On the Integration of Smart Grid and IoT

Salvatore Cavalieri[1][a], Giulio Cantali[2] and Andrea Susinna[2]
[1]University of Catania, Dpt. of Electrical Electronic and Computer Engineering (DIEEI), A. Doria, 6, Catania, Italy
[2]Consortium COMETA, S. Sofia 64, Catania, Italy

Keywords: IEC 61850, Smart Grid, Internet of Things, Web Services, REST, MQTT.

Abstract: The paper proposes a novel solution in the field of the integration of Smart Grid and Internet of Things. The definition of a web platform able to offer to a generic web user a RESTful interface to IEC 61850 Servers is proposed. The web platform enables the mapping of information maintained by an IEC 61850 server into MQTT messages.

1 INTRODUCTION

The smart grid (SG) is based on a new vision of the electric grid, which includes the maximization of the distribution of energy demand, the minimization of losses and the integration of renewable energy sources on a large scale, as pointed out in (Alotaibi, 2020; Mehigan, 2018; Shi, 2020). SG aims to overcome one of the main limitations of the current electric grid, related to the lack of integration of novel information and communication technologies.

Among the novel information and communication technologies there are those based on the Internet of Things (IoT), which play a strategic role in the era of Industry 4.0 as shown by (Xu, 2021; Hassan, 2020, Bader, 2020; Lu, 2017; Cotrino, 2020). The eXtensibleMessaging Presence Protocol (XMPP) and the Message Queue Telemetry Transport (MQTT) are some of the most known protocols in this field (IETF, 2004; OASIS, 2014; ISO/IEC, 2016). The REpresentational State Transfer or REST is an architectural style defined by Roy Fielding in his PhD dissertation (Fielding, 2000); a Web Service based on REST is called RESTful Web Service (Richardson, 2007). RESTful Web Services is a paradigm that can enhance the IoT application scope by making smart things part of the Web (Benomar, 2020).

The paper proposes a novel solution in the field of the integration of SG and IoT. In particular, the proposed integration involves IEC 61850, which is is an international standard defining communication protocols for intelligent electronic devices at electrical substations (IEC 61850, 2011; Falk, 2019).

The definition of a web platform able to offer to a generic web user a RESTful interface to IEC 61850 Servers is proposed. The web platform is based on a REST architecture and enables the mapping of IEC 61850 information model into MQTT messages. The platform will be called *IEC 61850 Web Platform* in the remainder of the paper.

2 RELATED WORKS

The current literature presents several studies about enabling IoT in SG, typically referred as IoT-enabled SG (Reka, 2018; Al-Turjman, 2019; Cavalieri, 2016; Cavalieri, 2021).

In (Tightiz, 2020) the authors present a review of the IoT protocols used in the SG aiming to achieve guidelines in utilizing the proper IoT protocol that can meet the SG requirements; addressing effective elements in applying IoT in the SG's future trends is another contribution of this paper. In (Shin, 2016) authors discuss integration of IEC 61850 and IoT. In (Ustun, 2020) an IEC 61850 and XMPP communication-based energy management in microgrids with integrated electric vehicles is introduced. In the paper (Jun, 2021), the XMPP and MQTT are applied to an IEC 61850-based grid, and the most suitable protocol for the micro grid environment is derived by comparing two protocols.

[a] https://orcid.org/0000-0001-9077-3688

Cavalieri, S., Cantali, G. and Susinna, A.
On the Integration of Smart Grid and IoT.
DOI: 10.5220/0011035300003179
In *Proceedings of the 24th International Conference on Enterprise Information Systems (ICEIS 2022) - Volume 1*, pages 709-716
ISBN: 978-989-758-569-2; ISSN: 2184-4992

Among the main approaches aimed to enable interworking between REST and SG domains, in (Urkia, 2018) a mapping between CoAP and IEC 61850-based substation automation systems in a SG environment is proposed. Based on REST, CoAP is a specialized web transmission protocol for use with constrained nodes and constrained networks. Another solution for the mapping of the IEC 61850 to RESTful Services is presented in (Pedersen, 2010).

The main feature making the proposal here present different from the other solutions present in the literature is the capability of offering several mechanisms, all enabling SG and IoT integration, in the same solutions. First of all, a RESTful interface to IEC 61850 Servers is available, allowing a generic web user to access the information maintained by the IEC 61850 server by a REST-based exchange. Then a mechanism to transmit information maintained by IEC 61850 Server, through JSON frames included in MQTT payloads has been defined based on pub/sub transmission mechanisms. Finally, the solution here proposed aims to introduce syntactic interoperability; the IEC 61850 Web Platform allows a user to share the description of the data types maintained by IEC 61850 Server, into a standard format (JSON).

3 IEC 61850 DATA MODEL

IEC 61850 is the leading standard for substation automation (IEC 61850, 2011), (Falk, 2019). It is intended to structure the intelligence of protection, control, monitoring and automation functions. The standard fulfils automation architecture requirements for utility subsystems, enabling communication among multi-vendor equipment.

IEC 61850 defines an object-oriented modelling of process data required for the power system automation. IEC 61850 data model has been primarily defined for the exchange of information within substations by the document IEC 61850-7-4 (IEC 61850, 2011). IEC 61850 data model is now extended for other domains, among which one can include distributed energy resources (DER)s by IEC 61850-7-420 (IEC 61850, 2011).

Figure 1 shows the main elements of the IEC 61850 data model. The top parent class is the intelligent electronic device (IED), which is hosted by physical device, i.e., the controller part of the device.

The IED consists of one or more Logical Devices (LDs), i.e., virtual representations of devices intended for supervision, protection or control of automated systems. LDs are created by combining several Logical Nodes (LNs) which represent various device functionality interfaces. Data Objects (DOs) are representations of the common information of logical nodes. DOs are typed by Common Data Classes (CDC) from IEC 61850-7-3 or IEC 61850-7-2 (IEC 61850, 2011). Each CDC describes the type and structure of the data object within the LN. Figure 2 gives the details of hierarchical structure of the Data Object Type.

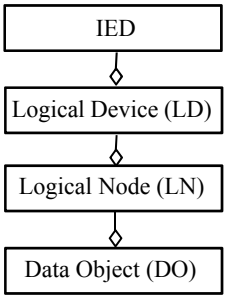

Figure 1: IEC 61850 Data Model.

A Data Object belongs to the Data Object Type; it may contain elements of the Data Attribute type and/or Structured Data Object type (i.e., Data Attributes and Structured Data Object, respectively). Like Data Object, Structured Data Objects are also defined by Data Object Types, as shown by Figure 2.

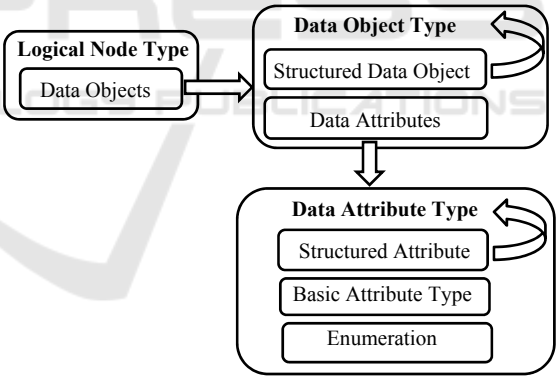

Figure 2: Data Type Template Hierarchy.

A Data Attribute is defined by the Data Attribute Type. It may be a Structured Attribute, or may be of a customized Enumeration type, or of a Basic Attribute type. In the simplest case, a Basic Attribute may be of basic type like Integer, Floating Point or Boolean. Like Data Attributes, Structured Attribute belongs to Data Attribute type, as shown by Figure 2.

The IEC 61850 standard provides a data exchange mechanism using an XML-based file format called Substation Configuration Language (SCL). SCL allows the representation of an IEC 61850 system configuration of electrical devices, including

representation of data and communication services, as described in (IEC 61850, 2011). Its main purpose is to allow an interoperable exchange of communication system configuration data between an IED configuration tool and a system configuration tool from different manufacturers. The SCL file is divided into sections, each of which provides different information. Header section includes general topics and details about SCL and file version. Communication section contains communication details. Substation section describes electrical topology for substation or any other electrical process. IED section describes devices capacities, functions and data it manages. DataTypeTemplates section describes functional data model by defining LNs, Data Objects and Data Attributes.

IED Capability Description (ICD) file is a specific type of Substation Configuration Language (SCL) file, containing a generic description of the whole capability range of a given device, including the functions and objects it can support. The ICD file is usually supplied by the developer/manufacturer.

IEC 61850 standardizes the set of abstract communication services allowing for compatible exchange of information among components of a Power Utility Automation System. IEC 61850 offers several types of communication models, among which there is the Client/Server type communication services model. An IEC 61850 Server may be used to maintain and make available to IEC 61850 Clients, its content is in term of data structured according to the IEC 61850 data model shown in Figures 1 and 2. An ICD file is always available in the IEC 61850 Server to describe its full content.

4 IEC 61850 WEB PLATFORM

The IEC 61850 Web Platform here proposed, is based on the adoption of a REST architectural style and is shown by Figure 3. As it can be seen, it offers to a Web User the access to one or more IEC 61850 Servers.

The term Web User is used in this paper to refer to a generic application running on a generic device which consumes the services offered by the IEC 61850 Web Platform. It is constrained neither to be IEC 61850 compliant nor to implement the IEC 61850 communication stack. The only constraints are the adoption of RESTful-based communication and the MQTT-based exchange of information.

The RESTful Web Service Interface shown by Figure 3, accepts requests submitted by an authenticated Web User.

The Middleware module inside the IEC 61850 Web Platform, performs all the operations needed to fulfil each request coming from a Web User. These requests may require data exchange with the available IEC 61850 Servers; for this reason, the Middleware includes an IEC 61850 Client used for the access to the IEC 61850 Servers. Communication between IEC 61850 Client and IEC 61850 Servers occurs according to the standard IEC 61850 communication protocol and services (i.e., using the IEC 61850 communication stack). The Middleware includes a particular module named MQTT Publisher, which is in charge to publish information taken from IEC 61850 Server, through a MQTT Broker, using MQTT protocol.

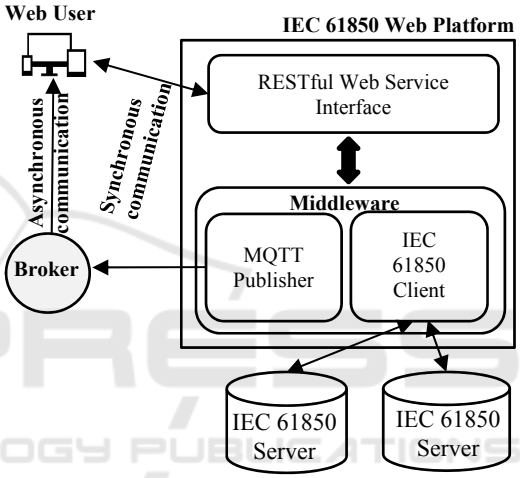

Figure 3: IEC 61850 Web Platform.

Communication between Web User and the IEC 61850 Web Platform may be synchronous (based on RESTful web services) and asynchronous (based on MQTT Publish/Subscribe Pattern), as shown by Figure 3.

Web User uses synchronous communication to interact with the Web Service Interface to request one of the services offered by the IEC 61850 Web Platform. POST requests are realized using JSON format. For each Web User's request through the RESTful Web Service Interface, the IEC 61850 Web Platform will send a relevant response. Due to the adoption of REST, communication between Web User and IEC 61850 Web Platform is stateless. Each Web User needing to use the IEC 61850 Web Platform through the Synchronous communication, must be previously registered (by user credentials in terms of username and password) and authenticated (through the use of signed token which is returned to the Web User).

Asynchronous communication is realized through the use of MQTT Brokers to allow the Web User to receive data produced by the platform; data is mainly originated by the IEC 61850 Servers. Web User will register to a particular topic in order to receive the information needed from the relevant MQTT Broker. The Broker may be chosen by the Web User, or he can use a given predefined Broker.

The following subsections will give more details about both the synchronous and asynchronous data exchange.

4.1 User Registration and Authentication

Use of the IEC 61850 Web Platform from the Web User may occur only after his registration. If the user is not yet registered in the system, he must issue a suitable POST Request to a specific Web Service Interface, in JSON format, the body of which must contain the credentials (username and password) with which the user intends to register. If the registration procedure succeeds, Web User will receive a POST response, again in JSON, indicating that the operation was completed successfully. If registration procedure fails (e.g., if the user is already present in the system), the platform response will specify the failure reason.

Before the registered Web User may proceed to request synchronous services to the platform, he must authenticate himself to the platform by entering his credentials. The user will send a POST request to another specific Web Service Interface relevant to the authentication service, specifying his personal credentials used during the registration. If the authentication request succeeds, the Web user will receive a response containing a signed token to be used in each of the next web service synchronous requests issued to the IEC 61850 Web Platform.

4.2 Accessing an IEC 61850 Server

The main aim of the Web Platform is to allow the access to IEC 61850 servers by the web. According to this aim, the Web User must pass to the platform the details about the IEC 61850 Server he desires to access. A POST request must be issued at a particular Web Service Interface containing these details; in particular, three parameters are required to be specified.

The first parameter represents the IP address of the remote machine hosting the IEC 61850 Server; the other parameter is the port on which the server is listening. Finally, it is requested that the Web User specifies the path in the IEC 61850 Server of the ICD file describing the content of the IEC 61850 data model. As said in Section 2, the ICD file contains the SCL description of the data model maintained by the IEC 61850 Server.

As consequence of this request, the middleware connects to the server specified in the POST request and retrieves the SCL file on the basis of the full path provided for by the web user. Once received, this file is locally stored; it will be used by the Middleware as explained in the following subsections. The IEC 61850 Web Platform will respond with a POST Response, pointing out the success of his previous request.

A disconnection procedure has been foreseen through a specific POST request issued by the Web User, when the data exchange activities with a specific IEC 61850 Server end. All the local resources allocated to maintain the SCL descriptions of the IEC 61850 Server accessed by the Web User are released, if not used by other users.

4.3 Publication of Data Types

Data type is an attribute associated with a piece of data that tells a computer system how to interpret its value. Two or more systems exchanging data must be capable of interpreting data; to achieve this, syntactic interoperability must be established, at least. This requires that the two systems must share a common data format and data structures. Considering the proposal here presented, Web User must be able to interpret each information exchanged with the IEC 61850 Server through the IEC 61850 Web Platform; this can be achieved only on the basis of the knowledge of the data types involved in the information exchange; this means that the data type descriptions of the data maintained in the IEC 61850 Server must be shared with the Web User.

For this reason, it has been defined a particular service allowing a Web User to retrieve the description of the entire set (or a subset) of data types maintained in each IEC 61850 Server and relevant to the information the Web User needs to exchange with the IEC 61850 Server. Again, a suitable POST Request can be issued to a specific Web Service Interface, through which the Web User specifies the specific data type or the set of data types he wishes to know. It has been assumed that the Web User will receive the description of the requested data types though a JSON-based payload inside MQTT frames, published by a Broker after subscription to a specific topic. In the POST request, the Web User will specify the data types requested and the Broker to be used for the publication of the topics. The Web User will

receive a response from the platform confirming the publication of the requested data type on the requested broker on a particular topic specified in the response. After the subscription to this topic, the Web user may retrieve the requested data types in JSON format.

The specification of the requested data types occurs through the use of a particular syntax defined in this proposal. It is important to recall that each information in the IEC 61850 server is maintained according to the hierarchical data tree structure shown by Figures 1 and 2; in particular, Figure 2 gives the details about the data type structure of Data Object.

It has been assumed that the syntax used to identify each IEC 61850 data type from the Web User point of view, reflects that of the data model of the IEC 61850 standard. It is defined as a sequence of names separated by "/". The data type identifier must first foresee the name of the IED maintained by the IEC 61850 Server. According to the IEC 61850-7-1 (IEC 61850, 2011), the Logical Devices inside the IED are identified by the attribute instance name (i.e. inst); for this reason, the value of this attribute is used in the data type identifier. Again, the standard IEC 61850-7-1 identifies each Logical Node by a particular concatenation of three attributes: Logical Node Prefix (i.e. prefix), Logical Node Class (i.e. lnClass), Logical Node Instance (i.e. inst); for this reason, it is assumed that the name of LN inside the structure of the data type identifier is made up by the same concatenation of these attributes. As Data Objects (inside a LN), Data Attributes, Structured Data Objects (inside DO), Enumeration and Basic Data Attributes (for the Data Attribute Type) are univocally identified by the name attribute, this last is used in the data type identifier for the relevant elements.

For example, let us assume that IEC 61850 data model features an IED whose attribute name has the value "BCU1M19"; moreover, let us assume that the IED contains a Logical Device whose attribute instance name (inst) is "C1". Among the Logical Nodes belonging to this Logical Device, let us assume that the LN features the value "LBAY" for the prefix attribute, the value "1" for the instance number (inst) attribute, and the value "MMXU" for the attribute lnClass. The concatenation of this values, according to the IEC 61850 standard, gives the name "LBAYMMXU1", which is used in the data type identifier. Among the Data Objects inside this LN, let us assume the presence of the Data Object with the name attribute set to "A", containing Data Attributes and Structured Data Objects. Among the Structured Data Objects that with name attribute equal to "phsB" exists. It is made up by a set of Data Attributes, among which there is that featuring a name attribute set to "cVal". Finally, it has been assumed that this Data Attributes contains the Data Attribute of struct type with attribute name equal to "mag". This Data Attribute contains only a Basic Data Attribute (FLOAT 32) with the name attribute "f". According to the scenario just described, the data type identifier of the BDA "f", will be: "BCU1M19/C1/ LBAYMMXU1/A/phsB/cVal/mag/f".

According to the example just done, the Web User submits a POST request including this data type identifier and the details about the Broker to be used for the publication, in order to have the publication of the data type description of the BDA "f" contained in the Structured Attribute "mag". The IEC 61850 Web Platform will send a POST response confirming the success of the previous request and giving back a topic identifier on the specified Broker. On the reception of this confirmation, the Web User will subscribe to this topic on the specified Broker. Subscription will allow the Web User to receive an MQTT frame containing the requested data type in JSON format. Figure 4 shows a realistic example of the content of this topic (in JSON).

```
{
  "DAType": {
    "id": "AnalogueValue_Float",
    "BDA": {
      "bType": "FLOAT32",
      "name": "f"
    }
  }
}
```

Figure 4: Example of JSON frame containing data type description.

The example just done requires that the Web User has a complete knowledge of the content of the IEC 61850 server in terms of the current hierarchical data model tree present in the server. Some times, this can not be achieved, and the Web User may have the need to explore the current IEC 61850 data model maintained by a specific server to look for a specific data type. For this reason, another solution has been defined in this work in order to allow the Web User to acquire information about the entire IEC 61850 data model structure present in the IEC 61850 server.

According to the proposed solution, the Web User may discover the full or partial structure of the data model, finding one or more data types of his interest. The Web user will perform several POST requests in order to explore the entire data model tree, until the requested data types are found. In order to achieve this, a particular syntax has been defined to allows the

Web User to make the requests to be passed to the platform. This syntax is again based on the rules described before for the definition of the data type identifier according to the IEC 61850 data model tree; moreover, the syntax contains particular keywords here defined and aimed to make easier the exploration of the data model.

The following keywords have been defined in order the Web User may explore the IEC 61850 data model tree:

- getAllIEDs. If the Web User specifies this keyword in his request, it will receive a topic named "IEDs", whose subscription to the proper Broker, allows to achieve JSON description of the IEDs maintained by the IEC 61850 Server. Considering the example seen before, the JSON frame shown by Figure 5, will be received through the subscription to this topic.

```
{
    "IED": {
     "configVersion": 1,
     "name": "BCU1M19",
     "type": "BCU_APPLIANCE",
     "manufacturer": "ABC"
    }
}
```

Figure 5: Example of JSON frame containing data type description of IED maintained by the IEC 61850 Server.

- getAllLogicalDevices. This keyword allows the Web User to make a request for the publication of the data structure relevant to the entire set of LDs contained in a specific IED. Considering the example seen before, and considering in particular the content of Figure 5, the Web User may specify the following string in the request made to the platform "BCU1M19/getAllLogicalDevices". The topic he will receive from the Platform will be "BCU1M19/LDevices"; through the subscription to this topic, the JSON frame shown by Figure 6 will be received.

```
{
 "IED": {
      "name": "BCU1M19",
      "LDevice": {
        "inst": "C1"
      }
    }
}
```

Figure 6: Example of JSON frame containing data type description of LD belonging to the IED "BCU1M19".

- getAllLogicalNodes. It allows the Web User to make a request for the publication of topic relevant to the entire set of LNs contained in a LD. Considering the example seen before, and considering in particular the content of Figure 6, the Web User may realize the following request "BCU1M19/C1/getAllLogicalNodes". The topic he will receive from the Platform will be "BCU1M19/C1/LNodes"; through the subscription to this topic, the Web User will receive the details about the LNs by a JSON frame, among which the LN "LBAYMMXU1" described before.
- getAllDataObjects. It allows the Web User to make a request for the publication of topics relevant to the entire set of Data Objects contained in a Logical Node. Considering the example seen before, the Web user may perform a request specifying the string "BCU1M19/C1/LBAYMMXU1/getAllDataObjects". The topic he will receive from the Platform will be "BCU1M19/C1/LBAYMMXU1/DObjects"; through the subscription to this topic, the Web User will receive the details about the DOs contained in the LN.
- getAllDA_SDO. It is used in the request aimed to acquire information about the entire set of Data Attribute and Structured Data Objects inside a Data Object.

Several operators have been defined in order to perform more powerful queries:

- ALL. The Web User may use this operator to achieve more information with only one request. For example, if the Web User specifies the string "ied1/ALL/getAllLogicalNodes", he can receive information about all the logical nodes belonging to whatever logical device contained in a specific IED ("ied1").
- &. Through this operator, the Web User may request the publication of several elements. For example, he may specify the string "ied1/Inverter/getAllLogicalNodes & ied1/Battery/getAllLogicalNodes" in the POST request; in this way, the Web User requires knowledge of the structure of the logical nodes contained in the Inverter and Battery logical devices of the IED "ied1".
- except. The Web user may exclude information of particular IEC 61850 elements in his request. For example, if the Web User specifies the request "ied1/ALL/getAllLogicalNodes except ied1/Battery", it gets the names of all logical nodes of all logical devices contained in ied1,

with the exception of logical nodes contained in Battery.

Combinations of the previous operators may be realized. For example, it could use the & operator to exclude multiple elements from a multiple search, such as requesting all the logical nodes of all the logical devices of the ied1 device with the exception of the logical nodes contained in Battery and Inverter: "ied1/ALL/getAllLogicalNodes except ied1/Battery & ied1/Inverter".

In the previous subsection, it has been told that for each IEC 61850 Server connected, the IEC 61850 Web Platform locally maintains an image of the ICD file retrieved from the server; the ICD file contains the SCL description of the data model maintained by the IEC 61850 Server. For each request received by the Web User, the Web Service Platform will explore this local image in order to find the information related to the IEC 61850 data model tree, as requested by the user. A JSON frame is built containing the description of the data types requested by the user, as shown by Figures 4, 5 and 6. These frames will be published through MQTT message by the requested broker, on a particular topic which is passed to the Web User through the POST Response. Subscription to this topic by the Web User, allows him the receipt of the requested data type description.

4.4 Subscription Request

Through the Subscription request service, the Web User requests the IEC 61850 Web Platform to publish the values of the variables of interest. This request is made only after the Web User has acquired knowledge about the information related to the data types of these variables. To use the service, the user sends a POST request to the IEC 61850 Web Platform containing two fields: variable identifier and interval.

Variable identifier field contains the information about the variable to be accessed. It is given according to the same formalism seen for the publication of data types. For example, considering the example pointed out in the previous subsection, the variable identifier "BCU1M19/C1/LBAYMMXU1/A/phsB/cVal/mag/f", refers to the variable "f" contained in the Structured Attribute "mag". The operator & may be used in order to specify a list of variables.

The interval field is used by the Web User to specify the desired sampling interval in milliseconds of the specified variables; the sampling interval corresponds to the interval at which the variables are sampled and the relevant values are sent to the Broker for the publication.

For each POST request made by the Web User, the Web Server Platform will send a POST response containing the name of the topic to which the Web User may be subscribe; once the subscription has been achieved, Web User will receive from the broker the values updated according to the frequency specified.

4.5 Updating Request

This service is used by the Web User to update the values of variables maintained by the IEC 61850 servers through a remote POST REST request.

The Web user must specify the variable identifier to be modified and the new value to be updated. The variable identifier must have the same syntax already exposed in the previous subsections.

5 FINAL REMARKS

The paper has presented a novel solution in the field of the integration of SG and IoT. Integration involves IEC 61850, Web Services and MQTT. The proposal features a RESTful web platform able to offer to a generic user a web service interface to IEC 61850 Servers. The web platform enables the mapping of information maintained by IEC 61850 server into MQTT messages. A very limited knowledge is requested by the Web User in order to be able to access the services offered by the platform. In particular, a very simple syntax to explore the IEC 61850 data model is requested without any knowledge about the IEC 61850 specifications and any need to use IEC 61850 communication stacks. The only technologies requested are REST and MQTT, which are considered the basic ones in the IoT.

The proposed platform has been implemented using Java language. The main implementation choices are the following ones. For the web User authentication, the standard JSON Web Token was used (RFC, 2015). The IEC 61860 Client inside the Middleware has been implemented using the open source library iec61850bean (IEC61850bean, 2021). The MQTT Broker has been realized by Mosquitto 1.6.12 (Mosquitto, 2021). The implementation of the MQTT Publisher inside the Middleware was realized using Eclipse Paho Java Client (Paho, 2021).

ACKNOWLEDGEMENTS

The research results presented in this paper have been achieved inside the PASCAL project (CUP G79J18000690007) funded by Sicilian region (Italy), within the European Regional Development (P.O. FESR 2014 -2020 line 1.1.5).

REFERENCES

Alotaibi, I., Abido, M.A., Khalid, M., Savkin, A.V. (2020). A comprehensive review of recent advances in smart grids: A sustainable future with renewable energy resources. *Energies* 2020, 13, 6269.

Al-Turjman, F., Abujubbeh, M. (2019). IoT-enabled smart grid via SM: An overview. *Future Gener. Comput. Syst.* 2019, 96, 579–590.

Bader, S.R., Maleshkova, M. (2020). SOLIOT—Decentralized data control and interactions for IoT. *Future Internet* 2020, 12, 105.

Benomar, Z., Longo F., Merlino, G., Puliafito, A. (2020). Enabling Secure RESTful Web Services in IoT using OpenStack. *IEEE 17th International Conference on Mobile Ad Hoc and Sensor Systems (MASS)*, 10-13.

Cavalieri, S. (2021). Semantic Interoperability between IEC 61850 and oneM2M for IoT-Enabled Smart Grids. *Sensors* 2021, 21, 2571.

Cavalieri, S., Regalbuto, A. (2016). Integration of IEC 61850 SCL and OPC UA to improve interoperability in Smart Grid environment. *Computer Standard Interfaces*. 2016, 47, 77–99.

Cotrino, A., Sebastián, M.A., González-Gaya, G. (2020). Industry 4.0 Roadmap: Implementation for small and medium-sized enterprises. *Appl. Sci.* 2020, 10, 8566.

Falk, H. (2019). *IEC 61850 Demystified*, Artech House: Norwood, MA, USA, 2019. ISBN 978-1-63081-329-1.

Fielding, R.T. (2000). Architectural styles and the design of network-based software architectures. *Ph.D. dissertation, Dept. Information and Computer Science, University of California, Irvine, CA, USA*, 2000. Available on line: http://www.ics.uci.edu/~fielding/pubs/dissertation/top.htm (accessed 17 December 2021)

Hassan, R., Qamar, F., Hasan, M.K., Aman, A.H.M., Ahmed, A.S. (2020). Internet of Things and its applications: A comprehensive survey. *Symmetry* 2020, 12, 1674.

IEC 61850 (2011). Communication Networks and Systems for Power Utility Automation; IEC Standards, Parts 1–10, Edition 2.0. *International Electrotechnical Commission*.

IEC61850bean. (2021). Available online: https://www.beanit.com/iec-61850/ (accessed 17 December 2021).

IETF. (2004). *XMPP RFC 3920*. Internet Engineering Task Force. Available online: https://xmpp.org/rfcs/rfc3920.html (accessed 17 December 2021)

ISO/IEC. (2016). *Information technology -- Message Queuing Telemetry Transport (MQTT)*. ISO/IEC 20922.

Jun, H.-J., Yang, H.-S. (2021). Performance of the XMPP and the MQTT Protocols on IEC 61850-Based Micro Grid Communication Architecture. *Energies* 2021, 14, 5024.

Lu, Y. (2017). Industry 4.0: A survey on technologies, applications and open research issues. *J. Ind. Inf. Integr.* 2017, 6, 1–10.

Mehigan, L., Deane, J.P., Gallachóir, B.P.Ó., Bertsch, V. (2018). A review of the role of distributed generation (DG) in future electricity systems. *Energy* 2018, 163, 822–836.

Mosquitto. (2021). Available online: https://mosquitto.org/ (accessed 17 December 2021).

OASIS. (2014). *MQTT Specification*. Vers.3.1.1.Available online: https://mqtt.org/mqtt-specification/ (accessed 17 December 2021).

Paho. (2021). Available online: https://www.eclipse.org/paho/index.php?page=clients/java/index.php (accessed 17 December 2021).

Pedersen, A.B., Hauksson, E.B., Andersen, P.B., Poulsen, B., Træholt, C., Gantenbein, D. (2010). Facilitating a Generic Communication Interface to Distributed Energy Resources: Mapping IEC 61850 to RESTful Services. *Proceedings of the First IEEE International Conference on Smart Grid Communications*, Gaithersburg, MD, USA, 4–6.

Reka, S.S., Dragicevic, T. (2018). Future effectual role of energy delivery: A comprehensive review of Internet of Things and smart grid. *Renew. Sustain. Energy Rev*. 2018, 91, 90–108.

RFC. (2015). *JSON Web Token*, RFC 7519, Available online: https://tools.ietf.org/html/rfc7519. (accessed 17 December 2021).

Richardson, L. , Ruby, S.. (2007). *RESTful Web Services*. Sebastopol, CA:O'Reilly, 2007.

Shi, Y., Tuan, H.D., Duong, T.Q., Poor, H.V., Savkin, A.V. (2020) PMU placement optimization for efficient state estimation in smart grid. *IEEE J. Sel. Areas Commun*. 2020, 38, 71–83.

Shin, I.-J., Song, B.-K., Eom, D.-S. (2016). Auto-mapping and configuration method of IEC 61850 information model based on OPC UA. *Energies* 2016, 9, 901.

Tightiz, L., Yang, H. (2020). A comprehensive review on IoT protocols' features in smart grid communication. *Energies* 2020, 13, 1–24.

Urkia, M.I., Casado-Mansilla, D., Mayer, S., Bilbao, J., Urbieta, A. (2018). Integrating electrical substations within the IoT using IEC 61850, CoAP and CBOR. *IEEE Internet Things Journal*. 2018, 14, 8.

Ustun, T.S., Suhail Hussain, S.M.S. (2020). IEC 61850 Modeling of UPFC and XMPP communication for power management in microgrids. *IEEE Access*. 2020, 8, 141696–141704.

Xu, L., Yu, X., Gulliver, T.A. (2021). Intelligent outage probability prediction for mobile IoT networks based on an IGWO-Elman neural network. *IEEE Trans. Veh. Technol*. 2021, 70, 1365–1375.