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Conceptual Design of IoT-Based AMR Systems Based on IEC 61850 Microgrid Communication Configuration Using Open-Source Hardware/Software IED

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Abstract: This paper presents an intelligent electronic device (IED) utilized for automatic meter readings (AMR) scheme using "Open-Source" software. This IED is utilized to measure a low-voltage intelligent electronic device) system with a boundless number of sensors, and it is accessible on the Internet of Things (IoT). The utilized equipment for this task is Arduino UNO R3 motherboard and fringe sensors, which are used for measurement of the referenced information. The Arduino motherboard is used not only for sole tranquility of equipment but also for serving as wireless fidelity (Wi-Fi) switch for the sensors. The personal computer is utilized to gather information and perform client-side calculations. The server works based on an open-source program written in Java programming language. The underlying objective of the proposed scheme is to make the meter based on the "*Do It Yourself*" methodology which requires considerably fewer funds. Also, it is conceivable by keeping easy to understand interface, information legitimacy, precision of measured information and convenience for the conclusive client. The information is measured in just about 1 ms which is superb for custom-designed IED. Furthermore, the measured qualities are calculated based on their RMS values to be used for analyzing and further presentation of data.

Keywords: Arduino; automatic metering reading; electric energy measurement; IEC 61850; Java; open-source

1. Introduction

The basis of this research is presented at the Second International Colloquium on Smart Grid Metrology, 2019 (SMAGRIMET) in Split Croatia [1], and for this paper, it is further expanded and explained more thoroughly. The distribution system operator (DSO) has its rules and standards which must be respected and maintained, so investors in renewable energy resources (RERs) have to be agile and acquire all necessary equipment to manage and operate their facility efficiently. To comply with the RERs with DSO's, requirements, and rules, various sets of tools exist on the market, including the automatic meter readings (AMR) and automatic meter management (AMM) systems. The goal of the AMR is to avoid the need for human intervention in the reading of electricity meters and to bypass manual readings, which imply the need for visiting every meter location and reading the presented value periodically [2]. The giant leap in the advancement of the metering technology, such which has not been introduced since the invention of the electromechanical meter in the 20th century, is without a doubt, AMR technology that enables automatically collecting of the data from smart meters and transferring that data to a central database for billing, troubleshooting, and analyzing [3]. Smart meters are used for consumption calculations, metering diagnostic, and receiving the data from wattmeter or energy metering devices in gas or electrical applications. The quality of the measured parameters in the smart grid and microgrids environments highly depends on the manufacturer of the device measuring these parameters, but also on the size of the sample, the time and interval of measurements, and the applicability of the device considering the mobility and the robustness, and that is only without mentioning the complexity of the software required for real-time analysis.

Devices intended for the measurement of physical values that are currently on the market vary in price and the quality of the measured data. The rule "the more expensive, the better" is not necessarily always true because it all comes back to the features and capabilities of the device and the customer's requirements. The main concept of the IED for AMR should cover accuracy and precision in correspondence with the valid standard for a group of measurements. Such a group of measurements implies the changes in the required class and level of accuracy when observing the path from an end-user to a transformer substation. Overall, calculation statistics in a smart grid system should be available even in the case of lesser accuracy, which is usually the case closer to the end-user. Some of the measurement techniques for water and gas are using wireless principle on concentrators, usually, the main differential concentrator that provides the data to the higher level "reading" company. The industrial solutions require higher accuracy class and are usually equipped with more precise measurement solutions. Hereafter, we can define a sort of high-level analysis and middle-level requirements with cost-efficient solutions, such as the one proposed by this paper.

While considering the smart grid and microgrid legal framework and regulative guidelines, it is most common to observe the brand name smart meters and AMR devices since such equipment usually has a track record of correct performance [4]. Also, since the providers of some commodity need precise and correct measurements while the consumers of that same commodity demand quality at the reasonable and fair price, it is in everyone's interest to measure and evaluate correctly. Lately, the case is that the innovations made possible the emergence of cost-effective and affordable AMR devices for which the market quality is yet to be established. Nevertheless, the new era of AMR devices is ongoing, in which the virtual every end-consumer can benefit from its convenience. Consequently, the number of smart measurements will increase by such applications, thus reducing the need for values estimation by hybrid methods similar to [5].

Just recently, individual consumers have been compelled to examine the meters physically and write down the numbers on the record. The record and the information provided have been utilized to figure out consumer's needs [1,6], the electrical power, as well as the utilization of water, gas, or fluid fuel. Innovative advancements enabled on the spot metering, especially in cases where estimating power is physically out of reach, "savvy meters" can handle the utilization. Mobile communication (GSM) enabled the remote readings of such "savvy meters" with instant messaging service integrated with the meters [7–9]. However, the costs of such solutions are not negligible, and the benefits of information transmission over GSM networks are evident only in intensive investment circumstances that can utilize such almost-smart meters [9,10]. Even though the need for smarter meter readings was driving the innovation of metering and estimation systems, which were essential for the industry, innovation propelled with "open-source hardware" (OSH) and "open-source software" (OSS) gadgets and instruments [11]. For a fraction of the base cost, an estimating solution can be assembled, including essential hardware for value estimation, the estimating transducers of signs in computerized structure, preparing units that gather the required signs [12], correspondence gear and correspondence conventions that convey information [13], and the server on which the program for the examination and/or capacity of information runs. OSH [11,12,14] has previously been utilized by the Arduino Mega and PIC 18LF4620/CC 2430/S3C 2440 frameworks. Programming the electronic devices for the cloud IoT approach is described in [11,14], and the proposal for profoundly versatile solutions based on Wi-Fi is presented in [12]. Since Arduino Mega uses old architecture, future work is considered as an option on the different core but with much bigger and stronger architecture, AVR XMega [15]. By this hardware, additional features will become possible by integration of hardware algorithms that are already part of the new XMega architecture. In that case, remote access to the measurement IEDs can be considered on a safer and secure level of service, or it can be based on different technology. IoT approach can be done on the wireless and remote level, but security must be highly defined.

PIC is also used in some DIY projects, while some of them already have an integrated physical layer. Those kinds of PIC architectures combine the regular 802.3 stack part on the same core. The network layer and connection with library support come on the transport layer, which can be custom-defined in firmware. Based on the mentioned samples in the combination of PIC18LFxx and one of the RF ZigBee 802.15.4 radio board/chip, the system can be improved in lots of directions. One of the very interesting features in the new method approach is a new design of radio chips with small power consumption like Texas Instruments CC2530 that represents the second generation of 802.15.4 standard.

Interoperable and regulated communication is necessary for effective control of small-scale systems, such as microgrids. IEC 61850 was considered more as an exception for microgrid communication among the more reassuring technologies than the usual practice, but this has been changed over time [16–18]. IEC 61850 standard has been initially produced for substation automation system (SAS), and later expanded to entire power utility digitalization. IEC 61850 standard has been initially produced for vertical SAS and later expanded to entire power utility digitalization enabling the generic substation events (GOOSE) control model. GOOSE is defined by IEC 61850 and utilizes electrical network for multicast services within four milliseconds via Ethernet or VLAN, similar to IEEE 802.1Q. Several IEDs on the market use a non-standard event reporting model, such as Fixed GOOSE, that integrates Generic Substation State Events over standard protocol. Also, IEC 61850 enables precise time distribution and clock synchronization in power grid with a precision of 1 µs. Such resolution enables efficient voltage and current sampling for differential protection, wide-area monitoring, and event recording in case of faults and busbar protection triggering. IEC 61850 protocol is an international standard protocol for substation and energy infrastructure communication connection and data exchange. Data defined by IEC 61850 can be mapped and translated into several other electronic devices supporting protocols, which makes IEC 61850 versatile and grounding standard for smart electronic devices. Also, it can be transferred via TCP/IP backbone, which makes him a universal transmission protocol. To structure these IEC 61850-based IEDs and to give incredible compatibility inside the substation, the standard defines a System Configuration Language (SCL) [19]. The SCL plans the IEDs in a substation in an accurate manner. The comparability of IEDs in a substation is practiced by presenting an IED to an Application system building instrument (ASBI) and returning it to the IED. This methodology is repeated for all IEDs in the framework until the whole framework is assigned to all IEDs. The all-out method for the course of action of IEDs in a substation is ordered in IEC 61850-6 (ed. 2) [11]. The SCL arrangement portrayal in an IEC 61850-based SAS has been for the most part recorded as a hard copy [13]. The expansive IEC 61850-based information model and arrangement delineation of SCL reports for an SAS have been discussed in [12]. In [14], an SCL has been proposed dependent on a powerful structure process and robotized assessment for the confirmation system.

This paper covers the issues of the IEC 61850 integration into virtually DIY IED, in this case, a smart meter, which accumulates the data and sends it to the server where the administrator can make the use of it and proceed with required tasks. The purpose of the paper is to analyze the specially crafted custom-made IED (CMIED), which has been recently utilized as a piece of microgrid metering framework. The applications where such CMIED can be used are islanding detection [20–23] and peak power shaving/diminishing [24]. Also, it can be used for the collection of precise data in a smart microgrid environment, but also communication with various devices such as brand name smart meters, substation switches, section breakers, information concentrators, etc. The data string of the electric power accumulated by IEDs is packed according to IEC 61850 standard for SCL and propagated through a proposed framework. Various IEDs can be based on OSH and OSS solutions, and by IEC 61850 integration, their usefulness can be further proved. To the best of authors' knowledge, the basic substation automation framework has been provided by IEC 61850, and this paper is the pioneer to address the conceptual design of IoT-based AMR systems in IEC 61850 microgrid communication configuration using IED based on open-source hardware/software.

The customers who have access to IoT and with attendance to generate energy from households have obstacles connecting their technological system of smart devices into one cohesive whole, which operates efficiently both individually and as a whole. This paper proposes some solution for connecting Smart Devices which are capable of "plug-n-play" into IoT with energy generating facilities which operate on IEC 61850 protocol without any need for an adapter like devices for information exchange. This solution is based on already available tools and materials from most online shops. The proposed solution is not limited by authors- defined data packages, it is capable of understanding custom made information. The proposed measurement system is limited to one voltage of three-phase voltages because of data readout understanding and calculations. Three-phase measurement is nothing more than two times more devices/sensors included in the experiment. This paper gives a multidisciplinary perspective on a solution that can be applied to households, substations, commercial applications, but it can also be used for educational or scientific purposes.

The rest of this paper is organized as follows: Section 2 presents the essential design and architecture of CMIED. Section 3 discusses the IEC 61850-based substation communication network (SCN). Section 4 gives the information on IEC 61850 integration by SCL and innovative CMIED engineering. Finally, Section 5 presents the conclusions of the paper.

2. Architecture of CMIED

Wi-Fi communication as a backbone has been suggested in the papers [5,6,9]. In this system, the AMR can use 802.3 and 802.11 to send data to a remote server. Such choice is based on the knowledge presented in [25] and the fact that this solution needs to be cost-effective. The data transmission is finished inside a pre-decided period as a cycle of information that consolidates everything on AMR structure. The period in which a data trade is done is designed in the hardware when the customer sets the parameters. Data sets sent for Wi-Fi transmission are inside the structure of hypertext markup language (HTML) variant 1.0, which is a tool for the presentation of sampling data on the simple graphical user interface (GUI).

The client can see the information on any device that can connect to the same Wi-Fi network, and that can handle the HTML 1.0 scripting language [26]. Features of Wi-Fi, provided in IEEE 802.11 standard [27], such as boundless information exchange, simple and brisk set up of all system settings, ease of execution, remote availability and so on, are the reasons this technology is chosen for the conformity stage of the proposed AMR framework.

The AMR results are provided through the Wi-Fi channel. That channel is expandable just by storing up another AMR meter that would transfer data over a Wi-Fi or explicitly from the Ethernet connection interface with the Wi-Fi switch inside the first AMR meter. In that case, the data pack would reach out to another Internet protocol (IP) address of the local-area network (LAN) and end up available to the customer. Such an approach can be expanded to use of concentrator like is done in some other applications [28] where is used a wireless remote system based on ZigBee technology.

The technique and structure of the AMR correspondence system are showed up in Figure 1.

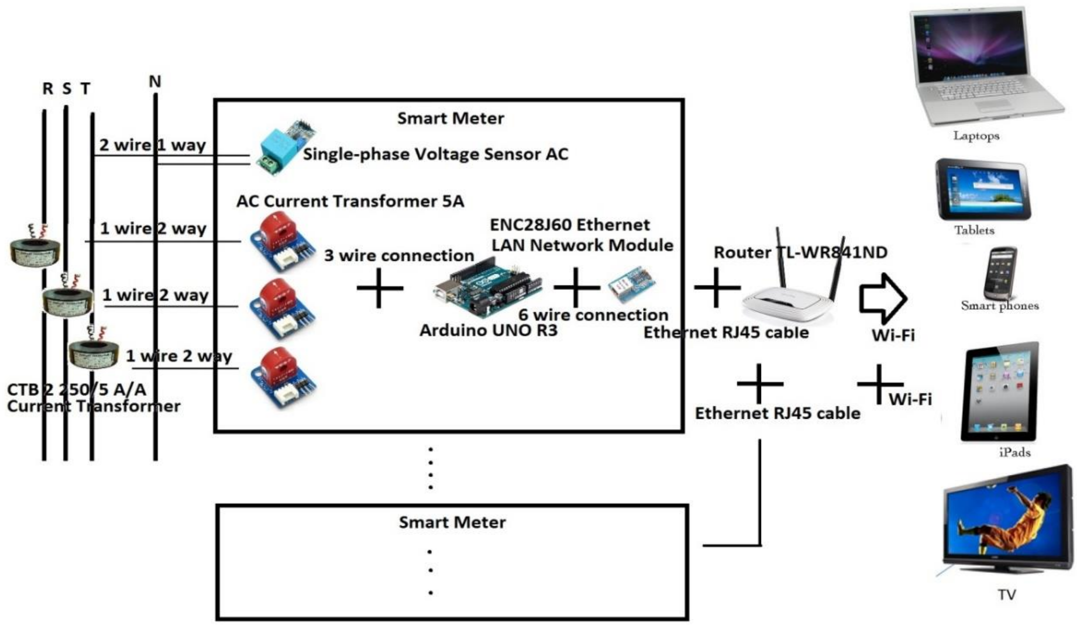

Figure 1. The architecture of the AMR system.

Information about current and voltage values is obtained with the help of basic equipment at power connections and by using current transformers. Measurement data is processed inside the Arduino Uno R3 board and transported to the Wi-Fi switch over the ENC28J60 module. The switch transmits data to a Wi-Fi network. Any device that has an HTML 1.0 interpreter and is connected to the same Wi-Fi network can see the data dynamically. Also, a server application that acquires and stores it on a hard drive can be appointed to any PC connected to the same Wi-Fi network.

All of the AMR system parts can be freely bought on the web stores of electronic items. They are alterable and adaptable to the customer. Since the electricity market is unregulated, it is imperative to have additional realization when securing fragments, as not all parts are proportionate in quality, nor are all compatible with each other. Writing computer programs for IED in case of substation management is done using solely JAVA programming language. The programming hardware is the Arduino motherboard and all additional peripherals [29].

3. IEC 61850-Based Substation Communication Network

SCN based in IEC 61850 contains several IEDs that perform well in terms of testing, protection, and control [30,31]. Each device is connected to intelligent hubs (LNs) and individual data queries following the IEC 61850 standard. During the action, IEDs communicate with each other over an established framework. In that way of communicating, every IED knows about all other present IEDs and their role in the grid. In that fashion, in the arrangement, each IED is taught about other IEDs' region in the SCN. To understand the whole framework, IEDs also need information on the subtleties of the substation, e.g., B. single line view, switchboard structure, and correspondence system view. This absolute information is conveyed to each IED by various exchanges of specific records. To ensure reliable exchange between different devices, IEC 61850-6 describes an ordering language called SCL. SCL records are exchanged during the setup process between different configurators and IEDs. For simplicity, the all-out method is part of multiple ensembles, for instance, transformers, medium, and low voltage level, or even substation related parts in which substation exchanges data with other substations/structures for line protection and various limits. This part is named as an endeavor. For the planning of such errands, different interfacing data exchanges occur among the endeavors. Particular on-screen characters drew in with the planning technique are the IED configurator, structure configurator, and the endeavor IEDs. The change of IED limit rests with the shipper of each IED. With full ownership of the device change, the ability to perform essential or advanced functions within the device is provided by the device owner. The types of SCL files that are subordinate to data exchange and exchange of rights between IEDs describe six notable types of SCL reports in IEC 6185: IED ability portrayal (ICD), instantiated IED depiction (IID), framework detail depiction (SSD), framework setup depiction (SCD), arranged IED depiction (CID), and framework trade depiction (SED). All these record types have particular archive extensions. Each archive contains an adjustment number and a rectification number to perceive changed and old records.

In the procedure of SCL planning, the last step is the creation of an SCD archive, which contains the widely inclusive point of view of the substation portrayal. This record fuses information on all IEDs, substation structure, data types for all related LNs, and the communication framework. IED's charge the individual ICD records to the IED configurator close to the beginning of the structuring methodology. If any alteration is required in the IED portrayal amid the building procedure, an IID record is sent out from IED to the IED configurator. Particular IED configurators generate out ICD reports and IID records from various IEDs, then sending them to the structure configurator. As such, the structure configurator contains the limit portrayal records from all the related IEDs. The structure subtleties are imported through a system-specific gadget as an SSD report. This SSD archive contains the base information of the system group and the portrayal of LNs of the substation. The system configurator unites this information with the current or departure of IED in the structure; a comparative technique is repeated to plan the system. The arrangement strategy for an SCN of a single substation is delineated in Figure 2.

For ease, the predefined number of IEDs is related to the SCN switch. The IED configurator and framework configurator are related to the framework in reconfiguration arrangement. Planning a reduced structure in a way that acts as two substations would be misleading as it lacks the time shift for different SED datasets when exchanged between different substations. Similarly, these SED records should be shared between all small network parts for better interpretation. It is not possible to exchange some SED data set mixes with the system described in IEC 61850-90-1. To solve this problem, a central configurator is introduced into the planning process. n this way, this article proposes an unprecedented WAN Measurement Configurator (or Micro System Structure Configurator) for small profile IEDs. This section explains the setup technique for WAN Meter Configurator, item by item. The proposed scheduling method is as follows: General directorates and workloads in the micro-network section are displayed with different IEDs in their neighborhood. Like this, distributed generation (DG) and consumer loads can be considered as a substation having various IEDs.

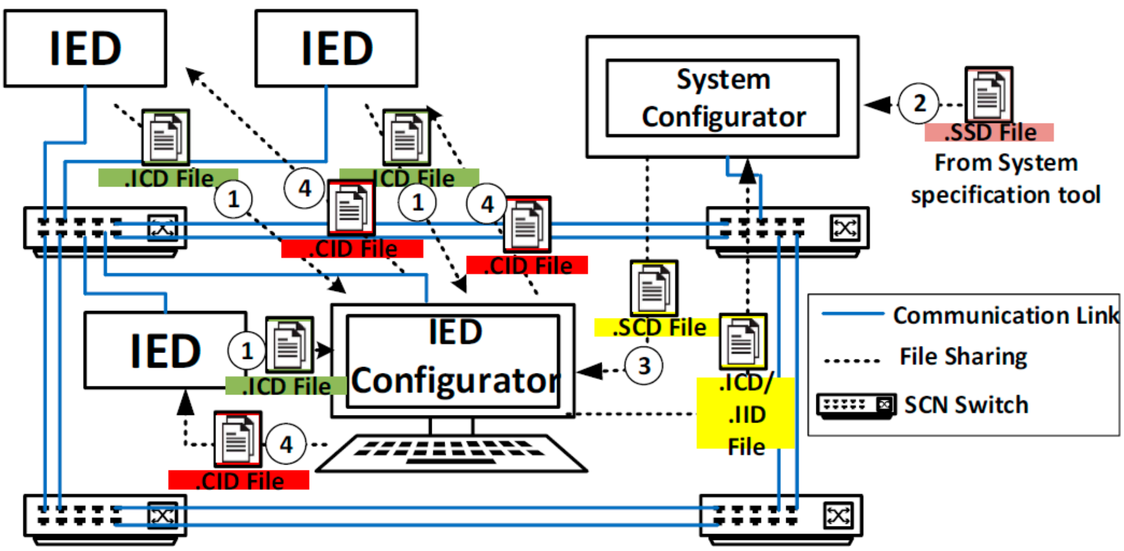

Figure 2. SCL file configuration for typical SCN.

Microgrid applications of the last SCD record from the structure configurator is conferred to the miniaturized microgrid level framework configurator (MLSC). The MLSC is the authority which deals with the trading of SED archives between various system configurators for creating the updated adjustment of SED record. For this, the most important SCD reports of all system configurators were collected and included in the SSD recording of microgrid section data. The created SED record in this method is then passed to the structural configurators (specifically DG or load) of the microgrid. An illustration of consolidating the all-out microgrid organization plan procedure is showed up in Figure 3.

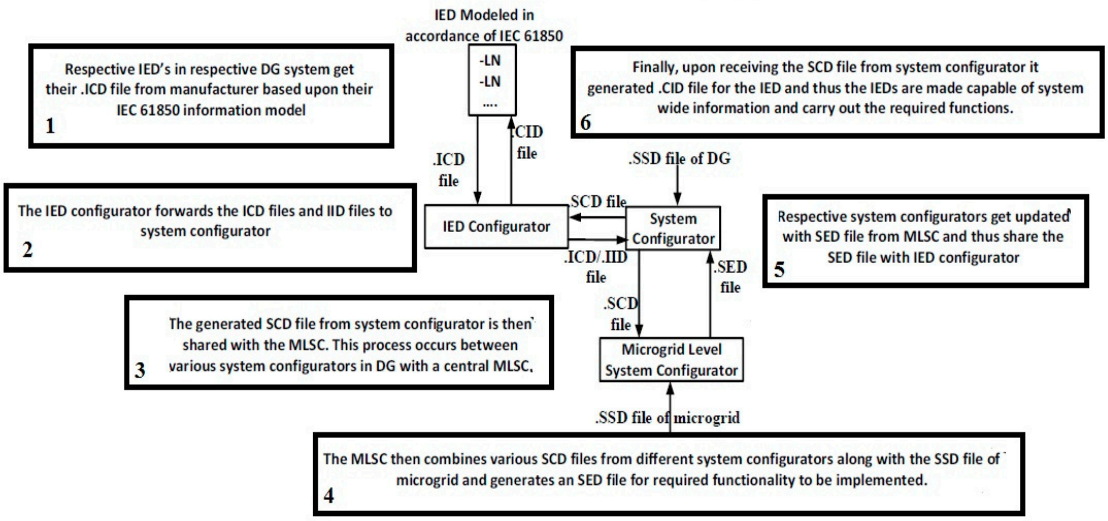

Figure 3. IEC 61850 microgrid communication configuration process.

Figure 3 IEC 61850 microgrid communication configuration process where the pipeline of data transmission is presented in file transfer manner. It is shown starting the process by modeling data into ICD file and finishing by receiving. CID file by IED.

To outline the scaled downscale system configuration process, the arrangement method using created SCD archives is explained over a test scaled-down structure set-up.

4. The Symbiosis of CMIED and IEC 61850

IEC 61850 files are all the same in syntax structure; they are very similar to XML annotation used in most of the application configurations: web apps, desktop-based apps, mobile phone apps, etc. An example of an SCD configuration file is presented by Figure 4, describing the protection scheme for photovoltaic (PV) distributed generator in microgrid.

Figure 4. SCD file example for PV IED packed information.

For the testing purposes, a protective relay data is considered to be data transferred to an SCD report to reduce the size and represent IED connection. The orchestration of the spread of the concentrated security parcel requires the configuration of the SCL dataset. This arrangement occurs in two essential advances. A major advance is that the IEDs that differ with a particular structure is organized in the same manner as in a standard SCN explained in past sections. This is called a neighborhood plan. As a result, the MLSC interface structure configurator is used to create SED records for a standard application, for example, to bind together a security strategy. This is referred to as the overall arrangement in this research. The neighborhood structure requires one last SCD record for the system. The IED configurator retrieves the data (with LV and data objects) of all the estimated IED properties from the sensor and packs it into the ICD dataset. Each IED has its ICD record provided by the manufacturer. In this article, open-source programming takes on the task of creating an output device for uniquely obtained ICD records until IEC 61850 based communication proceeds. IED device is customized in Java programming language and introduced into PC from where information is transmitted further by RS 232/RS485 to Smart Grid framework arrangement or/and to IoT Gateway by message line telemetry transport (MQTT), as portrayed in Figure 4. Figure 4 shows the SCD file example for PV IED packed information. On left is presented listing of abbreviations for some of substation parts like breaker, transformer, busbar etc. On right is sample of XML like SCD file where are those abbreviations used in listing like manner for next device to be able to add its listing etc. SCD file is received by router who organize communication line and forwards it to command station for data acquisition. Also, Table 1 presents measurement from Improvised Electronical Device which transmits data to IoT cloud by IEC61850 protocol. Its only one phase measured.

The IED Configurator sends certain ICD records from the IED to the System Configurator. The structure configurator creates an SCD record merging all the ICD archives and includes topological system information from the SSD reports. A late-created SCD report is sent to an IED Configurator, which creates CID records and sends them to the appropriate IEDs in the system.

Table 1. Example of measurements for on phase of the real PV system.

26 December 2016 18:00:10	Voltage: 225 V Current: I1 = 10.10 A
26 December 2016 18:00:19	Voltage: 224 V Current: I1 = 10.09 A
26 December 2016 18:00:32	Voltage: 222 V Current: I1 = 10.18 A
26 December 2016 18:00:40	Voltage: 224 V Current: I1 = 10.15 A
26 December 2016 18:00:48	Voltage: 223 V Current: I1 = 10.14 A
26 December 2016 18:00:58	Voltage: 224 V Current: I1 = 10.09 A
26 December 2016 18:01:07	Voltage: 222 V Current: I1 = 10.17 A
26 December 2016 18:01:13	Voltage: 224 V Current: I1 = 10.11 A
26 December 2016 18:01:25	Voltage: 223 V Current: I1 = 10.16 A
26 December 2016 18:01:33	Voltage: 224 V Current: I1 = 10.16 A
26 December 2016 18:01:43	Voltage: 224 V Current: I1 = 10.13 A
26 December 2016 18:01:55	Voltage: 223 V Current: I1 = 10.18 A
26 December 2016 18:02:07	Voltage: 223 V Current: I1 = 10.09 A
26 December 2016 18:02:15	Voltage: 224 V Current: I1 = 10.17 A
26 December 2016 18:02:24	Voltage: 223 V Current: I1 = 10.05 A
26 December 2016 18:02:37	Voltage: 223 V Current: I1 = 10.12 A
26 December 2016 18:02:53	Voltage: 224 V Current: I1 = 10.21 A
26 December 2016 18:03:10	Voltage: 224 V Current: I1 = 10.16 A
… … … … … … … … … … … … … … … … … .	

5. Conclusions

This paper illustrated the bond between CMIED and IEC 61850 protocol for communication between devices in smart grid or microgrid environments. The proposed setup is not only limited to electrical applications but can also be extended to the IoT so that any CMIED can communicate with the cloud without a negative impact on the framework and dedicated pipeline. The program required to interpret the measurement data and values estimated for the SCL or MQTT rack is unique and should run all the time on the IED to allow consistent transmission of information across defined communication channels. Thanks to the Java language, this application can query CMIED devices across multiple platforms. This article suggested an adaptive open-source technology that can be used to tailor custom, low-cost IED interactions between IoT and electrical applications. The cyber-security issues regarding the proposed conceptual cyber-physical framework are the subject of the future publications of the authors.

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Abbreviations/Acronyms

The following abbreviations are used in this manuscript:

AMR	Automatic meter readings
IED	Intelligent electronic device
LV	Low voltage
IoT	Internet o Things
Wi-Fi	Wireless fidelity
RMS	Root means square
DSO	Distribution system operator

RER	Renewable energy resources
AMM	Automatic meter management
OSH	Open source hardware
OSS	Open source software
SCL	System Configuration Language
SAS	Substation automation system
ASBI	Application system building instrument
CMIED	Crafted custom made IED
HTML	Hypertext markup language
IID	Instantiated IED depiction
SSD	Framework detail depiction
SED	Framework trade depiction
WAN	Wireless are networks
MQTT	Message queuing telemetry transport
LN	Communication Network
IID	Instantiated IED depiction
ICD	IED Capability Description
SCD	Substation Configuration Description
CID	Configured IED Description
SED	System Exchange Description

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