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TECHNICAL SPECIFICATION

Microgrids –
Part 3-4: Technical requirements – Microgrid monitoring and control systems

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MICROGRIDS

**Part 3-4: Technical requirements –
Microgrid monitoring and control systems**

FOREWORD

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IEC TS 62898-3-4 has been prepared by subcommittee 8B: Decentralized electrical energy systems, of IEC technical committee TC 8: System aspects of electrical energy supply. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
8B/154/DTS	8B/178/RVDTS

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

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62898 series, published under the general title *Microgrids*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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- withdrawn,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

INTRODUCTION

Microgrids can serve different purposes depending on the primary objectives of their applications. They are usually seen as means to manage reliability of supply and local optimization of energy supply by controlling distributed energy resources (DER). Microgrids also present a way to provide electricity supply in remote areas and to use clean and renewable energy as a systemic approach for rural electrification.

At present, there are many types of microgrid, often composed of distributed generation, battery energy storage, load, and other equipment. To achieve the effective integration and cooperative operation of the above equipment, a set of computer systems is often required, which is normally named as microgrid monitoring and control system. With the popularization of microgrids, the industry urgently needs a standard to specify the system architecture, component composition and functional requirements of microgrid monitoring and control system.

There are also various types of microgrid monitoring and control systems. For large scale (installed power > 100 kW) microgrid, its monitoring system and control system is more complex, usually using independent servers, workstations, remote terminal units, and others. Its communication protocol and data model can be based on the IEC 61850 series, and the system consists of a master station level and a local equipment level. For small-scale microgrids below 100 kW level, such as household microgrids with photovoltaic power generation and battery storage, it is relatively expensive to configure a complex microgrid monitoring and control system. At this time, the microgrid will generally adopt lightweight and cheap technical solutions, and the microgrid monitoring, control and energy management function will often be combined into a single device. Sometimes, for the small microgrid in remote mountainous areas, microgrid monitoring and control system based on the Internet of Things and cloud computing architecture is often used to realize the local autonomy and remote monitoring of the micro grid.

IEC TS 62898 series is intended to provide general guidelines and technical requirements for microgrid projects.

IEC TS 62898-1 mainly covers the following issues:

- determination of microgrid purposes and application,
- preliminary study necessary for microgrid planning, including resource analysis, load forecast, DER planning and power system planning,
- principles of microgrid technical requirements that should be specified during planning stage,
- microgrid evaluation to select an optimal microgrid planning scheme.

IEC TS 62898-2 mainly covers the following issues:

- operation requirements and control targets of microgrids under various operation modes,
- the basic control strategies and methods under various operation modes,
- the requirements of electrical energy storage (EES), relay protection, monitoring and communication under various operation modes,
- power quality.

IEC TS 62898-3-XX subseries technical specifications deal with the technical requirements of microgrids.

IEC TS 62898-3-1 mainly covers the following issues:

- requirements for microgrid protection,
- protection systems for microgrids,
- dynamic control for transient and dynamic disturbances in microgrids.

IEC TS 62898-3-2[1] covers the energy management system of microgrids.

IEC TS 62898-3-3 covers the self-regulation of dispatchable loads of microgrids.

This document covers microgrid monitoring and control systems (MMCS). It aims to provide requirements to address state monitoring and operation control problems in microgrids.

[1] Under preparation.

MICROGRIDS

Part 3-4: Technical requirements – Microgrid monitoring and control systems

1 Scope

The purpose of this part of IEC 62898 is to provide technical requirements for the monitoring and control of microgrids. This document applies to non-isolated or isolated microgrids integrated with distributed energy resources. This document describes the specific recommendations for low-voltage (LV) and medium-voltage (MV) microgrids.

This document focuses on standardization of the architecture, functions, and operation of microgrid monitoring and control systems (MMCS). It teases out the general functions of MMCS and provides technical requirements for MMCS. This document includes the following aspects of MMCS:

- system architecture,
- information exchange with other devices/functions in microgrid,
- performance requirement,
- main function descriptions.

The system architecture for MMCS:

- For a large scale (installed power > 100 kW) microgrid, microgrid energy management system (MEMS) and MMCS are normally separated. MMCS normally contains data servers, application servers, workstations, routers, information safety devices, SCADA, communication system, distributed generation controller, microgrid central controller, load controller, grid connection interface device and other ancillary equipment.
- For a small user-side microgrid (normally less than 100 kW), MEMS and MMCS are normally merged into one embedded device with system on chip, which is named as microgrid controller.

Main functions of MMCS:

- Data acquisition and processing, including collecting real-time data from the distributed generation, load, switches, transformers and reactive power compensation devices, and calculation and analysis of the acquired data.
- Database management, including maintaining, synchronizing, backing up, restoring the acquired data, and providing the data interface with other internal and external applications.
- Human-machine interface, including the real-time monitor screen and interface which is capable of remote control, mode switching, manual data entry, etc.
- Anti-maloperation locking and alarm, to lock the maloperation based on the predefined rule and logic.
- Time synchronization, including receiving the time synchronization signal from Global Navigation Satellite System (GNSS) or network time protocol (NTP) and synchronizing the time of each device within the microgrid.
- Local power quality evaluation and control the ability to collect information of out-of-limit voltage, power factor, harmonic, etc. and carry out control to improve power quality accordingly.
- Frequency/voltage regulation during steady state operation of an isolated microgrid to provide voltage and frequency inside an accepted operation range.

- Sequence of operations, or steady transition from power-off to start-up and from start-up to power-off.
- Switch control of devices within microgrids, including turning on and off loads, generation units, transformers, reactive power compensation devices, etc.
- Islanding detection, including real-time detection on power outage of the upstream distribution system.
- Operation mode transition, including transition from grid-connected mode to island mode and transition from island mode to grid-connected mode.
- Active and reactive power control, including load shedding (if required), load sharing and controlling the active and reactive power in real time according to the MEMS or manual command.
- Black start, the ability to initiate power sources and loads to ensure the microgrid can initiate operation from a non-energized state.
- Interface with the protection system or earthing system when adaptations are required according to the microgrid operating modes.

2 Normative references

The following documents are referred to in the text in such a way that some or all their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60870-5-101, *Telecontrol equipment and systems – Part 5-101: Transmission protocols – Companion standard for basic telecontrol tasks*

IEC 60870-5-104, *Telecontrol equipment and systems – Part 5-104: Transmission protocols – Network access for IEC 60870-5-101 using standard transport profiles*

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

IEC 62443 (all parts), *Security for industrial automation and control systems*

IEC 62586-1, *Power quality measurement in power supply systems – Part 1: Power quality instruments (PQI)*

IEC TS 62898-1, *Microgrids – Part 1: Guidelines for microgrid projects planning and specification*

IEC TS 62898-2, *Microgrids – Part 2: Guidelines for operation*

IEC TS 62898-3-1, *Microgrids – Part 3-1: Technical requirements – Protection and dynamic control*

IEC TS 62898-3-2:—[2], *Microgrids – Part 3-2: Technical requirements – Energy management systems*

IEC TS 62898-3-3, *Microgrids − Part 3-3: Technical requirements − Self-regulation of dispatchable loads*

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[2] Under preparation. Stage at the time of preparation: IEC DTS 62898-3-2:2023.

IEEE Std 1815-2012, *IEEE Standard for Electric Power Systems Communications-Distributed Network Protocol (DNP3)*

IRIG-B Standards Documentation (IRIG.ORG) [viewed 2023-08-07]

Modbus Standards Documentation (Modbus.org) [viewed 2023-08-07]

NTP Standards Documentation (ntp.org) [viewed 2023-08-07]

OASIS Standards Documentation, MQTT Version 5.0 (oasis-open.org) [viewed 2023-07-24]

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

IEC Electropedia: available at http://www.electropedia.org/

ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
microgrid
<electric power system> group of interconnected loads and distributed energy resources with defined electrical boundaries forming a local electric power system at distribution voltage levels, that acts as a single controllable entity and is able to operate in island mode, no matter if it is standalone or grid-connected

Note 1 to entry: This definition covers both (utility) distribution microgrids and (customer owned) facility microgrids.

[SOURCE: IEC 60050-617:2017, 617-04-22, modified – "in either grid-connected or island mode" has been changed to "in island mode, no matter if it is standalone or grid-connected".]

3.1.2
microgrid monitoring and control systems
MMCS
computer or PLC based system performing real time monitoring and control of microgrid

Note 1 to entry: In large grid or large microgrid, such a system is also designated by PMS (Power Monitoring System).

3.1.3
microgrid energy management system
MEMS
system operating and controlling energy resources and loads of the microgrid

[SOURCE: IEC 60050-617:2018, 617-04-25]

3.1.4
distributed energy resources
DER
generators (with their auxiliaries, protection and connection equipment), including loads having a generating mode (such as electrical energy storage systems), connected to a low-voltage or a medium-voltage network

[SOURCE: IEC 60050-617:2017, 617-04-20]

3.1.5
renewable energy resource
RES
non-fossil energy resource such as wind, solar, hydropower, biomass, geothermal, etc

3.1.6
low voltage
LV
set of voltage levels used for the distribution of electricity and whose upper limit is generally accepted to be 1 000 V for alternating current

[SOURCE: IEC 60050-601:1985, 601-01-26]

3.1.7
medium voltage
MV
any set of voltage levels lying between low and high voltage

Note 1 to entry: The boundaries between medium- and high-voltage levels overlap and depend on local circumstances and history or common usage. Nevertheless, the band 30 kV to 100 kV frequently contains the accepted boundary.

[SOURCE: IEC 60050-601:1985, 601-01-28]

3.1.8
generic object-oriented substation event
GOOSE
mechanism used in the IEC 61850 series to meet the requirements of substation automation system fast communication

3.1.9
inter-range instrumentation group-B
IRIG-B code
time information transmission system that loads the time synchronization signal and the time code information such as second, minute, hour and day into the signal carrier with a frequency of 1 kHz

3.1.10
network time protocol
NTP
time synchronization protocol that serves computer clocks via the network

3.1.11
power system stability
capability of a power system to regain a steady state, characterized by the synchronous operation of the generators after a disturbance due, for example, to variation of power or impedance

[SOURCE: IEC 60050-603:1986, 603-03-01]

3.1.12
point of connection
POC
reference point on the electric power system where the user's electrical facility is connected

[SOURCE: IEC 60050-617:2009, 617-04-01]

3.1.13
power conversion system
PCS
device that can control the charging and discharging process of a battery storage system, and carry out AC-DC conversion

3.1.14
state of charge
SOC
available capacity in a battery pack or system expressed as a percentage of rated capacity

[SOURCE: ISO 12405-4:2018, 3.20]

3.2 Abbreviated terms

DER	Distributed Energy Resource
DSO	Distribution System Operator
EPS	Electrical Power System
ESS	Energy Storage System
GOOSE	Generic Object-Oriented Substation Event
GIS	Geographic Information System
GUI	Graphic User Interface
GNSS	Global Navigation Satellite System
IRIG-B	Inter-Range Instrumentation Group-B
LV	Low Voltage
MV	Medium Voltage
MMCS	Microgrid Monitoring and Control System
MEMS	Microgrid Energy Management System
MQTT	Message Queuing Telemetry Transport
NTP	Network Time Protocol
POC	Point of Connection
PLC	Programmable Logic Controller
PCS	Power Conversion System
PQI	Power Quality Instrument
RES	Renewable Energy Source
SOC	State of Charge
UPS	Uninterruptible Power Supply

4 Overview

4.1 General

The operation control system of a microgrid can be divided into three layers according to the time scale, namely the energy management layer, the monitoring and control layer and the protection and dynamic control layer.

MMCS mainly concerns the monitoring and control layer in the microgrid system.

Functions listed in Figure 1 are project dependent. Some functions can be omitted depending on the scale or application of the microgrid. However, MMCS shall at least perform data acquisition and processing, database management, maloperation locking, switch control of devices, active and reactive power control of devices. In Annex B, MMCS functions are performed or detailed in some actual application cases.

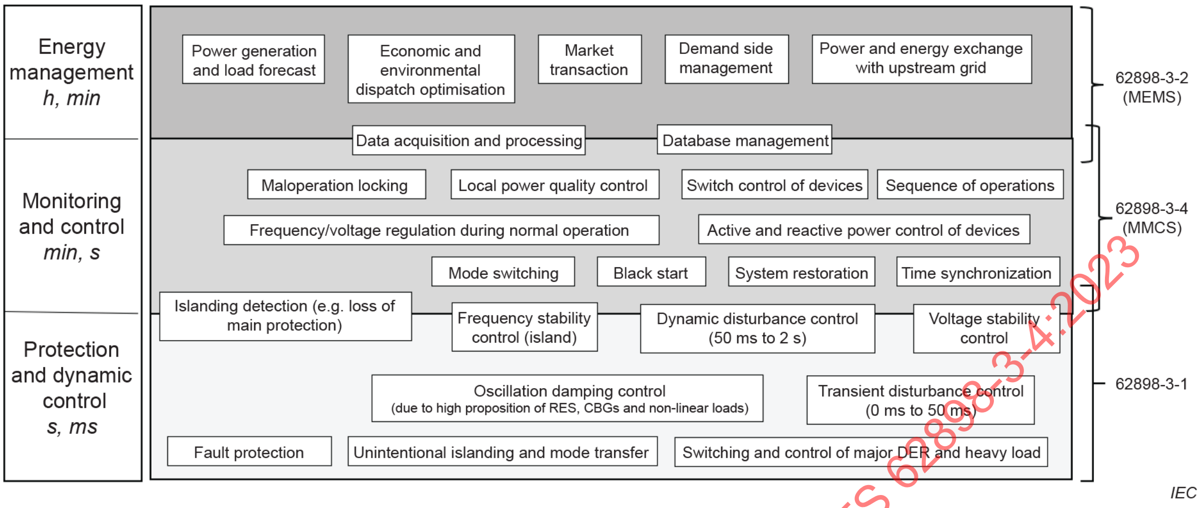

Figure 1 – Functional mapping for operation and control of microgrids

4.2 System architecture

4.2.1 Stand-alone MMCS

For a large scale (installed power > 100 kW) microgrid, MMCS normally exist as a stand-alone system, which is intended to handle only the monitoring and control layer. It is configured to have the functions involving time scales in the range of seconds to minutes, such as data acquisition and processing, active and reactive power control, frequency/voltage regulation during normal operation of isolated microgrid, islanding detection and mode switching.

MMCS can adopt a hierarchical or distributed architecture shown in Figure 2, such as master station layer (or central control layer) and local control layer. The layers are connected by a communication network. Distributed architecture has the advantage that the failure or disconnection of one device in the system does not affect the normal operation of the other part of the system. The system can also stay operational when an equipment or the network at the central control level fails.

MMCS normally contains the whole set or parts of the following: SCADA, communication system, distributed generation controller, microgrid central controller, load controller, grid-interfacing device, cyber security protection devices and other secondary equipment. The above equipment can be sophisticated or simplified according to the scale and functional requirements of the microgrid.

For a large scale (installed power > 100 kW) microgrid, MEMS and MMCS are normally separated. MMCS can exchange data with MEMS in the microgrid. MMCS monitors the data of devices, assuring the parameters to stay within a pre-defined operating range, and sends information to the MEMS. MEMS gives operational orders to MMCS and MMCS executes the orders by controlling switches, distributed energy resources and loads in the microgrid. If the MEMS control orders according to economic criteria would violate power system stability constraints, MMCS should make a corrective control to ensure the power system stability.

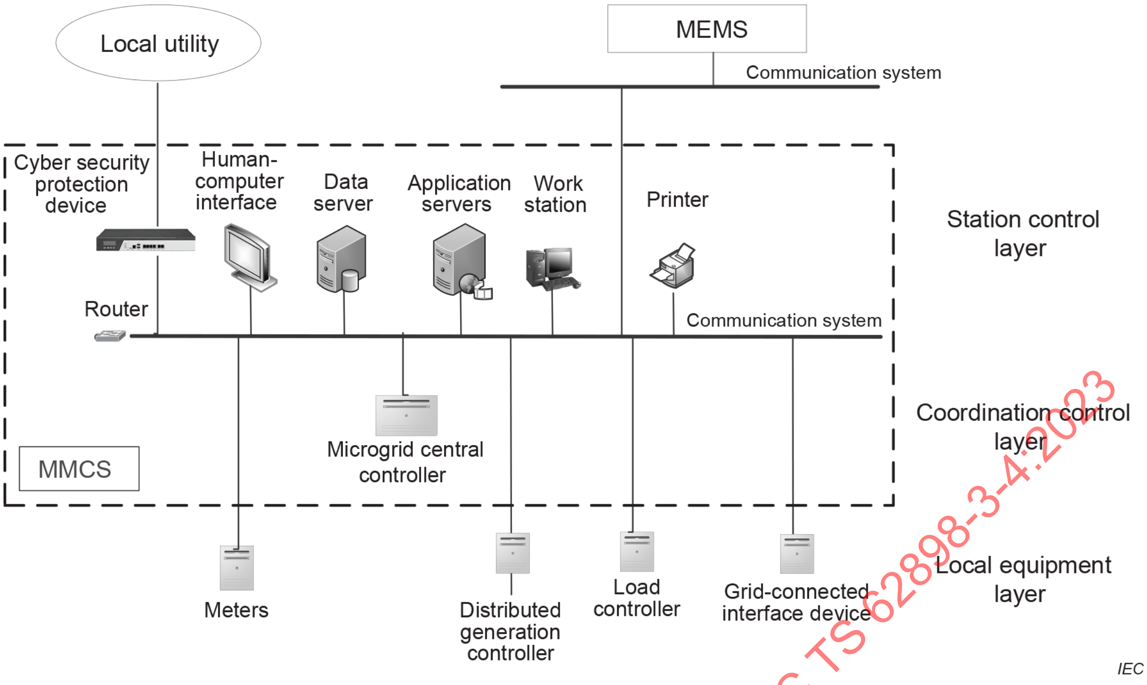

Figure 2 – Structure of MMCS

4.2.2 Integrated MMCS

For a small user-side microgrid (installed power ≤ 100 kW), MEMS and MMCS are normally merged into one embedded device with system on chip, which is named as microgrid controller.

Microgrid monitoring and control module as a system integrated into a microgrid controller is intended to handle the second layer of operation and control system. It is configured to have the functions with short time scales (minute, second), such as data acquisition and processing, active and reactive power control, frequency/voltage regulation during normal operation of isolated microgrid, islanding detection and mode switching.

The integrated MMCS shall have a communication module, a human-machine interface module, a data storage module, a power module, a calculation and processing module.

4.3 Hardware and software architectures

4.3.1 Hardware

4.3.1.1 General

MMCS could be a stand-alone system or integrated system.

4.3.1.2 Stand-alone system

For a stand-alone system, MMCS should include the front-end processor, data server, application server, workstation, Ethernet switch, routers, sensors, meters, and other equipment. The number of servers and workstations can be adjusted according to the scale of microgrid and requirement of calculation.

MMCS shall configure firewalls, isolation devices, or other cyber security equipment. For additional information on cyber security requirement, see IEC 62443-4-2.

4.3.1.3 Integrated system

For an integrated module, MMCS should be implemented as an integrated control module, i.e. based on a PLC (Programmable Logic Controller).

4.3.2 Software

MMCS software shall include the operating system, supporting platform and application software.

The supporting platform software should be capable of performing functions such as data acquisition management, database management, network communication management, graphics management, report management, authority management, alarm management, calculation, statistics, etc.

The application software should adopt a modular structure with a fast response speed, flexible expandability, and error detection capability. When the application fails, MMCS shall prompt an alarm message, and the operation of other applications shall not be affected.

4.3.3 Database

For large microgrids, MMCS should configure a real time database and a historical database. The historical data shall be saved periodically, the data storage period and storage resolution should depend on the scale of the system.

4.4 Communication and cyber security

4.4.1 Communication

The microgrid communication involves external communication and internal communication. The external communication is applied for information exchange between the microgrid and the upstream grid dispatching system called "dispatch centre" and the internal communication is applied for information exchange among MEMS, MMCS, DER and/or other internal equipment of the microgrid. In the case of an isolated microgrid, i.e., not connected to an upstream large grid, it is not required to establish a communication link with a dispatch center (dotted point lines in Figure 3 and Figure 4), but a communication link with an upper control system or cloud functions could be required.

The communication protocols shall be defined according to the interoperability requirements. For example, the communication protocol can be the IEC 61850 series, IEC 60870-5-101 or IEC 60870-5-104.

For internal communication, the number of layers depends on the structure of the MMCS.

Internal communication for structure 1: Stand-alone MMCS

Under a three-layer architecture, the protocols of IEC 60870-5-101, IEC 60870-5-104, DNP3 (Distributed Network Protocol, IEEE Std 1815), IEC 61850 series, Modbus (Modbus specification shall conform to terms specified in Modbus.org or IEC 61158 series/IEC 61784 series), MQTT (MQTT specification shall conform to terms specified in oasis-open.org), etc. can be applied between MMCS and MEMS, and the IEC 61850 series, Modbus and other protocols can be applied between MMCS and the DER and internal equipment of microgrid. The communication medium used for the microgrid can be optical fibre, twisted pair, wireless, etc. according to specific application conditions.

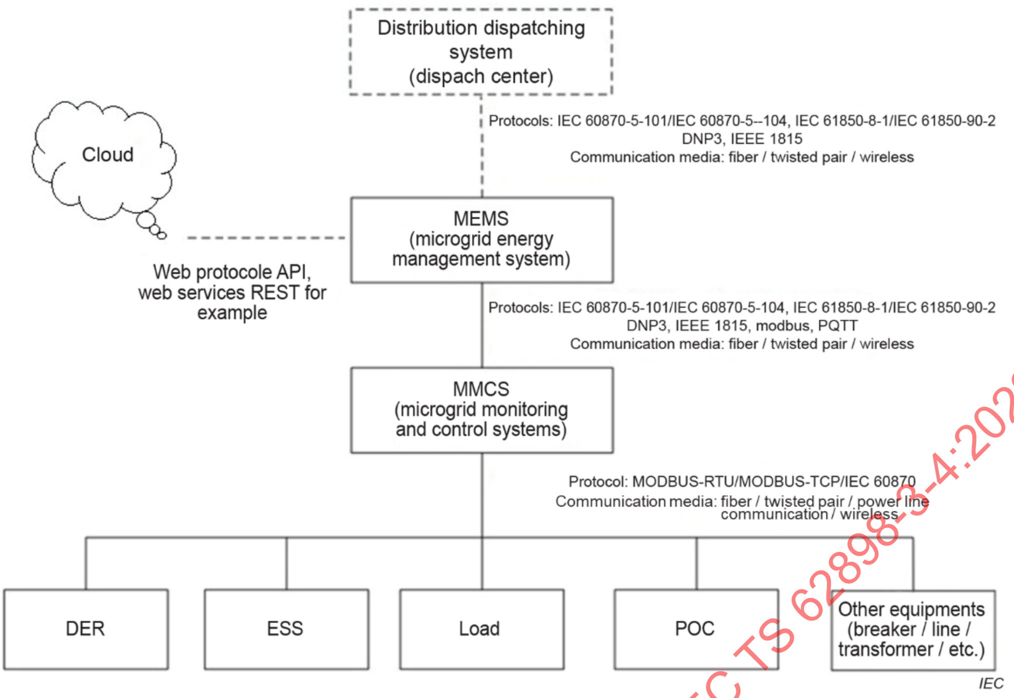

Figure 3 – Typical three-layer communication for structure 1

<u>Internal communication for structure 2: Integrated MMCS</u>

Under a two-layer architecture, the protocols of the IEC 61850 series, Modbus and other protocols can be applied between MMCS and the DER and internal equipment of the microgrid. The communication medium used for the microgrid can be optical fibre, twisted pair, wireless, etc. according to specific application conditions.

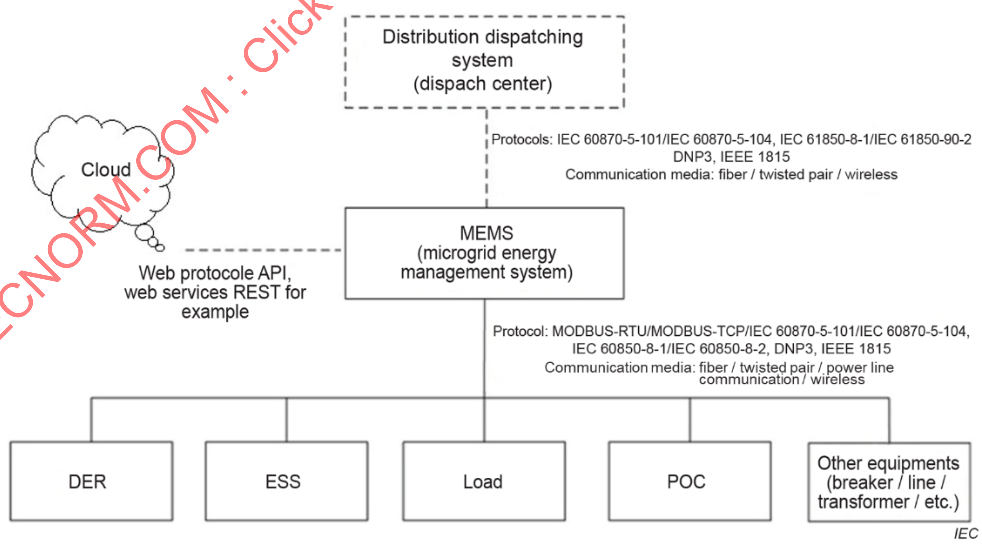

Figure 4 – Typical two-layer communication for structure 2

4.4.2 Cyber security

The cyber security strategy of MMCS shall be aligned with the IEC 62443 series, which defines security levels and associated requirements for Industrial Automation and Control Systems (IACS).

The IEC 62443 series defines four different security levels (SL1 to SL4), with specific requirements applicable to system level specified in IEC 62443-3-3 and component level specified in IEC 62443-4-2. The required level remains specific to each microgrid application and its required security profile. The manufacturer or system provider shall declare the security level of the MEMS and its components, as defined in the IEC 62443 series.

Cyber security functions of MMCS should be shared with MEMS (see IEC 62898-3-2), and the declared security level can be common.

5 Functional requirements

5.1 Data acquisition and processing

5.1.1 Data acquisition

MMCS shall be able to collect analog and digital real-time data. Data could be collected from MEMS, microgrid central controller, DER, loads, power conversion system, battery management system, communication protocol converter, etc.

MMCS shall be able to collect data regarding the scale and DER of the microgrid. The data include but are not limited to the following:

- busbar voltage/frequency, current, and power for all the microgrid,
- switch position of power distribution units for a large scale microgrid,
- DC power/current/voltage, AC power/generation, etc. of renewable energy resources like photovoltaics or wind turbines,
- forward/reverse active power generation, forward/reverse reactive power generation of Power Meter Devices (PMD) for microgrid with respective energy resources or PMD,
- power quality for the microgrid with power quality instrument,
- internal temperature, DC power/current/voltage, and AC power/current/voltage from power conversion system for the microgrid with ESS,
- battery group terminal voltage/current/SOC, single battery voltage/current/SOC, and temperature from battery management system for the microgrid with ESS.

Annex A gives an example of information to be collected by the MMCS. For additional information on the data models, see IEC TR 61850-90-23 and CIM of IEC 61970 series.

5.1.2 Data processing

MMCS shall be capable of calculating and analysing the collected data. Data processing could include but is not limited to the following functions:

- data source selection and automatic calculation: includes statistical analysis of real-time maximum, minimum, average, and total of specified data by minute, hour, day, week, month, quarter, year, or customized period,
- logical assessment of status signals of breakers and switches,
- counting the number of position changes of specific equipment,
- statistical analysis of remote-control performance,
- ageing equipment evaluation,
- statistical analysis of power quality criteria,
- manual adjustment of data and status.

MMCS shall be capable of performing an integrity check of the collected data and giving off-limit alarm. Data detection and alarms include but are not limited to the following functions:

- data integrity check, automatically filtering undependable data, and setting data quality labels according to the operating status of the microgrid,
- setting a limit for different source of data in different periods,
- threshold-crossing alarm definition, alarm activation, alarm shunt, screen call, alarm information storage, etc.

MMCS shall be capable of storing the collected data. Data storing includes but is not limited to the following functions:

- classified storage and management of various raw data and application data,
- storage of event sequence record and operation record.

5.2 Database management

The database management of MMCS should have the functions of database synchronization, offline file storage, database backup and database recovery. Database management is not mandatory for small scale microgrids (installed power < 100 kW).

The database of MMCS should support the provision of a unified real-time or quasi-real-time data service interface according to the visitor's authority and access type.

Real-time database management should be used for the communication and processing of real-time data and provide a unified support for real-time applications. The real-time database should run on memory or hard disk drive, supporting data replication between applications, and data synchronization between multi-node replicas.

Real-time database management can provide data maintenance tools. It can support the definition of classes, attributes, and relationships. It can support the addition, deletion, modification, query, location, and filter operation of specified objects.

Quasi-real-time database management can be used for minute-level historical data storage and statistics, storing alarm events, models, and other non-real-time data. It can provide graphical and command-line database tools to complete table definition, data manipulation, database configuration and other tasks.

5.3 Human-machine interface

MMCS should provide flexible and convenient human-machine interaction means for operators through workstations in order to ensure the monitoring and control of large scale microgrids. Human-machine interface has other possibilities depending on the size of microgrid and type of applications.

MMCS should have the real-time monitor screen with one-line diagram, GIS (Geographic Information System) diagram (if required), GUI (Graphical User Interface), and communication network diagram, distributed generation status, etc. The display forms can provide the following functions if required:

- multi-screen display, multi-window graphics, stepless zoom, roaming, drag and drop, hierarchical display, etc.
- monitoring screen of electrical components can have a topology colouring function, which can reflect the power flow, voltage level, switch status and other operation information.

The graphic/modelling editing forms can provide the following functions if required:

- graphic model library integrating with modelling tool can establish the network model and network library while generating one-line diagram,
- modification of dynamic data, which is convenient to edit, modify and generate,

- network topology management tool, which supports users to define equipment primitives, and to copy various primitives with model properties.

MMCS should have a microgrid operation and control interface, which is capable of remote control, mode switching, manual data entry, etc. The human-machine interaction forms can provide the following functions if required:

- setting various parameters, logs, and clocks according to operation requirements. Modifying the analog limit value and switch status with the corresponding authority control,
- realizing manual settings, signboard operation, locking/unlocking operation, remote control, and adjustment functions with the corresponding authority control,
- querying and accessing the collected data.

Human-machine interaction should be capable of prompting alarm signals. This function can be provided as follows if required:

- alarm signal prompting can include graphics, voice, text, etc.,
- human-machine interaction can support alarm query, predefined alarm level customization, statistical analysis, alarm confirmation, clearance, and event sequence display,
- the alarm information can be layered, graded, classified, and displayed on the screen whose content can be manually defined.

5.4 Anti-maloperation locking and alarm

MMCS shall support various types of automatic anti-maloperation locking functions, including conventional anti-maloperation locking based on the predefined rule and logic and anti-maloperation locking based on topology analysis.

All the operation instructions from MMCS shall be verified to help prevent maloperation. In case of error, an alarm shall be given, and the execution of the instruction shall be blocked.

MMCS shall have various forms of alarm functions, supporting alarm confirmation and elimination, alarm information storage, sequence display of main events, etc. Historical records of various alarm information shall be kept for future reference, and the storage time shall depend on the scale of the system. The system alarm function of MMCS should be capable of performing alarm statistical analysis and alarm level customization.

MMCS shall have the function of classified management and information filtering of alarm. According to the level of alarm information, priority management can be implemented to facilitate the timely processing of important alarm information and help the microgrid deal with various emergencies. MMCS can conduct online a real-time analysis and reasoning on the operation state of the microgrid according to the preset logic and reasoning model, automatically report microgrid abnormalities and put forward fault handling guidance.

According to the importance and the degree of impact on the microgrid operation, the alarm of microgrids can be divided into three categories: accident, warning, and notification.

- Accident alarms are caused by circuit breaker trips and protection device action signals caused by abnormal operation, and other signals affecting the safe operation of the microgrid system (including system communication interruption, fire alarm of fire system, etc.).
- Warning alarms include status abnormality, threshold-crossing, abnormal events, etc. of the microgrid.
- Notification alarms are signals reflecting various operating states of the equipment and the detailed information after the accident trip or abnormality, such as switch position and protection functionality (self-test of protection devices/system).

The alarm mode can adopt automatic push alarm or screen flashing, and audio alarm including graphics, voice information, text, printing, etc.

MMCS can have the function of shielding a single alarm signal. After shielding, the alarm signal will no longer sound when it appears, but the shielding operator should be authenticated and the operator, shielding time, recovery time and other information should be recorded.

5.5 Time synchronization

MMCS shall be capable of receiving the time synchronization signal from the GNSS or NTP (network time protocol) and synchronizing the time of devices when it is required within the microgrid.

The master station level device in MMCS shall receive one of the following standard synchronization clock signals from MMCS: IRIG-B code (priority), pulse signal, time message (serial port) and Ethernet time synchronization signal.

When the MMCS loses time synchronization, it shall automatically alarm and record the event of losing synchronization. MMCS should continue to synchronize devices inside the microgrid based on local clock.

5.6 Local power quality control

MMCS should monitor power quality in microgrid, including 2^{nd} to 40^{th} (or 50^{th} for some countries) order harmonics component in voltage/current, total harmonic distortion in voltage/current, three phase voltage/current unbalance, voltage deviation, direct current component, power factor, outages, flickers, etc. This function is optional and requires power quality instrument (PQI). PQI shall conform to the terms specified in IEC 62586-1.

PQI should be installed at POC. If power quality at POC does not meet the predesigned requirements, MMCS should provide options to improve the local power quality. Otherwise, MMCS shall carry out an operating mode transition operation and enable the microgrid to operate in island mode or be suspended.

NOTE Power quality indices are defined by relevant national and international standards, for example, EN 50160 defines power supply characteristics in Europe, IEC 63222 series gives guidelines for power quality management, etc.

If power quality compensators are mounted to improve power quality and/or power factor, MMCS shall monitor the operating status of compensators. Specifically, requirements on voltage deviation, voltage fluctuation, voltage flicker, harmonic, three-phase voltage unbalance, direct current are specified in the relevant standards.

The measurement methods for the power quality monitors are given in IEC 61000-4-30.

5.7 Frequency/voltage regulation during steady state operation of isolated microgrid

MMCS shall be capable of regulating the set points and operation mode of voltage sources to provide voltage and frequency in the accepted operating range for the system during steady operation. For dynamic conditions, IEC TS 62898-3-1 shall be referred to.

When the microgrid operates in island mode, the internal DG units shall be able to actively control the voltage and frequency. The system shall have at least one power generation as a grid forming source, which can supply sustainable and steady frequency and voltage, such as an energy storage system with U/f mode or droop control mode, diesel generator with governor and exciter, etc.

MMCS should be capable of changing the grid forming source according to the state of the system. When the battery energy storage system is used as the grid forming source, if the SOC of the battery energy storage system reaches the minimum limit, MMCS shall be able to switch to other main power source in time.

When there are multiple grid forming sources in the system during island operation, MMCS shall be able to coordinate their frequency droop setpoints and voltage droop setpoints.

5.8 Sequence of operations

MMCS shall be able to control the actions of equipment within the microgrid according to the predefined sequence and realize the basic functions including start-up for grid connection, power-off in grid-connected or island operation.

MMCS shall be able to close the POC switch, put in the DERs and loads, and smoothly transition the microgrid from power-off status to grid-connected operation status.

MMCS shall be able to force out the DERs and loads, and smoothly transition the microgrid from grid-connected or island operation status to power-off status.

5.9 Control of device switching

MMCS shall be capable of turning on and off the loads, generation units, POC switches, transformers, reactive power compensation devices, etc.

The on/off control can be manual or automatic. The level of switching control operation from low to high can be classified as local control, site control, and remote control.

When manual switch control operation is performed, MMCS shall be capable of monitoring the operation, allowing the supervisor to monitor and safeguard from local panel or remote site.

MMCS can support both local and remote switch control modes, and remote switch control shall pass anti-maloperation verification.

5.10 Operating mode transition

5.10.1 General

According to the size of the microgrid, MMCS can participate in or carry out the transition of the microgrid between two operation modes (for additional information on operating mode transition, see IEC TS 62898-3-1 and IEC TS 62898-3-2):

- transition from island mode to grid-connected mode,
- transition from grid-connected mode to island mode.

MMCS shall be capable of controlling the switches at POC, distributed generation and loads to maintain the microgrid working normally during mode switching.

MMCS can perform intentional interrupted transition or seamless transition during mode switching.

MMCS shall be capable of automatically carrying out the transition of microgrid from grid-connected mode to island mode when "loss of main" protection trips the POC switch (the "loss of main" protection is generally required and defined by local utility specifications and shall be able to open the POC in case of fault on the utility feeder which supplies the microgrid or in case of strong voltage sag. "Loss of main" protection shall conform to the terms specified in IEC TS 62898-3-1). When the grid recovers from failure, MMCS shall be capable of returning microgrid operation back to grid-connected mode either automatically or after receiving higher order instructions.

5.10.2 Transition from island mode to grid-connected mode

Transition from island mode to grid-connected mode can be intentionally seamless. In case of seamless transition, the synchronization control shall be carried out, before MMCS carries out the transition from island mode to grid-connected mode. When MMCS is tasked with operating mode transition, it shall allow transition from island mode to grid-connected mode only if the voltage amplitude, frequency, and phase angle in the microgrid and at the POC meet the synchronization requirements.

For large microgrids, the transition control of MMCS from island mode to grid-connected mode shall be executed according to the instructions from distribution system operator (DSO).

For small user-side microgrids, the transition control of MMCS from island mode to grid-connected mode can be decided according to the customer requirements.

When MMCS carries out the transition from island mode to grid-connected mode, it shall be able to ensure an uninterrupted power supply.

5.10.3 Transition from grid-connected mode to island mode

The transition of microgrid from grid-connected mode to island mode has two types: intentional switching and unintentional switching caused by external disturbance (unintentional action shall be conform to the terms specified in IEC TS 62898-3-1).

For large microgrids, the planned switching control of MMCS shall be executed according to the instructions of DSO. The power exchange between the microgrid and the main grid should be reduced to a small controllable value close to zero before the intentional transition from grid-connected mode to island mode.

MMCS can carry out the transition from grid-connected mode to island mode, if the "loss of main" protection trips, or voltage, current or power quality at the POC exceed a specific limit.

The transition from grid-connected mode to island mode should be carried out according to local grid code requirements.

5.11 Active and reactive power control

5.11.1 General

MMCS shall be capable of controlling the active and reactive power of distributed generation, battery storage and loads in real time according to the MEMS or manual command.

5.11.2 Active power control

MMCS shall control the active power output from distributed generation, charging/discharging of energy storage system (ESS) and controllable loads.

In grid connected mode, active power control strategies include:

- active power limitation control at POC (import/export),
- POC scheduling curve tracking control,
- ESS charging/discharging scheduling curve tracking control.

MMCS shall be able to control the power exchange between microgrid and grid in accordance with local grid codes or utility grid dispatching command.

MMCS shall monitor active power output from grid forming source. In island mode, MMCS shall have an action on the setpoint of droop P/f functions to ensure power sharing. In grid-connected mode, the MMCS could have an action on the local sources to meet "droop P/f" functions required by grid codes.

MMCS shall be able to perform load shedding if required.

MMCS should be able to perform load sharing and peak shaving according to the schedule from MEMS or local command.

MMCS should provide frequency support to the main grid for the ancillary services.

5.11.3 Reactive power control and voltage control

5.11.3.1 Reactive power control

MMCS shall be capable of reactive power control and voltage control during steady state according to the grid code requirements. The reactive power and voltage operating modes include power factor control mode, reactive power control mode, and voltage control mode.

According to the selected reactive power and voltage operating mode, MMCS shall be able to regulate the parameter settings or variation range including voltage limits, reactive power limits, power factor limits, dead zones, time limits, slopes, etc.

MMCS should be capable of setting the involvement order of all reactive power compensation equipment.

For non-isolated microgrids, MMCS can accept and implement instructions of upstream dispatch centre to provide reactive power support to the POC based on the ancillary service or local grid codes.

5.11.3.2 Voltage control

MMCS should optimally set volt-var operation in microgrid. During microgrid grid-connected mode, it is recommended to adopt the power factor control or reactive power control mode. During microgrid island mode, MMCS shall adopt the voltage control mode.

MMCS adjusts the parameter settings or ranges (including voltage threshold, reactive power threshold, power factor threshold, dead band, time limits, ramp rate, etc.) on the base of the selected control mode.

MMCS can participate in voltage regulation by regulating the reactive power output from microgrid in accordance with voltage at POC depending on the customer requirement or grid codes.

Power factor at POC should be controlled to stay within a given range according to the customer requirement or grid codes. Utility grid dispatching centre sets the control strategy, voltage reference, voltage adjustment ratio, etc. MMCS should be capable of setting a switching sequence of reactive power compensators.

5.12 Islanding detection

MMCS shall be capable of performing islanding detection.

According to the size of the microgrid, MMCS can take part in or carry out islanding detection mainly through three algorithms which are active, passive, and remote detections.

Active detection algorithm is implemented by injecting a small amount of power or current interference by means of an inverter control signal. In grid-connected mode, voltage and frequency are set by the upstream grid and the interference has a negligible effect on the normal operation. In island mode, the response of the interference gives significant information for the microgrid. Therefore, by detecting the response from the whole concerned grid, islanding can be detected.

Passive detection algorithm does not require additional power generation control. When islanding occurs, power in microgrid changes. Generally, change in active power causes a change in frequency while change in reactive power causes a change in voltage. When power generation and load demands are not in balance, voltage magnitude and frequency at POC fluctuates. Therefore, islanding can be detected by monitoring the rate of change of frequency, voltage fluctuation, and phase change. "Loss of main" protection functions are described in IEC TS 62898-3-1.

Remote detection is based on the monitoring function of the upstream primary substation. The status of the circuit breaker of upstream tie-line is monitored by the upstream primary substation. If the circuit breaker of upstream tie-line is open, MMCS can detect island operation of the microgrid.

5.13 Black start

According to the size of the microgrid, MMCS can participate or carry out black start functions (refer to IEC TS 62898-1, IEC TS 62898-2).

If black start feature is required for microgrid, MMCS shall support the following requirements:

- MMCS shall be capable of initiating power source and load to ensure microgrid to transit from black-out to island operation.
- MMCS shall be able to sequentially control the input of equipment in the microgrid according to the selected black start strategy and control the microgrid to smoothly transition from shutdown or power failure to island operation.
- MMCS should be able to configure black start strategy library, supporting black start strategy selection, power supply configuration, and black start delay setting.
- MMCS shall be capable of performing manual step-by-step operation and supporting remote control.
- During black start process, MMCS shall be able to automatically select power supply with self-starting capability as the main reference power supply to provide the reference voltage and frequency for the system.

Annex A
(informative)

Example of collected information of MMCS

A.1 Microgrid operating data

A.1.1 Status data

a) position information of the circuit breaker, isolating switch, and grounding switch,
b) operating status of non-isolated/isolated microgrid,
c) action information of relay protection, switch and breaker within microgrid.

A.1.2 Measurement data

A.1.2.1 Distributed power supply measurement data

a) photovoltaic measurement data
   1) PV module measurement data: DC current, DC voltage, DC power,
   2) PV inverter measurement data: three-phase voltage, three-phase current, active power, reactive power, power factor,
b) wind power measurement data

   Three-phase voltage, three-phase current, active power, reactive power, power factor,
c) diesel generator/ gas turbine (gas internal combustion engine) measurement data

   Three-phase voltage, three-phase current, active power, reactive power, power factor, rotation speed, fuel/gas consumption, engine/turbine temperature.

A.1.2.2 Energy storage measurement data

a) battery measurement data

   DC current, DC voltage, DC power, capacity, state of charge (SOC), battery temperature,
b) energy storage inverter measurement data

   Three-phase voltage, three-phase current, active power, reactive power, power factor, frequency.

A.1.2.3 Load measurement data

Three-phase voltage, three-phase current, active power, reactive power, power factor.

A.1.2.4 Measurement data of reactive power compensation equipment

Three-phase voltage, three-phase current, and reactive power.

A.1.2.5 Measurement data of auxiliary equipment

The voltages and currents of AC and DC power supplies.

A.1.2.6 Microgrid measurement data

a) measurement data on each side of the transformer

   Three-phase voltage, three-phase current, active power, reactive power, power factor, frequency,
b) measurement data at POC

   Frequency, three-phase voltage, three-phase current, active power, reactive power, power factor, voltage flicker, voltage deviation, harmonics, frequency deviation, etc.

c) location information of the main transformer taps.

A.1.2.7 Electric power data

a) active and reactive power on both sides of each transformer,

b) active and reactive power at POC,

c) active and reactive power of distributed power supplies,

d) active and reactive power of batteries,

e) active and reactive power of loads.

A.1.2.8 Meteorological and other data

Ambient temperature, humidity, atmospheric pressure, light intensity, wind speed, wind direction, intensity of solar radiation, etc.

A.1.2.9 Statistical calculation data

a) photovoltaic daily power generation, total power generation, and actual power generation curve,

b) wind turbine daily power generation, total power generation, and actual power generation curve,

c) diesel generator daily power generation, total power generation, and actual power generation curve,

d) gas turbine (gas internal combustion engine) daily power generation, total power generation, and actual power generation curve,

e) battery daily charge, total charge, daily discharge, and total discharge,

f) the maximum load and time of occurrence; the maximum voltage/current among the three phases of the load and time of occurrence,

g) microgrid daily power generation, total power generation, actual power generation curve, and actual load curve,

h) distributed power supply active and reactive power generation,

i) battery active and reactive power generation,

j) load active and reactive power generation.

A.2 Microgrid equipment operating status data

A.2.1 Primary equipment operating status data

Operating status and abnormal detection alarms of primary equipment such as transformers, circuit breakers and combined appliances, distributed power supplies, energy storage devices, reactive power compensation equipment, etc.

A.2.2 Secondary equipment operating status data

Operating status and abnormal detection alarms of secondary equipment including the soft pressure plate for equipment, the self-checking, blocking, and timing status for equipment, the communication status and alarm signals of equipment, the protection setting, the diagnosis result of the health status of equipment, etc.

A.2.3 Auxiliary equipment operating status data

AC and DC power supply operating status, abnormal detection alarms, working conditions, power failure alarms, security protection, fire protection, access control alarms, and environmental abnormal alarms.

A.3 Microgrid forecast data

a) PV power generation forecast data (for the next 4 hours or the next day),
b) wind power generation forecast data (for the next 4 hours or the next day),
c) load forecast data (in future 4/24 hours).

A.4 Distributed energy planning data

a) battery charging and discharging planning (for the next 4 hours or the next day),
b) diesel generator power generation planning,
c) gas turbine power generation planning,
d) distributed power generation planning (for the next 4 hours or the next day).

Annex B
(informative)

Examples of actual microgrid applications and the associated functions of MMCS

B.1 Application CN1: MMCS of microgrid with photovoltaic and battery compacted with monitoring and control system of intelligent office park

B.1.1 General

This project is located in Qingyuan, Guangdong Province, China. Chengchuang industrial park has four office premises and a newly built intelligent power distribution room. The Qingyuan Chengchuang Industrial Park microgrid is a non-isolated microgrid established by Digital Grid Research Institute, CSG.

The microgrid shown in Figure B.2 includes a 150 kWh energy storage system, a 150 kW power conversion system, a 150 kW photovoltaic power generation system and a microgrid power distribution cabinet.

The energy storage system in this microgrid uses lithium iron phosphate batteries. The rated power of the energy storage system is 150 kW, and the battery capacity is 150 kWh. The energy storage system is connected to the 380 V microgrid busbar through a 150 kW power conversion system.

The microgrid system of this project supports grid-connected operation, island operation, and mode switching.

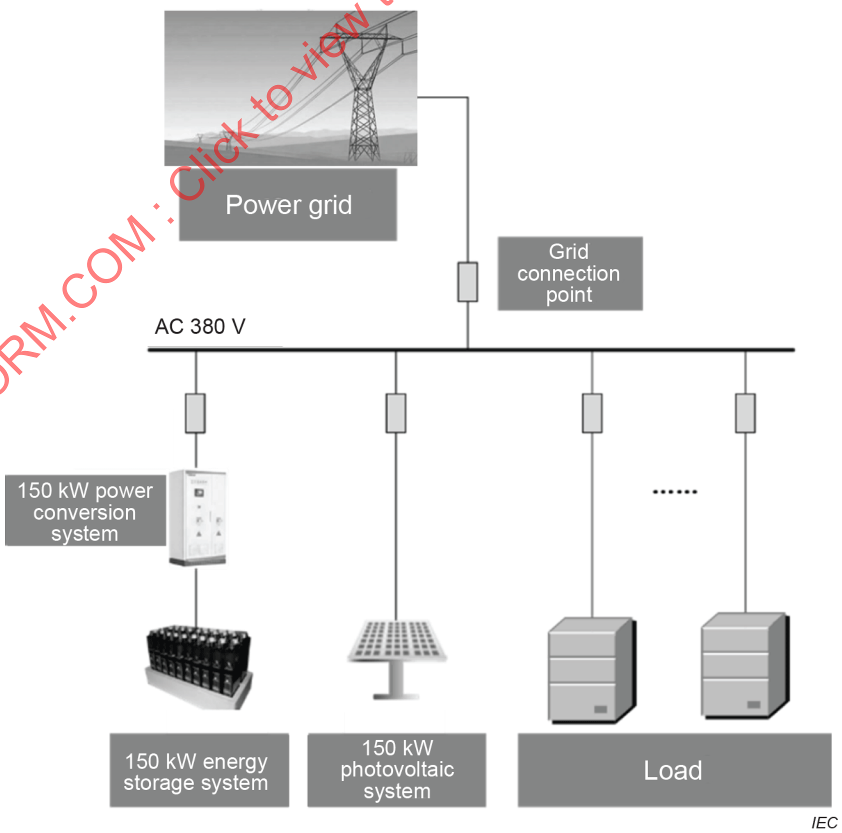

Figure B.1 – Primary structure of Chengchuang microgrid

B.1.2 System structure of MMCS

As shown in Figure B.2, the MMCS of this microgrid communicates with the PLC based controller, power conversion system, photovoltaic power inverters, electric meters, fast switches through network, RS-485 bus, obtaining information such as remote measurement, remote signalling, electric parameters, and events. The microgrid central controller collects data like POC voltage/current and switch position from power conversion system through RS-485 bus and controls the circuit breaker and power conversion system for mode switching.

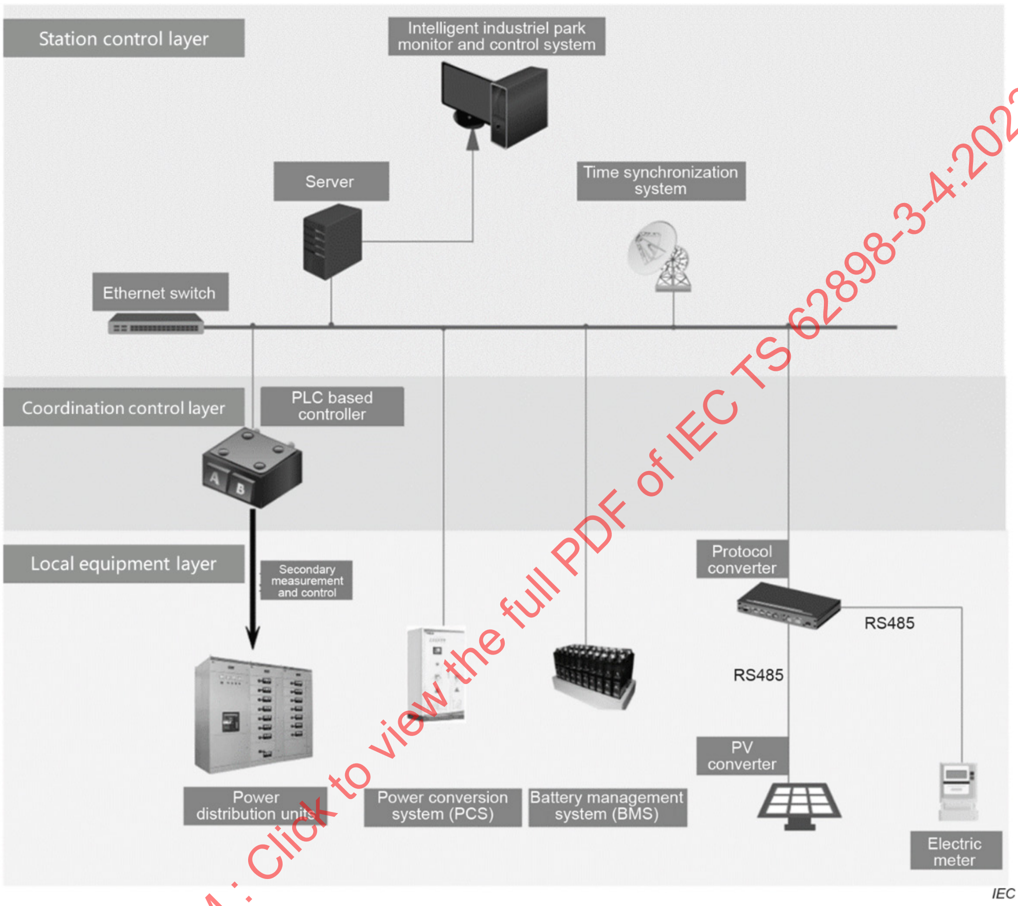

Figure B.2 – System structure of MMCS

B.1.3 Main functions of MMCS

1) Microgrid operation monitoring

   Provide customizable panoramic and comprehensive human-machine displays for various roles such as distributed energy investment and operation personnel, microgrid management and operation personnel, and electricity users. The functions include comprehensive power flow monitoring, energy monitoring, comprehensive energy balance monitoring, and differentiated interaction demands between various users of microgrids.

2) Distributed energy operation monitoring

   Real-time monitoring of distributed energy operating status and power quality of POC, such as voltage, current, power, frequency, etc. The monitoring data can be selected according to the operating conditions of each energy source. Support distributed energy system monitoring, including converter monitoring, protection and control device monitoring, reactive power compensation device monitoring, meteorological environment detection data monitoring, etc.

3) Energy storage system operation monitoring

Perform data interaction with the battery management system, acquiring the operating information of the energy storage system, energy storage components and other equipment. Collect operating data of energy storage system, including voltage, current, state of charge, temperature, switch state, alarm, etc. Collect operating data of the power conversion system, including voltage, current, temperature, switch state, alarm, etc.

4) Load monitoring

Real-time monitoring of microgrid loads, including grid-supplied loads, data centre loads, air-conditioning system loads, electric vehicle loads, etc.; the load of important users, sensitive users, large users, and peak-shift users, etc.

5) Intelligent alarm

Analyse failure and abnormal information in the microgrid power distribution and utilization, such as line voltage/current threshold-crossing, distribution transformer overload, etc., and give alarm prompts in the form of graphical discoloration, flashing, sound, etc.

Conducting real-time analysis of system operations, including switching actions and telemetry modifications. This involves the comprehensive aggregation of alarms, ranging from remote control notifications to reliability alerts. By harnessing automated reasoning guided by pre-established rules, this process yields fault analysis results.

6) Point of connection control

To avoid disturbance of POC from affecting the power flow of the distribution power grid, the power of the POC is maintained within a predetermined range by adjusting the power of energy storage and photovoltaics, so that the microgrid becomes a controllable source/load, thereby enabling friendly access to the grid.

7) Peak shaving

MMCS can control the energy storage output according to the peak shaving needs issued by the dispatch centre. It is also possible to set the peak-to-valley output curve locally, generating electricity at peak electricity price and consuming electricity at valleys, so as to obtain the profit from the peak-to-valley electricity price difference and improve the economic benefits of the microgrid.

8) Mode switching

According to the distributed energy configuration, load situation and grid characteristics of the microgrid, provide feasible control strategy for microgrid in both grid-connected and island operation, and realize the arbitrary selection and switching of strategies in the feasible set under the two operating states.

9) Black start control

MMCS can perform black start control, which can realize the self-recovery of the system after the stability control fails.

B.1.4 Applications

The MMCS in this application case is used in an industrial microgrid of a data centre. The focus is on ensuring a reliable power supply to the data centre. A software platform with the energy Internet as the means of information dissemination is built to realize the coordination and mutual support of each module of the park micro grid and the comprehensive management of the park at the same time.

B.2 Application CN2: MMCS of MV small hydropower microgrid for solving power supply problems in remote areas

B.2.1 General

The distributed small hydropower microgrid is located in Xinxing Town, Yunfu City, Guangdong Province. There are many small hydropower stations in Xinxing Town, and the peak-valley difference of load is large. The voltage in Xingxin Town often exceeds the upper limit in flooding period, while exceeds the lower limit in drought period. The overvoltage and undervoltage conditions are threatening the safety of electrical equipment. The electric customer load is small, scattered, and grows slowly in Xingxin Town. The construction of traditional substations is expensive, and the cycle is long, which leads to a long payback period of construction investment, low utilization rate of equipment, and waste of power grid resources. To improve the consumption of small hydropower generations, and improve the power supply reliability of Xinxing Town, the 10 kV distributed small hydropower microgrid was built.

The main single line diagram of the small hydropower microgrid is shown in Figure B.3. There are many small hydropower stations in the power supply area of 35 kV Jiaoshan substation in Xinxing Town. The substation has 410 kV outgoing line bays. The load installed capacity of Xiangshun branch line is 1 250 kVA, and the small hydropower of Xiachang branch line is 1 730 kVA. The load capacity of Xishui branch line is 670 kVA, and the small hydropower is 5 300 kVA. The load capacity of Caotian branch line is 40 kVA and the small hydropower is 5 300 kVA.

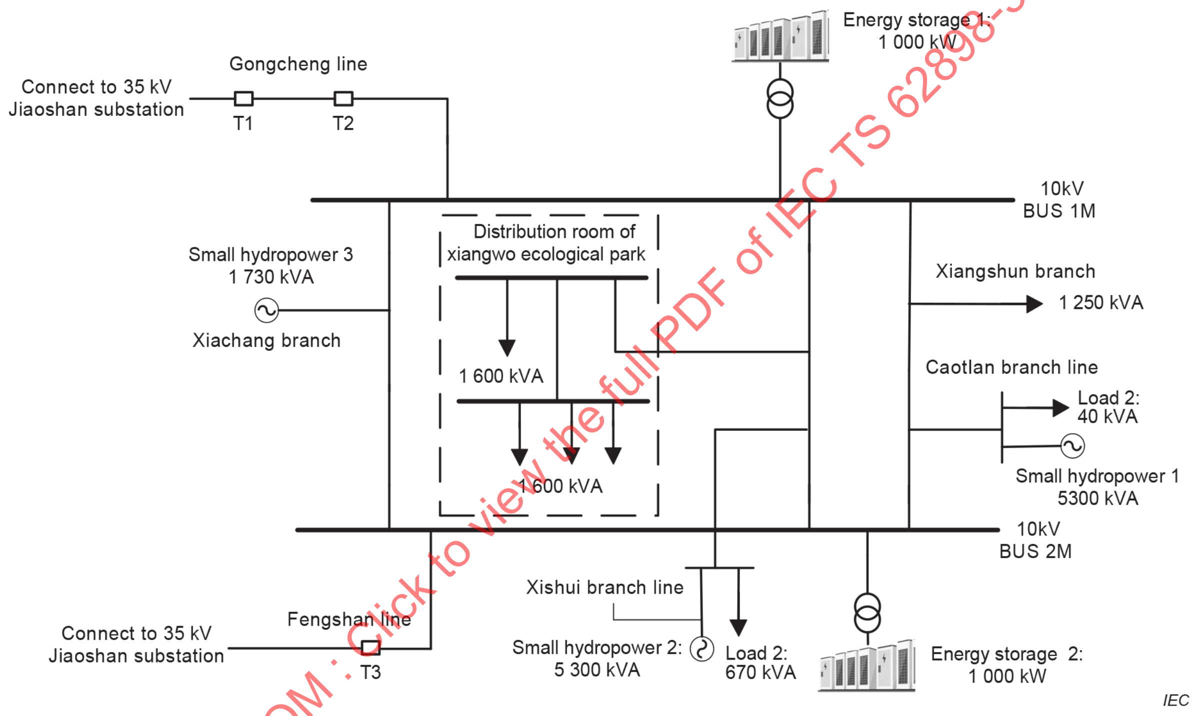

Figure B.3 – The main single line diagram of the small hydropower microgrid

B.2.2 System structure of MMCS

The main structure of MMCS is shown in Figure B.4. The MMCS is configured with multiple workstations, servers, and an embedded central controller. Communication among these components is established using the communication protocol specified in IEC 60870-5-104. This connectivity enables the MMCS to gather a range of information, including system measurements, remote signalling, equipment settings, and system events. The central controller collects the information of energy storage and loads in local control layer through GOOSE and controls the circuit breaker and power conversion system for mode switching.

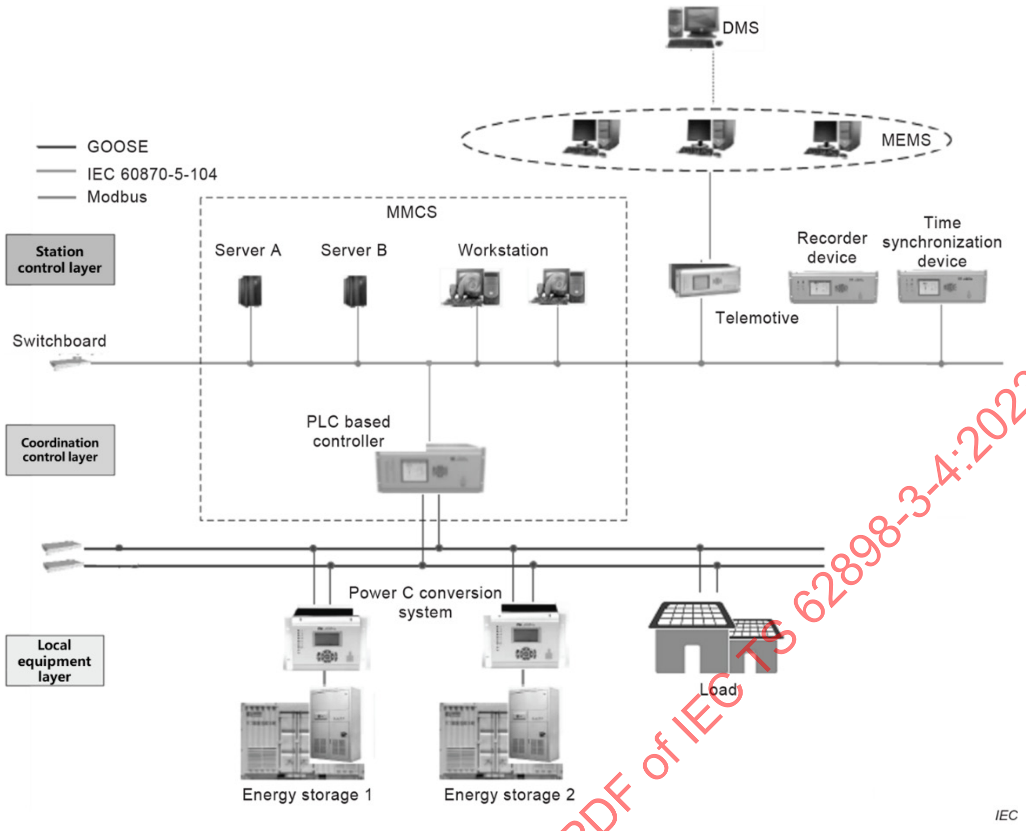

Figure B.4 – The main structure of MMCS

B.2.3 Main functions of MMCS

B.2.3.1 Operation mode

The main operation modes of the small hydropower microgrid include:

- grid-connected operation mode,
- off-grid operation mode,
- outage state.

B.2.3.2 Operation mode switching

The small hydropower microgrid is mainly switched between shutdown, grid-connected operation mode and island mode in the following situation.

- power outage during grid-connected mode,
- black start,
- power outage during island mode,
- planned transition of different operation modes.

B.2.3.3 Grid-connected control strategy

The control strategy during grid-connected mode is as follows:

- ensure the voltage runs in the normal range,
- the load in the microgrid power supply area will not be cut off,
- minimize the amount of wastewater from small hydropower stations,
- reduce the number of switch actions as much as possible.

B.2.3.4 Black start control strategy

Control principle:

- When ESS is serving as the main power source during black start, ESS's transformer zero voltage energization strategy should be adopted to mitigate the excitation surge that might activate PCS protection.
- When the second ESS main power source is deployed, it should be synchronized and closed simultaneously.
- When closing different branches, it is necessary to conduct segmented connection whenever possible to prevent excessive charging current in the lines and excitation surge in the transformer, which could activate PCS protection.
- By implementing a sequential startup approach that alternates between hydroelectric power and loads, the process of gradually restoring power supply can effectively minimize disruptions to the primary power source.

Problems:

- The hydroelectric branch possesses an excessively large capacity, making segmentation for switching infeasible. This results in substantial excitation surge impact during the black start process and presents challenges in maintaining power balance.
- The hydroelectric units lack adjustability, relying solely on the 2MW energy storage for power balance. In the event of increased future loads, ensuring uninterrupted power supply throughout the entire network becomes uncertain.

B.2.3.5 Control strategy of off-grid operation mode

Control principle:

- Off-grid operation should make the power deviation between hydropower and load as small as possible, so that the energy storage operation can be in a safe range.
- The power supply is guaranteed according to the set load priority, and the guaranteed time of the highest load is at least 1 hour. When the power supply of the highest load cannot be guaranteed for 1 hour, the power supply range is reduced.

Problems:

- At present, the hydropower branch line can only be switched as a whole, which makes it difficult to match the power of the load. Therefore, it is suggested that the hydropower branch line should be switched by stages.

B.2.3.6 Control strategy of island to grid-connected

Operating conditions:

- Operating conditions: When the voltage of the large power grid is restored, the island to grid-connected control can be implemented, so that the microgrid can be switched to grid-connected operation autonomously.

Control principle:

- Close the branch switches T1, T2 on Gongcheng Line and T3 on Fengshan LIne from the connection point. If the branch to be closed is not in the off-grid operation state, the switch can be closed directly.