Data Communication in Microgrid

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***Abstract*—In this article we discuss five microgrid implementation scenarios involving distributed energy resources, demand response and hierarchy of energy storages in microgrid and distribution system operator. We focus on centralized management and communication within microgrid and propose corresponding microgrid data communication baseline architecture. The proposed architecture considers communication within four layers - Dispatch, Control, Information, and Physical layers is based on today's communication and data model standards suitable for the mentioned layers.**

***Keywords*—microgrid; battery energy storage; distributed energy resource; IEC 61850; energy management system**

I. INTRODUCTION

The microgrid is an independent energy system that serves specific area, which is connected to the upstream power grid on the one hand and to the customers on the other hand. Microgrid operators can be viewed as a separate economic entity. It is therefore in his interest to reduce costs and increase profits. As distribution may, by its very nature, have elements of a monopoly business, it is to some extent regulated in all countries mainly in terms of distribution fees. In the microgrid there can be placed a small-scale units of power generation - Distributed Energy Resources (DERs). The consumers that have DERs and also supply energy to the microgrid are called prosumers [1, 2]. In the microgrid as well as in prosumer premises there can be realized the concept of hierarchical energy hubs, where different types of energy can meet and be transformed according current needs [3]. For the microgrid is a very important component the Battery Energy Storage (BES). Its usage employs not only power storage but using batteries can be realized many useful scenarios as peak shaving [4, 5], load shaping [6, 7], load shifting. BES, along with active appliance control are essential elements that enable compensating sudden jumps or drops in consumer energy consumption (demand response). From the microgrid point of view, in addition to the exchange of energy between consumers, the exchange of information between energy consumers and producers is also important, which will enable the efficient management of the electricity produced within the microgrid.

In [8] the authors reviewed the corresponding communication aspects for microgrids - paradigms (such as Request/Response, Publish/Subscribe) and network response times (according to the IEC 61850 and IEEE 1646/1647) needed for various microgrid functions. In [9] the main communication protocols include: IEC 60870-5/DNP3, IEC 61850, communication with Energy management systems - EMS (IEC 61970), DMS (IEC 61968), communication with meters IEC (62056), IEC (61107). As actual are viewed DNP3 over ethernet, IEC 61850 and his object model and Substation Configuration Language (SCL). For the legacy protocols with Client-Server (Master-Slave) architectures with bus network topologies [10], there is push towards "over TCP/IP" version, such as Modbus or Profibus over TCP/IP, DNP3 over TCP/IP. Besides TCP/IP, recently there is also growing a trend towards the use of new communication technologies based on Common Information Model (CIM), which can help to maintain the Network Digital Twin. From the point of view of individual appliance management, it would be possible to use the newly formed Matter Alliance [11], to which all major smart home device manufacturers have joined, and the defined standard itself should serve as a unifying standard for most standards available today.

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In the following section, we will present five different scenarios in terms of energy management produced in the microgrid and propose a solution for data communication, i. exchange of data and information necessary for efficient electricity management within the microgrid.

II. SCENARIOS

In this section we first describe overall situation for considered part of the power grid from which we derive each scenario by adding or removing components from microgrid. The scenarios differ by presence and location of BES. We have identified 3 separated locations of BES each with their own functional specificities which we elaborate further in respective scenarios. The overall situation is depicted on Fig. 1. Hierarchical location of BES is:

a, BES 0 – Prosumer battery located at customer premises behind their delivery point meter,
b, BES 1 – Microgrid battery located and operated by grid operator, which can be used be multiple customers,
c, BES 2 – Energy Supplier virtual battery located outside of the microgrid.

It is important to control the entire system [8]. This management includes, in particular, a strategy for dealing with the energy produced in the microgrid. From the point of view of the production management strategy, we can speak of two ways:

a, central management,

b, decentralized management.

In this article, we will focus on centralized management and communication within it. In this case, each local source is connected to a central Microgrid Control (MGC) system that it informs about its production. At the same time, the control system monitors the consumption of all delivery points.

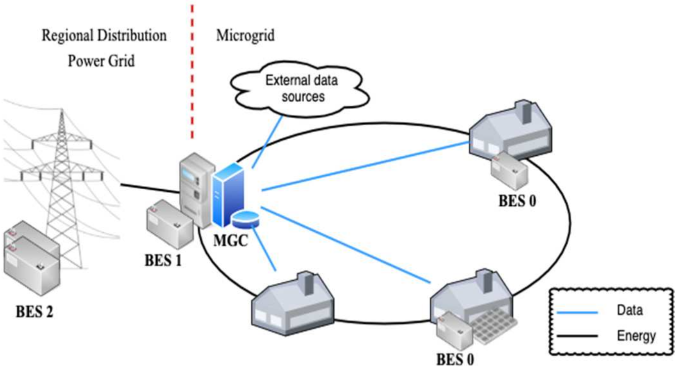

Figure 1. Microgrid with multiple local BES hierarchically located

For the control system to be able to effectively manage the sale and purchase of electricity, it must be able to predict the production and consumption of electricity. External sources of information, which may include weather, sunshine, etc., should help him with this.

A. Scenario 1

Scenario 1 describes the operation of a microgrid without any battery system. Microgrid has its connected prosumers who produce and consume energy. In this scenario is no degree of freedom and all energy produced from local sources is either be consumed or exported from the microgrid to the upstream energy grid. The microgrid consists of several consumption points with different consumption. Scenario 1 could be illustrated by Fig. 1, but without any BES.

In the event of a surplus of energy produced, which cannot be consumed within the microgrid, the management will take care of its sale to a upstream supplier. The control system also actually balances the microgrid imbalance, therefore it is desirable that the microgrid has its own defined balance group, within which balancing takes place and the surpluses are then sold to another supplier (i.e., to another balance group).

Central management system also fulfills the role of a clearing authority, which will ensure financial settlement between the two parties to the transaction based on central, pre-known rules.

In general:

$$P_T = P_E + P_D \tag{1}$$

Where P_T is the total price of electricity when it is supplied from the main grid, P_E is the price of electricity and P_D is the price for the supply of electricity, all other charges being included in this price. Since, when supplying electricity surplus to the grid, it is usually sold only at the price of the energy itself (P_E), so when selling within the microgrid, the price of the electricity (P_S) may fluctuate in the range of:

$$P_S \in \langle P_E, P_T \rangle \tag{2}$$

At a price lower than P_E for a local producer pays to sell energy to the grid, and at a price higher than P_T, it is more advantageous for the consumer to buy energy directly from the grid and not from another microgrid producer.

This price is applied to the offered E_{OUT} or the required E_{IN} volume of energy. Furthermore, for simplicity, assume that electricity is traded at an average price within a microgrid

$$P_G = P_E + \frac{P_D}{2} \tag{3}$$

In such an organized system, it is necessary to ensure that only authenticated agents can send requests to the system, and to ensure the pairing of the physical fulfillment of the order with its financial fulfillment.

The operator of this control system should be the operator of the microgrid as an authority that is above the individual customers and in its interest is to maintain the stability of the system, with a strictly related requirement for a balanced balance of electricity production and consumption. From the point of view of the currently adopted EU legislation [2], the operator of this broker could also be an energy aggregator [12], which is completely separate from the operation of the microgrid. Alternatively, it is possible to accumulate multiple roles in one subject.

B. Scenario 2

Scenario 2 is very similar to the previous one. The microgrid does not contain any batteries and all electricity must be consumed or sold at the time of production. However, the control system has one degree of freedom, the control system can influence the consumption of individual customers by controlling its selected appliances. It can decide to do so, based on positive predictions of consumption and production profiles. An example of such operation could be turning the air conditioning on/off. Together with such a possibility of interfering with consumption, the customer's consent comes together with technically set restrictions. The constraint ensures that even if the conditions of profitability change during the program run, the program will although complete correctly.

C. Scenario 3

Scenario 3 is another extension of previous scenarios. There is an additional degree of freedom – the presence of energy supplier virtual battery located outside of the microgrid that participants can recharge according to the agreed rules before selling their produced energy outside the microgrid – denoted as BES 2 in Fig. 1. They can also use this energy for their own needs. The virtual battery service is a service that has recently spread among electricity traders as a form of flexibility associated with the advent of smart meters. The main logic of the virtual battery operation is the storage of the produced energy in the battery free of charge and its subsequent drawing only at the price of distribution fees at the time of higher consumption. Since this is a virtual battery, its capacity is not limited in any way, so it is possible to store all the electricity produced.

From the point of view of the microgrid, this is only an economic change, as no energy has to be sold in principle, it is only stored in a virtual battery and consumed later.

For system control, the situation is much simpler, because the whole system is controlled by one logic, therefore all DER try to produce when they are able and surpluses that are not consumed directly at the end customer are stored in a virtual battery. The battery also serves as an element of load shaping and peak shaving [4]

The communication in this case is similar to the previous scenario, where it is necessary for each element of the network to follow the central unit and to submit to the joint organization of the microgrid. The central unit also evaluates the financial flows and ensures the settlement of individual participants and the microgrid operator.

From the point of view of the prosumer, the possibilities of how to use the produced energy have thus expanded, besides using the energy for your own consumption, or selling it to another customer within microgrid, we can store it on battery.

From the point of view of the stability and economics of the network, the conditions and prices should be set to suit this order of prioritization. The network operator is dealing with a situation similar in that it seeks to ensure the stability of the network while maximizing the profit from the battery system to balance the investment in the battery as soon as possible and decides whether and how to charge the battery to meet the economic needs of both it and the Community. However, these needs must be corrected by the main task of the network operator and that is the stability of the microgrid.

D. *Scenario 4*

In this scenario an additional degree of freedom is added - a microgrid battery located and operated by microgrid operator, which can be used in addition to BES 2 by local prosumers. This corresponds to Fig. 1 with BES 2 and BES 1. There is still only one battery in the microgrid, so the control of its charging and discharging is exclusively subordinate to the need to maintain the expected imbalance.

If the BES 1 is charged, the control system has still an alternative to storing the produced energy in a virtual battery BES 2.

E. *Scenario 5*

In this scenario we add the last considered degree of freedom - prosumer batteries located at customer premises behind their delivery point meter. This corresponds to Fig. 1 with BES 2, BES 1, and BES 0. From the point of view of microgrid management, the decision-making logic and, to a certain extent, the energy flow thus change quite significantly. Each connected DER will primarily produce to his BES 0. However, since battery recharging is fundamentally dependent on the weather and the time of day, in case of full charged his BES 0, a common battery BES 1 could be available, as well as the BES 0 from other prosumers. This is managed by the microgrid operator control.

If BES 1 is also charged, there is a possibility to use the capacity of the virtual battery BES 2.

F. *Remarks to scenarios*

As in the previous sections, there are two philosophical views on governance. Centralized, which is very similar to previous scenarios. Decentralized management, respecting ownership relations sets far more challenges for the orchestration of the whole system, but also opens other possibilities of using the battery, from the owner's point of view. With such a hierarchical ordering and use of batteries, there are several alternative charging strategies [13]. The management system will know the minimum cost of energy storage at all levels, as well as the cost of transporting energy within the microgrid, together with the price of purchasing electricity from the parent system, so that it can make the right decisions. We focus in the next chapter on data communication part.

III. Data comunication protocols and layers

In terms of information exchange within the microgrid, we distinguish 4 layers [14]:

- Dispatch Layer
- Control Layer
- Information Layer
- Physical Layer

From the Dispatch Layer point of view, it is important to ensure efficient management of electrical i.e., ensuring a balance between its production, storage, and consumption. This includes, among other things, prediction, and planning of the use of local energy sources, management of battery storage and consumption of individual customers, as well as the purchase and sale of electricity from the grid or on electricity exchanges. These functions are provided by both the MGC, which can be viewed as Energy Management System (EMS) owned by the microgrid operator and the Home Energy Management System (HEMS) of the individual prosumers (see Fig. 2). IED (Intelligent Electronic Devices) blocks represent the appliances and DERs.

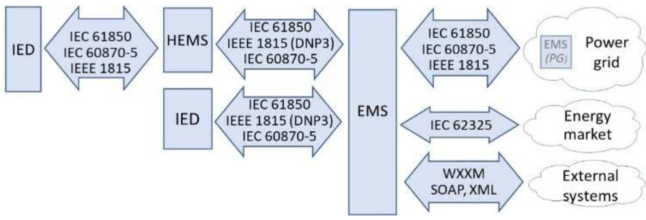

Figure 2. Proposed microgrid Dispatch Layer protocols

The role of the Control Layer is to ensure the execution of decisions from the Dispatch layer, i.e., manages the production of energy and its distribution to appliances, to or from batteries or, in the case of surplus, to or from the grid (Fig 3).

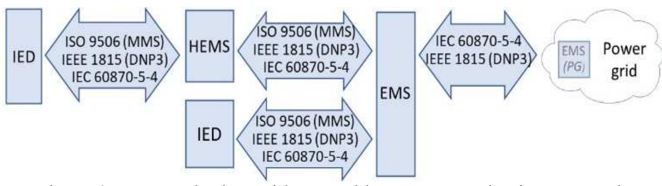

Figure 3. Proposed microgrid Control layer communication protocols

The Information Layer is responsible for the reliable exchange of information between the individual elements of the microgrid. To fulfill this task, it is necessary to have appropriate data / information models as well as protocols ensuring their exchange between individual elements. In addition to general information models, such as CIM microgrids also use special models, such as Object Models for Batteries (IEC 61850-90-9) or Weather Information Exchange Model (WXXM) (Fig. 4).

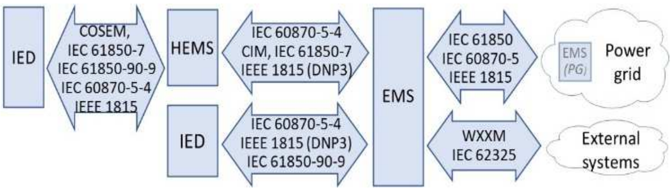

Figure 4. Proposed microgrid Information layer architecture

Physical Layer ensures the actual exchange of data in the form of packets. In the past, data exchange took place mainly via serial buses (RS232, RS485) at speeds from several kbps to 10 Mbps. Today, almost every prosumer has access to the Internet and its own Ethernet-based LAN, so the use of TCP/IP as a unified technology for internal and external communication within the microgrid seems to be optimal. In the future, we anticipate that all IEDs in the microgrid will support TCP/IP communication. At present, however, it will still be necessary to communicate with devices without TCP/IP support by their supported protocols and to provide TCP/IP mediation via Gateways, which will ensure both conversion on layers 1-3 RM OSI and in terms of the information model (Fig. 5).

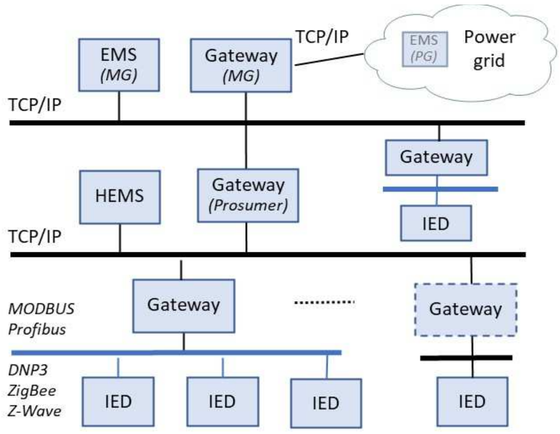

Figure 5. Proposed microgrid data communication baseline architecture

IV. CONCLUSSION

To achieve reliable and robust networks, the communication infrastructure requires the combination of advanced computational and analytical methodologies and self-healing protocols. In our paper we focused on microgrids with Distributed Energy Resources controlled by a central energy management system. According to various locations of battery energy storages we analyzed five different scenarios and then have proposed microgrid communication architecture considering communication within four layers (Dispatch layer, Control layer, Information layer and Physical layer) that used up to date communication and data model standards which have been evaluated as the most suitable for the communication within mentioned layers. The proposed microgrid communication architecture and proposed protocol suits allow data communication and exchange of information between microgrid and other information systems (power grid, energy market and other information systems, e.g., weather forecast) as well. This enables implementation of predictive and more sophisticated energy management algorithms which can results in more efficient battery and energy management.

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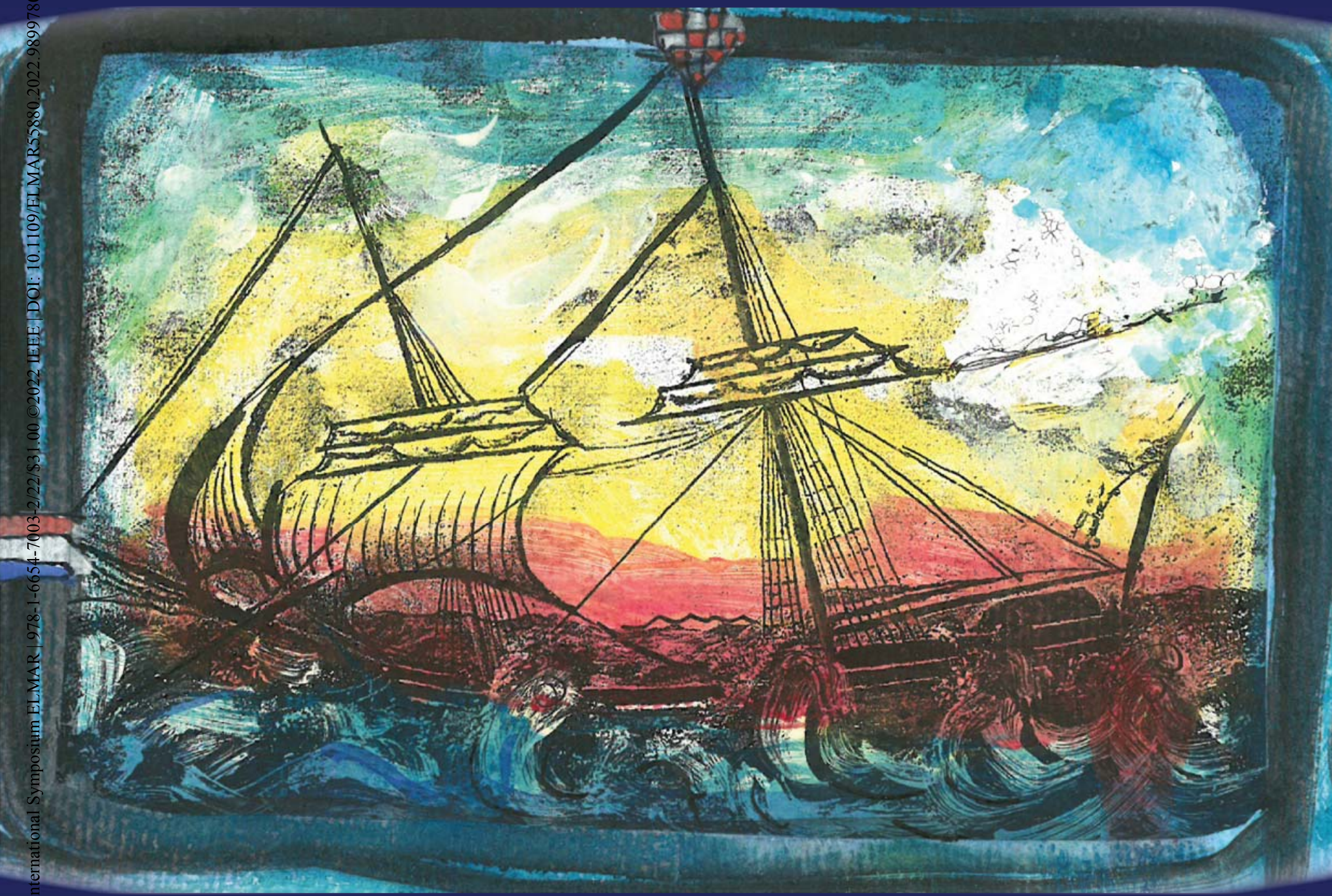

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