EcoStruxure™ Microgrid Operation Large

For Large and Critical Applications

Functional Specifications

DOCA0371EN-00
02/2025

www.se.com

Legal Information

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Safety Information

Important Information

Read these instructions carefully, and look at the equipment to become familiar with the device before trying to install, operate, service, or maintain it. The following special messages may appear throughout this documentation or on the equipment to warn of potential hazards or to call attention to information that clarifies or simplifies a procedure.

The addition of this symbol to a “Danger” or “Warning” safety label indicates that an electrical hazard exists which will result in personal injury if the instructions are not followed.

This is the safety alert symbol. It is used to alert you to potential personal injury hazards. Obey all safety messages that follow this symbol to avoid possible injury or death.

DANGER

DANGER indicates a hazardous situation which, if not avoided, **will result in** death or serious injury.

WARNING

WARNING indicates a hazardous situation which, if not avoided, **could result in** death or serious injury.

CAUTION

CAUTION indicates a hazardous situation which, if not avoided, **could result** in minor or moderate injury.

NOTICE

NOTICE is used to address practices not related to physical injury.

Please Note

Electrical equipment should be installed, operated, serviced, and maintained only by qualified personnel. No responsibility is assumed by Schneider Electric for any consequences arising out of the use of this material.

A qualified person is one who has skills and knowledge related to the construction and operation of electrical equipment and its installation, and has received safety training to recognize and avoid the hazards involved.

About The Document

Document Scope

The aim of this guide is to provide specifier, facility manager, building owner a comprehensive technical description of the Schneider Electric's EcoStruxure Microgrid Operation Large **(EMO-L)** functions and features.

Validity Note

This guide applies to the EMO-L models and firmware versions described in the following table:

Commercial reference	License Name	License Description
EMOLCTRL	EMO_L_Controller for Microgrid Large and Critical Applications	EPAS GTW license with ADD on MG Application, Linux based
EMOLHMI	EMO_L_HMI (Server + Client)	EPAS UI -1 lic per PC up to 120000 tags

General Cybersecurity Information

In recent years, the growing number of networked machines and production plants has seen a corresponding increase in the potential for cyber threats, such as unauthorized access, data breaches, and operational disruptions. You must, therefore, consider all possible cybersecurity measures to help protect assets and systems against such threats.

To help keep your Schneider Electric products secure and protected, it is in your best interest to implement the cybersecurity best practices as described in the Cybersecurity Best Practices document.

Schneider Electric provides additional information and assistance:

- Subscribe to the Schneider Electric security newsletter.
- Visit the Cybersecurity Support Portal web page to:
  - Find Security Notifications.
  - Report vulnerabilities and incidents.
- Visit the Schneider Electric Cybersecurity and Data Protection Posture web page to:
  - Access the cybersecurity posture.
  - Learn more about cybersecurity in the cybersecurity academy.
  - Explore the cybersecurity services from Schneider Electric.

Online Information

The information contained in this guide is likely to be updated at any time. Schneider Electric strongly recommends that you have the most recent and up-to-date version available on www.se.com/ww/en/download.

The technical characteristics of the devices described in this guide also appear online. To access the information online, go to the Schneider Electric home page at www.se.com.

Related Documents

You can download the technical publications and other technical information from our website at https://www.se.com/ww/en/download/.

Information on Non-Inclusive or Insensitive Terminology

As a responsible, inclusive company, Schneider Electric is constantly updating its communications and products that contain non-inclusive or insensitive terminology. However, despite these efforts, our content may still contain terms that are deemed inappropriate by some customers.

Trademarks

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Cybersecurity Best Practices

Overview

The objective of cybersecurity is to provide increased levels of protection for information and physical assets from theft, corruption, misuse, or accidents while maintaining access for their intended users. There are many aspects to cybersecurity including designing secure systems, restricting access using physical and digital methods, identifying users, as well as implementing security procedures and best practice policies.

This section provides information on how to secure your system from a malicious cyber-attack.

Refer to Schneider Electric's product security brochure for Recommended Cybersecurity Best Practices.

To communicate a security topic affecting a Schneider Electric product or solution, go to Vulnerability Management Policy.

NOTICE
POTENTIAL COMPROMISE OF SYSTEM AVAILABILITY, INTEGRITY, AND CONFIDENTIALITY Change default passwords or passcodes to help prevent unauthorized access to device settings and information. Disable unused ports or services and default accounts, where possible, to minimize pathways for malicious attacks. Place networked devices behind multiple layers of cyber defenses (such as firewalls, network segmentation, network intrusion, detection and protection). Use cybersecurity best practices (for example: least privilege, separation of duties) to help prevent unauthorized exposure, loss, modification of data and logs, interruption of services, or unintended operation. **Failure to follow these instructions can result in unintended data loss or loss of application function.**

Product Defense in Depth

It is advised to Implement a layered network approach incorporating multiple security and defence controls in your IT and control system to minimize data protection gaps, mitigate single points of failure, and establish a robust cybersecurity posture. The greater the number of security layers within your network, the more challenging it becomes to breach defences, compromise digital assets, or cause disruptions. All communicating equipment's access should be restricted to authorized staff only (using locked enclosures and locked technical room).

Defense in Depth Measures Expected in the Environment

Schneider Electric recommends a Defense-in-Depth approach to cyber security for its customers. Defense-in-Depth is a hybrid, multilayered security strategy that provides holistic security throughout an industrial enterprise.

Cybersecurity Policy

Security plan, policies, and procedures that cover risk assessment, risk mitigation, and methods to recover from disaster. Policy is available with up-to-date guidance on governing the use of information and technology assets in your company.

Perimeter Security

Firewalls, authentication, authorizations, VPN (IPsec) and antivirus software to prevent unauthorized access.

Monitoring and Update

Monitoring and update provides:

- Surveillance of operator activity and network communications.
- Regular updates of software and firmware.
- Monitor and restrict use of shared user account.

Security Hardening Guidelines

Device Hardening

Password management, user profile definition, and deactivation of unused services to strengthen security on devices. Controls against malware - detection, prevention, and recovery controls to help protect against malware are implemented and combined with appropriate user awareness.

Securing Network

NOTICE

POTENTIAL COMPROMISE OF SYSTEM AVAILABILITY, INTEGRITY, AND CONFIDENTIALITY

Use cybersecurity best practices to help prevent unauthorized access to the software.

Failure to follow these instructions can result in unintended data loss or loss of application function.

Improve security of networked devices by using multiple layers of cyber defense (such as firewalls, network segmentation, and network intrusion detection and protection). Disable unused ports or services and default accounts to help minimize pathways for malicious attackers.

To reduce the security risks associated with networks, follow these guidelines:

- Use firewalls and other security devices or settings to limit access to the host network, based on your security risk assessment.
- When using a firewall:

  Restrict communication to the expected ports, as per your network configuration. Only open those ports that are necessary for network communication.

- When using network switches:

  Close or disable unused network ports to prevent unauthorized connection of network nodes or PLCs.

Securing PCs

Patching

NOTICE
POTENTIAL COMPROMISE OF SYSTEM AVAILABILITY, INTEGRITY, AND CONFIDENTIALITY
Apply the latest updates and hotfixes to your Operating System and software.
Failure to follow these instructions can result in unintended data loss or loss of application function.

Ensure all windows updates and hotfixes, especially windows security updates are regularly applied to machines running EcoStruxure Power Commission application.

Allowlisting

Zero-day cybersecurity attacks take place before a software vendor is aware of a cybersecurity misuse. This means that neither software, nor anti-virus programs have been created or updated to protect against the zero-day threat or attack. Application allowlisting is recommended to protect against zero-day attacks. This specifies an index of approved software applications and processes (in our case, EcoStruxure Power Commission application) that are permitted to be present and active on PC.

Secure Disposal Guidelines

Secure disposal refers to systematically retiring outdated legacy software and hardware without compromising business needs or compliance requirements. It can be done in two ways:

- First, it uses a rigorous process to analyze the overall solution portfolio and identify the best (or all) candidates for disposal.
- Second, it employs innovative technology that can extract data from difficult legacy environments and store it in an accessible but fully compliant central repository.
- Secure disposal of media containing customer data with an option for reuse can be done by the customer, Schneider Electric or 3rd party service provider.

Disposal Strategy and Design

To define disposal strategy with the purpose of maximizing the Return of Investment (ROI) and minimizing disruption, analysis of solution architecture should be performed. Analysis outcomes should be documented.

Disposal Implementation

Disposal implementation should follow a comprehensive design effort. Implementation is not complete until proven and validated by rigorous testing with a complete documentation trail.

Secure Operation

NOTICE
POTENTIAL COMPROMISE OF SYSTEM AVAILABILITY, INTEGRITY, AND CONFIDENTIALITY Use cybersecurity best practices and follow recommended operation guidelines while using the application. **Failure to follow these instructions can result in unintended data loss or loss of application function.**

Recommended Operation Guidelines

It is recommended to close EcoStruxure Power Commission application before switching the user account or logging out of user account.

Do not install untrusted extensions in web browser. Follow your organizations IT policy for the safe use of web browsers.

Periodically review application event logs.

Disable unused Universal Serial Bus (USB) ports.

Network Monitoring

When using a firewall:

- Periodically monitor the firewall to ensure the configuration has not been changed, and that the firewall status does not indicate communication has occurred on unexpected ports.
- Only open those ports that are necessary for network communication.
- When using network switches: Periodically monitor the switch to ensure the configuration has not been changed, and that the switch status does not indicate communication has occurred on unexpected ports.

Monitoring PC

Back up the project file regularly and store it in a secure, separate, non-shared location.

Install operating system patches and anti-virus software updates on the PC, as they are released.

Periodically monitor the Windows accounts available on the PC to ensure that only the necessary personnel can log on to the PC, with the appropriate level of access. Remove inactive or unnecessary user accounts.

Review the windows system events log to monitor logon and logoff activity on all the PCs, and to detect attempted unauthorized activity.

Periodically review user accounts and their roles and privileges to ensure compliance with your organization’s policy.

Account Management Guidelines

Securing User Access

NOTICE
POTENTIAL COMPROMISE OF SYSTEM AVAILABILITY, INTEGRITY, AND CONFIDENTIALITY Use cybersecurity best practices when configuring user access. **Failure to follow these instructions can result in unintended data loss or loss of application function.**

Cybersecurity policies that govern user accounts and access, such as least privilege and separation of duties, vary from site to site. Work with the facility IT system administrator to ensure that user access adheres to the site-specific cybersecurity policies.

Recommendations to optimize cybersecurity in a protected environment:

- Make sure not to use a shared user account. Use a separate account for each user.
- Assign users only the essential permissions needed to perform their role.
- Revoke user permissions when no longer needed due to role change, transfer, or termination.

Awareness and Education

Knowledge is the first step to prevent cyber intrusions. Review the following resource to increase your cybersecurity awareness.

The Schneider Electric Cybersecurity Portal contains cybersecurity news, security notifications, and additional resources.

Schneider Electric Cybersecurity Support Overview

The Schneider Electric cybersecurity support portal outlines the Schneider Electric vulnerability management policy. The aim of the Schneider Electric vulnerability management policy is to address vulnerabilities in cybersecurity affecting Schneider Electric products and systems to protect installed solutions, customers, and the environment.

Schneider Electric works collaboratively with researchers, Cyber Emergency Response Teams (CERTs), and asset owners to ensure that accurate information is provided in a timely fashion to protect their installations.

Schneider Electric's Corporate Product CERT (CPCERT) is responsible for managing and issuing alerts on vulnerabilities and mitigations affecting products and solutions.

The CPCERT coordinates communications between relevant CERTs, independent researchers, product managers, and all affected customers.

Schneider Electric Cybersecurity Support Portal

The support portal provides the following information:

- Cybersecurity vulnerabilities of products.
- Cybersecurity incidents.
- Interface that enables users to declare cybersecurity incidents or vulnerabilities.

Security Notification

Product security notification posted can be viewed via Schneider Electric website: https://www.se.com/ww/en/work/support/cybersecurity/security-notifications.jsp

Vulnerability Reporting and Management

Cybersecurity incidents and potential vulnerabilities can be reported via the Schneider Electric website:Report a Vulnerability.

For more information on cybersecurity for EcoStruxure, visit the website:

https://www.se.com/ww/en/work/solutions/cybersecurity/.

EcoStruxure Microgrid Operation Large

Introduction

This document should be used for general specification purposes only. The final solution design is based on the customer project requirement.

The design of each Microgrid project varies based on size, power and voltage levels, types of Distributed Energy Resources (DER), electrical loads, and environmental factors. The environmental factors, such as location, climate, standards and regulations, utility interconnection requirements, local energy pricing, physical layout, main drivers, and cost criteria, are project-specific and define the solution's design.

Hence, a preliminary engineering study should be performed by Schneider Electric or a third party, to model the physical and economic environment and context. The study helps the engineering team in determining the types and power ratings of the Microgrid components to be used and aids in proposing the appropriate technical design and configuration of the EcoStruxure Microgrid Operation Large solution.

Overview

EMO-L is a Microgrid controller. Microgrid and DER technologies are increasingly chosen by the energy industry as the strategy to provide cost-effective, resilient, and adaptable supply of sustainable energy. With Microgrids, DER can operate in parallel with the grid or selectively islanded in the event of electricity outage or to reduce energy cost.

A Microgrid is a managed group of DER such as:

- Energy production sources for example, solar panels, combined heat and power facilities (CHP systems), gensets and so on.
- Energy storage systems for example, Battery Energy Storage System (BESS), thermal energy storage system and so on.
- Shed able loads that can be shed during an outage.

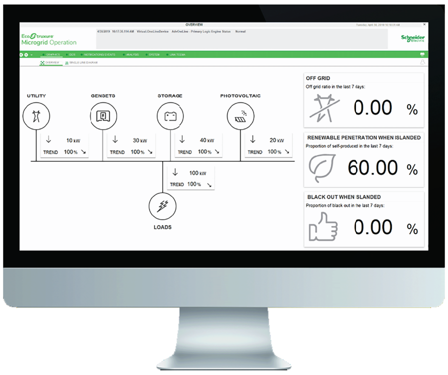
Features

EMO-L is a controller with dedicated HMI which allows the monitoring and control of the DER systems within the Microgrid.

EMO-L offer comprises of:

- Microgrid Controller

- HMI: Ecostruxure Power Operation or EPAS-UI.



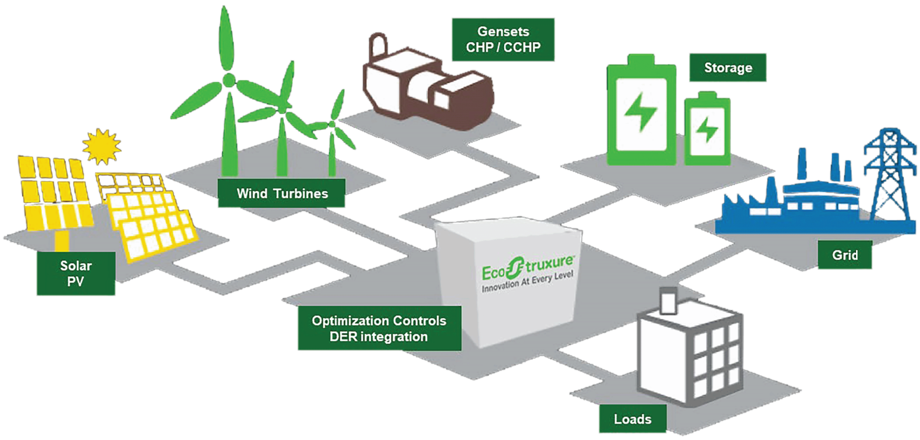
The features of EMO-L Microgrid are:

- Ensure the stability of the Microgrid by synchronizing the energy production sources, loads, and energy storage systems based on the energy requirement.
- Automatically disconnect and re-connect the Microgrid from or to the grid (islanded mode or grid-connected) in case of abnormal electrical conditions such as grid blackout.
- Maintain the frequency and voltage in the Microgrid during islanded or off-grid mode within an acceptable operating range.
- Perform dynamic electrical topology computations in real time to manage the energy production or consumption.
- Adapt the power production of each DER.
- Shed non-critical loads when the Microgrid power production is lower than the demand.
- Island management of the Microgrid.
- Real-time control of DER.

EMO-L Architecture

Microgrid Concepts

A Microgrid is a combination of interconnected loads and DER within clearly defined electrical boundaries, controlled as a single entity, and operating in parallel with the grid or in an intentional islanded mode.



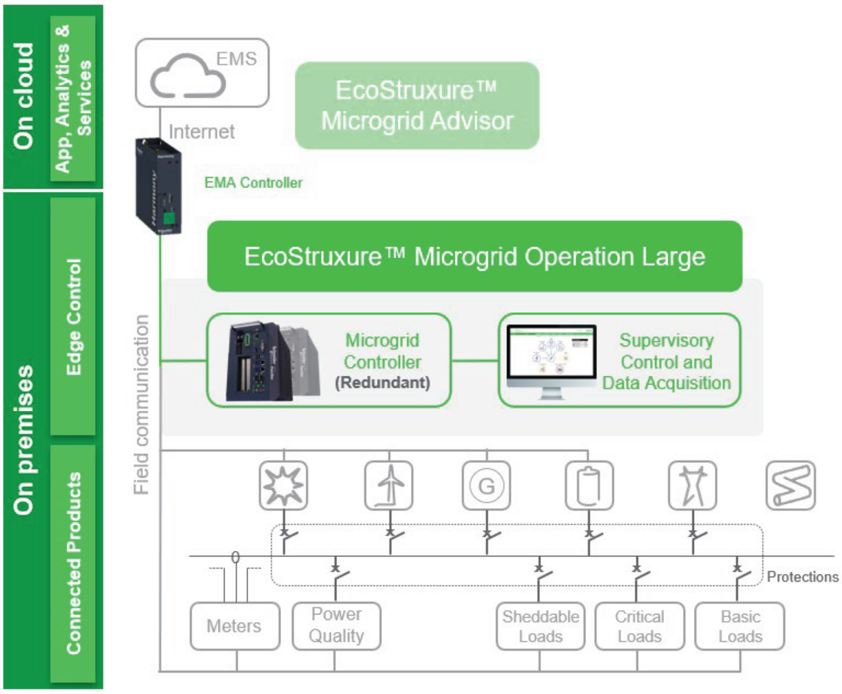
A Microgrid provides a decentralized, digitized, and decarbonized alternative to expensive and polluting fuels.

A Microgrid is composed of:

- Electrical network: medium and/or low voltage, with the related protective and measuring devices.
- Microgrid management and control solution (such as EMS, PMS, SCADA)
- Grid

  NOTE: The grid may not be present in case of pure islanded application, called as off - grid Microgrid.
- DER (such as PV, Storage, wind turbines, Genset and CHP)
- Loads

Microgrid Management System



Microgrid Management System consists of two major subsystems:

- Energy Management System (EMS): EMS is a software-based control system that oversees the operation of the entire Microgrid when the site is connected to the grid and optimizes the utilization of various DER within the system. The main goal of the EMS is to ensure efficient and reliable energy supply while managing the energy demand in the Microgrid.
- Power Management System (PMS): PMS is responsible for the real-time control and coordination of power flow within the Microgrid by managing the switching and islanding operations. The PMS manages the real-time control and coordination of power flow to ensure safe and stable operation.

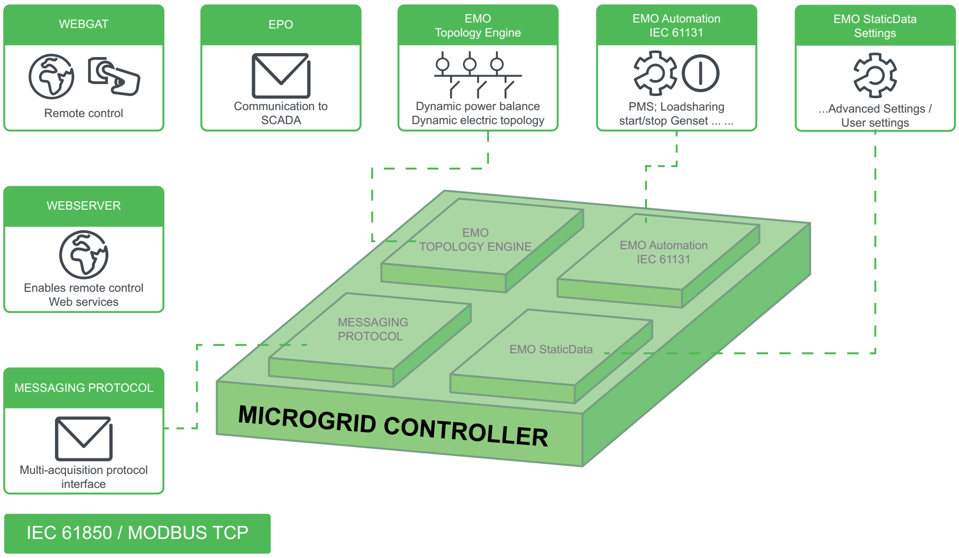
In this guide, the EMO-L solution which is the PMS dedicated to large and critical Microgrid application is described. EMO-L is based on EcoStruxure Power Automation System solution (EPAS). For further information about the EPAS solution please contact Schneider Electric or consult the website to get more detailed information.

EMO-L Software Modules

EMO-L Microgrid controller is a modular solution concerning software and functional levels. EMO-L Microgrid controller functions are configurable as per the requirements. The EMO-L Microgrid controller is composed of the following modules:

- Topological Engine
- EMO Automation
- Messaging Protocol (internal messaging bus exchange)
- EMO Static Data
- WebGAT

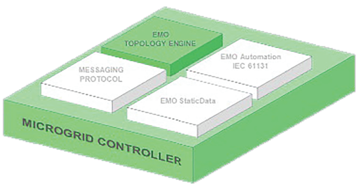
NOTE: EMO Studio provides the final data base which should be uploaded to the EMO controller, the Web EPAS Gateway Administration Tool (WebGAT) controls this operation.



EMO Topology Engine

Topology engine module is a dedicated internal component that dynamically analyzes electrical and power balance information in real time and publishes the results on the network using IEC 61850 and/or Modbus protocol.

Electrical network topological changes occur frequently in Microgrids structures, mainly due to the transition to islanded mode of operation and due to the intermittency of the power supply from the renewable energy sources. EMO-L Microgrid controller uses real-time information from the topological engine to determine and perform required control actions when pre-defined configured situations or parameters are met.



The following parameters are monitored by the EMO Topology Engine:

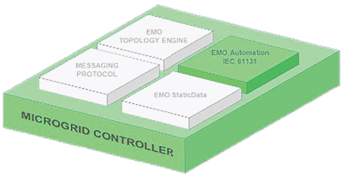
- **Topology of Microgrid electrical network:** Topological engine constantly computes the electrical network topology and islanding parameters, retrieves, and reports the state of the electrical network and its components (circuits breakers, busbars, and so on) in real time.

- **Power production per island:** Computes the energy production per island, the power delivered, rated nominal power and power capacity, voltage, and frequency in real time. The computation is performed for each group of available DER types.

EMO Automation

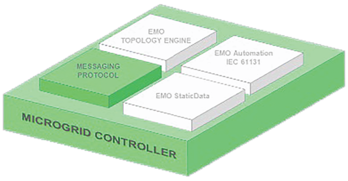
EMO Automation is the main component of EMO-L. It controls and manages the different islands of the installation, the DER operation and maintains network stability considering external criteria such as operator constraints.

EMO Automation module is based on ISaGRAF IEC 61131 and it allows adaptation of the algorithms as per requirements within its programming capabilities.



Messaging Protocol

EMO-L messaging protocol module is a bidirectional messaging interface (kernel) in charge of the acquisition and transmission of messages or data using various protocols.



The following communication protocols are supported by EMO-L messaging protocol module:

Lower layer interfaces

- **MODBUS TCP**: EMO-L messaging protocol module communicates in MODBUS TCP with DER and loads in the scope of Linux EcoStruxure Power Operation System (EPAS) gateway.

  It receives and publishes status data, measurements, setpoint values and control commands. It sends MODBUS TCP communication status on MODBUS network.

- **IEC 61850**: EMO-L messaging protocol module communicates in IEC 61850 in the scope of Linux EPAS. It receives and publishes status data, measurements, setpoint values and control commands.

  It sends IEC 61850 communication status on IEC 61850 network.

- **DER interfaces**

  EMO-L interacts with a set of different field equipment to perform control and management functions. Field equipment are from different suppliers.

  The following table summarizes expected DER interfaces and communication protocols:

Interface	Modbus	IEC 61850
Diesel generator controller	✓	✓
PV system	✓	✓
BESS	✓	✓
IED	✓	✓

NOTE: The feasibility of protocol implementation will be evaluated based on project needs and constraints, however this list is provided as a general overview.

Upper layer interfaces

EMO-L can communicate with an upper layer management system using multiple interfaces in parallel with bidirectional communication.

EMO-L messaging protocol module interfaces and communicates with EMA using MODBUS TCP. It receives and publishes status data, measurements, setpoint values and control commands.

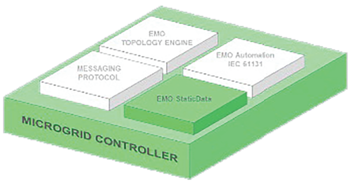
The following table summarizes the connections and protocols managed with upper layer management elements:

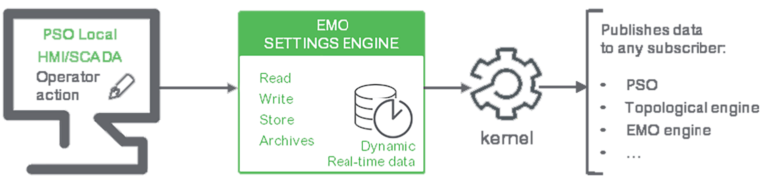
Interface	Modbus	DNP3	IEC 61850
EcoStruxure Microgrid Advisor (Schneider Electric EMS solution)	✓		
EMS/ADMS/SCADA	✓	✓	✓
Local HMI SCADA	✓	✓	✓

Distributed Network Protocol (DNP3): DNP3 is a set of communication protocols used between components in process automation systems. Its main use is in utilities such as electric and water companies.

EMO Static Data - Settings Engine

EMO-L settings engine provides real time dynamic access for PMS algorithms settings and allows the Microgrid operator or commissioning engineer via local HMI to modify Microgrid controller settings to fine-tune system configuration to suit the size and other current needs of the project.





EMO-L - Hardware and Software Solution

EMO-L is built on two iPC:

- The first is the Microgrid controller with redundancy capabilities mainly in charge of executing the power management of the Microgrid.
- The second one executes the Microgrid user interface (HMI or/ SCADA) for monitoring and controlling the DER and loads within the Microgrid.

The entire system can interface with an Energy Management System (EMS) such as the EcoStruxure Microgrid Advisor (EMA) providing energy optimization through forecasting and economic dispatch, and/or a Remote-Control Center, SCADA or ADMS. EMO-L solution also integrates different IED acting as DER interfaces.

Microgrid Controller

EMO-L has been tested on the two following hardwares:

NOTE: It is recommended to use the **Perfectron SCH3X1 Microgrid controller – Fanless Power Automation Computer**.

- Perfectron SCH3X1 Microgrid controller – Fanless Power Automation Computer

		System	I/O Interfaces
	9V to 48V Ultra-Wide DC power input Relative humidity: 5% to 95%, non-condensing Operating T°C range -40°C ~ 60°C	Intel ® Core™ i7-9700TE 32 GB DDR4-2666MHz 128 GB SSD 2 x 2.5" Easy swap SSD Tray TPM, FTDI support	1 x DP, 1 x DVI, 1 HDMI 6 x USB 3.0, 2 x SB 2.0 2 x COM (RS232/ 422/485)

- Advantech UNO 148 – FANLESS DIN- RAIL iPC.

		System	I/O Interfaces
	9V to 36V DC power input IP20 Relative humidity: 5% to 95%, non-condensing Operating T°C range: -20°C ~ 60°C with airflow	11th GEN Intel ® CoreTM I CPU Up to 64 GB DDR4-3200MHz 1 x 2.5" HDD/SSD (2 with optional kit) 2 x 3.5" HDD by i-module TPM 2.0	2 x DP 4 RJ45 3 x USB 3.0, 1 x USB 2.0 4 x RS232/422/485

Microgrid Controller Redundancy

EMO-L can implement redundant Microgrid controllers that can back up each other in the event one of them becomes unavailable unexpectedly. The redundancy in the Microgrid controllers helps to maintain and ensure the continuity of the Microgrid. EMO-L Microgrid controller redundancy is based on two identical controllers having the same behavior and running the same software with the same database configuration, protocols, and I/O mapping.

One of the controller is set as the main controller and the other as the backup controller. Both the controllers operate in either active mode or standby mode but only one of the redundant controllers is active at a time. If the controller in active mode becomes unavailable, the transfer to the controller in standby mode is performed automatically to help prevent data loss.

Human Machine Interface or Supervisory Control and Data Acquisition

EMO-L integrates a dedicated local Microgrid Human Machine Interface (HMI) or Supervisory Control and Data Acquisition (SCADA) designed to suit Microgrid monitoring and control specific needs.

HMI or SCADA performs the following actions:

- Enables the control commands or functions from the Microgrid controller to the different actions of the Microgrid structure.
- Displays information coming from the Microgrid controller for example machine status, notifications, power flows, switch status, and so on.
- Provides millisecond time-stamped sequence of event recording to enable event reconstruction and analysis.

  The event system is customizable for local and cloud service needs. These events are available for the operator via mobile device and workstation as well as complementary applications.

The SCADA is preferably based on EcoStruxure Power Operation (EPO) solution for which, a library of single line diagrams as well as pre-designed elements are available.

EMO-L is a flexible solution with interoperability capabilities that allows leveraging already existing third-party SCADA in the Microgrid (brownfield projects). EMO-L can be synchronized with any kind of SCADA using the recommended protocols.

Within Schneider electric portfolio, EMO-L is working with the two offers presented in the following sub chapters. Screen templates are provided based on customer's requirement to use the EPO.

EcoStruxure Power Operation

EPO application helps the operator to monitor, control, and troubleshoot issues with the electrical distribution system. It manages and interacts with the electrical distribution system and the specialized devices connected to the application. The EPO main monitoring and control capabilities are as follows:

- High performance real-time communications.
- Native system redundancy and scalable architecture.
- Extensive protocol support and open data exchange.
- Highly customizable with scripting and an open API.
- Cyber-resilient networks and servers.
- Monitor complex auto-transfer schemes.
- Remotely control breakers.

Power Monitoring and Control

Power Monitoring and Control allows the visualization of the energy usage and power demand, analyzes electrical waveforms, and makes effective and cost savings decisions. High performance real-time visualization of animated one-line diagrams allows you to gain situational awareness of the state of your power system from anywhere, and it allows operators to perform remote control.

It complies to internationally recognized energy and power quality standards such as ISO50001, CBEMA, ITIC, IEEE519 and EN50160.

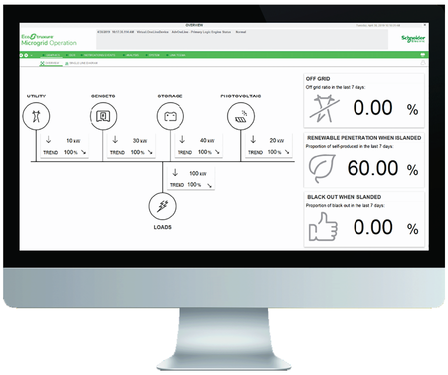
Power Availability

EPO provides sequence of event analysis for the operator to manage complex power and energy alarm and events data with high-integrity precision event timestamps, directly from intelligent electrical devices (meters and breakers). EPO acknowledges when, where and in what order events occurred to uncover the root cause, so the operator can make informed decisions.

It supports open protocols such as Modbus, IEC-61850, IEC- 60870-5-104, SNMP, OPC DA, OPC AE, DNP3, BACnet/IP, and more.

The capabilities for power availability are:

- Rich data integration for connected devices (for example Masterpact MTZ, ION7650, and PM8000).
- Sequence of Events Recording (SER) (1ms).
- Power quality waveform viewer (COMTRADE).



EcoStruxure Power Automation System User Interface

EcoStruxure Power Automation System User Interface (EPAS-UI) is an another SCADA solution that can be used for the microgrid interface. It is Intuitive, scalable, and customizable and EPAS-UI is dedicated to electrical networks and sub-stations. This software also helps in monitoring, supervision, and control capabilities to reduce the risk of your operational activities.

For any question or support regarding EPAS-UI, refer to our website link or raise a request.

EMO-L - Power management System

Features

The purpose of EMO-L is to interact with the DER interconnected to the Microgrid installation to achieve various goals depending on the electrical conditions and the DER operating modes. It includes:

- Generators (Gas Turbine Generators, Steam Turbines Generators, Diesel Generators, CHP)
- Battery Energy Storage System
- PV inverters

In order to achieve this purpose, the primary responsibilities of EMO-L are:

- Acquisition of necessary DER data such as healthiness status, running status, operating mode, frequency and voltage measures, active and reactive powers measures.
- Regulation of the frequency and the voltage on each island (electrical sub-network) to maintain them within their respective predefined acceptable ranges. This regulation is essential to keep the electrical and electromechanical machines, as well as protection IED, in their nominal electrical conditions of running.
- Regulation of the exchanged power within the Microgrid and with the main distributor grid. This regulation is essential to ensure the stability of the electrical power distribution, balancing the loads and the power sources, avoiding blackout, regulating the power shared with the grid generally to limit the imported or exported power for contractual or economic reasons, and/or to target a predefined power factor following the local grid code requirements, protect the assets within the Microgrid installation.
- When a genset is used among the DER, two strategies may be applied. The first one called Fuel eraser strives to limit the usage of the genset energy consumption. The second one, called fuel saver, tries to limit the genset running at its minimal power rate (setting of the control) when it is used.
- Steering the voltage sources to provide to the Microgrid a voltage reference (grid or other voltage source) . This steering may require transitions between the voltage operating modes.
- Manages the transitions between the operating modes. Transitions from grid - connected mode to islanded mode and reverse, or between grid forming sources in islanded mode, involve significant transients in the electrical distribution system which are managed to provide more reliable power supply and continuity.

To achieve these duties, four main functions are implemented within EMO automation, which are executed cyclically or alternatively, depending on the use case and scenario expected by the customer. The four main functions are:

- Operating mode management
- Electrical topology management
- DER management
- Load management

The EMO automation, the automation component of EMO-L, is a software component standing on ISaGRAF workbench. EMO-L can be adapted to fulfill the customer’s requirements, the needs of the application, according to the DER and loads embedded features or characteristics using its programming capabilities. If this kind of adaptation requires an amount of workload, EMO-L offers a set of pre-defined functions which are used to the customer’s use case by configuration task.

Operating Modes Management

The main function of EMO-L is to manage the operating modes of the Microgrid, such as:

- Connection with the grid.
- Transitions between the voltage and frequency reference sources.
- Operators interaction with the Microgrid - automatic and manual mode.

EMO-L can manage several islands in parallel, ensuring the interconnection or disconnection between islands are in specific operating conditions.

Transitions Sequence

EMO-L helps to manage the transitions from grid connected mode to islanded mode and vice versa. When moving from the grid connected mode to the island mode, the alternative energy source is started by the EMO-L and will become the voltage and frequency reference instead of the grid itself: either the GENSET or the BESS. In the Microgrid application terms, the reference alternative source is called the anchor source.

NOTE: EMO-L can disconnect a part of the Microgrid (island) if the Microgrid design and configuration allows it.

According to the feature embedded in the anchoring source, the transitions are either:

- **Open**: the transition is achieved going through a stage where there is no voltage present on the island main busbar. This transition is applied when a grid loss event occurs.

  On the current version of EMO-L, a predefined automatic sequence with generator or BESS as an anchor source and voltage source switching according to power or energy conditions is provided. Adaptation can be achieved by programming work to follow another source strategy when transition.
- **Close**: no voltage interruption on the island main busbar occurs during the transition. This transition is used for energy sources synchronization or when it changes to the grid connected mode.

Transition from Grid Connected Mode to Islanded Mode

EMO-L enables the manual or forced transition from grid-connected mode to islanded mode.

EMO-L performs the following actions to accomplish this transition:

Action	Description
Topology management Monitor the grid availability	The Microgrid controller monitors and analyzes the grid electrical variables in real time (through a specific relay) to detect when the electrical conditions required to disconnect the Microgrid from the grid.
Automatic switch to island mode	As soon as the Microgrid controller identifies the grid power outage, it switches to islanded mode.

Load Shedding	The Microgrid controller initiates load shedding of a prioritized list of electrical loads. This action will adapt the loads' current (and inrush currents in case of a blackstart) to power capabilities of the sources chosen to play as the voltage and frequency reference instead of the grid. In islanding sequence, EMO-L initiates the shed to preselected group of load: • Shed Essential Load • Shed Standard Load
DER management and control CSI to VSI Management	The Microgrid operator selects the alternative voltage and frequency reference energy resource for the island, according to the customer's priorities. The Microgrid operator starts the alternative source, changing its operating mode if required. During the Grid outage, the switch from CSI to VSI is done based on the capability of the DER.

Transition from Islanded Mode to Grid Connected Mode

EMO-L is designed to provide the Microgrid structure with a stable transition from islanded mode to grid-connected mode by managing and controlling the stability of frequency and voltage and balancing the power generation and loads.

EMO-L enables reconnecting of the Microgrid to the utility grid. The voltage and frequency differences need to be detected and synchronized before reconnecting without disruption of the system power supply.

Action	Description
Topology management	The Microgrid controller manages grid connection and interaction to trigger the transition sequence toward the grid connected mode. Information is composed by grid availability and grid operator authorization to reconnect.
Automatic synchronization to the utility grid	The Microgrid controller manages and controls the re-synchronization to the utility grid. For the DERs, the utility grid becomes the frequency and voltage reference.
Main incomer breaker re-closing	Once the Microgrid frequency and voltage are in the acceptable range for t time, EMO-L initiates the sequence to close the main breaker through a synchro-check relay.
Load restoration	When grid is connected, EMO restores all the loads.

Microgrid Power Regulation in Grid Connected Mode

EMO-L performs the following actions during grid connected mode:

Action	Description
DER management Export management	The Microgrid controller controls and manages the generation sources within the Microgrid depending on the power demand. It also performs control actions to balance the generation and consumption in case of export or import of power to the grid. EMO-L prioritizes the usage of available renewable energy instead of other polluting sources. The Microgrid controller monitors the power exported at the utility point of connection in real time. When exported power exceeds a

	predefined threshold, the Microgrid controller loads the battery energy storage system if any, curtails the PV production.
Load sharing	Adjust active power (P) by control / command of distributed generation (sources, storage). Adjust reactive power (Q) by control/command of distributed generation (sources, storage).
BESS management	EMO-L monitors the energy SoC (battery state of charge) of the BESS. It manages and control the determined minimum and maximum SoC in order to increase or decrease PV production to avoid damage caused by BESS overcharging. The Microgrid controller manages the charge /discharge of the BESS according to the SoC level and the strategy defined by the energy management layer.

For more information on the regulations performed, see the following chapters:

- EMO-L DER management, page 32.
- EMO-L Load Management, page 41.

Microgrid Power Regulation in Islanded Mode

EMO-L is designed to provide the Microgrid with stable conditions in islanded mode by managing and controlling the frequency and voltage and balancing the power generation and loads.

EMO-L performs the following actions during islanded mode:

Action	Description
DER management Power reserve (spinning reserve)	The Microgrid controller calculates the power balance of all energy sources in real time, taking into account of their operating mode, that is, forming or supporting type (e.g. rotating machine, grid-forming inverters) considering the capacity of the machine and the ongoing produced power. The operator can configure the reserve ratio of power for the entire Microgrid. Based on this ratio, EMO-L provides enough P/Q reserve by starting or stopping generators.
DER management Load sharing	The Microgrid controller ensures Microgrid stability by maintaining the frequency and voltage within a predefined range by managing the active and reactive power production (P/Q) based on real-time measurements.
DER management Energy source management	The Microgrid controller controls and manages the energy sources within the system according to power demand. EMO-L manages the DER start or stop sequence priorities and set points based on customer strategies and needs. EMO-L prioritizes the usage of available renewable energy instead of other polluting sources.

DER management and control PV curtailment BESS	Maintains the stability of the Microgrid even when the ratio of PV energy supply is too high. The Microgrid controller curtails PV production when it detects an excess of the PV production. EMO-L manages the storage of energy during PV production as well as the use of this stored energy when PV is not producing.
Load management Load shedding Load Restoration	The EMO-L sheds loads according to loads priorities when facing an unexpected loss of source. The Microgrid controller has the ability (once it determines it is appropriated), to reconnect load feeders and re-energized by order of priority based on the loads previously shed. This ability must be initiated by the operator from the graphical user interface.

Fuel Saver - Genset as Anchor Resource

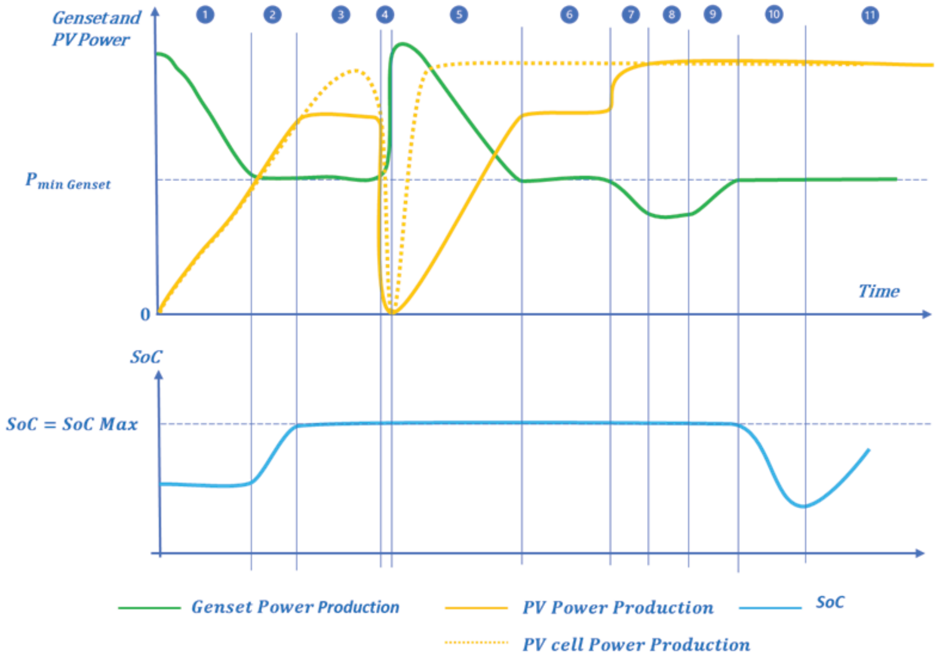
In the following example, EcoStruxure Microgrid Operation (EMO) strives to minimize the fuel consumption of the microgrid and uphold Genset operating at its minimum operating rate power, set by default at 30% of maximum load to avoid wet stacking of the fuel engine.

In Fuel Saver mode, regardless of the anchoring source, the fuel-based generator or BESS, the strategy of the feature is to reduce the fuel consumption and CO_2 emissions. The BESS is optional, saying the strategy considers the presence or not of the BESS. To prioritize the utilization of renewable assets, EMO-L maintains the Genset power at its minimum operating level as much as possible.

The total power demanded by the load(s) is greater than the power produced by the Genset when running at its minimum operating power:

1. Power produced from the PV is prioritized and maximized to satisfy the remaining demand of the loads. As sun is rising, the PV power slowly increases, causing the Genset power to decrease as the PV supports more of the loads.
2. If present and BESS SoC allows, the available excess power produced by the PV is used to charge the BESS. Genset is operating at $P_{\text{min Genset}}$ (set by default to 30% but customizable from local HMI). PV power is still able to increase while maintaining Genset at this optimum level and using excess power to charge the BESS.
3. PV is curtailed to keep the Genset running at $P_{\text{min Genset}}$ as BESS SoC reaches SoC $_{max}$, meaning excess PV power produced can no longer be used to charge the BESS and grid export is not allowed in the present use case (used as example).
4. PV power is reduced abruptly due to a cloud crossing, forcing the Genset to compensate by increasing its power production above $P_{\text{min Genset}}$.
5. The cloud has passed, and PV power availability increases abruptly (yellow dash line). EMO-L slowly increases the PV power with PV smoothing function until the Genset power is once again at $P_{\text{min Genset}}$.
6. Genset power is maintained at $P_{\text{min Genset}}$ by curtailing the PV.
7. This stage is an example of behavior when the PV curtailment is not applied. The PV power increase up to its peak, forcing the genset to run below its minimal power rating. This strategy is applied when there is no BESS or if it is fully charged when present.
8. Steady state is reached.
9. Loads are increasing and the extract power is provided by the genset coming back to its minimal power rating.

10. As loads are still increasing, the excess power demand is then taken by the BESS discharging. If the power provided by the PV and Genset, operating at its minimum power, is insufficient to supply the loads, the BESS is discharged to close the gap, providing its SoC allows this. If still insufficient, the PV and the BESS not able to supply the remaining power, the Genset will operate above its minimum operating power to produce the remaining power required to satisfy the loads.
11. The loads decrease below the sum of the power of the PV and the genset. The Genset continues to run at its minimal power rating, no curtailment applied and the BESS is charged again. In the case where the power demanded by the loads is below the minimum operating power of the Genset, the PVs will be fully curtailed, and the BESS will be charged to maintain the Genset at minimumBESS operating power. If the BESS SoC is at its maximum and unable to be charged, the Genset power will then run below its minimum operating power.



Fuel Eraser - BESS as Anchor Resource

In the following example, EMO-L strives to not run the Genset as much as we can. This is the operating mode when a BESS with grid forming capability is present in the installation. In islanding event, prioritization is done on the BESS usage, if the BESS SoC allows it. And when the SoC reaches the lower limit, then the Genset is started and the microgrid goes to the fuel saver mode.

EMO-L Electrical Topology Management

EMO-L Electrical Topology Management consists of the following:

- Grid Connection Management - Grid Code.
- Coupling Microgrid with the Grid.

Grid Connection Management - Grid Code

Grid codes describes safety, security requirements and obligations to be followed for the correct operation of an electrical system interacting with the public grid. They may vary depending on the site, grid operator and country. Grid codes are normally defined in electricity regulations, norms and/or standards. Also, specific grid codes for DER systems must be applied. When one or several generators are intended to operate in parallel with the supply network, the agreement of the utility is required. The utility specifies the conditions of operation of the generators and specific requirements.

The utility generally requires information concerning the generators, such as:

- Level of the short circuit current injected by the generators in case of fault on the supply network.
- Maximum active power intended to be injected in the supply network.
- Operating principle of the voltage control.
- Capability of the generators to control the power factor of the installation.

In case of fault on the utility supply network, the instantaneous disconnection of the generators is generally required. It is achieved by means of a dedicated control functions specified by the utility. This control function may operate according to the below criteria:

- Under-voltage and over-voltage
- Under-frequency and over-frequency

The islanding function generally orders the opening of the main circuit breaker ensuring the connection of the installation to the utility while the generators continue to supply the totality of the internal consumers or a part only if they are not sized for the full power required. In this case, load shedding must be simultaneously executed with the opening of the main circuit breaker.

Considering the power regulation point of view, these grid connection codes are related to the following:

- Active and reactive powers (power factor) at the point of common coupling.
- Grid protection requirements due to bidirectional electricity flows.
- Voltage and frequency stability requirements.
- Islanding procedures.

When considering the grid connection management, the following options are allowed:

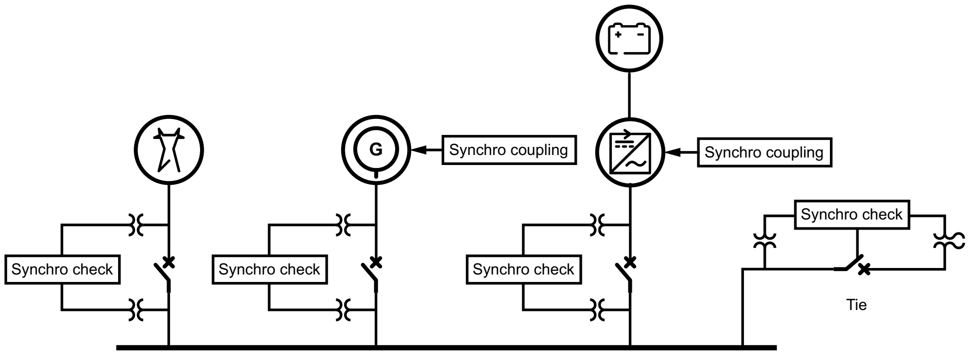
- In autonomous mode, EMO-L Microgrid controller monitors and analyzes the grid in real time, detecting when to disconnect or reconnect to the grid based on electrical conditions. A relay manages the switching device at the interconnection point, following grid codes, with reconnection typically requiring operator authorization.
- External trig order: Islanding or reconnection transition is triggered by the grid operator through an external communication link.
- Internal trig order: Islanding or reconnection sequence is triggered by the grid operator through the HMI or the SCADA.

NOTE: When the External trig order or Internal trig order is planned, the transition may be achieved without any voltage interruption.

Coupling Microgrid with the Grid

EMO-L helps to synchronize power sources without interruption of the main busbar's voltage in which the DER are connected, in other words without interruption of the power delivered to the loads. This is also called as close transition.

When targeting a close transition, the power synchronization is compulsory to avoid any electrical voltage and current transitions among the DER which make their protection relays to trip and even destroy the asset. The power synchronization can be achieved during a reconnection to the grid. Generally, a power synchronization occurs in two phases: the voltage synchronization and the interconnection switch closing when voltages and frequencies are synchronized.



Principles of the Power Synchronization

The following two voltage source sides are considered:

- Reference side - Reference voltage source on which the microgrid is synchronized to.
- Slave side (Microgrid busbar) - side to be synchronized, a DER when the synchronization concerns the connection to the island main busbar.

The objective of the power synchronization is to make the amplitude, frequency and phase angle of the three voltages of the slave side matching the closest possible to the reference side. To achieve this, synchro-coupling features are required for the DER which will be synchronized. The available two options are:

- Synchronization by EMO-L. The DER being in (V/F) control mode, EMO-L adjusts the voltage and frequency set points of the DER to align them with the voltage and frequency of the reference target. The interconnection switching device closing order is sent by EMO-L after checking the voltages synchronism along a window. Once the interconnection switching device is closed, the operating mode of DER will be changed to avoid any issue.
- Synchronization by the DER: The synchro-coupling feature is one of the functions of the DER controller. EMO-L launches the synchronization sequence, providing to the DER controller the handle of the interconnection switching device. The voltages synchronization and the closing order is performed by the DER controller. Once the interconnection device is closed, the operating mode of DER will be changed.

Synchro Check Function

The synchro-checking is to verify the voltages on both sides of an opened interconnection switching device are synchronized (voltages gaps in amplitude, frequency and phase angle are in the tolerances of the settings).

A synchro-check relay is a protective function which avoids the closing of interconnection switching device in case of misalignment of the voltages, which would provoke an electrical transient on the DER being connected. A safe closing of the interconnection switching device is possible only when these values are compatible with the pre-set parameters.

EMO-L DER Management

EMO-L embeds a DER management and control function in charge of driving and interacting with each of the DER in the Microgrid, considering the type of DER and its operating modes. The DER's control achieved by EMO-L depends on the features included in the DER.

Within the scope of the present guide, a DER is considered as an electrical power source. The electrical power produced by a DER is computed by the voltages and currents measured at the DER terminals. But any DER is not a power source, it is either a voltage source or a current source. Some DER can switch from one mode to another mode. According to all the DER characteristics, the strategy to control the DER is adapted.

NOTE: Only voltage source can be used as an anchor source (voltage and frequency reference) in the island mode.

EMO-L provides pre-programmed actions to control the behavior of the generators, BESS and PV system. Mostly, the DERs in a Microgrid use inverter technology to convert DC power to AC power. EMO-L considers the type of the DER inverters in place within the customer's Microgrid to accordingly well-manage and control DER units to achieve their desired operating conditions. EMO-L prioritizes the usage of available renewable energy instead of other sources.

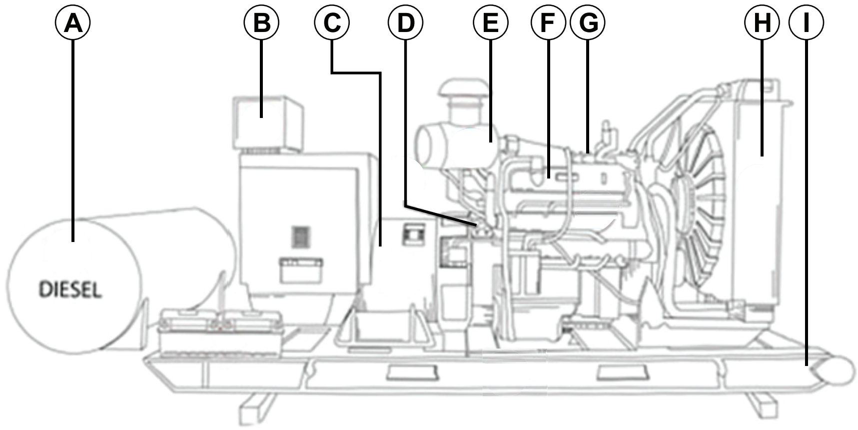
Genset and CHP Control

A Genset is a combination of an engine (prime mover) and an alternator. The engine converts the chemical energy of a fuel (diesel, gasoline, or gas) into mechanical energy. The mechanical energy produced by the engine is used to spin the alternator rotor through the magnetic field between the rotor and stator, creates a voltage on the alternator stator due to the electromagnetic induction phenomenon, converting mechanical energy to electrical energy. An alternator is made of two main parts: rotor and a stator. When connected to a load, which demands for current flow, then the generator produces power.

Cogeneration or Combined Heat and Power (CHP) is the use of a heat engine to generate electricity and useful heat at the same time at high efficiency. With on-site power production, losses are minimized and heat wasted is applied to facility loads in the form of process heating, steam, hot water, or even chilled water. CHP can be located at an individual facility or building, or it can be a district energy, Microgrid, and/or utility resource that provides power and thermal energy to multiple end users. CHP can be paired with other distributed energy technologies like solar photovoltaics and energy storage.

In this EMO-L guide, a CHP is seen as a Genset. Only the electrical behavior of the CHP is considered and controlled by the algorithm.

NOTE: Genset and CHP shall be considered as voltage sources.



A Fuel System

B Control Panel

C Alternator

D Voltage Regulator

E Exhaust System

F Engine

G Lubrication System

H Radiator

I Base Frame

Generator Protection

The generators are protected by dedicated protections. For medium size generators, the following protections are used:

- Phase to phase and phase to earth over current.
- Percentage biased differential
- Negative sequence over current
- Overload
- Stator frame fault
- Rotor frame fault
- Reverse active power
- Reverse reactive power or loss of field
- Loss of synchronization
- Over and under voltage
- Over and under frequency
- Overheating of bearings

It is recommended to check with the manufacturer ability in providing a short circuit current ensuring the operation of the phase-to-phase short circuit protection when ordering a generator(s). In case of difficulties, the boosting of the generator's excitation is required and shall be specified.

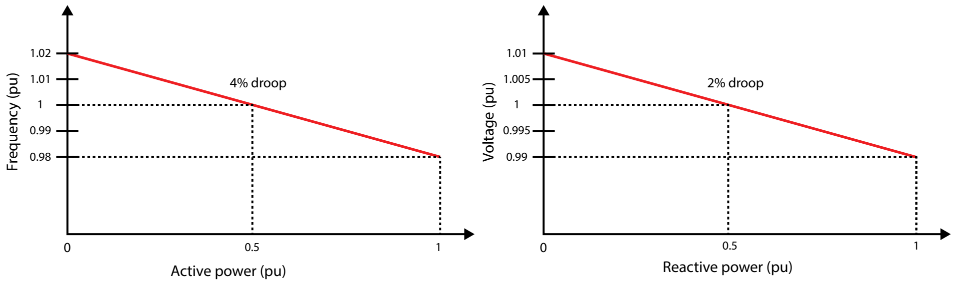
Generator Voltage and Frequency Control

The voltage and the frequency are controlled by the primary regulator(s) of the generator(s) provided by the genset manufacturer. The frequency is controlled by the speed regulator(s), while the voltage is controlled by the excitation regulator (s). These two regulations are considered as primary regulations while different operating modes are provided:

- Frequency by the speed regulator or governor, is to control the rotational speed of the engine linked to the alternator rotor. The frequency of the AC voltage is directly linked to the engine speed. Among the external control mode provided, the main modes used are:
    - Isochronous or constant frequency mode
    - Droop frequency / active power mode (F/P)
    - Constant active power set point
- Voltage by the AVR or AVC regulator, is to control the excitation voltage of the genset rotor. Several external control modes can be used:
    - Constant voltage mode
    - Droop voltage or reactive power (V/Q mode)
    - Constant reactive power setpoint
    - Power factor mode (PF mode)

Droop Curve

Droop control is a technique to control synchronous generators in electric grids. The droop curve represents how much the frequency and voltage are allowed to deviate from their nominal values to account for changes in power demands. In the most common type of droop control, frequency and voltage vary linearly with respect to active and reactive power.



The droop function is the control compensation applied by the genset controller when a power disturbance appears within the electrical network. It can be applied either on Frequency or active power compensation or on Voltage or reactive power compensation.

All active (reactive) power increase induces a frequency (voltage) decrease. The droop curve is characterized by its slope. For example, with a nominal frequency of 50Hz, a slope of 4% ensures a frequency between 49 Hz and 51 Hz along the full power range of the generator.

Inverter Control

An inverter is characterized by its capability to be a voltage source and a frequency reference.

The following two types of DER inverters are available:

- Grid-tied or Grid Following
- Grid Forming

Grid-tied or Grid Following

The inverter should be connected to a voltage source to be able to inject power and it is made to disconnect from the grid whenever voltage or frequency is more than acceptable boundaries. In case of PV inverters, the inverter is seen as a current source. The two types of inverters are:

- Grid-feeding - imposes its output active and/or reactive power to the connected grid at any voltage frequency and amplitude.
- Grid-supporting - adjusts its output active and/or reactive power to support grid voltage amplitude and/or frequency.

Grid-Forming

The inverter does not need the initial presence of a voltage source and can operate alone during Microgrid islanded mode or in parallel with other grid forming DER, contributing to the regulation of the frequency and voltage. In that case, the inverter is seen as a voltage source and becomes a voltage and frequency reference for the other DER and loads connected to the same Microgrid.

When connected to the Grid, the voltage and frequency reference is imposed by the grid itself. Inverter with grid-forming capability only (without any other feature) has no capacity to impose its own voltage and frequency reference against the grid. In Grid-Connected mode, when transition to the grid connected mode on a close transition, EMO switches the grid - forming inverter in VSG or droop - mode. Grid-forming inverter must change its operating mode, from voltage source operating mode to current source operating mode. The inverter in grid following mode allows the power control of the inverter according to customer use cases.

Control Mode

From a Microgrid operation perspective, the control of operating modes are focused on the inverter.

The following three modes are commonly identified:

- Active – reactive power (P/Q) control mode
- Voltage – frequency (V/f) control mode
- Droop/VSG control mode

Active – Reactive Power (P/Q) Control Mode

The inverter is Grid-Following or grid-tied. The inverter matches the busbar voltage and frequency, and generates power based on a P and Q set points provided by the control. Before the inverter can start, a grid-forming energy source, like a genset or a grid mains connection, must be connected to the busbar.

If the grid-forming genset or mains trips, the inverter cannot keep the voltage and frequency stable. The inverter therefore also stops power injection within the busbar it is connected to, which causes a blackout.

Voltage – Frequency (V/F) Control Mode

The inverter is Grid-Forming, meaning a voltage source. The inverter tries to keep the output voltage and frequency constant (usually at the nominal voltage and frequency defined through the settings of the inverter). This allows the inverter to generate power and frequency without any gensets or mains connected to the busbar.

However, since the inverter keeps the voltage and frequency constant, the inverter generally cannot be connected in parallel with a genset or grid mains connection. The constant voltage and frequency would conflict with other voltage and frequency sources. Therefore, if a genset or mains is connected to busbar, the inverter must generally switch back to P/Q mode. Depending on the inverter, a blackout might be required. Some inverters support running in V/f mode while parallel with other identical inverters (which are also in V/F mode).

Droop/VSG Control Mode

In inverters, droop control mode is also called VSG mode (Virtual Synchronous Generator mode). The inverter acts like a generator, which allows the inverter to always be grid-forming. In addition, in droop mode, the output voltage and frequency are controlled using predefined droop slopes. This allows the inverter to be connected in parallel with gensets and sometimes in mains connection.

EMO-L DER Regulations

When several DER are interconnected, being or not connected to the utility grid, they cannot work independently, otherwise they would oppose their actions. In this case, a secondary level control loop is necessary to coordinate them. This is one purpose of EMO-L.

The secondary regulation achieved by EMO-L, introducing a split with the primary regulations achieved by the DER controllers themselves, allows the synchronization of all the DER interconnected in parallel to achieve the common target of the Microgrid installation. If all primary regulations can be directly and locally set by an operator through the DER HMI, the secondary regulation replaces the human interaction with these primary regulations. This automation layer controls the primary regulations.

The secondary regulation is not as fast as the primary one, however it allows to improve the control of the operating points of the DER and to improve the global network's electrical stability and the efficiency of the DER units.

One prior function of EMO-L is to regulate the frequency and the voltage on each island (electrical sub-network) to maintain them within their respective predefined acceptable ranges. This regulation is essential to keep the electrical and electromechanical machines, as well as protection IED, in their nominal electrical conditions of running.

When a voltage source DER at a consumer's Microgrid installation operates in island mode (utility power supply disconnected), the voltage and the frequency at the main busbar the DER is connected to are both fixed by the DER and its control system. The DER operates in Voltage or Frequency (V/F) mode.

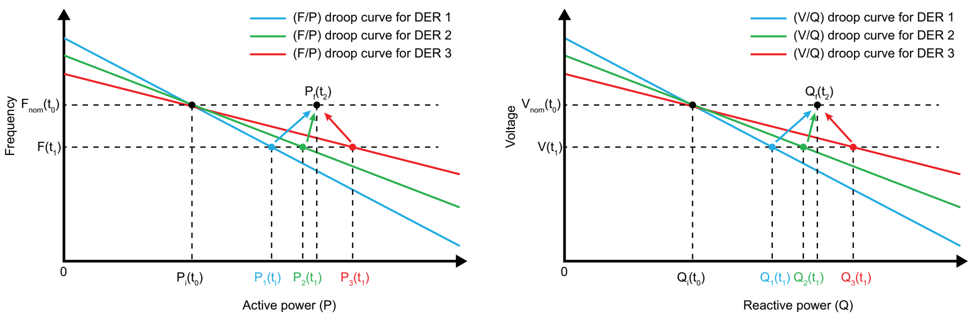
When main island busbar is connected to the utility power supply, the voltage and the frequency are both fixed by the utility. The control system of the DER with grid forming capabilities (generator or BESS) must be switched from Voltage or Frequency mode (V/F control mode) to Active power or Reactive power mode (P/Q control mode). When considering an inverter base DER, this control mode modification may be accompanied with a change of source mode.

EMO-L F/V Control Mode

When there is no active grid connection in the Microgrid electrical network, at least one DER acts as the voltage and frequency reference to ensure service continuity while the Microgrid operates in island mode. This responsibility is fulfilled by either a generator or a battery energy storage system (BESS) with grid-forming capability. In Microgrid operations, this reference voltage and frequency source is referred to as the anchor source. Any load power fluctuations are managed by this single anchor source. In the case of using one DER as the anchor source in an island, the operating mode for a generator is F/V isochronous mode, while for a BESS, it is grid-forming mode.

Some Microgrid installations require multiple DER to serve as the voltage and frequency reference, mainly because load power fluctuations can exceed the capacity of a single DER. In this case, EMO-L ensures the synchronization of voltage and frequency across all these DER. To achieve this synchronization, all DER contributing to voltage and frequency regulation should be set to (F/P) and (V/Q) droop modes for effective management. When referring to battery energy storage systems (BESS), the droop mode is known as VSG.

In island mode, for the power sources that regulate the voltage and frequency of the island busbar, EMO-L applies regulations to compensate for the operating points sliding along the droop curve of each DER. This compensation is applied either to frequency and active power or to voltage and reactive power.



The above figure illustrate behavior of the (F/P) and (V/Q) working points of threeDER connected in parallel, when a power demand, active or reactive, appears within the electrical network. (Fnom(t0)/Pi(t0)) and (Vnom(t0)/Qi(t0)) are the initial (F/P) and (V/Q) operating points before the power demand appears.

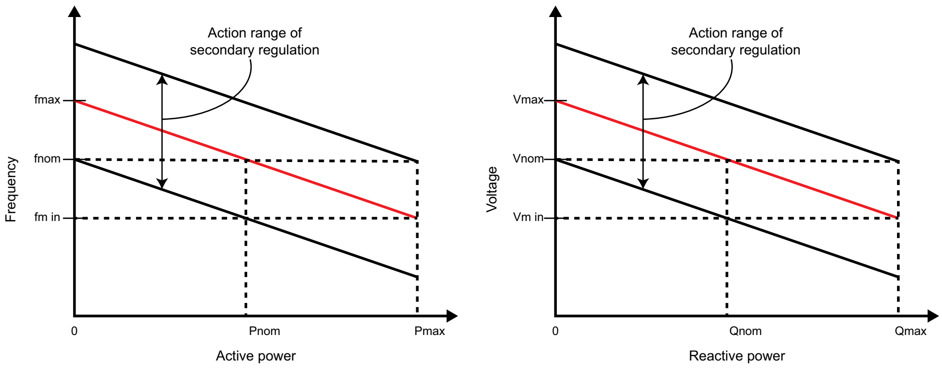
Assumption is made that at each steady state operating point reached, the power SoC of each DER controlled in that (F/V) control mode is the same. In other words, the rate of the current power delivered by the maximal power that can be delivered, has the same value for each DER. We will see how EMO-L is ensuring this condition by applying its regulation.

In the present example, three DER are connected to the same busbar and are sharing the same voltage and frequency. Then an active or reactive power demand increase appears, inducing a decrease of the frequency or voltage of the main busbar the DER in (F/V) control mode are connected to. Thanks to the primary regulation of each DER, the (F/P) and (V/Q) operating points slide along their relative droop curve, reaching the next operating points (F(t1)/P1,2,3(t1)) and (V(t1)/Q1,2,3(t1)). The droop curve characteristic being different for each DER, the power SoC reached by each primary regulation is different. Lower is the rate of the droop curve, higher is at t1 the power contribution of the DER after the power demand change.

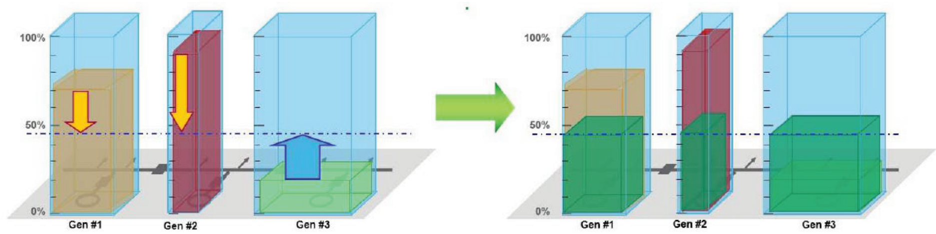
EMO-L then applies a secondary regulation on each DER to come back to the nominal frequency and voltage for the island. This regulation applies in the two axes of the (F/P) and (V/Q) droop curves, reaching for each DER involved the same final operating points at t2 (Fnom(t2)/Pf(t2)) and (Vnom(t2)/Qf(t2)):

- Vertical axis: the compensation helps to get back the operating points to the nominal frequency and voltage.
- Horizontal axis: a (P/Q) load sharing compensation is applied so that the power SoC will be the same for each DER contributing to the (V/F) regulation of the busbar.

This regulation can be interpreted as a vertical sliding of each DER’s droop curve, within the range as shown on the below figure:



The below figure illustrates the equilibrium strategy applied by EMO-L on the power SoC of all the DER working in parallel. The width of the rectangle represents the DER power capacity. From the departure condition on the left hand, in which the power share is uneven, the load sharing function lowers the production of the first two DER and raises the production of the third one to reach a global production distribution proportional to the DER respective power capacities (both active and reactive powers).



EMO-L P/Q Control Mode or Load Sharing

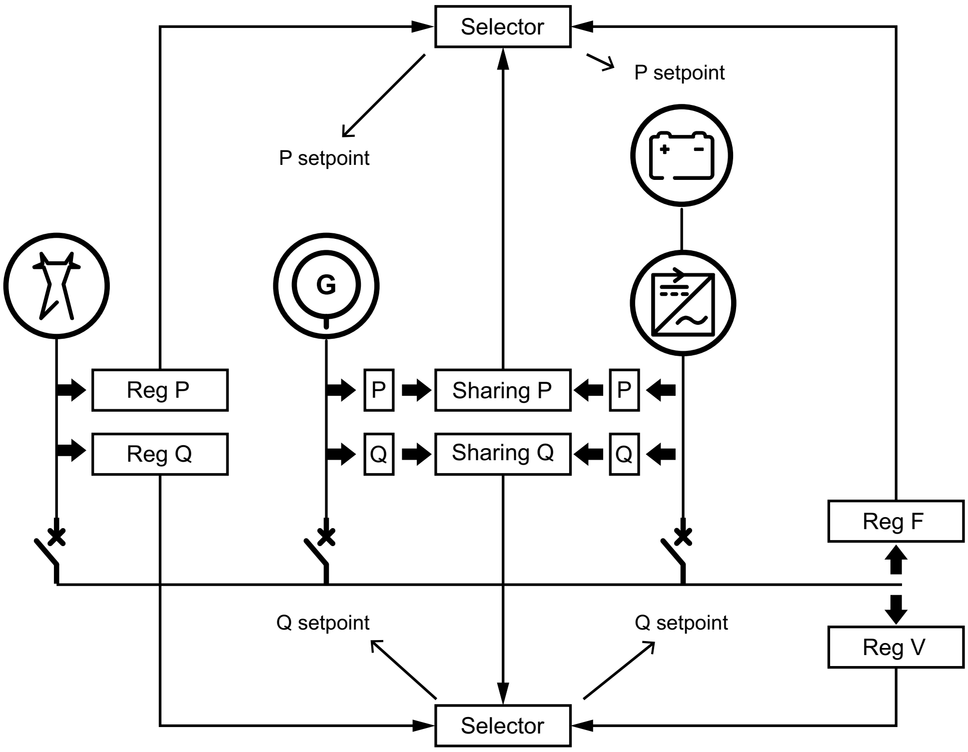
The function of the P/Q control mode or load sharing function, is to control the exchange of active and reactive power within the installation and with the utility. This function is required to maintain continuity and stability of the power supply without overloading problems. EMO-L sharing function monitors the electrical network mainly through the information provided by the topological engine. The load sharing function considers the DER's capability, the generated power, the DER's operating modes, the imported/exported power of the active grid connection.

The following characteristics are taken into consideration when controlling a DER:

- Minimum and maximum power. If the limit is reached, the load sharing function stops sending control that decreases or increases the production and generates an alarm in the HMI.
- Maximum acceptable raising and lowering of power production (also called step up or down or incremental or decremental reserve margin). The load sharing is performed in several steps, compatible with the acceptable limits, to reach the final target.
- Minimum production level at which the load sharing function can operate.
- Minimum production level at which the generator can be disconnected.

The EMO-L controller takes into consideration the overall electrical network and accordingly adapts the DER's targets in active power and reactive power while respecting the DER's capacities and limits. The regulation is performed independently on each island (electrical sub-network) of the Microgrid installation.

The following principle of operations are used in most of the applications:



- The amount of the active and reactive power exchanged with the utility are set by the operator. The settings may be specified by the utility according to the grid code.
- The control system maintains the values of the exchange at the required values by acting on the controls of the DER.
- The control system computes and shares of the required active and reactive powers between the DER remained in operation.

Through this P/Q control mode, EMO-L:

- Prioritizes the usage of renewable energies, minimizing the consumption of the generators.
- Curtails the PV to protect either a BESS which is already full or to avoid injecting reverse power to the generator.
- Smooth the PV fluctuation by driving accordingly the BESS to avoid huge power fluctuation on the generator.

When the Microgrid is connected to the grid, the P/Q control mode allows the following:

- Strictly limit the value of the active power imported from the utility at the amount which cannot be provided by the DER when the demand of the installation exceeds their capability.
- Maintain at zero the imported active power, when the demand of the installation remains below the capability of the DER.
- Maintain the power factor of the installation at the contractual value specified by the utility.
- When the capability of the DER in providing reactive power is exceeded, the additional reactive power required to comply with the contractual power factor shall be supplied by a dedicated capacitor bank.

In grid connected mode, the grid power import export regulation is intrinsic of P/Q regulation of EMO-L. In the same way, this P/Q regulation applied at the point of common coupling with the grid maintains the power factor of the site within the limit defined by the utility, according to the grid code applied.

When the Microgrid or the island within the Microgrid is in the islanded mode, the P/Q control function:

- Shares/balances active and reactive power generation.
- Contributes to the voltage and frequency regulation.

EMO-L can prioritize reactive power as per type of the DER. Add all the control done to target power management according to DER present.

Spinning Reserve Management

EMO-L is designed to manage several generators in parallel, with or without the grid. EMO-L can also operate BESS.

The EMO-L automation analyzes the spinning reserve power of rotating machines to ensure power stability and meet operator criteria. Based on the computation of active and reactive power needs, EMO-L calculates the available spinning reserve on the Microgrid. If the spinning reserve is over a threshold defined by operator, then EMO-L will ask for a new energy source to start to increase the energy source capacity. The decision process takes account the power generation capacity of the BESS being connected to the Microgrid.

The start and stop command of the genset takes account the starting phase delay to get the new generator elected fully operational. EMO-L automation automatically elects rotating machine to start when production becomes insufficient. At the same time, it elects rotating machine to stop when there is an overproduction situation.

Battery Energy Storage System Management

The BESS must not go below a minimum and must not exceed a maximum State of Charge (SoC). Minimum and maximum SoC settings are customizable and are to be defined based on project requirements.

- The Microgrid controller provides fast load shedding (if there is a battery system and if we need more power than it can deliver) of a prioritized list of electrical loads and the energy storage system with grid-forming inverter switches from CSI to VSI mode, for the remaining loads to stay on-line connected.
- State of Charge (SoC) Management. EMO-L engine embeds algorithms to analyze the SoC of the energy storage system and optimize power delivery by considering the state of the charge values for the load sharing strategy to be deployed by EMO-L engine.

  NOTE: Operator can set minimum or maximum energy storage percentage and limit energy storage per DER.

EMO-L monitors the SoC of the BESS. It manages and control the determined minimum and maximum SoC in order to increase or discrease PV production to help avoid damage due to BESS overcharging. The Microgrid controller manages and controls the energy import or export capacities of the BESS.

PV Inverter Curtailment

Photo Voltaic (PV) power production depends on the real-time sun irradiance high, which on a time scale of a few minutes is deemed as unpredictable. Curtailing feature applies to projects integrating PV systems and need to curtail PV power production (or limit energy exported from PV system to the Microgrid electrical network) due to system stability conditions or grid codes constraints.

The Microgrid controller manages PV production and can shed PV energy production in specific cases (for example instability, energy production excess). The EMO-L engine manages PV sources curtailing based on topological, power balance and forecasting constraints.

EMO-L Load Management

The Load Management maintains the voltage and frequency reference source in its optimal operational power rate. EMO-L Load Management provides priority based load shedding and load restoration functions based on the criticality of loads. The priority of the loads is determined based on their type or importance and according to customer's needs and can be modified by the Microgrid operator.

Load Management (coded) including the following main functions:

- Load Shedding - Disconnection of loads.
  - Visual notifications of circuit breakers (CB) opening commands.
- Load Restoration - Reconnection of loads.
  - Visual notifications of CB closing commands.

Load Shedding

During operations, electrical power system might encounter disturbances leading to an unbalanced situation in the network when the load demand becomes greater than the power generation. Under such circumstances, the available power supply may not be able to support the plant's actual load, and remaining DERs might get overloaded or limited. Such situations initiate damages on the electrical assets and lead to a total collapse of the electrical system and thus a total disruption of the grid.

Load shedding of EMO-L is a real-time automation function which helps to shed non-critical loads when the electricity production or consumption becomes inadequate or out of balance with respect to one another. Production sources tripping, critical bus tripping and frequency drift are events which can initiate a load shedding situation.

Loads are shed according to their priority and is provided during system configuration and can be modified by the energy manager.

NOTE: Low priority loads are shed first.

The aim is to keep the continuity of service on critical loads to ensure DERs don't get overloaded and to help prevent a complete system blackout.

When very fast time response of shedding action is required, EMO-L can be combined with iFLS, which is a complementary application running on a separate controller.

Load Restoration

The load restoration function reconnects load feeders after a load shedding scheme occurred, once shed condition has been cleared and required power has been restored. Loads are restored according to their priority, reversely to the priorities set for the load shedding function.

The load restoration function is performed manually by the operator from the local HMI or SCADA.

NOTE: Loads with higher priority are restored first.

Glossary

A

ADMS: Advanced Distribution Management System

AVC: Automatic Voltage Control

AVR: Automatic Voltage Regulator

B

BESS: Battery Energy Storage System

C

CB: Circuit Breaker

CSI: Current Source Inverter

D

DER: Distributed Energy Resource

E

EMA (EMS): EcoStruxure™ Microgrid Advisor: software platform for site's flexibility management

EMO-L: EcoStruxure Microgrid Operation Large

EMS: Energy Management System

EPAS-UI: EcoStruxure Power Automation System User Interface

EPAS: EcoStruxure Power Automation System

EPO: EcoStruxure Power Operation

G

GOOSE: Generic Object Oriented Substation Event

H

HMI: Human Machine Interface

I

IED: Intelligent Electronic Device

iFLS: Intelligent fast load shedding

iPC: Industrial Power Computer

P

PMS: Power Management System

PV: Photovoltaic

S

SCADA: Supervisory Control And Data Acquisition

SoC: State of Charge (of the battery)

SoO: Sequence of Operations

V

VSI: Voltage Source Inverter

Printed in:
Schneider Electric
35 rue Joseph Monier
92500 Rueil Malmaison - France
+ 33 (0) 1 41 29 70 00

Schneider Electric
35 rue Joseph Monier
92500 Rueil Malmaison
France

+ 33 (0) 1 41 29 70 00

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DOCA0371EN-00