Multi-RCAT modem for Small-Scale PV Systems and Renewable Energy Communities

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***Abstract*—In recent years, there has been a significant trend in the energy sector to build small-scale photovoltaic plants (PVPs). Such PV plants are a good tool to accelerate the drive towards zero-emission infrastructure in Europe. At the same time, however, they bring a lot of pressure to adapt the existing power grid to their unique requirements. This paper discusses the key features and typical communication technologies in Smart Grid systems, which can be utilized by small-scale PVPs. Based on the discussed features and challenges of small-scale PVPs, a modem prototype unit for reliable and secure communication is introduced. The proposed modem utilizes multiple wired and wireless technologies to ensure the best possible scalability and adaptability for most scenarios that may occur in Smart Grid communication scenarios.**

***Index Terms*—PLC, Power Line Communication, Small-Scale PV, PVE, Renewable Energy, Energy Community**

I. Introduction

In Europe, the trend of increasing electricity generation from renewable sources has been very significant in the recent years. The main factor behind this are European Union's efforts to utilise renewables as efficiently as possible to build zero-emission infrastructure and buildings with the aim of achieving climate neutrality by 2050 [1]. Furthermore, by 2030, according to [1], 42.5% of the total energy consumed in the European Union should come from renewable sources. In the Czech Republic in 2023, according to [2], 44% of electricity was generated by burning fossil fuels, mainly coal. However, a significant increase in the adoption of photovoltaic power plants (PVPs) is also clear in the case of the Czech Republic at the same time. Additionally, PVPs made 4.2% of the total electricity generated. While the share of energy produced by PV plants with a power output above 100 kW has increased very slowly over the last years, the increase for PV plants with lower power output is very significant according to [3]. This trend shows a significant increase in small-scale PVPs with an output of up to 10 kW, whose total output more than doubled in 2023, indicating a significant increase in the number of residential buildings that use small-scale PVPs to generate electricity. These small-scale PVPs have several significant advantages from a community energy perspective [4]. Despite the initial high cost, they are economically advantageous for households, mainly because of the long-term reduction in household utility costs.

Small-scale PVPs also provide means to enable energy independence of buildings and offer a pathway to zero-emission infrastructure. However, the biggest drawback of these installations is their impact on the overall distribution network and infrastructure, which may not be sufficiently prepared for large amounts of decentralised energy sources and may not be able to react quickly and flexibly enough to the generated electricity surpluses in case of unforeseen circumstances or fault conditions. These surpluses can have a bad impact on the balance of the distribution network. A reliable management system in the distribution network is needed to achieve this.

Such system requires reliable real-time communication between the PV inverter and the Smart meter or electricity meter. It is also necessary to ensure that the PV inverter can be regulated and possibly disconnected from the power grid in the event of power surpluses, to reliably prevent economic losses. For the monitoring purposes in decentralised grids, it is also advantageous to monitor changes, disturbances or possible faults on the grids as efficiently as possible and to send real-time reports of fault or atypical conditions. This can be achieved, for example, by using an appropriately chosen algorithm or artificial intelligence model as described in [5]. In addition, it is necessary that such communication is secured and cannot be tampered with or modified from the outside in any way, to prevent unwanted disconnections or connections of the PV inverter to the distribution grid, which could cause economic losses either on the side of the customer, i.e. in the case of small PV mostly households, or on the side of the distributor. As discussed in [6], communication between Smart

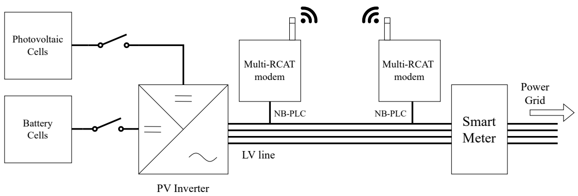

Fig. 1: Topology of PV Inverter and Smart meter system.

meter and PV inverter brings various challenges and problems. Typical communication scenario can be seen on fig.1.

II. Communication technology

The need for stable and reliable communication between devices in a Smart Grid network requires the implementation of a suitable communication protocol. It appears advantageous to implement a system that can support several independent communication technologies and is capable of switching between these technologies when stable connection cannot be guaranteed by some. For Smart Grid applications, a large variety of different communication technologies, both wired and wireless, are presently used. The communication protocols used in Smart Grid applications are often designed to ensure two-way communication between the smart devices in the network. The article [7] gives an overview of the advantages and disadvantages of the most commonly used technologies and standards.

A. Wired Technologies

For communication between smart devices in power grid applications it is advantageous to use PLC (Power Line Communication) technology. Its major advantage is the possibility of using the already established electrical infrastructure as a transmission medium. From [11] can be seen that the use of Narrowband PLC (NB-PLC) technology is a suitable candidate for the use case of Smart Grids and Community Energy. This technology is characterized by a narrow transmission bandwidth in VLF, LF and MF band (3–500 kHz), resulting in its resistance to noise and interferences and a relatively long transmission distance. In Europe, the CENELEC band (3-148,5 kHz) is used. High Data Rate (HDR) NB-PLC technology also offers the ability to transmit data with data rate up to 500 kb/s. Among other things, as described in [12] study, the use of NB-PLC technology appears to be advantageous in terms of possible coexistence with BB-PLC on a single line without cross-interference, the possibility of worldwide deployment of the device, as well as the optimisation of communication for energy sector applications using this technology.

Utilizing PLC technology as the main form of communication in the power grids can also be advantageous in terms of easy implementation of measurements on power lines. Study [8] proposes utilizing of PLC communication as tool for measuring and monitoring the degradation and ageing of power line cables. In [9] it is proposed that PLC technology can be used as a tool for mapping the topology of an unknown low voltage power network.

Another possible wired technology implemented is communication using optical fibre as the transmission medium [7]. However, as mentioned in the article, compared to metallic cables, which are the transmission medium for PLC technology, optical fibers are more resistant to interference. At the same time, however, they are more expensive to build and more difficult to repair faults. The use of fibre optics necessitates the construction of new transmission infrastructure in locations. This presents a major disadvantage for deploying communications over this transmission medium for small-scale to medium-scale PVPs.

B. Wireless Technologies

In environments where the deployment of metallic or fiber communication technologies is not available, a variety of wireless technologies can be used. The advantages and disadvantages of the most used wireless technologies are summarized in [7]. Among the most widely used is the Zigbee protocol, which is an extension of the IEEE 802.15.4 standard. Bluetooth technology is also frequently deployed. Compared to Zigbee, its implementation is more challenging. The use of Sub-1GHz ISM band frequencies is also widespread. As stated by [7] and [10], the most used UHF bands are 412–475 MHz and 860–960 MHz. All the technologies mentioned so far transmit in the unlicensed ISM frequency band. However, the use of licensed bands can also be observed in Smart Grid networks, in particular LTE and 5G technology and its extensions for sensor and automated systems: LTE Cat-M and NB-IoT. Compared to unlicensed band technologies, these do not require the construction of a separate infrastructure. It is already available and managed by the mobile network providers in the deployment region. In this case, however, the disadvantage is the centralized nature of such communication, where communication must be carried out over the mobile operator's network, as mentioned in [7], which can negatively influence the real-time character of the communication.

III. Proposed prototype unit

The proposed modem offers the possibility of utilizing several communication technologies commonly used in Smart Grids networks. This is very advantageous in case of its deployment in small-scale to medium-scale PV systems. Since in this case, as mentioned in section I, it is mainly PV plants located in residential buildings. In this case it is often not possible to ensure the presence and reliability of all frequently used communication technologies. At the same time, it is necessary to ensure reliable communication between the PV inverter, which connects the PV to the power grid network and transfers DC voltage from solar panels to AC voltage, and the associated electricity meter, which is built at the interface between the household power grid and the distribution grid, precisely for these objects. A reliable local communication needs to be built here to control the connection between the distribution grid and the home grid. The proposed modem

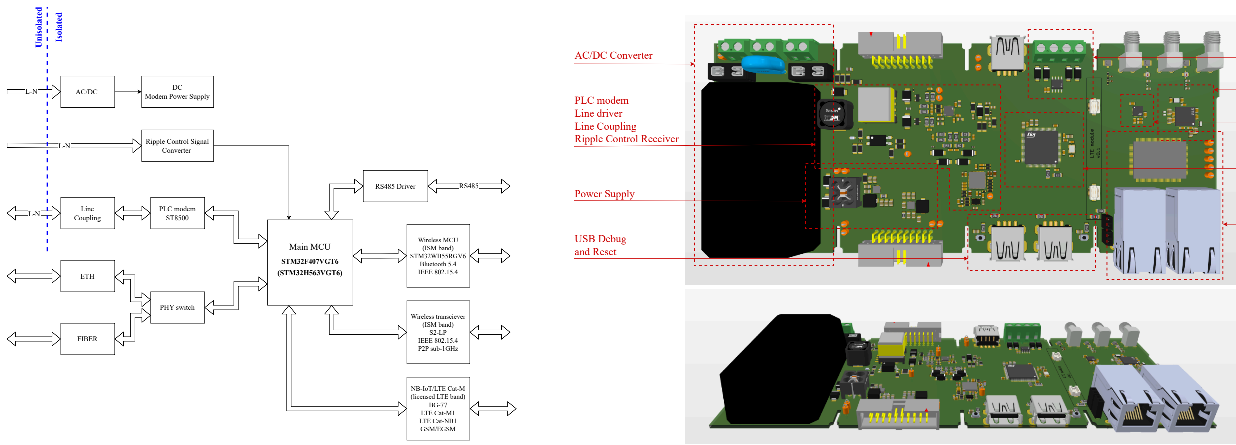

Fig. 2: (a) Block diagram of modem, and (b) the 3D model of the modem prototype.

can be described as a Multiple Radio and Cable Access Technology (Multi-RCAT) device.

Multi-RCAT devices provide the ability to communicate based on a combination of both wireless and wired communication technologies. The main advantage of the proposed modem is its capability to use multiple transmission technologies and the ability to switch between these technologies based on the specific requirements of the environment in which the modem is deployed. For the use with small-scale PVPs in Renewable Energy Communities implementing of one wired and wireless technologies is considered. The modem combines both wired and wireless communication within a local area network, making it a versatile device suitable for most typical deployment scenarios considered for the community energy scenario. In addition to that the proposed modem supports the possibility of receiving and digitalizing the Ripple Control signal, which is used in the Czech Republic for controlling and switching between tariffs in the Smart Grid network.

The modem acts as a communication link between the PV inverter and the associated meter. It provides a point-to-point connection between these two nodes on the local grid network. Additionally, the proposed modem provides the capability of controlling the consumption and production in small-scale PV plants and households based on the function of digitalized Ripple Control commands. Furthermore, the modem can also be used for statistical data collection and smart metering in the local network, or to record faults and line changes as previously mentioned in section II.

To provide the best flexibility, the proposed modem supports several different communication technologies, the use of which varies based on the deployment conditions. The modem is a hybrid device capable of providing both wired and wireless communications. Primarily wired communication is assumed. For community energy applications, the deployment of PLC technologies appears to be the most advantageous. As mentioned in section II, NB-PLC communication has major advantage in terms of the possibility to use the already present power lines as a transmission medium. NB-PLC technology is also less susceptible to disturbances that may arise in the power grid due to the narrowband frequency transmission. Modem is proposed to utilise SiC PLC modem ST8500. According to the [14], this modem is prepared for deployment with The G3-PLC communication stack, which is standardized by G3-Alliance. This brings advantage in easy integration of the proposed modem with existing network and helps with quick development and future deployment of the prototype mode in real-life scenarios. Together with PLC technology, implementation of Ethernet communication is also considered.

In addition to the metallic link, the modem also considers the possibility of connecting to a fibre optic line for cases where these technologies are available, and their use is more advantageous due to increased interference on the power line. As previously discussed in section II, such communication is more reliable and stable, but needs dedicated fibre cabling.

In case of impossibility of using a wired connection, the modem also provides the possibility of wireless communication. To ensure redundancy, at least two wireless technologies are considered for each use-case, where at least one of them is always in the unlicensed frequency band. This is advantageous, for example, if there is no cable infrastructure in the deployed area, if the distance between the Smart meter and the PV inverter is too long, or the exact topology of the power grid is not known. LTE license band communication is utilized. Modem supports LPWAN standards LTE Cat NB2 and LTE CatM1 with help of wireless LPWAN module BG77. Both standards are characterised by the ability to transmit data over long distances with good coverage even in less accessible areas, possibly within buildings. In addition to that, both technologies have very high coverage rates in the Czech Republic. The modem also provides the possibility of wireless communication in the unlicensed frequency bands. For this purpose, communication protocol based on IEEE 802.15.4 standard in 2.4 GHz frequency band and Bluetooth communication are utilized. This function is provided by the wireless microcontrollers from the STM32WBx5 family. Lastly, point-to-point communication in Sub-1GHz band can be used. S2-

LP transceiver was selected, mainly because its relatively easy integration with SiC PLC modem ST8500. Together they can utilize G3-Hybrid communication stack, which is developed by G3-Alliance.

As already mentioned, the modem also provides the possibility of receiving Ripple Control signals, which are used as control commands in the power grid applications in the Czech Republic. The modem has the function of digitalizing these commands, which can subsequently be used in the control of small PV plants in households, as well as Renewable Energy Communities.

For dynamic switching between the available communication technologies, it is assumed to implement a failover function that ensures this switching with respect to the detected or expected interference in the network and selects the most suitable transmission protocol and transmission medium from the available ones. This redundancy in the system can ensure that there is no loss of information or failures caused by such losses. This can ensure and guarantee the best possible response of the system to sudden changes and prevent fault conditions caused by interference or leakage into the power grid that may occur in the energy communities utilizing Small-Scale PVEs.

IV. Conclusion and Future Work

In this paper, key features of the reliable system for communication in small-scale PVPs Renewable Energy Communities and typical communication technologies employed in Smart Grid systems were discussed. The contribution of this article is threefold. Firstly, based on the discussed parameters developed prototype unit of the modem for this use case was introduced. The proposed modem, mainly aimed at providing safe and reliable communication between the PV inverter and the peripheral electrometer or Smart meter for small-scale PV systems, represents an important element in the energy distribution network considering the trend of increasing number of new small-scale PV systems primarily in residential areas. The presented modem combines several important functions that are essential for communication in networks of this kind. It provides a hybrid solution that assumes the possibility of real-time communication and response to changes in the network.

Secondly, by digitalizing Ripple Control commands used in the Czech Republic, the modem provides flexible and quick reaction to changes in the distribution network, either based on the expected energy balance, but also in case of unforeseen variations. Lastly, the modem provides a good tool for analysing the connectivity within the local energy network. Based on the measured parameters of the network, it could be possible to switch between the implemented communication technologies and select the most appropriate one to avoid communication failures and problems that may be caused by such failures.

Future work will be devoted to testing and validation of the proposed prototype for different scenarios that may arise in the case of small PV plants, with emphasis on communication reliability. The proposed unit will be used for measuring and testing of the communication between Smart meter and PV inverter in the typical scenarios. Reliability and security of the proposed prototype will be evaluated.

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