN – General Switch
  - – CBR – Breaker (was removed from tPredefinedCommonConductingEquipmentEnum)

- The production of tTapChanger was enhanced to allow a "TypeOfLTC" parameter so that there could be differentiation between regular, phase, and ratio tap changers.
- Changes to the Equipment Container relationship were made in order to align with CIM and allow other equipment containers besides Substations, Bays, and VoltageLevels.
- Additionally, a new section type has been added to support planning information.

5.7.3.4 Mapping recommendations

In order to relate the UML model classes for equipment to the IEC 61850 SCL representation of equipment, it is necessary to unambiguously map one to the other. Annex D summarizes the recommended mappings.

5.7.3.5 General recommendations

- Need to agree to common definitions for all the classes used to model the substation. Recommendations for the definition to use are made from among the possible sources of definitions, including IEC Glossary, IEC TC 57 Glossary, IEC 61970/IEC 61968 UML model, and IEEE Dictionary. IEC 61850 does not provide any authoritative definitions for the terms used within the SCL substation section/XSD.
- Need persistent IDs in IEC 61850. Recommendation is to add RDFID (equivalent to rdf:id in CIM XML)
  - SCL files have internal referential integrity through the use of names. However, when merged/imported and mapped to the CIM, names will be duplicated.
  - Use of names only would also make it difficult to pick up incremental changes.
- Units need to be aligned.
- Proposed alignment for CIM Measurements and MeasurementValues with IEC 61850 measurement objects.
- Proposed alignment for SCADA and control.
- Proposal to expand communications models in the CIM to align with IEC 61850 communications objects
- IEC 61850 needs to make better use of CIM Profiles (layer 2) to restrict general CIM model for specific business purpose rather than creating specialized UML models.

5.7.3.6 Naming conventions

In CIM, when RDF Schemas are used (as in IEC 61970 with CIM XML), elements correspond directly with UML classes, attributes or associations. The element tag names consist of:

- the class name when they represent a UML class, e.g. PowerSystemResource;
- the class and attribute names concatenated, when they represent a UML attribute, e.g., PowerSystemResource.pathName, where PowerSystemResource is the class name and pathName is the attribute name;
- The class and association end-side role name, when they represent a UML association, e.g. PowerSystemResource.OperatedBy_Companies, where PowerSystem Resource is the class name and OperatedBy_Companies is the association end side role name.

In XML schemas, there is a difference between elements or attributes and their type.

In CIM, when XML schemas are used (as in IEC 61968), elements correspond directly with UML classes and attributes:

- the element tag names consist of the UML class or attribute name;
- the names of the type of these elements are the same as the element names.

In IEC 61850, SCL schemas distinguish between elements (or attributes) and their types. This is reflected in the corresponding UML diagrams. So in SCL :

- the name of the XML type of an element is the name of the UML class (this is reflected by the “t” character that prefixes all UML class names);
- the name of the XML type of an attribute is the name of the UML attribute type. These attribute types are either prefixed with a “t” when it is an SCL defined type or with “xs:” when the attribute type is an XML datatype;
- the name of the XML element is the name of the association end-side role name corresponding to a UML class;
- the name of an XML attribute is the name of the UML attribute.

So there are differences between the CIM and IEC 61850 in UML naming and XML naming. These should be aligned. There are two key issues:

- the naming conventions used for UML naming of classes, attributes and associations are different;
- the naming transformation rules between UML and XML and RDF are different.

Regarding the transformation from CIM classes to SCL, the following rules are suggested for SCL:

- element names should follow the CIM UML class name convention, which is the UpperCamelCase rule, e.g., PowerSystemResource;
- element type names should be UML Class class names prefixes with “t” (note this changes the UpperCamelCase rule and should be reconsider latter to get consistent rules that would require a “T”), e.g., tPowerSystemResource;
- attribute names are the same as UML attributes names and follow a lowerCamelCase rule, e.g., pathName;
- attribute type names are the UML attribute type name prefixed with a “t” when the attribute type is a CIM datatype or prefixed with the “xs” prefix when it matches an XML datatype.

5.7.3.7 Instance naming

To be able to share CIM and IEC 61850 SCL models, it is essential that a consistent approach to naming be adopted. Both the CIM and SCL share similar naming attributes, only the name of the attributes is different. Table 1 shows a recommended mapping between the CIM and IEC 61850 naming attributes.

Table 1 – CIM and IEC 61850 naming attributes

CIM description of naming attribute	**CIM IEC 61968/IEC 61970**	**IEC 61850**
Unique name for all objects with the same parent (i.e, at the same level of the substation/product hierarchy)	*IdentifiedObject.name*	*name*
Human readable name for operator interfaces	*IdentifiedObject.aliasName*	*desc* – used at engineering time
Unique identifier within entire system based on concatenation of names of all objects in hierarchical path	*N/A*	*reference*
Globally unique identifier	*IdentifedObject.mRID*	*MRID*
Description of object or instance	*IdentifiedObject.Name.description*	*text*

IEC 61850, however, goes further than the CIM in specifying that the name and reference attributes shall follow the IEC 61346 naming standard:

- *name* is a single level designation that is unique within the container object, e.g., a Substation "London" contains VoltageLevels with the names "400" and "70". This name corresponds to IdentifiedObject.name in the CIM;
- *reference* is a multi-level designation that is unique within the system and consists of the concatenation of the single level designations for the object itself and all container objects, e.g., "London/400" for one of the VoltageLevels. There is no equivalent in the CIM.

6 Technology mappings for TC 57 standards

6.1 General

This part of the architecture describes the lower level technologies that are used to encode data as well as to actually implement the services and carry messages between devices or applications. Technology neutral and technology specific service descriptions are defined in two forms as defined in OMG's Model Driven Architecture (MDA):

a) As Platform Independent Models (PIMs) using UML and text. These standards are independent of the underlying technologies used to implement them. This ensures these standards remain relevant as the under-lying technologies evolve.

b) As Platform Specific Models (PSMs), which specify implementations in various technologies, such as XML, Java, Web services, etc. PSMs ensure interoperability between different vendor's products for a given choice of technology.

For most of the TC 57 standards, such as IEC 60870-6 (TASE-2), IEC 61850, IEC 61968, and IEC 61970, services are written in a generic fashion that permits several different technology profiles to be used. For instance, IEC 61850 may be implemented using either the

Manufacturing Message Specification (MMS) [IEC 61850-8-1] or web services [future IEC 61850-8-2], while IEC 61970 may use web services or a legacy technology platform such as Microsoft COM. It is also possible to map a device-oriented data model (for example IEC 61850) onto a data point-oriented protocols, such as IEC 60870-5-101/104 [IEC TS 61850-80-1] or DNP3 [future IEC TS 61850-80-2] for migration strategies.

6.2 Use of XML

6.2.1 General

XML is being used in several TC 57 standards as a standard way to exchange information:

a) IEC 61850 – basis of the Substation Configuration Language (SCL) to describe IED configurations and communications systems. XML files based on the XML schema defined in SCL are used primarily to exchange IED and communication system configuration data between an IED configuration tool and a system configuration tool from different vendors. Files created using SCL are also used to transfer the IEC configuration data from the IED configuration tool to IEDs in the switchyard.

b) IEC 61968 – basis for developing message payload standards for exchanging information between independent systems and applications concerned with distribution management and market operations. XML schemas based on the CIM are defined for each message payload defined in the IEC 61968-x series of standards.

c) IEC 61970 – basis for exchanging power system network models that are used in energy management systems and market systems. RDF schemas derived directly from the CIM UML models are used to define the information content for these exchanges as an XML document.

6.2.2 IEC 61850 SCL use of XML

The SCL is based on XML. The SCL syntax definition is described as an XML Schema. While UML is used to illustrate the inheritance structure of the main SCL elements as well as the containment relations between the SCL language elements, an XML schema definition is the normative specification for SCL. The UML diagram in Figure 27 provides an overview of how the SCL schema is structured.

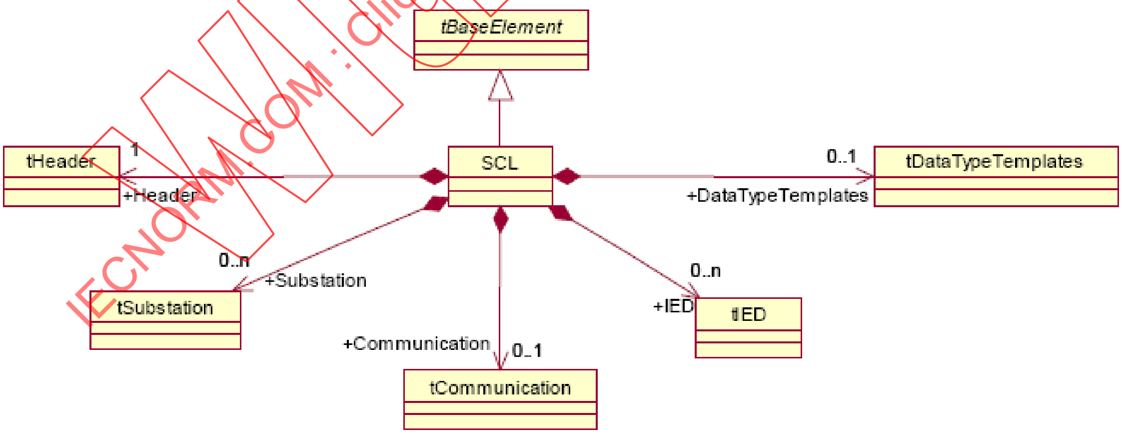


Figure 27 – Overview of SCL schema

As can be seen, the SCL schema is considered to be an SCL element derived from the more general BaseElement schema type (which provides for containment of private and text definitions) and functions as a container. The SCL element can then contain elements like substations, IEDs, communications, and data type templates as well as a header. All these elements have a type. The transformation rule from UML to XML Schema is the element name are the role name and their type is the UML class name (that is prefixed with “t”).

It is important to note that this and all other UML diagrams used in the IEC 61850-6 standard are in fact profiles that are used to show relations between SCL language elements, and not between the objects represented by the elements, which are shown in Figure 19. An attempt was made, however, to keep the XML element relations as close to the object relations as possible.

In CIM, UML diagrams are used to model physical class relationships, so that all aspects of the objects represented by these classes are captured in the class definitions and relations between classes. When represented in XML schemas, the elements and types are all derived directly from the UML class. But when profiles (like CPSM or IEC 61968 messages) are created and represented, only the relevant elements and types are derived directly from the UML class.

For example, the tSubstation element type shown above in Figure 27 is not the same as a Substation class in the CIM, because it has only the required elements needed for substation configuration. The tSubstation element type shown in the diagram refers to the Substation section of the SCL XML schema, where all the other elements, such as tVoltageLevel and tBay are defined. By contrast in the CIM UML, the Substation is defined in UML as a class with a definition, attributes, and associations to other classes, such as VoltageLevel. Although an XML schema for the CIM can then be automatically generated from the CIM UML for all or a portion of the CIM, XML schema is only one format for the CIM that can be derived from the UML. Additional formats include RDF schema, XMI, OWL, PTL, and MDL. Others can be added as technology evolves.

6.2.2.1.1 Substation section

The Substation section contains multiple Substation elements. Each of these elements corresponds to the objects in the SCL Substation model part. To describe whole networks, it is possible to have several substation sections, one for each substation served by the substation automation system (SAS). By means of logical nodes attached to the primary system elements, this section additionally defines the SA system functionality (for example, in an SSD file), or, in the case where the logical nodes are already allocated to IEDs (SCD file), the relation of IED functions to the power system.

UML diagrams are used to describe the detailed relations and constraints between the various elements comprising this section. However, all the various types of elements comprising this section are defined in XML, as described above.

6.2.2.1.2 IED section

The IED section describes the configuration of an IED: its access points, logical devices, and LNodes instantiated on it. It also defines the communication services offered and instantiated data and its default or configuration values. There is one IED section for each IED in the SAS. Each IED contains multiple IED elements. Each of these elements corresponds to the IED objects in the SCL IED model part. All the IEDs comprising a substation automation system for the substation specified in the substation section are contained in this section.

6.2.2.1.3 Communication section

The communication section describes the communication connection possibilities between LNodes by means of logical buses (i.e., subnetworks) and IED access points. The IED sections already describe which LDs and LNodes are reachable across a certain access point on an IED. The communication section describes how these access points are connected to common subnetworks.

6.2.2.1.4 Data type templates section

This section defines LNode types in terms of templates of the data for a LNode. These templates are built from data elements.

6.2.3 IEC 61968 and IEC 61970 XML based on the CIM

6.2.3.1 General

In the IEC 61968 and IEC 61970 series of standards use of XML, it is important to understand that behind all information exchanges defined in these standards is a single, common semantic model (or ontology), the Common Information Model (CIM), which is documented in UML. This ensures consistency across all currently defined exchanges as well as any future exchanges defined in XML or any other exchange format, such as Java or C++. It also permits XML to be autogenerated from the UML via software tools as described below.

6.2.3.2 IEC 61968 XML schemas for messaging

The message payloads that comprise the IEC 61968 standards for information exchange between distribution management systems are specified using W3C XML schema. IEC 61968-3 to -10 specify the information content of a set of message types that can be used to support the business functions defined in the IRM. Each part addresses a different part of the IRM.

UML use cases are used to identify the message types needed for each set of business functions. UML can also be used to show which CIM classes are used in each message payload.

The contents of the message payloads are based on a static information model defined in UML (the CIM) to ensure consistency of XML element names and data types. In other words, the XML element names and data types used in each message schema are derived directly from the definitions provided by the CIM UML rather than in the XML itself. The exception is for the elements used to define the message header. This is referred to as CIM/XML schema-based messaging.

6.2.3.3 IEC 61970 XML documents using RDF schema

The IEC 61970 standards use RDF/XML as a way to format the exchange of various types of information exchanges between applications within an EMS or between an EMS and other systems involved in utility generation and transmission operations. RDF/XML is just one of the ways used to create a serial format of instantiated models specified in UML. The content of the resulting XML documents is based on the CIM static information model defined in UML. Similar to the IEC 61968 series approach, the resulting XML element names and data types used in each XML document are derived directly from the definitions provided by the CIM UML rather than in the XML itself.

As mentioned above, CIM profiles are defined as separate standards to specify which parts of the CIM are mandatory and optional to satisfy the information exchange requirements of a particular use case. The most important profile currently in use is the Common Power System Model (CPSM) profile standard IEC 61970-452. The W3C RDF schema is used to specify the syntax of the resulting XML files. The use of RDF for exchanging power system models is specified in IEC 61970-501 and IEC 61970-552. The latter document describes how complete power system network models as well as incremental and partial updates to an existing base network model are to be formatted. This is referred to simply as CIM/XML file transfers.

6.2.4 Reconciling the use of XML

It is preferable that a single common information model (i.e., the CIM) be used to create the XML according to well-defined rules (i.e., XML Naming and Design Rules (NDR)) to ensure all XML schemas are consistent and use the same tags with the same name and meaning.

IEC 61968 and IEC 61970 are currently developing an XMI NDR document in order to share a common XML schema for all XML that is based on the CIM. It is recommended that the SCL in IEC 61850 and all other XML uses also be based on this XML NDR document wherever objects that are needed are already represented in the CIM. This should start with the hierarchical relationships for containers and inheritance in the CIM (i.e., ControlArea, Substation, VoltageLevel, Bay, Transformer, etc.). At some more detailed level in the hierarchy, it may then make sense to specialize one of the existing classes in the CIM to embrace existing IEC 61850 models, if the CIM does not adequately represent the device properties needed. However, even here the CIM can be extended to add needed specializations, as WG14 has done with that portion of the IEC 61968 standards that needed specialized device models or other specialized objects used in distribution applications.

If the SCL is intended to be an external view of configuration data to be archived and made available to other applications, then it would be most helpful if the XML schema used by the SCL were based on the same information model used by those applications.

7 Strategic use of reference architecture for harmonization and new work items

7.1 General

The reference architecture defined in this technical report provides a foundation for determining where harmonization is needed. The following are suggested as starting points.

7.2 Use of common object modelling language and rules

The Unified Modelling Language (UML) was selected by TC 57 as the language of choice for object modelling. UML provides notations for class diagrams, state diagrams, event sequence diagrams, and a host of other types of model notations that are independent of the underlying technology platform. One of the main advantages of this approach is that it facilitates harmonization between data models in different working groups by facilitating the acceptance of a common semantic model for all new standards in TC 57. Without a common language, it is difficult to maintain and leverage a common semantic model. For example, the use of UML for both the IEC 61968 and IEC 61970 series of standards ensures a transformer, for example, is represented in exactly the same way and with the same definitions whether the technology used for information exchange at system interfaces is based on XML schema, RDF schema, or even Java.

Another benefit is that there are several CASE tools available for UML to:

- prepare models and navigate them as well as to auto-generate the Word documents needed by the IEC to progress them as standards.
- generate XML documents for file or message payload creation whether using XML schema or RDF schema.
- generate WSDLs for Web service implementations based on the CIM.

UML has already been adopted by WG13, WG14, WG16 and more recently by WG10 where possible. It is recognized that other modelling languages are also in use and probably cannot be changed where standards are already published, but the goal should be to have a single, common modelling language.

7.3 Harmonization at model boundaries

The reference architecture provides a way to relate the various TC 57 standards. As stated earlier, from a harmonization point of view, the two most important places where having identical models really matters is:

a) at interfaces where software implementing one standard interface to software implementing another standard. An example is a SCADA server that acquires data using one model (e.g., IEC 60870-5-101, TASE.2 or IEC 61850) and then serves it to applications using another model (e.g., CIM);
b) where these object models purport to represent the same physical real-world object. Ideally it would seem to be desirable to have one set of models used consistently by all

interfaces. At a minimum, the attributes shared by both models should have consistent naming and data representation. Where object models are needed by EMS applications, there would be an advantage to having a control-centric view of the device models.

References [1] and [2] in the Bibliography provide more details on this use of the reference architecture.

7.4 Resolution of model differences

WG19 was created to resolve model differences where there is overlap and to develop a vision for TC 57 for the future. In this role it functions as a sort of architecture board for TC 57. The reference architecture provides a framework for relating all the various standards to each other. Members comprise model experts from each of the affected working groups. The objective is to determine where commonality and consistency are needed, and how it can be achieved. Some of the recommendations from this working group are included in this report.

The initial focus for WG19 was to achieve consistency between the IEC 61970/IEC 61968 CIM and the IEC 61850 object models. Where there are common classes or attributes, the goal should be to reuse existing classes in order to have consistent names and data representation to eliminate the need for name mappings and data transformation. This has, in fact, already been accomplished to some degree:

- many of the SCADA data elements (e.g., timestamps, quality codes) in the IEC 61970 CIM have been changed to conform to the representation in IEC 61850;
- the IEC 61970 topology has been adopted in the IEC 61850 SCL by creating a new class and associations in the CIM to tie in the IEC 61850 object models.

More work remains, but this has already eliminated some duplication through reuse of CIM classes by IEC 61850, and even more importantly, simplified the work of deploying both sets of standards in the field.

7.5 Basis of a future vision for TC 57

For the future, where important classes or attributes are needed for a new model, every attempt should be made to search for and reuse classes in existing models before deciding to create new models. Also, as technology evolves and new needs arise in the utility enterprise, growth and new directions in TC 57 need to be grounded on the existing body of work with a goal of ensuring compatibility between old and new.

7.6 Process of starting new work in TC 57

There is a need for guidelines on how to extend the work of TC 57. The guidelines should describe the process to follow for each new work item to ensure compatibility with existing work. This would permit an evaluation to be made of the impact on existing standards and on the CIM. In particular, this process would help to bridge the language gaps that may exist between those with an IT-orientation and view of the world (WG13/14) and those with a device-orientation and view of the world (WG10). Often times these different perspectives make it difficult to see how to apply existing standards developed by another working group, whereas a dialog at the time of formation of the NWIP may uncover areas where collaboration would be beneficial to the end user of the standards produced as well as save time spent in “reinventing the wheel.”

To address these issues, WG19 prepared a set of guidelines known as “TC 57 Good Working Practice" (GWP) (see [3] in the Bibliography). The GWP provides guidance on many other issues such as managing TC 57 working group meetings responsibilities and roles of the chairman, secretary, and WG conveners.

8 Future reference architecture for power system information exchange

8.1 General

This clause addresses the vision of a future reference architecture for power system information exchange and a long term strategy for TC 57 that reaches beyond simply resolving the differences in existing standards TC 57 standards.

8.2 Vision statement

The future reference architecture for power system information exchange is intended to provide a roadmap for future work in standards development within TC 57 that takes into consideration new utility industry needs, directions in new available technology to address these needs, and other relevant activites of a broader nature. It also seeks to establish a strategy for addressing these needs, such as IntelliGrid, the GridWise Architecture Council, etc. Whereas existing TC 57 standards have focused on the exchange of information, the future vision needs to focus on enabling the broader use of that information to support electric power industry business processes, such as information management, integration, presentation, decision making, etc.

A related goal of this vision to support business needs is to enable the concept of entering data once, having it associated with a common utility semantic model, and then being able to share it with all applications, systems, and other utilities and suppliers that need access to this data.

8.3 Fundamental architecture principles

The fundamental architectural principles espoused by TC 57 include:

a) Focus not on expanding the scope of the current TC 57 charter, but rather to improve what we do within that scope.

b) Guide the work of TC 57 to ensure the standards produced fit into a well-thought out framework rather than attempting to provide a prescriptive architecture for use by utilities in their enterprise.

c) Embrace both TC 57 standards (models, services, etc.) as well as other relevant IEC and IT industry standards. In particular, need to strive for seamless architecture which includes all TC 57 standards and to elaborate harmonization needs and approaches where seams are needed or cannot be avoided.

d) Embrace best practices for foundational aspects of architecture, such as security, network management, metadata management, etc., from ground up.

e) Consider interfaces to and the scope of other related TCs and industry consortiums via liaisons, technology transfer, and coordination activities to facilitate use and development of their standards (and vice-versa). Examples include IEC TC 88, TC 65 and TC 8; OPC; OMG ; UN/CEFACT and their Core Components Technical Specification (CCTS).

f) Build on best industry thinking regarding architectures, such as those envisioned by Intelligrid, CIGRE D2.24 EMS Architectures for the 21st Century, and the GridWise Architecture Council.

g) TC 57 standards should be model-driven and metadata-driven to ensure they share a common semantic model. The primary value of the CIM is to provide a semantic model behind all information exchanges between systems and applications rather than for direct use in interfaces.

h) A layer of insulation is needed to protect interfaces from changes in the CIM model.

i) Interfaces in real-world systems need to reflect specific user-driven business constraints in addition to embracing a standard semantic model.

j) Embrace layered architecture based on internationally accepted concepts, such as those specified by the UN/CEFACT Modelling Methodology (UMM) and Core Components Technical Specification (CCTS) to include:

   1) an abstract information model which is independent of any specific applications or business function. This layer should provide a way to combine information models from different sources in a seamless fashion to define utility semantic model;

   2) a business context layer to restrict the abstract information model to suit specific enterprise information requirements;

   3) business entities that can be related directly with business process objects.

k) TC 57 architecture should be independent of any particular IT framework, such as Service Oriented Architecture (SOA), but support implementation over all current and future IT platforms:

   1) a corollary is that standards should be developed and maintained at an appropriate level of abstraction to allow independence from technologies used to deploy the standards (i.e., using platform independent models (PIMs));

   2) where mappings to a specific technology are needed to ensure interoperability, such mappings should be developed as companion platform specific model (PSM) standards.

l) Include criteria for determining when a system complies with the reference architecture.

m) Architecture should explicitly identify interfaces where compliance to standards can be validated.

n) Include guidelines for when to apply which standards/technologies included within scope of TC 57.

o) Include strategies for integration with legacy systems.

p) Give priority to user awareness and usability.

8.4 Strategy

8.4.1 General

The basic strategy is to start with these foundational principles and drive to more explicit statements reflecting those principles. This section describes a strategy for development of standards that are based on the CIM and other abstract information models as the source of the semantics embodied in the TC 57 standards.

8.4.2 Information model

The information model comprises the CIM plus other project-based CIM extensions, models from other industries incorporated via semantic mapping, and enterprise corporate models to provide a path for a utility to create a custom information model that maximizes the use of the CIM while permitting the inclusion of information models from other sources. Having this layer separated from the business context layer would provide greater international acceptance since it would make the information model itself more independent of individual country or regional differences.

Within TC 57, the CIM should be utilized wherever possible across TC 57 as TC 57 is promoting a common modelling methodology using UML across all Working Groups. WG19 believes that it would be preferable if both CIM and SCL experts are involved in this process. As described in document 57/732/INF, IEC 61970 and IEC 61850 harmonization issues, the Maintenance Use Case illustrates the importance of seamless control centre to substation modelling; data entry should be performed once and then electronically propagated as needed.

All new TC 57 standards should use/extend the CIM as the common semantics for their configuration/engineering modelling, and IEC 61850 for SCADA-oriented IED and field device communications. Other existing standards would likely take a mapping approach.

In recognition of the fact the most CIM users need to customize their information model with private extensions (i.e., add new classes, attributes, and relationships) as well as using different names for some business entities, the TC 57 architecture needs to provide guidance in how to make these extensions, and then to submit them as proposals for changes to the CIM standard in some cases. Therefore, there needs to be a consistent process articulated for how to submit changes, track progress on acceptance, and access the revised standards.

8.4.3 Business context

The purpose of the business context is to tailor the information model to suit specific application needs or specific country and regional constraints by applying restrictions on the information model. Examples include tightening cardinality and defining specific features as mandatory, restricting string lengths, and changing data types from string to a utility's specific enumerated values. There may be certain contexts that are the subject of standards. However, the architecture should embrace both development of such standard contexts as well as provide a standard methodology for developing custom contexts.

There is a need for recognition of a separation or boundary between the information model and the business context layer that is used both in developing standard profiles or interfaces as well as by the end user in applying business contexts unique to an enterprise.

8.4.4 Interfaces

Interfaces in real-world systems will usually have specific requirements imposed by the end user utility that go beyond the standards. For example, each utility using TC 57 standards will almost always go beyond the CIM to add additional classes, attributes, and relationships as well as naming rules.

Naming and Design Rules (NDR) should be used by all TC 57 working groups developing interface standards as well as end users to design interfaces based on the CIM. NDR allows a user to define their own interfaces based on the CIM. NDR concepts apply to any type of interface independent of implementation approach – i.e., for XML schema, RDF schema, OWL, and others.

8.4.5 Service model

Services are defined to be independent of underlying technology implementations. Mappings to specific technologies are also the subject of standards to ensure interoperability.

Service models are designed to be independent of the payloads, and vice versa.

Services include IEC 61850 services and other industry-independent services such as Web services and Java messaging service. Mainstream information technologies should be evaluated prior to creating new equivalent approaches. Guidance is needed on when to use each of these services, since there is a fair amount of overlap in functionality.

8.4.6 Industry trends to consider

8.4.6.1 General

Following up on the principal of embracing best practices from other relevant organizations, the following in particular should be considered in the future TC 57 reference architecture.

8.4.6.2 Trends

a) Many standards organizations that deal with business vocabularies are ramping up their work on XSD naming and design rules, often dubbed as NDR. The work within TC 57 to develop NDRs for TC 57 standards should be an important component of future TC 57 standards.

b) UN/CEFACT core components technical specification has been adopted by other standards organizations (OAGi, OASIS UBL, etc.) as a foundation to define basic data types and business semantics. More importantly, the UN/CEFACT TMG BCSS group is working with OAGi to develop the UML Profile (UMP) for rendering the CCTS in UML. There are also groups within UN/CEFACT working to develop actual core component library of business objects, NDR, standards for message assembly, etc.

c) There are other standards such as the UMM of UN/CEFACT, the SOA related standards being developed at OASIS, etc. that will have an impact on the use of business vocabulary standards such as CIM.

d) Development of Ontology Definition Metamodel (ODM) from OMG, which could provide a bridge from UML to OWL, could have an impact on how CIM is to be profiled.

8.4.6.3 Industry consortiums

8.4.6.3.1 ISO/RTO council (IRC)

Created in 2003, the IRC serves as a coordination vehicle formed "for the purpose of promoting communication, providing mutual assistance, developing effective processes and tools, and otherwise coordinating in areas of mutual consent." The IRC is made up of the RTO/ISO chief executives.

8.4.6.3.2 ISO/RTO Information Technology Committee (ITC)

Formed "for the purpose of promoting communication, the ITC provides mutual assistance and coordinating in areas of mutual consent with regard to the development of information technology practices affecting ISO/RTO operations in electric industry." The ITC acts to further the goals and purposes of the IRC. It also facilitates interactions among the ISOs/RTOs and provides a means to collaborate and identify areas of technology standardization for the ISO/RTO entities. As appropriate, the ITC submits recommendations to the IRC for review and approval. In addition, the ITC coordinates interaction with the ISO/RTO Standards Review Committee (SRC), an entity that manages standardization activities between the IRC, NERC, and NAESB.

8.4.6.3.3 ITC's Enterprise Architecture Standardization (EAS) project

The EAS was formed to create a technical reference architecture and supporting standards that will facilitate ISO/RTO cost reductions by increasing competition among software vendors and enable improvements in operational efficiency. The goals of the EAS project are to:

- create a technical reference architecture for the ISO/RTO community;
- identify the core set of ISO/RTO functions (architecture framework);
- define interoperability standards for selected applications within the energy management and market operations sub-systems;
- define an extendable standard to enable business process monitoring and logging; and
- provide a template that can be used in RFP's and as part of vendor contracts

8.4.6.3.4 EAS and CIGRE D2 WG24 (formerly VLPGO WG2)

It is important to clearly distinguish between the activities of Working Group 2 of the Very Large Power Grid Operators (VLPGO), known as EMS Architectures of the 21st Century (now CIGRE D2 WG24), and the enterprise architecture standardization project. While these activities share some similar high-level goals, they are largely focused in different (and complementary) areas and are taking different approaches.

The EAS project is addressing the simplification of the integration of system components from multiple vendors; the group plans to submit its work to the IEC for incorporation into the appropriate international standards. This will incorporate other IEC standards (such as CIM) as appropriate and focuses on the information exchange between individual systems components.

Rather than developing new standards, the VLPGO work is directed toward producing a universal, reusable set of technical (not functional) specifications for the individual system components, to be made publicly available for incorporation into solicitations for such software. While it refers to various standards, it will not create a new standard: rather, it is focused on the publication of a common reference document that can form the basis for the evaluation of the technical characteristics for such system components.

The VLPGO activity is focused on the design, performance, and other characteristics of the software components that would be integrated using the work of the EAS project. If both projects are successful, more robust, scalable, and maintainable components will be available for integration using standardized messages and interactions. The VLPGO would include the EAS work (or the standards that result from it) in its specifications, while software that conforms to the VLPGO specifications would be more easily adaptable to incorporate the EAS-developed standard messages.

8.4.7 User awareness and usability

a) Leverage open communications between CIMug, IEC TC 57 and the working groups to develop a set of consistent and concise marketing materials to clearly define what CIM and related standards are about, what values they bring, what areas they can be used, and how they can be used.

b) Define the process for ownership, version management, model inputs, model extension, and model issue resolutions for CIM. This will build stronger credibility of the standards and help preserve the user's investments in CIM based implementations.

c) Enforce similar communications and better documentation for related standards from CIM.

d) Create more detailed and enforceable specifications to ensure standards compliance can be tested consistently and independently, which will allow tool vendors to provide necessary tools for validation and compliance testing.

8.4.8 CIM modelling technology and language strategy

8.4.8.1 General

Currently the CIM is modelled in UML, which provides a GUI in the form of class diagrams, activity/sequence diagrams, use cases, and other graphical forms. UML tools permit model maintenance to be accomplished via this GUI.

UML is also a good language for expressing and viewing semantic models, which is an important capability for supporting the end user needs to implement and manage business processes, business entities and relationships in a platform independent way. It can also be used with software tools to automatically generate standard XML documents for exchanging models, including XMI and RDFS-formatted XML. Proprietary format versions are also available, such as .mdl and .cat that are supported by IBM Rational tools.

OWL and RDF excel in ontological modelling, where there is a need to mathematically express relationships between entities more precisely, but is not as well suited for supporting a common semantic model for use in defining and deriving specific message payloads and file contents. For instance, class diagrams and other graphic representations provided by UML are not currently defined for OWL and RDFS – editing is usually done directly in XML dealing with XML tags with XML editing tools. However, the power of precisely defining relationships could be an important future capability that should be utilized by TC 57 in an appropriate way.

Currently TC 57 supports RDF schema and XML schema (referred to as CIM/RDF and CIM/XSD, respectively) to provide serialization formats for encoding the UML model for information exchange. Given there are legitimate use cases for each, TC 57 should support these encoding standards and others as the need arises. In addition, consideration should be given to adding OWL to provide more in depth support for business intelligence, data analysis, and semantic integration needs. The following subsections recommend a strategy to be followed for each.

8.4.8.2 CIM/UML – Modelling

a) CIM, the UML model itself, should remain in the form of UML.

b) CIM needs have a UML Profile (UMP) to ensure that the evolution and extension of the model is consistent, and the resulting model is semantically expressive, controlled and unambiguous. This UMP is different than the NERC profile concept which acts on the model itself. This profile is a way to specify a subset of UML constructs to use when developing the CIM, therefore allowing for a much more consistent model representation. A potential candidate for such a UMP could come from UN/CEFACT TMG. Alternatively, IEC TC 57 could develop its own profile as long as it meets a set of requirements agreed upon by the CIMug. The goal should be consistency and precise semantic expression so that forward engineering to other formats becomes predictable with a defined set of rules.

c) The working groups should consider migrating the CIM to UML 2.0 only when the UML 2.0 is widely supported by a large number of tool vendors in a consistent fashion.

d) There is a need to enforce proper versioning, better documentation, a clear process for model inputs and issues resolution, and a model extension mechanism to ensure long term value.

e) CIM data types need to be updated to be more consistent and in line with other standards such as those from UN/CEFACT and ISO.

f) Review modelling constructs including associations, inheritance hierarchies, etc. to ensure best practices from a semantic modelling perspective.

g) The UML tools used by TC 57 need to meet the following requirements:

   1) support the auto-generation of the necessary IEC MS Word documents, such as the IEC 61970-301 CIM base IS;

   2) support for the full range of UML diagrams, such as the class diagrams, use cases, activity/sequence diagrams, and others, not only for viewing the information model but for maintaining directly via the GUI;

   3) support robust import/export capabilities in XMI for model exchange.

8.4.8.3 CIM implementation technologies

8.4.8.3.1 CIM/RDF and CIM/OWL

a) RDF was chosen as a rendering technology for power system model exchange at the time when XSD was still under development. It was the right technology for the power system model due to the complexity and large data volume of a typical control centre network model. It continues to be an appropriate technology for this purpose. However, there are limitations which continue to present challenges for interoperability using this standard. Some of the key issues are:

   1) data types in RDF are not specific and powerful enough to ensure specific data representation within an instance of RDF/XML; however, OWL improves on this by providing support for the XML schema data types. Still, this does not provide support for all the data types in the CIM;

   2) there are extensions to the standard RDFS, such as "cims" as defined in IEC 61970-501, that prevent it from being fully validated by a generic RDF tool; the current open source CIM validator tool designed for these extensions can validate these but does not catch all potential errors for interoperability purposes;

3) there are conventions built into the specification that may result in slightly different interpretations, which creates interoperability issues;

4) Web services are only supported in XSD; neither RDF nor OWL are supported in the Web services standards. This limits the usefulness of RDF and OWL for use in an enterprise integration framework that is typically based on Web services and service oriented architectures;

5) RDF and OWL do not have the same level of tool support for graphics editing, validation, transformation, data base generation and processing, as XSD. Most tools are open source, whereas XSD has many fully supported tools at reasonable prices.

b) There are several options regarding the current CIM/RDF standard:

1) maintain it along side a new standard based on CIM/OWL in recognition of the existing field implementations currently in use;

2) move CIM/RDF to CIM/OWL so that it can provide better semantic control and data type definitions. Since OWL standard builds on top of RDF, it is a natural evolution for CIM/RDF;

3) move CIM/RDF to CIM/XSD so that the structure and data type of its instance data is much more precise and defined. As long as the specific XSD structure provides a good referencing model so that the resulting XSD and XML document is not just hierarchical in nature, it is a technically viable alternative that takes advantage of XSD technology.

c) CIM/OWL in general will have many other uses cases. Therefore when considering CIM/RDF and CIM/OWL, one shall consider all possible use cases before settling on a technical solution. This could complicate the development of CIM/OWL for power model exchange. Use cases should be separated and perhaps the CIM/OWL for power model exchange could be a subset of CIM/OWL in general. The CIM/OWL could open up more opportunities for utilities to leverage CIM as a common information model. Its development will pose new and different requirements are to how CIM should evolve as well.

8.4.8.3.2 CIM/XSD

a) A Naming and Design Rules (NDR) document describes a standard way to create XML Schema from a message payload definition in UML. As creating XML Schema for an information model can be made in many different ways, the NDR is essential to ensuring interoperability is achieved when XSD defined message payloads are exchanged. The message payload itself is XML.

b) WG14 standards should also address rules for extension, restriction, and compliance. Whether that is part of the NDR is not significant, but these topics need to be covered so that specifications are developed to enable tool vendors to develop a suite of capabilities for implementation and independent compliance testing.

c) TC 57 should develop methodologies for end users to create their own interfaces (see earlier discussion). The NDR based on XSD is an important enabler for this.

d) XSD is the prevailing technology to express data types for data exchange, especially for system integration. XSD will be major technology to be used with a CIM-based semantic model. With Web services and the robust tool support available, XSD offers many advantages to expressing an implementation model while maintaining semantic links back to the CIM.

e) All information exchanges except for power system model exchanges should be based on XSD. This also offers the end user utilities the broadest choice for tool support.

8.4.8.4 Transformation between the different CIM formats

Rules for converting from CIM/UML to CIM/RDF, CIM/OWL, and CIM/XSD, as well as rules for transformation between the XML-based formats needs be clearly documented. The CIM/UML profile needs to provide for a set of default rules to be defined so that the forward engineering from CIM/UML as a Platform Independent Model (PIM) to a Platform Specific Model (PSM) is predictable. A proper version management framework must be in place for both the model and its derivative formats such that there is a clear relationship between a version of CIM and a version of RDF or XSD or OWL. Vendors and users could implement a version of PSMs while allowing the CIM to continue to evolve.

8.5 Vision for the next generation of CIM and related standards

8.5.1 General

The following diagram depicts a vision for the next generation of CIM and its related standards (see Figure 28).

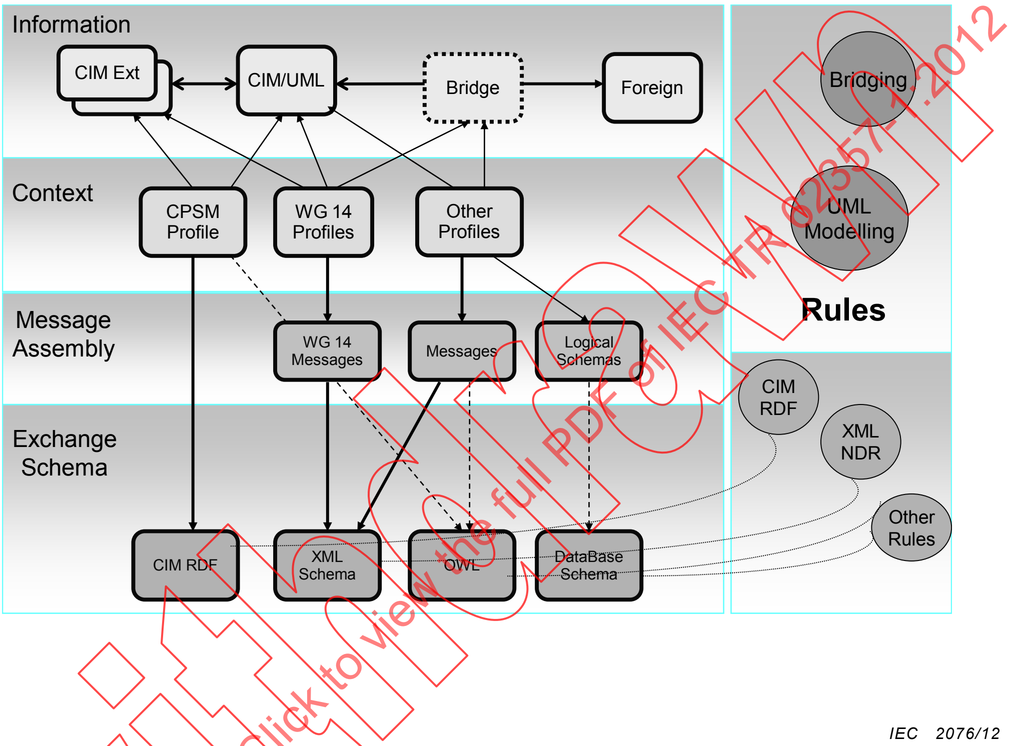


Figure 28 – Vision for next generation CIM and related standards

As shown, the future vision embraces some new concepts in a three layer architecture not currently incorporated into the CIM and related standards architecture:

a) **Information layer** – This layer includes the CIM/UML but provides for the reality that there are other sources of information as well as the CIM that need to be taken into consideration when creating CIM-based information exchanges or repositories. These different models/standards and ways of bridging them together comprise the Information layer.

b) **Contextual layer** – This layer formally recognizes that only a subset of the models in the information layer is needed for any particular interface or message definition. The profiles contained in the CIS standards defined in this layer:

   1) define a subset of the models in the Information layer needed for a particular business purpose as well as constraining those model elements to address specific business needs, and

   2) provide a way to incorporate model elements from the different information sources in the information layer in addition to the CIM.

c) **Message assembly layer** – This layer defines the structure of a message that carries the profile information and what kind of operation should be performed with message payload.

d) **Exchange schema layer** – This layer provides for specific schemas for the profiles defined in the contextual layer.

An important feature of this layered architecture is that for the first time there are clear boundaries defined between the information models in the information layer and the business context in the contextual layer. Without this distinction the current CIM has suffered from an "identity crisis" trying to be an information model that also incorporates business context in a non-uniform way. The tension is created by trying to have the CIM be both general and generic enough to be used in any application while being as specific and constrained as possible to include descriptions more useful to an application in a specific business context. It is not possible to satisfy both objectives in an information model, although attempts have been made in some cases by incorporating poor modelling practices, such as having an attribute mean one thing if the context is A, but something else if the context is B, where the context is indicated by the value of a flag attribute.

Another important concept embodied in the layer architecture is the notion that layers 1-3 represent a Platform Independent Model (PIM) of an information exchange or interface, thus creating a clear boundary between the PIM and the implementation layer, where there may be multiple technology implementations of that profile. The standards in the exchange schema layer then are the Platform Specific Models (PSMs). So it can be seen that the TC 57 layered architecture embraces the OMG Model Driven Architecture (MDA) concepts of PIMs and PSMs.

For example, the CPSM profile has been standardized in the IEC 61970-452 CIS and is one layer of the Platform Independent Model (PIM). The other PIM layers are the information and message assembly layers. One PSM is the RDF/XML schema implementation of this profile which has been standardized as IEC 61970-501 and IEC 61970-552.

In Figure 28, the common profile object as shown can be implemented in several technologies, each with its own schema, including RDF/XML schema, XML schema, and a relational database schema. This implies that a profile shall be specified at a high enough level of abstraction to allow it to be implemented in various, different technologies.

Each layer is described in more detail in the following subsections.

8.5.2 Information layer

8.5.2.1 General

The important architectural features enabled by the layer are described in the following subsections.

8.5.2.2 Multiple sources of information and metadata

In the current CIM standards, the CIM in UML is the only recognized source of metadata for defining XML messages or files. Although it is possible to extend the CIM with private extensions, and in fact is expected, the goal has been to eventually incorporate those extensions into a later revision of the CIM UML model if the extensions prove to be generally accepted. In any case, the standard CIM UML model with private extensions is the only recognized source for creating a semantic model as the basis for a model-driven architecture.

The information layer in the future reference architecture vision, on the other hand, embraces the notion that there are other sources of metadata that a utility enterprise needs to include in its semantic model without trying to make it a part of the CIM standard. Conceptually, some kind of a bridge, as shown in Figure 28, is needed to create links to these other metadata, similar to the way associations between classes in UML link different parts of the UML model. Whether or not this bridge becomes the subject of future standards is unclear.

These other information models denoted as foreign sources in the diagram could include models from other standards bodies or industry consortiums, such as GML or MultiSpeak. Other possible sources include other TC 57 standards, such as the IEC 61850 substation automation standards. In fact, this is a very powerful way of achieving harmonization of the

IEC 61968/IEC 61970 CIM-based standards with the IEC 61850 standards. Rather than trying to change these standards to be the same in the information layer where there is overlap, the differences can be resolved in the contextual layer by making it possible to include attributes from both sets of standards in a profile, as elaborated more completely in the contextual layer section below.

8.5.2.3 Abstract general purpose information models

Recognizing the information layer as separate and distinct from the contextual layer has other benefits as well. The CIM can now be thought of as purely an abstract information model that is general enough to be used in a variety of business contexts. So for example, when defining an attribute describing a generator control mode, the CIM can simply provide a string data type. In the contextual layer, the string can be replaced with an enumeration that is appropriate for the country where the CIM is being used. This has the advantage of making the generator control mode in the CIM reusable in many different contexts as well as providing a standard way to constrain the permissible values in a particular business context. This has the benefit of providing for the possibility of validity checking of the instance data to ensure only one of the permitted values is used in an information exchange implementation that includes this attribute.

Another problem this addresses is caused by the use of inheritance in the CIM model. Attributes that are inherited from a parent class have only a general purpose name. In the contextual layer the name can be changed to include some reference to the specialized class where it is being used, so that in a particular message payload or file in the implementation layer, it will be clear what object the attribute applies to.

8.5.3 Contextual layer

8.5.3.1 General

The contextual layer provides for the definition of profiles to define a subset of the information models contained in the information layer that are needed in a specific business context. Business context or constraints are also applied in this layer. This notion embraces many of the concepts described in the UN/CEFACT Core Components Technical Specification (CCTS). Profiles may also incorporate the identification of services to be used for information exchange.

8.5.3.2 Profile as a subset of the CIM

The notion of profiles is not new. For example, the CPSM profile shown in Figure 28 is currently used to define the subset of classes and attributes that are needed to exchange power system models between RTO/ISOs for maintaining network models of neighboring regions. So the context is transmission grid reliability.

8.5.3.3 Profiles and multiple information sources

In the new vision shown in the diagram, the concept of a profile has been substantially expanded, so that a profile can apply a business context to a subset of metadata from multiple information models via the bridge concept. As shown in Figure 28, the profile object in the contextual layer incorporates metadata from the CIM, private extensions to the CIM, and via the bridge, other information models as well. The key is maintain traceability back to the source to facilitate long term management and maintenance of the profiles as new versions of the information model standards are published.

8.5.4 Message assembly layer

This layer defines the structure of a message and what kind of operation should be performed on the payload of the message in a given business context. It should specify:

- the message header, including what kind of action is to be performed on the message payload;

- the way that context elements could be grouped to provide some structure for the payload data;
- sequencing of complex elements in the payload;
- where user-defined extensions are allowed.

8.5.5 Exchange schema layer

This layer includes standards for concrete implementations of information exchanges and interfaces to the level of specificity required for achieving interoperability between products/applications/systems from different suppliers. These standards also form the basis for compliance testing to validate system interfaces. As such, they shall be technology specific.

Since these PSM standards are based on the PIMs in the upper layers, it is important that they include clear rules for how they are derived from the PIMs. For example, there are several XML schema structures that can be generated from a single profile definition – each one correct but different, and not interoperable. So it is important that the PSM standards also include rules for creating the PSM from the PIM. For example, as shown in Figure 28, three different PSMs may be derived from the common profile. Each has a different set of rules. For generating CIM/XML files based on RDF schema, rules are needed to define the subset of and extensions to the RDF schema elements as defined by W3C to be used. These are incorporated in IEC 61970-552 so that there is one accepted way of using RDF schema to create the file metadata. Similarly, for the XML schemas defined by WG14 for message exchange between distribution systems, a set of rules is needed to define how the XML schemas are to be derived from the common profile. These are defined in the NDR technical report. As a last example, a project may define a new technology mapping to a relational database with its own set of rules outside the standards arena.

8.5.6 Concrete messages and the four layer architecture

Figure 29 illustrates how this four layered architecture all fits together to define a concrete message payload for information exchange based on the CIM. Note that this illustration shows only the CIM as a source of the information metadata, but the concepts apply regardless of the information source.

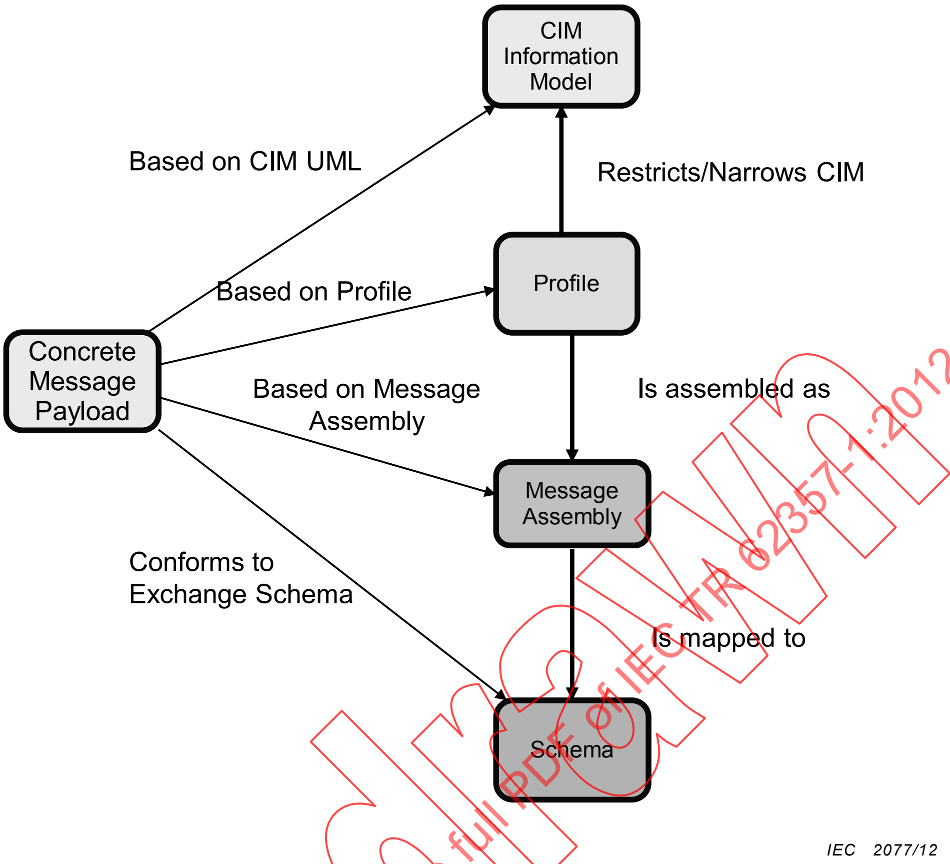


Figure 29 – Role of architecture layers in message payload definition

The CIM information model is shown as the source of the information metadata used in the message payload. The profile defines the subset of the CIM that is to be used in the message payload, thus restricting the CIM to only those parts needed for the particular business process and information exchange in view. It also adds business context to that subset of the CIM to take the CIM from a general purpose application-independent information model to a semantic model that better represents the specific business context and is thus application-dependent. However, at this point the profile is still abstract (i.e., technology neutral). The message assembly layer then defines the specific structure of the message payload according to specific rules. The message XML schema is then generated from the message assembly, profile and CIM following the standard rules for mapping to XML schema, when the desired concrete message payload is to be an XML document.

As may be seen in the diagram, the concrete message payload needs to conform to only the message payload standard defined in the XML schema for compliance testing, although traceability should be maintained back to:

a) the CIM/UML for the information metadata,

b) the profile for the business context restrictions, and

c) the message assembly for the structure of the message.

With this view of conformance, compliance testing can be better understood. This is an area that is currently not well defined from an architectural perspective, i.e., how to test for compliance with CIM standards, or even more basic, what is the meaning of compliance with CIM standards.

Figure 29 illustrates where compliance is necessary to achieve interoperability and claim “compliance with the CIM.”

8.5.7 Next steps

To implement this vision, a strategy needs to be developed to put the new architecture in place. That will require a number of actions:

a) review of existing standard specifications to determine what changes are needed to realize the vision;
b) preparation of missing specifications so the CIM and its related standards can work as a complete and interoperable set. This is an evolution from the semantics point of view, but there needs to be a major overhaul from the syntactic point of view to ensure usability and consistency among various CIM related standards;
c) more collaboration by TC 57 with other similar standards bodies;
d) acceleration of the pace of CIM-related standards development.

This new architecture described here is intended to provide a vision of where TC 57 standards should be heading. However, the development of the strategy is beyond the scope of this technical report.

8.6 IEC 61850 standards strategy

8.6.1 General

The long range vision for the IEC 61850 series is to extend as much as possible the use of IEC 61850 at the field level, as one of the Smart Grid pillars, as well as supporting communication between the field and remote control centres. In addition, realizing the concept of a seamless profile as articulated in the next subsection continues to be a goal.

8.6.2 Seamless profile concept

For historical reasons the first protocols specified by TC 57 were the telecontrol protocols of the IEC 60870-5 series based on remote terminal units (RTUs) in substations for the communication between substations and control centres. Such RTUs are connected to the equipment in substations by a parallel wired interface. This RTU technology is still in place but will increasingly be replaced by computerized substation systems with distributed Intelligent Electronically Devices (IED's) using local communication networks. With the standard series IEC 61850 the communication in substations is described by virtual (not standardized) devices consisting of standardized logical nodes with functional grouping of objects using abstract communication services mapped to "real" protocols.

In such computerized substation systems it is still possible to connect to control centres with RTU-based telecontrol protocols, as e.g. with a protocol of the IEC 60870-5 series using a virtual RTU gateway for protocol conversion (objects and services). This also includes the use of IEC 60870-5-104 over IP networks. But as an option, the client-server based protocol part specified by the IEC 61850 series for the LAN-environment can be used as well as telecontrol protocols in the WAN eliminating the need for such gateways. This solution is called a **seamless communication profile** allowing seamless communication from the primary process equipment and IEDs in substations up to the control centre and any other application that needs to exchange information with IEDs, e.g., engineering station and condition monitoring station. It is important to note that seamless in this sense implies the existence an abstract communication layer (abstract nodes, objects and services) similar to the PIM layer described earlier. Seams will still exist on the real communication layer (i.e., PSM layer) if different protocols are used for substation communication and telecontrol. Even if the same protocols are used, seams may still exist with substation proxies. Nevertheless the seamless abstract communication layer allows a more efficient data management of the overall control systems eliminating unnecessary protocol conversions and has the potential to reduce cost of implementation and over the live cycle of systems. This is analogous to having a common semantic model in the IT world.

A typical system implementing the seamless profile would either directly interconnect the IEDs over the substation network with a router to the control centre or via a central substation host acting as a proxy. Typically such a substation host has a process data base and can perform application services needed by the control centre such as routing, filtering, general interrogation.

Before any communication between control centre and substation can take place, the process data models and system configurations of both sites shall be synchronized by the exchange of configuration data common to both substation and control centre. The substation configuration data is defined with the substation configuration language (SCL) and is a subset of the total set of substation configuration data as well as including as device specific data the description of related power resources (topology and primary equipment), the mapping to real protocols, and communication network configurations. Device specific object names can be associated with power resources names and alias names to enable the association of device objects to instances of power resources governed by the Common Information Model (CIM) used in control centres. Note that work is in progress at TC 57 to harmonize the SCL with CIM as far as possible to support the seamless profile and other profiles with minimum conversion and mapping.

9 Conclusion

A new reference model for TC 57 is proposed to provide a framework for future standards development and for resolution of differences in object models within standards currently under development. It is hoped that by providing an overview and more concrete framework for standards development, more insight will be available to all contributors for the harmonization of TC 57 object models. This will in turn lead to greater acceptance of TC 57 standards in new product development and fewer incompatibilities requiring custom adapters and gateways for implementing new computer systems and network for power system control.

Furthermore, now that the TC 57 standards, especially the IEC 61968/IEC 61970 CIM and IEC 61850 standards, have been recognized as pillars for realization of the Smart Grid objectives of interoperability and device management, it is imperative that a correct understanding of these standards and their application be made available to the key stakeholders and all other interested parties involved in implementing the Smart Grid.

The reference architecture for power system information exchange is constantly evolving as new standards are developed and existing standards are modified. As a result, this report should be treated as a living document, wherein future editions of this technical report will be needed to reflect the latest new developments as well the results of harmonization efforts within TC 57.

10 Acknowledgements

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Annex A
(informative)

Object models and mappings within TC 57

A.1 TC 57 object models

Table A.1 below shows some of the common elements of a power system that are modelled in the different standards produced by TC 57. While this list is not complete, it does illustrate the overlap between the different standards.

Table A.1 – TC 57 object models

Objects modelled	IEC 61970/ IEC 61968 CIM	IEC 61850 ACSI	IEC 60870- 6 TASE.2	IEC 60870-5 - 101/104
Measurand	x	x	x	x
Status	x	x	x	x
SCADA point	x	x	x	x
Control point	x	x	x	x
Substation	x	SCL/Id		
Switch	x	SCL/Id		
Transformer	x	SCL/Id		
Connectivity	x	SCL		
Schedule	x		x	
Information buffer		x	x	
Generator	x	SCL/Id		
Generator outage report			x	
Contract	x			

A.2 IEC 61850 models and mappings

IEC 61850-7-2 specifies several models and abstract services, known as the ACSI, to facilitate horizontal and vertical information exchange on and between station level, bay level and process level. Since IEC 61850-7-2 is abstract (e.g., no concrete communication packets defined), other parts of IEC 61850 are used to map the abstract services and models into concrete communication protocols and packets.

IEC 61968 specifies a set of verbs that can be used as a short hand way of describing services. IEC 61968 verbs are completely abstract since IEC 61968 does not describe specific technologies. IEC 61970-402:2008 Annex C contains a mapping of IEC 61968 verbs to IEC 61970 services.

Table A.2 below shows which parts of IEC 61850 currently contain the mappings of the IEC 61850 and TASE.2 abstract services as well as IEC 61968 verbs (see 3.5.2 for issues involving a TASE.2 aggregator).

Table A.2 – Service capabilities of IEC 61850, TASE.2, and the verbs of IEC 61968

IEC 61850-7-2 model	IEC 61850-7-2 currently mapped in:	IEC 61850 interfaces	Communication style	TASE.2 equivalent service available
Association	IEC 61850-8-1	1,3,6,7,9	client/server	yes
Server	IEC 61850-8-1	1,3,6,7,9	client/server	yes
Logical device	IEC 61850-8-1	1,3,6,7,9	client/server	no
Logical node	IEC 61850-8-1	1,3,6,7,9	client/server	no
Data	IEC 61850-8-1	1,3,6,7,9	client/server	yes [a]
DataSets	IEC 61850-8-1	1,3,4,5,6,7,9	client/server	yes
Reporting				
Unbuffered	IEC 61850-8-1	1,3,6,7,9	client/server	yes
Buffered	IEC 61850-8-1	1,3,6,7,9	client/server	yes [b]
Substitution	IEC 61850-8-1	1,3,6,7,9	client/server	no
Logging	IEC 61850-8-1	1,3,6,7,9	client/server	no
Control				
Direct operation	IEC 61850-8-1	1,3,6,7,9	client/server	yes
Select before operate	IEC 61850-8-1	1,3,6,7,9	client/server	yes
Enhanced control	IEC 61850-8-1	1,3,6,7,9	client/server	no
Generic substation events	IEC 61850-8-1	4,5, 8 (2)	publish/subscribe restricted to within substation LAN only due to timing constraints.	no
Sampled measured values	IEC 61850-9-1 IEC 61850-9-2	4,5 (8, 2)	stream based. Restricted to substation LAN only.	no
File transfer	IEC 61850-8-1	1,3,6,7,9	client/server	no
Configuration language	IEC 61850-6 IEC 61850-8-1	1,3,6,7,9	client/server	no

[a] Some of the data types defined in IEC 61850 series are not transferable by TASE.2 (e.g. Unicode data).

[b] While TASE.2 does permit periodic reporting of multiple data changes, it does not buffer data for retransmission after a communication link failure and restoration.

Annex B
(informative)

Comparison of circuit-breaker models within TC 57

B.1 General

This annex compares the different models of a circuit breaker within TC 57.

B.2 IEC 61970/IEC 61968 circuit-breaker model in the CIM

B.2.1 General

The model of a circuit-breaker in the CIM is quite complex, due to the fact that the CIM models all aspects of a circuit-breaker – both its role as an electrical device in a network and its role as an asset owned by a utility. All aspects are modelled in UML in the CIM as one, contiguous electronic model, even though the classes that comprise the CIM model may reside in different packages and be part of more than one series of standards of IEC standards. The result is a normalized model that is independent of any particular application's use of that model.

B.2.2 Role as network electrical device

The CIM provides a model of a circuit-breaker as an electrical device in a network. Figure B.1 shows the circuit breaker modelled as the breaker class, which is a specialization of a more generic switch. In fact, the total set of attributes modelled for a circuit breaker is a composite of all the attributes inherited from its several parent classes as shown in Figure B.1 as follows: Switch, ConductingEquipment, Equipment, and PowerSystemResource. (Like the breaker, most all classes in the CIM that can be instantiated inherit naming attributes from the Naming class). The breaker is contained by an EquipmentContainer. The breaker's electrical connectivity to other devices to form a topological network is modelled via a terminal and ConnectivityNode on each side of the breaker. The state of a breaker is an attribute of DiscreteValue (a specialization of MeasurementValue) associated with the breaker via the terminal. Any other measurements associated with a breaker are also modelled as MeasurementValues associated with the appropriate terminal. Measurements typically also are associated to an EquipmentContainer instance as well. The packages that each class belongs to are show in parenthesis for each class.

This electrical model is part of the IEC 61970-301 CIM base standard. It is modelled in UML as part of the overall CIM model. Since a circuit breaker is one device in a complete power system model, its relationships with other devices is an essential part of the model.

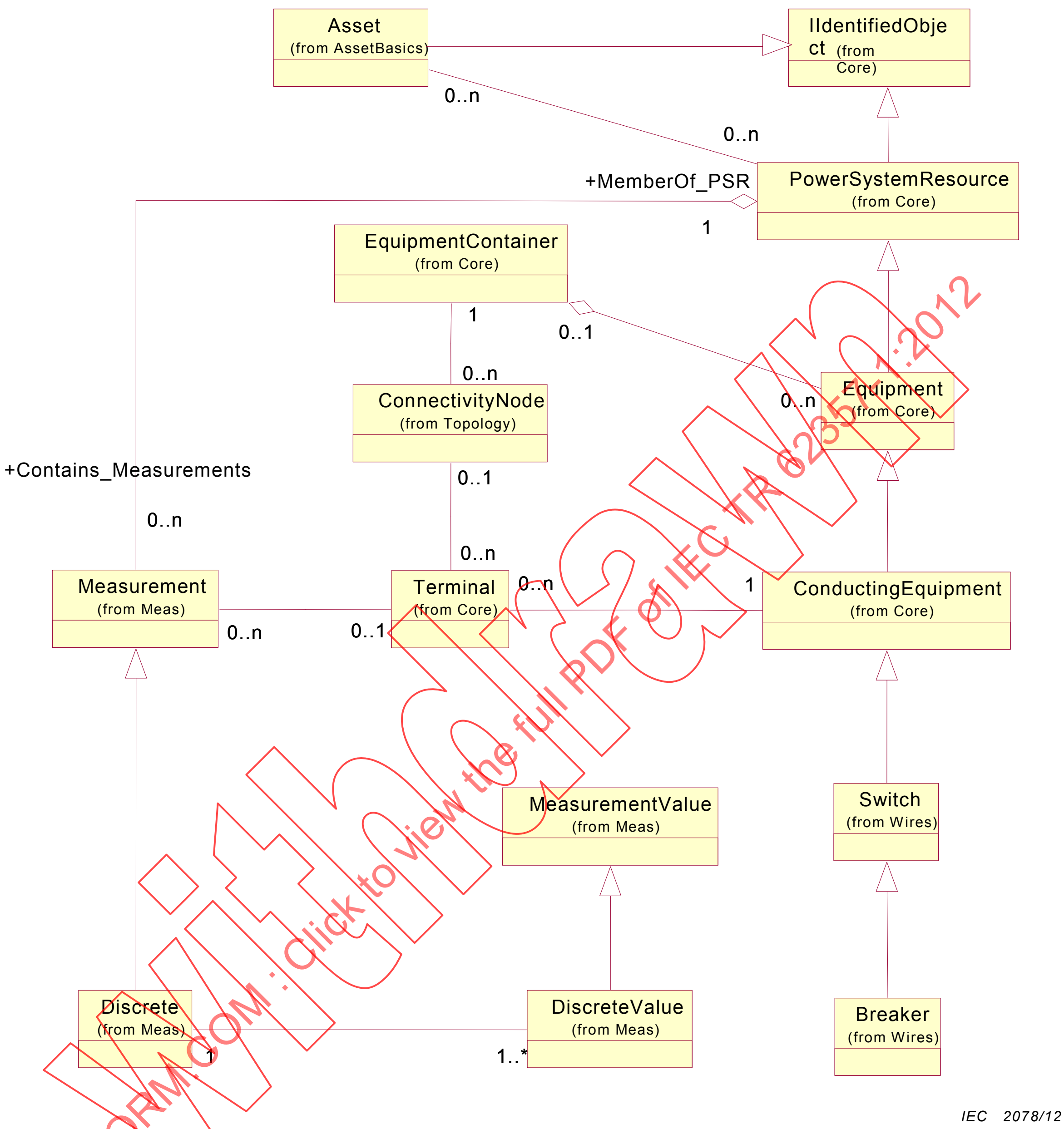

Figure B.1 – IEC 61970 CIM model for a circuit-breaker

B.2.3 A simple network example with a circuit-breaker

To illustrate how the circuit breaker object would appear in an electrical network, a simple example is given in Figure B.2. The example shows a transmission line with a T-junction spanning two substations and a substation having two voltage levels with a transformer between them. The transmission line consists of two different cables. One of the voltage levels is shown with a busbar section having a single busbar and two very simple switchgear bays connecting to the busbar. The circuit breakers are shown as dark square boxes – one between the busbar section and the high side transformer windings of transformer T1, and one between a disconnect switch (shaded diamond) and the AC line segment Cable 1.