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Integration of IEC 61850 SCL and OPC UA to improve interoperability in Smart Grid environment

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ABSTRACT

Integration of the several heterogeneous and geographically dispersed actors in Smart Grid environment is currently hampered by the usage of non-interoperable and proprietary automation solutions. Standards-compliant integration is an indispensable requirement for successful Smart Grid automation. The international standard IEC 61850 has been recognised as one of the fundamental components for reference Smart Grid architectures. Nevertheless, certain parts of the IEC 61850 definitions seem inadequate to compete with the accelerated Smart Grid evolution. For this reason, current literature presents solutions able to surpass the main limitations of the standard, improving harmonisation in Smart Grid; among them, there is integration of IEC 61850 data model with OPC UA information model. According to the current literature, integration of IEC 61850 with OPC UA does not involve the IEC 61850 engineering process, based on a particular language called Substation Configuration description Language (SCL). The paper will present a common Smart Grid scenario where interoperability could be improved extending the idea of the integration between IEC 61850 and OPC UA also to the SCL-based engineering capabilities of the IEC 61850 standard. The paper will present a proposal of mapping between IEC 61850 SCL and OPC UA, describing the relevant algorithm, its implementation and performance evaluation.

1. Introduction

Smart Grid involves significant number of heterogeneous and geographically dispersed actors with intermittent energy sources such as distributed energy resources (DERs), energy storage systems (ESSs) and electric vehicles (EVs) [1,2]. Integration of these Smart Grid entities has resulted in novel decentralised management system architectures such as virtual power plants (VPPs) [3] and smart homes/buildings [4] while also introducing new solutions for optimised control [2,5].

Fulfilling Smart Grid vision means the enabling of the two-way flow of power and information, and creating prosumers (power grid actors that are both producers and consumers of electricity). Reaching this goal has several prerequisites in a form of communication [6] and electrical infrastructure [7] along with intelligent automation systems [8]. Mainly, this goal is hampered by usage of non-interoperable and proprietary automation solutions, as the Smart Grid entities require scalable integration frameworks and optimised management techniques that exceed the capabilities of conventional automation solutions. Therefore, standards-compliant integration is an indispensable requirement for successful and secure Smart Grid automation [9].

The international standard IEC 61850 [10] has been recognised as a globally accepted solution enabling integration of heterogeneous devices and applications in the power system automation domain. It is identified as one of the fundamental components for reference Smart Grid architectures [11].

Nevertheless, certain parts of the IEC 61850 definitions are inadequate to compete with the accelerated Smart Grid evolution [12]. This is most notable in selection of manufacturing message specification (MMS) [13] as middleware technology for the vertical communication in IEC 61850 systems (i.e., between field devices and applications). MMS is regarded as an inappropriate approach for Smart Grid [5].

Current literature provides for proposals of solutions able to surpass the aforementioned issue; among them there is integration of IEC 61850 with OPC UA [14–16] to perform harmonisation in Smart Grid; the overall idea is based on the mapping of IEC 61850 data model to OPC UA information model [5,12,17–19]. By providing this mapping, it is possible that pure OPC UA clients without any previous knowledge of the IEC 61850 can make use of the relevant data and type model, just exploring the information model maintained by an OPC UA Server. Results present in the current literature demonstrate that this solution results in communication architecture for Smart Grid with many advantages in terms of security, interoperability and internet communication [20].

According to the literature, the focus of the integration between IEC 61850 and OPC UA is currently limited to the IEC 61850 data model defined in the IEC 61850-7 of the standard series [10]. Mapping of IEC 61850 with OPC UA does not involve, at this moment, the IEC 61850 engineering process, as clearly pointed out in [5].

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The engineering process for IEC 61850 systems is based on the exchange of XML documents, which are formatted according to the *substation configuration description language* (SCL), defined in the part 6 of the IEC 61850 standard, i.e., IEC 61850-6 [10]. The engineering process consists of configuration of communication entities, electric networks and communication network topologies; this process is relatively static and most commonly used for substation automation systems. IEC 61850 engineering process is based on engineering tools for configuration of substation automation systems; a very detailed analysis of available configuration tools under IEC 61850 standard was presented in [21].

In some Smart Grid scenarios, interoperability could be improved by extending the idea of the mapping between IEC 61850 and OPC UA also to the part 6 of the IEC 61850 standard, which defines the SCL, as said. Section 2 will point out a common Smart Grid scenario, highlighting the advantages which may be achieved by the integration of IEC 61850-6 SCL with OPC UA. For this reason, the aim of this paper is that to propose a mapping of the entire set of elements featured by IEC 61850-6 SCL into the OPC UA information model. The proposal is original, as no other solutions are present in the current literature.

The paper is organised as it follows. Next section will present an example of Smart Grid scenario inside of which the proposal has been conceived; the description will allow the reader to clearly understand the advantages of the proposed mapping and why this proposal may be able to improve interoperability in some of the Smart Grid environments like that here presented. Then, after a brief overview on IEC 61850 (mainly focusing on the SCL) and OPC UA (focusing on the information model), the paper will present the proposal of integration of IEC 61850 SCL with OPC UA information model; the mapping of each single part of SCL documents with OPC UA objects will be clearly described. Finally, information about current implementation and performance evaluation of the proposed mapping algorithm will be given in the last section of the paper.

2. Smart Grid scenario

Electrical distribution systems that have traditionally operated passively to move electricity from the high-voltage transmission grid to end-use customers were never designed for bi-directional flows that could originate from any point on the system and from any one of dozens of different types of DERs. Also, distribution system operations were not designed to integrate or coordinate thousands of flexible customer and merchant DER.

For this reason, an emerging integrated distributed electricity structure is even more adopted; it can be considered a new approach of electric distribution in Smart Grid, featuring energy sources and operating decisions broadly decentralised and localised. Fig. 1 provides a conceptual schematic view of the emerging integrated distributed structure. It is characterised by a complementary mix of centralised and distributed resources including generation, energy storage, power flow and stability control devices, and control systems including sensing devices and load management capabilities. These resources are owned and controlled by a number of parties, including utilities, merchant distributed generators, merchant energy storage, demand aggregators, energy services firms and customers. To provide safe and reliable electric service, such a system requires an integrated and coordinated operational paradigm that clearly delineates roles and responsibilities between the two main actors shown in Fig. 1: transmission system operator (TSO) and one or more distribution system operators (DSOs).

TSO is the inter-area system operator and has the fundamental role to provide reliable open-access transmission service. This entails maintaining supply–demand balance and transmission reliability by scheduling and dispatching resources and interchange transactions with other regional balancing authorities. Additional challenges of TSO are large-scale integration of renewable sources and managing and mastering congestions.

DSO is a regional system operator and has the main role to maintain safety and reliability of the local distribution system. This involves regular reconfiguration or switching of circuits and substation loading for scheduled maintenance, and to isolate substation and distribution feeder faults and restore electric service. DSO are also responsible to ensure local voltage, power factor and phase balance maintained within engineering standards. Due to the presence of a greater number of DERs, in addition to the functions explained before, the DSO is defined by a new minimal set of functional responsibilities. This includes reliably operating the local distribution system below each substation, which will entail coordinating operations of the interconnected DERs. DSO has to ensure that DER-provided services are properly coordinated, scheduled and managed in real time so that the TSO has predictability and assurance that DER committed to provide transmission services will actually deliver those services across the distribution system.

Fig. 1 shows a typical organisation of a DSO. It is made up by several DSO operational centres, each managing many electric power distribution systems; a power distribution system is made up by a primary substation and several secondary substations. Fig. 1 shows examples of passive customers (i.e., only consuming electricity, like buildings and factories) and active customers (i.e., also producing electricity, like photovoltaic plants and wind energy systems) connected to the secondary substations.

Each DSO Operational centre is typically based on supervisory control and data acquisition (SCADA) system collecting information and managing the entire set of electric power distribution systems assigned to the DSO operational centre.

The role of the DSO involves strict interactions between DSO operational centre, between different DSOs and mainly with TSO (allowing scheduling interchange between TSO and DSOs). This means that information exchange/cooperation between these players gets more and more important; communication system has to be standardised (i.e., using standard data formats, protocols and channels) and flexible; information security must be also guaranteed.

Information exchange is ideally organised using a cascading system. IEC 61850 is generally adopted to allow information exchange inside each electric power distribution system (i.e., among primary and secondary substations). The same standard may be also used to realise the exchange of information between each DSO operational centre and the electric power distribution system. About the exchange of information between SCADA systems, DSOs and TSO, in this paper, it has been assumed that it occurs using OPC UA. Introduction pointed out the importance of this standard to harmonise information exchange in Smart Grid; as said, results present in the current literature demonstrate that adoption of OPC UA results in communication architecture for Smart Grid with many advantages in terms of security, interoperability and internet communication [20]. Fig. 1 shows the different communication standards assumed in this Smart Grid scenario.

The use of OPC UA for the exchange of information between SCADA systems means that each SCADA must expose a data set, the so-called OPC UA AddressSpace containing OPC UA objects (described in Section 4), which common client applications can explore, read and write (if allowed). The data set must be configured in order to reflect the real structure of each electric power distribution system connected to the SCADA; the entire set of information describing the electrical components present in the primary and secondary substations must be mapped into the OPC UA objects contained in the OPC UA data set published by each SCADA.

Building the entire OPC UA data set for each SCADA system may be very time-consuming because primary and secondary substation systems may feature a huge number of information to be published (e.g., list of devices installed, details about internal communication, list of functions and services available inside a substation). As said in the introduction, the IEC 61850-6 standard defines the SCL to allow the description of each (primary or secondary) substation; suitable SCL-based documents are able to describe each component present in a substation.