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Principles of Power Management in a Smart Microgrid Based on Std. IEC 61850

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***Abstract*—In recent years, the structure of the electrical power system has changed, and all aspects of power generation have shifted towards bidirectional and smart methodology. The Microgrid (MG) as a popular concept for the modern grid and advanced communication techniques play major role in future smart grids. In this regard, this paper presents the principles of MG power management from communication point of view. Moreover, there have been recent efforts to standardize MGs, and it is in terms of these advances that the current paper present the investigation based on IEC 61850 standards. Finally, the hierarchical levels of both the power and communications sides are discussed, and the responsibility of each level is summarized based on the standards.**

***Index Terms*—Communications link, Hierarchical control, IEC 61850 standard, Microgrid, Smart grid**

I. Introduction

Microgrids consist of a number of Distributed Generation (DG) systems organized together in a way that increases the system capacity and improves power quality. The smart grid dictionary defines an MG as a small power system formed of various self-contained generators (such as wind turbines and photovoltaic cells), storage systems (such as batteries and supercapacitors), transmission elements, and distribution and energy management devices, which are capable of operating in either island or grid-connection modes [1]. In a modern grid, since each part of the system can act as a supplier or a consumer, the exchange of information among the various parts of the system is required. Indeed, the integration of Information and Communication Technologies (ICT) into existing power system is one of the major differences between smart MGs and traditional electrical system [2]. Generally, MG systems consist of two main parts: the power system and the communications system. A functional block description of these two parts, along with the information exchanged between them, is shown in Fig. 1. From power system point of view, an MG is composed of three different units: the *Generation* part, the *Energy storage system* (ESS) and the *Load*; the critical point in such a system is to control the generation and ESS by managing the power between them.

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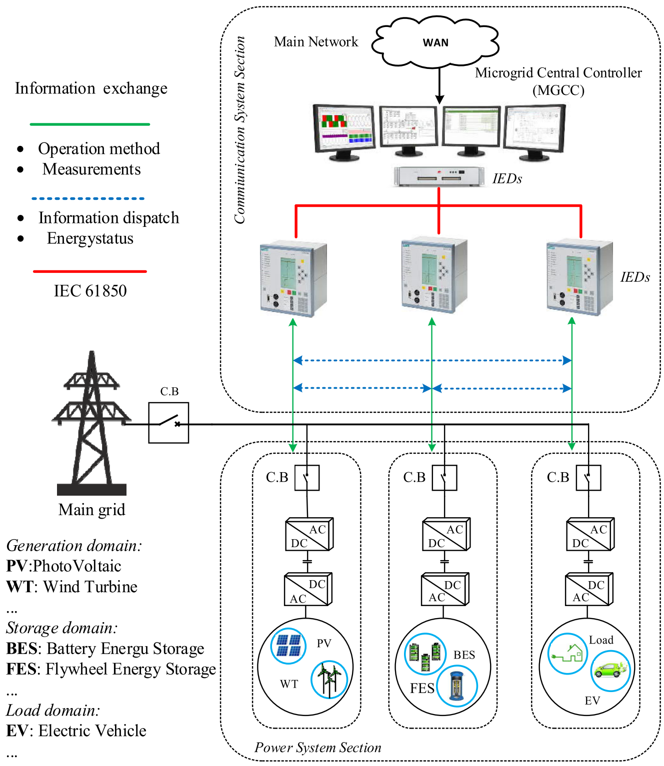


Fig.1 Functional block description of a MG

To achieve optimum operating performance, hierarchical control needs to be implemented. A comprehensive investigation of MGs from the power system side is presented in [3]; on the basis of this, the hierarchical control can be described as having four levels for MGs. The control levels are responsible for processing (*inner control loop*), sensing and adjusting (*primary level*), monitoring and supervising (*secondary level*), and maintaining and optimizing (*tertiary level*). Moreover, The IEC 62264 standard applied to MGs considers hierarchical control of the system and is presented in [4].In this regard, the present paper just focuses on the communications side and investigates the section based on the IEC 61850 standard. From the communications point of view, in a large MG with high amount of equipment it is very difficult for the Supervisory Control and Data Acquisition systems (SCADAs)/Energy Management Systems (EMSs) to identify devices and the operation mode needed to implement the correct control methodology. Moreover, to deliver power with high reliability and quality to the main grid or the demand side, a rapid and reliable system of control is required. Therefore, most previous efforts have aimed at establishing a standard information system with the rapid exchange of information and "plug and play" functions. In the communications part of an MG, there is also a hierarchy of exchange information divided into three different levels, called the *station*, *bay*, and *process* levels. The IEC61850 standard deals with the exchange of data and information between the *station* and *bay* levels. IEC 61850 is a part of the IEC Technical Committee 57 (TC57) reference architecture for monitoring, controlling, and measuring power systems and IEC 61850-7-420 has been nominated to deal with MGs [5]. At present, an information model and methods for implementing have been provided for different parts of MGs [6], Intelligent Electronic Devices (IEDs) as a gateway to the bay level [7], hierarchal management, and economic scheduling [8]. A straightforward model for communication and cooperation between system operators, DGs, and ESSs with a centralized configuration is presented in [9] to control and supervise such systems. In [10], IEC 61850 relations to substations and the distribution automation system is presented, and a hierarchical information structure is described in [5]. However, all the current research into IEC 61850 for MGs follow the preliminary arrangements and cannot provide smart functions in the MG on both the communications and power system sides. In [11], a solution for an adaptive microgrid operation based on IEC 61850 is elaborated; however, the research is focused on the communications side, so a control methodology to provide the initial signal from the power system part still needs investigation.

In order to fill in all the above research gaps, the hierarchical operation methodology of an MG in both the power system and communications parts is presented in this paper for island and grid-connection modes on the basis of the IEC 61850 standards. The paper is organized as follows: communications preliminaries in MGs are presented in Section 2. Section 3 discusses the hierarchical control of power management in MGs and investigates the responsibility of the communication section based on IEC 61850. Finally, the paper concludes in Section 4.

II. COMMUNICATION PRELIMINARIES IN MICROGRIDS

Due to the high accuracy achieved by the communication technique, it is extremely important that smart MGs have a control method based on communication interfaces in the secondary control and intelligent agents in the tertiary control in order to optimize reference values in the control. As described above, the hierarchical information structure for monitoring and managing MGs based on IEC 61850 can be defined in three different levels, which are explain in detail as follows [5] [7][12]:

- *Station level* (Human–Machine Interface (HMI) and SCADA systems): on this level the MG is generally managed and operates in both automatic and manned management modes. The responsibilities of this level are:
  - ✓ To establish an interface between the MG and main grid (to connect and disconnect MG)
  - ✓ To selecting the management mode (centralized, decentralized, island, or grid connection modes)
  - ✓ To send the generated reference values for voltage, frequency, and price of energy to lower levels.

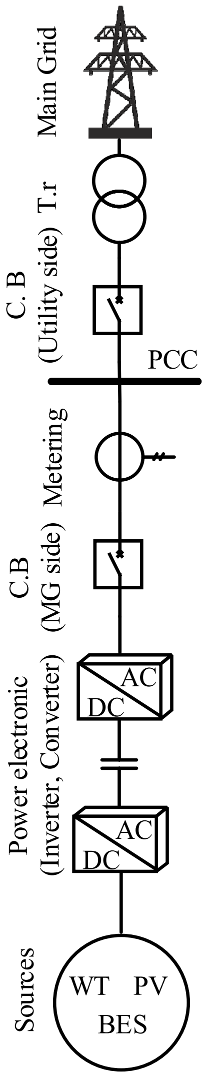
- *Bay level* (protection relays and control devices): Supervising, monitoring, and controlling the MG are all performed in this level. The metering and monitoring data from lower levels is received and sent to the station and process bus after meeting management targets. The duties of the level are:
  - ✓ To regulate and adjust generation and consumption.
  - ✓ To ensure the security of the MG electrical system, especially during island mode operation.
  - ✓ To meter and monitor for the purposes of power management, based on the operation condition.

- *Process level* (Current or Potential Transformers (CTs, PTs), Circuit Breakers (CBs), and DG and ESS output/input): This level has a direct interface with the power system and their power electronic devices (such as inverters and converters). The output power of the sources and the power management in ESS is based on a signal received from the bay level. Generally, each device on this level has its own data manager, measurement, and conversion modules. The tasks of this level are:
  - ✓ To control the output value of the power system sources
  - ✓ To send and receive the measuring value of the voltage and frequency and to collect reference values
  - ✓ To perform energy management (especially in the ESS section)

All the devices and equipment in these three levels connect to each other through the *station* and *process* buses. Generally, communication between metering, smart sensors, protection, and control equipment in the process level is based on the sampling value (SV) message method used by the process bus, while the protection and control equipment operates on the basis of the Generic Object-Oriented Substation event (GOOSE) message approach for the bay level in the same bus. Since implementation of an intelligent control is a system requirement, an additional level must be added to the hierarchical information structure when multiple MGs are implemented in a system. This additional level called the master level.

This "master level" is located on top of the other three levels and interfaces with all of them so as to manage the system through a smart approach and to communicate through the servers with the core of the MMS. To implement a complete model of equipment in a cluster of smart MGs, logical nodes based on IEC 61850 must be used.

Table.1: A list of LNs in feeder of an inverter-based source



Power system structure	Logical Node	Definition	Logical Node	Definition
Protection	PTOC	Time over current	PTUV	Time under voltage
	PIOC	Instantaneous over current	PTOV	Time over voltage
Transformer	TVTR	Voltage transformer	TCTR	Current transformer
C.B (Utility side)	XCBR	Circuit breakers	CSWI	Switch controller
PCC	DCRP	DER plant corporate characteristics at PCC	DPST	Status information at PCC
	DOPA	DER operational authority at PCC	DCCT	DER economic dispatch parameters
	DOPR	Operational characteristics at PCC	DSCC	DER energy and/or ancillary services schedule control
	DOPM	Operating mode at PCC	DSCH	DER energy and/or ancillary services schedule
Metering	MMTR	Metering	MMXU	Electrical measurements
C.B (MG side)	CSWI	Switch controller	XCBR	Circuit breakers
Power electronic	MMDC	Measurement of intermediate DC	ZRCT	Rectifier
	WCNV	Wind turbine converter information	ZINV	Inverter
Sources – Wind turbine	WTUR	Wind turbine general information	WSLG	Wind turbine state log information
	WREP	Wind turbine report information	WALM	Wind power plant alarm information
Sources – Photovoltaic	DPVC	Photovoltaics array controller	DPVM	Photovoltaic module characteristics
	DTRC	Tracking controller	DPVA	Photovoltaics array characteristics
Sources – ESS (Battery)	ZBAT	Battery systems	ZBTC	Battery charger

In IEC 61850, IEDs consist of an assortment of Logical Devices (LD) and, on the lower level; LDs consist of a group of Logical Nodes (LN). A LN in IEC 61850 can be seen in this case as data from either the generator or demand side. The data is determined on the basis of a special class defined by IEC 61850 and covers all required characteristics for describing an LD (e.g., protection relay, CB, power electronics, etc.). The list of LNs in a feeder of an inverter-based source system is summarized in Table 1. According to the IEC 61850-7-4 standard, the first letter in the name of each LD shows its category. For instance, T means instrument transformer and TCTR and TVTR are current and voltage transformers, respectively; X is used for the switchgear section and XCBR is a circuit breaker.

III. Microgrids based on IEC61850

MGs can operate in either island or grid-connection mode, and power converters in this system operate on voltage and frequency bases in island mode and on active and reactive power in grid-connection mode. In both operation modes, sensing, transferring, and exchanging data is done through communication interface. The synergistic regulation of MG control schemes and the operation of a circuit breaker at the point of common coupling, based on IEC 61850, are shown in Fig. 3. The first step in MG control is the control of the source operating point using power electronic devices; this is responsible for determining the frequency and voltage inside the sources. The voltage reference value for the inner control loop is determined through the primary control level and depends on the state of the MG connection. Accurate references are required for effective management, and these are passed through sensing and adjusting in the primary control. Indeed, the primary control level is used to adjust the frequency and amplitude of the voltage references, taking into account the calculated deviations in frequency (Δf) and voltage (ΔV) that originate from the upper control level. The strategy of the control level is to use an independent local control to increase the reliability of the power system. Hence, these two levels (inner control loop and primary control) can be implemented in the power system section without any communication link (e.g: by droop control). However, two other control levels (secondary and tertiary) are based on communication links and are implemented in the *bay* and *station* levels; the reference value for primary and secondary control levels are then

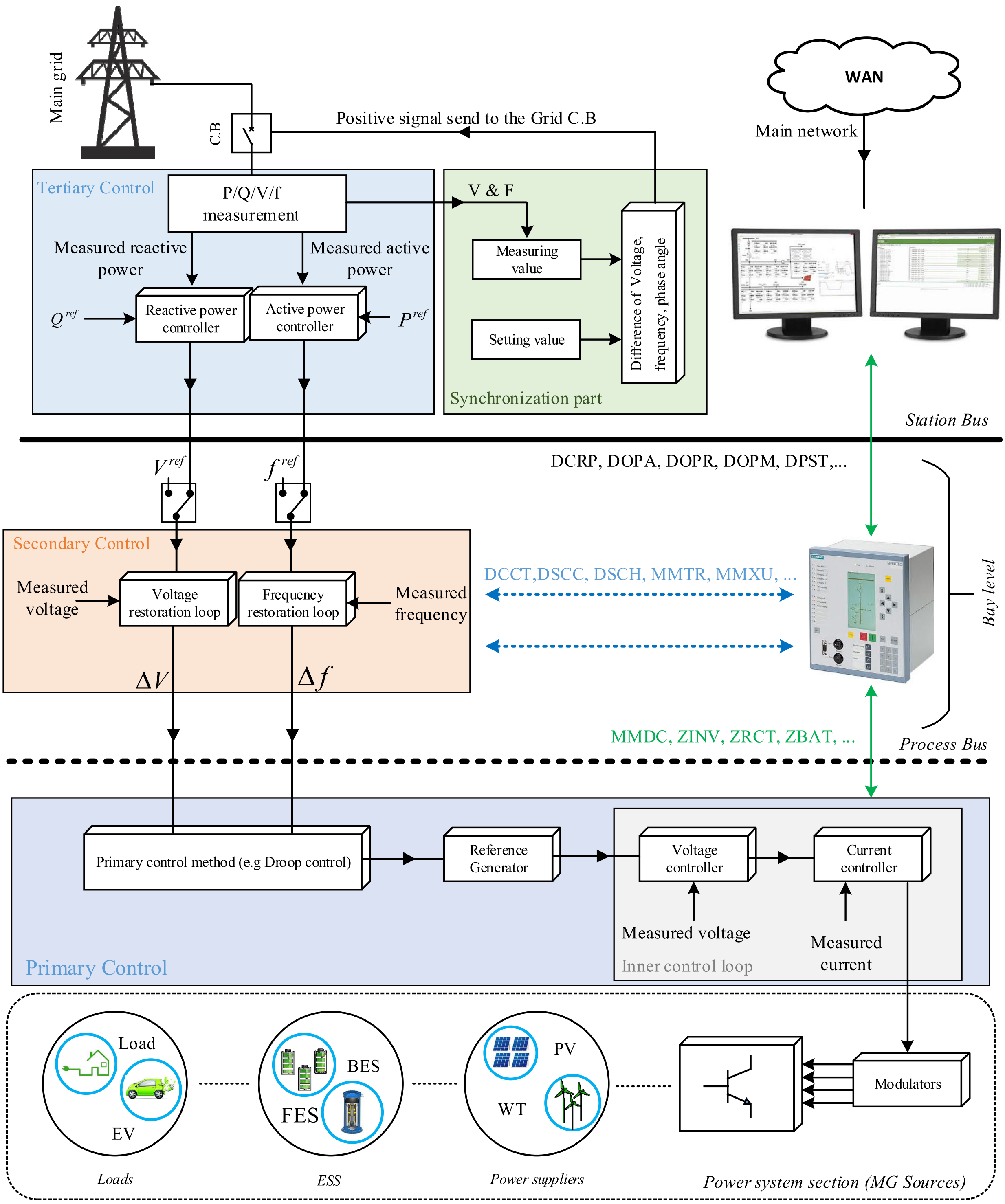


Fig.3 A hierarchical structure of MG based on IEC 61850

available in the *process* and *station* buses, respectively. The secondary control deals with the MG and power management (using ESSs) in island mode, and also regulates output power on the basis of network data in grid-connection mode, so as to ensure that the frequency and voltage deviations are regulated toward zero after changes on the load and generation sides. The secondary control serves the power system by correcting the grid frequency and voltage deviations within an allowable limit—e.g., ±0.1 Hz in Nordel (North of Europe) or ±0.2 Hz in UCTE (Continental Europe); voltage magnitude is maintained in the -10% to +10% range. The *bay level* receives the measuring value, such as power generation of sources, the available capacity of the ESSs, and the load demand, through the *process bus*. On the other hand, the reference value of the voltage and frequency, as well as the operation mode of MG (e.g., centralized, decentralized, and island or grid connected mode) is received from the *station bus*. The data collected from the *process* (measuring value) and *station* buses (reference value) are compared with each other, and the measurement error is sent to the primary control to restore the voltage and frequency. In the final step, the tertiary control level establishes an interface between the MGs and the main grid in order to exchange information from the secondary control with the network, for maintenance and optimization purposes. On the third level, the power flow is managed by regulating the voltage amplitude and frequency when the MG is in grid-connected mode, so at first the ratio of *P/Q* is measured from the *station bus* (reflecting the active and reactive power of the main grid). The value is then compared with the reference for the active and reactive power. Then through a controller on the third level, the desired reference value of the voltage and frequency are generated for the secondary control level. When any unplanned islanding issue occurs with the MG, the tertiary control attempts to absorb *P* from the grid, so if the grid is not present, the MG disconnects from the main grid for safety, and the tertiary control is disabled. On the other hand, a synchronization check is required to reconnect the MG to the main grid. For the first step in the module, the measured value of the voltage, frequency, and phase angle is compared with the set values (from the main grid). Then, having checked all these conditions, a positive signal is sent to the CB in the PCC to close and to connect the MG to the main grid. Moreover, the position of the CB is set to the *bay level* to clarify the situation of the MG and to prepare the desired reference value for each level of the hierarchical control.

IV. CONCLUSION

The power system and the communications section are two important parts of a microgrid. In this paper, the procedure of providing a reference value and their related signals from the communication side for both island and grid connection modes is presented based on IEC 61850 standards. Based on the research, the role of the communications part is most significant in the hierarchical control—and especially for secondary and tertiary control—so a high speed of data transfer between the different units and the main grid is required. Indeed, standardization provides a smarter MG by optimizing the efficiency of the system. Different communication methodologies for transferring data between different pieces of equipment and the performance of protection devices based on IEC 61850 are topics in this research area that require future work.

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