A PLUG & PLAY CONCEPT FOR IEC 61850 IN A SMART GRID

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ABSTRACT

This paper presents a Plug & Play concept for IEC 61850 in a Smart Grid. Since the traditional engineering process of the standard is outlined for substation automation, it shows some weaknesses in other Smart Grid applications like the integration of distributed energy resources. To overcome these weaknesses IEC 61850 has to support the Plug & Play function. After justifying this assumption, we describe a Plug & Play reference architecture based on well-known protocols like UPnP and DPWS. We study how the concepts of the reference architecture can be applied to IEC 61850. Several changes and additions, e.g. with respect to discovery mechanisms, are proposed enabling IEC 61850 to support Plug & Play for Smart Distribution.

INTRODUCTION

Different activities are on its way to identify the relevant standards for a Smart Grid, to harmonize existing ones and to close the potential gap. Examples for activities are the work by NIST [1], the IEC [2] and in Germany by the BDI [3] and E-Energy [4].

IEC 61850 is listed as one of the core standards in the aforementioned activities and will play an important role in the Smart Grid. Originally developed for substation automation different extensions are already available or are in progress, e.g. for hydroelectric power plants (IEC 61850-7-410), distributed energy resources (IEC 61850-7-420) and communication between substations, and adaptations to other domains exist, e.g. for wind turbines (IEC 61400). The standard covers an object-oriented data model and abstract communication services as well as mappings to specific communication services (e.g. MMS as defined in Part 8-1). Furthermore, a configuration language (System Configuration description Language (SCL)) is introduced in Part 6 of the standard.

Part 6 of IEC 61850 also describes an engineering process. This process is designed for substation automation systems. The engineering process is part of the installation of the substation and changes in service are the exception. Often the discussions about IEC 61850 in a Smart Grid focus on the data models and the protocol only. The engineering process in a dynamic environment is not considered and a static engineering like in a substation is assumed.

For some use cases this assumption might be valid. For example, for a virtual power plant (VPP) with a small number of plants, which are under the control of the VPP operator, a well-defined engineering process of the automation as part of the installation of the VPP seems reasonable. On the other hand, a multitude of the Smart Grid use cases shows some degree of dynamics. For example, an aggregator contracts distributed energy resources or shiftable loads from several prosumers (PROducer + conSUMER) to offer bundles on energy markets. Hence, the aggregator system is faced with a variable number of prosumers and has to support joins and leaves of them at any time. This means, the system or in general the Smart Grid has to support some kind of Plug & Play. Here, the term Plug & Play describes a mechanism to enable automatic discovery and zero configuration of devices connected in a network to access information and run services of the devices.

In this paper we evaluate how suitable IEC 61850 is for Plug & Play. A concept is derived for making IEC 61850 Plug & Play capable. Section 2 gives an introduction to the engineering process of the standard and identifies the gaps for a Smart Grid. For comparison, we study two popular Plug & Play architectures, i.e. UPnP (Universal Plug and Play) and DPWS (Device Profile for Web Services), and summarize the steps of a Plug & Play mechanism in Section 3. For each step we evaluate in Section 4 how it is realized with IEC 61850 and identify gaps of IEC 61850 to support Plug & Play. Section 5 concludes the paper.

ENGINEERING WITH IEC 61850

The engineering process for substation automation is described in Part 6 of IEC 61850. Edition 2 of this part was released at the end of 2009, which introduces additional concepts.

IEC 61850-6 defines the System Configuration description Language (SCL). It can be used to describe the IED configurations and communication systems. The description of the relation between the substation automation system and the substation (switch yard) or, in general, the utility automation system and the process is also possible. Additionally, the switch yard topology itself as single line diagram and allocations of automation functions to parts and equipment of it can be described.

The focus of the standard is on the specification and description of substation automation systems and on IED capability description. Furthermore, Edition 2 extends the scope of the standard with concepts for the exchange of system interfacing information between different projects and the exchange of IEC modifications.

In sum six different SCL description file types are defined in IEC 61850-6. These are the System Specification Description (SSD), the System Configuration Description (SCD), the IED Capability Description (ICD), the Configured IED Description (CID) and since Edition 2 also the System Exchange Description (SED) and the Instantiated IED Description (IID). In a nutshell, the engineering process is as follows:

- the system specification tool defines the SSD file
- the IED configuration tool defines the ICD file
- the system configuration tool imports the SSD and ICD files, it binds the IEDs to process functions and primary equipment and engineers the communication connections. The result of this step is the complete SAS engineering summarized in the SCD file. Additionally, the subset with the relevant information for one IEC can be exported as CID file
- the CID file is imported into the IED configuration tool to load all configurations into the device (as CID or with an proprietary format)

For the sake of brevity, the roles of IID and SED files are skipped in this paper and the interested reader is referred to IEC 61850-6.

The engineering process described in the standard was defined for substation automation systems and does not hold in general in Smart Grids.

In several Smart Grid applications it is unlikely that a static engineering process is done for the whole system. The Smart Grid shows dynamics and the engineering has to be adapted to these circumstances. It has to become an online process supporting the Plug & Play feature for IEDs.

Furthermore, the tool landscape for the engineering of processes in a Smart Grid is not established yet. As outlined in the introduction we assume to see for some use cases in a Smart Grid an engineering which is similar to SAS. However, multiple other use cases exist where we will see neither a system configuration tool like in substation automation nor the use of all the different SCL description file types. An example is the aggregator system described in the introduction.

The reasons for dynamics in a Smart Grid are manifold and occur on different timescales. On small time intervals, i.e. hours or days, the IP address of the communication unit at the prosumer may change when standard Internet access like DSL and public networks like the Internet are used. In this case communication connections can neither be engineered statically nor based on IP addresses. Furthermore, communication failures may occur when public networks are used instead of dedicated communication links like in a substation environment.

Other reasons for dynamics can be caused by the prosumer. In the case of demand response or control of distributed energy resources like combined heat and power the user's preferences cause constraints on the operation and limit the control options for third parties. In exceptional cases like holidays the devices are switched off and are not available for Smart Grid applications at all.

At even longer time intervals contracts with the prosumers become effective or expire and cause a change of the portfolio at an aggregator or other Smart Grid players.

The challenge of automation systems in Smart Grids is to cope with changing communication parameters, unavailability of devices and changes in the portfolio. Hence, the use of the SCL description file types, especially SCD and CID files, may change under these requirements.

PLUG & PLAY ARCHITECTURE

What is this "Plug & Play" about? The term became popular with Windows 95 to describe the function of automatically configure new hardware components into a computer system without the intervention of the end user [5].

Meanwhile, Plug & Play is used in a much wider scope, e.g. to plug-in peripherals to PCs without the need to install drivers or manual setup or to enable automatic discovery and zero configuration of devices connected in a network. To identify the properties of a concept for Plug & Play we analyze two specifications as reference: the UPnP Device Architecture [6] and the Devices Profile for Web Services (DPWS) [7]. Like IEC 61850 both use TCP/IP and other Internet protocols and specifications (e.g. XML).

Two different roles exist in the UPnP architecture: controlled devices (short: devices) and control points. In the terminology of DPWS these are denoted device and client, respectively. A device functions in the role of a server, responding to requests from a control point. UPnP is designed for home networks, proximity networks and networks in small businesses and commercial buildings. Device Control Protocols (DCP) for different domains exist, e.g. for home automation. DPWS targets a resource-constrained Web service implementation and is used in research projects for automation use cases [8], [9].

In the UPnP device architecture the Plug & Play concept consists of six steps: Addressing, discovery, description, control, eventing and presentation. With messaging (including addressing), discovery, description, eventing augmented with security the DPWS standard covers nearly the same topics. Briefly, the steps of the UPnP protocol are described in the following with additional information about similarities and differences to DPWS (see [6] and [7] for further details):

Step 0: Addressing

UPnP networks are built on dynamic IP addresses. (As in [6] we consider IPv4 here. For the sack of simplicity we do not consider multi-homed devices with more than one network interface.) A device runs as client the Dynamic Host Configuration Protocol (DHCP). If a DHCP server is available, it retrieves an IP address. If no server is available,

the device runs Auto IP to automatically retrieve a unique IP address from a subset of reserved addresses (see RFC 3927 for more detail in the case of UPnP 1.1).

Step 1: Discovery
After connecting to the network, the device runs a discovery protocol where it advertises its services to control points. Furthermore, the protocol offers search functions for control points to find devices of interest. The communication is based on multicast messages. Alternatively, DPWS has also a managed mode where a discovery proxy is present which handles all discovery messages from devices and control points. The information exchange is limited to few essential specifics about the device and its services (e.g. type, id). Further details about the device are exchanged during the next step (see Step 2: Description). The discovery protocol also includes messages for graceful leaving the network or updating interface information.

Step 2: Description
After discovering a device a control point can retrieve the device's description to get information about the capabilities of it. The file is provided directly from the device and is expressed in XML (and WSDL in the case of service descriptions for DPWS). The description file contains also information about other logical devices, functional units and services. Furthermore, the description of the service includes a list of commands and its parameters as well as a list of variables to describe the state of the service at run time.

Step 3: Control
After retrieving the description of a device a control point can send control messages to a device's services. The control message initiates an action on the device and any action specific-values are returned. The effects of the action may change the run-time state (variables) of a service.

Step 4: Eventing
Eventing is used to inform control points about state-changes in devices. Thus, it is linked to control messages. From the information in the description file the control points know about variables which characterize the state of a service. Control points can subscribe to variables of a service to receive update information. The service publishes these updates when a variable changes. UPnP supports unicast as well as multicast eventing.

Step 5: Presentation
Presentation is complementary to control and eventing. It exposes an HTML-based user interface where the user at the control point sees the device status and may control the device.

PLUG & PLAY CONCEPT FOR IEC 61850

In this section we take the properties of the Plug & Play architecture from the previous section and evaluate how to realize them with IEC 61850. Furthermore, gaps are identified and possible extensions are proposed to fill them. The focus is on the concepts. Thus, we do not require that IEC 61850 uses the same protocols or technologies used in UPnP or DPWS.

Step 0: Addressing
In a Substation Automation System (SAS) a local network is used which is owned and controlled by the utility. Hence, static IP addresses can be assigned in the engineering process. As outlined in previous sections this can not be assumed in general in a Smart Grid, where beside utility-owned networks also leased lines form telecommunication carriers or even public networks, e.g. the Internet, are used. Hence, the communication with IEC 61850 has to work also with dynamic IP addresses and in networks where protocols like DHCP are used. Furthermore, the automation functions and the needed communication links can not be engineered (once) on the basis of IP addresses. CID files with static IPs and engineered communication associations based on IPs can not be used under these requirements.

Step 1 & 2: Discovery & Description
A discovery mechanism is not needed in a well-defined engineering process of a substation automation system. However, as outlined in the previous sections we may not see a well-defined engineering process in Smart Grid applications. Unfortunately, the discovery mechanism of UPnP and DPWS are developed for private networks where multicast communication is assumed to be available. This is not the case for the Smart Grid using wide area networks.
We propose to use a registry for Smart Grid services where IEDs publish the description of their capabilities and services. This registry provides lookup services for Smart Grid players like aggregators to discover IEDs with the needed properties. We propose to use the ICD file type as the description. This means each IED runs a registration process after going online: It connects to the registry which is assumed to be known and uploads its ICD file to the registry. The registry stores the ICD file along with the IP address e.g. in an XML database.
The aggregator can query the database with respect to different properties, i.e. IED name or function. To query a function the names of the logical node classes from IEC 61850-7-4 or 7-420 can be used. As query result the registry returns the IP address of the IED and possibly also the ICD file. Alternatively, the ICD file can be downloaded directly from the IED after building up a communication connection.
Finally, the IEC 61850 client at the aggregator can dynamically build up associations or reporting connections. The whole process is summarized in Figure 1.
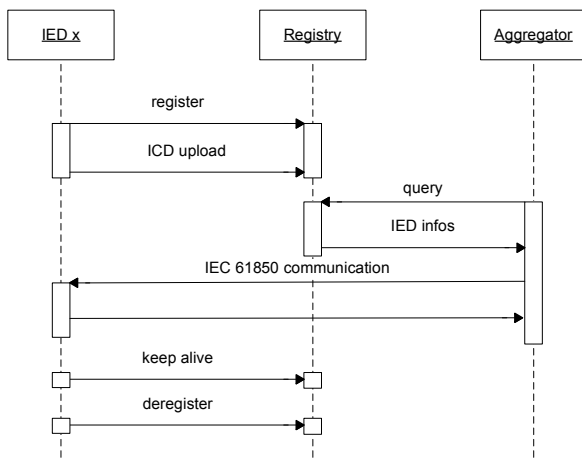
Figure 1: New discovery mechanism for IEC 61850 capable devices in a Smart Grid

IEDs can go offline intentionally or unintentionally. In the former case we assume a gracefully shutdown during which the IED deregisters at the registry. To cope with the latter case IEDs realize a keep-alive mechanism and send periodically heartbeat messages to the registry.

The registry approach is not new. Also in DPWS a discovery proxy is specified, which supports that devices and control points find each other. Furthermore, other concepts for the Internet can be used as reference architecture. UDDI (Universal Description, Discovery and Integration) [10] is one example and realizes a registry where businesses can publish their service listings (described in the WSDL (Web Services Description Language) format) and find each other to interact over the Internet.

Step 3 & 4: Control & Eventing

Step 3 and 4 of the Plug & Play concept is realized in detail by IEC 61850. Part 7-2 of the standard defines the Abstract Communication Service Interface (ACSI). Among others reporting services for eventing and control models are defined. We do not see any extensions or changes for Smart Grid applications.

A discussion of mapping ACSI to specific communication services is out of the scope of this paper.

Step 5: Presentation

Tools for the presentation of SCL description file types exist from different vendors. An example is the IEC browser from Siemens. It allows to connect to an IEC 61850 server and to read all data objects of it. Furthermore, some data objects can also be changed by the user.

CONCLUSION AND FUTURE WORK

Several standardization roadmaps show that IEC 61850 is a key standard for Smart Grids. This standard was originally developed for substation automation systems. The Smart Grid has other requirements which can not be fulfilled with the current version of the standard. This paper studies the engineering process specified in Part 6 of the standard and proposes extensions to better support a wider range of Smart Grid use cases. The extensions are derived from Plug & Play architectures based on state-of-the-art protocols like UPnP and DPWS. To the best of our knowledge this is the first approach to apply Plug & Play concepts to IEC 61850.

ACKNOWLEDGEMENTS

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