ASSESSMENT AND OUTLOOK OF THE OPENNODE SMART GRID ARCHITECTURE

Florent LEMÉNAGER
EDF R&D – France
florent.lemenager@edf.fr

Céline JOANNIC
EDF R&D – France
celine.joannic@edf.fr

Raúl SORIANO
ITE – Spain
raul.soriano@ite.es

Raúl BACHILLER PRIETO
Iberdrola – Spain
rbpr@iberdrola.es

Marta ALBERTO MONFERRER
ATOS – Spain
marta.alberto@atos.net

Nicolas ESPEJO PORTERO
Nucleo – Spain
Nicolas.espejo@nucleodf.com

Ralf MOSSHAMMER
Siemens - Austria
ralf.mosshammer@siemens.com

ABSTRACT

With the arrival of new usages and stakeholders, the increase in fluctuating distributed energy resources, and the regulatory framework for grid operators, automation, monitoring and controllability are rising challenges for the distribution networks.

The OpenNode project (www.opennode.eu), funded by the EU's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement Number 248119, brings together nine organizations from six European countries to tackle these issues. To address these topics, the OpenNode partners have developed an architecture combining smart metering with grid automation, which would allow today's power networks to evolve into smart distribution grids, enabling reliable and efficient grid operation.

In order to elaborate this system, the OpenNode project has focused on the research and development of: (1) An open Secondary Substation Node (SSN), an essential control component of the future smart distribution grid; (2) A MiddleWare (MW) to couple the SSN operation with the utility systems for grid and utility operation; (3) A modular communication architecture based on standardised communication protocols.

The paper describes the characteristics of the system and its benefits. We will go through the logic that led to the specification and implementation choices. The final assessment process will be detailed to provide an evaluation of the project's output.

INTRODUCTION

The three main challenges the European industry is facing at this moment are the massive integration of Distributed Energy Resources (DER) and Electric Vehicles (EV), the necessity to cope with an always-increasing capacity requirement, and the stakeholder diversification separating grid operation, power provisioning, metering services and others.

To address these challenges OpenNode proposes the realisation of a massively distributed system of **Secondary Substation Nodes** (SSN) within the Secondary Substations (SS) for monitoring and automation of metering services and grid management.

A **Middleware** (MW) system is needed to cope with the stakeholder diversification and the flexibility required to operate the network, deployed grid architecture and management methods. The MW is both the link between stakeholders and distribution grid automation services and also the scheduler and orchestrator of the embedded SSNs distributed system.

A **modular communication architecture based on open standards** has been designed to grant the flexibility needed by the stakeholder diversification and will cope with the massively distributed system of SSNs deployed in the distribution grid.

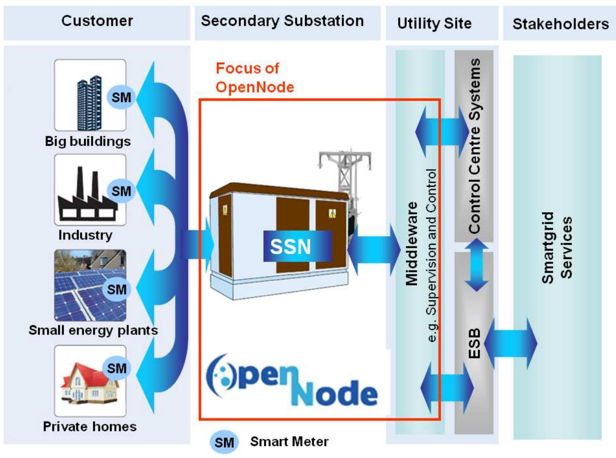

Figure 1: OpenNode architecture

This system has been designed to follow an evolutionary approach, based on the following key concepts:

- Modularity: To allow a high decoupling between functionalities and permit a high adaptability.
- Extensibility: To allow the development and deployment of new functionalities by third parties on MW and SSNs.
- Distribution of intelligence: Related to the previous item. A smart design of the extension modules allows the functions to be shared between the MW and SSNs.
- Open common reference architecture (OCRA).

OpenNode's reference architecture is made publicly available to the community for helping in the improvement of the architecture and allowing new actors, manufacturers and providers to enter the market.

- Open standards: The architecture is entirely based on open standards.
- Cost effective: Due to the massive deployment of SSNs necessary to manage a distribution grid, lowering the cost of the solution per substation has been a primary goal of the project. The OCRA and the use of open standards together with the optimisation of the architecture in sensing and controlling inside the SSN help in this matter.

This paper describes how the OpenNode's approach has been set out to reach these goals, from specifications to real prototypes.

OPENNODE: FROM DESIGN TO REALITY

The project consortium realized three real SSN prototypes (two physical and one virtual) and one MW in order to assess the proposed architecture. How the system has been developed is summarised as followed.

Functional Specifications

With the system architecture agreed on, functional specifications were determined, focused on the three major challenges the project was aiming to tackle. That is:

- How to improve the distribution grid monitoring to cope with volatile states in the grid;
- How to integrate the "smart" substation automation devices to increase the distribution grid efficiency;
- How to interoperate with the different roles i.e. operation of smart meters and power and grid operation.

The needs of all actors to interact with the OpenNode system (customers and stakeholders) were considered. A list of functions was drawn up to cover as many aspects of the smart distribution grid that the OpenNode system could enable. These functionalities were classified based on their priority for the stakeholders involved. Then, three different groups of functions arose, following an approach similar to the classification done in the OPEN meter project:

- Basic Requirements: that shall be implemented in the prototypes within the project runtime and that correspond to short term needs for the stakeholders. (e.g.: Remote switching of MV lines)
- Optional Requirements: provide value-added services that might be required in some cases. They are not strictly required to be implemented in the OpenNode prototypes. (e.g.: SS transformer tap changer)
- Advanced Requirements: considered of high value services but correspond to longer term needs and state of the grid. They might be implemented in the future. (e.g.: Small distributed generation management)

Taking these business needs as a starting point, a UML model was used in order to formalize them into grid and metering use cases covering the requirements previously defined. This facilitates the representation of functionalities of this complex system from the user point of view and allowed to identify their application scope. Prototypes need to be compliant with sequence diagrams that describe scenarios covering the different aspects of each use case, definition of interactions between elements of the system and the messages and data exchanged.

Smart Grid communication standards

Two principal "communication paths" were identified for the system: metering and automation.

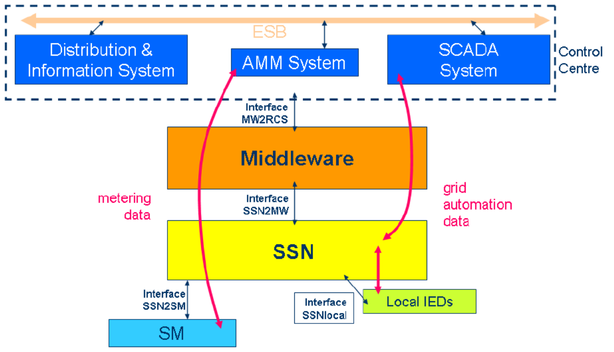

Figure 2: OpenNode's communication paths

The metering data must be transferred from the SMs up to the MW and the Utility systems via the SSN. For the interface between SM and SSN, the solution is based on the outcome of the OPENMeter project, DLMS/COSEM and PRIME. For the interface between SSN, MW and upper layers, a WebService based on DLMS/COSEM was made especially for SMs data transferring. Moreover, in order to test another future oriented Utility integration approach, a representative Common Information Model (CIM) data exchange with COSEM harmonized data was defined.

Regarding the automation data, two realities were faced:

- The necessity of having as soon as possible a first prototype to provide real test experiences and that could interact with current secondary substation and Control Centre legacy automation protocols (IEC 61870-5-104);
- The expectations of the partners of testing automation future oriented protocols such as IEC 61850.

It was decided to develop two versions of the grid automation communication interface between the SSNs and the MW. The first one, called "fast" solution, is based on legacy IEC 60870-5-104 compliant with today's SCADA systems, while the second "enhanced" version transported IEC 61850 data between the SSNs and the MW using the flexible and future oriented WebService defined in the standard IEC 61400-25-4 Annex A

Flexible architecture

The software architecture specified for the SSN allows for modular adding/removal of both devices and algorithms, thus providing maximum configurability and extensibility of the system. Core requirements for the SSN architecture can be summarized as:

- Being modular in design and separating the core automation layer from user-provided functions with a clear interface;
- Providing a security architecture for assigning access to automation/metering data only to relevant applications;
- Being able to add/remove additional devices via industry-standard protocols (IEC 61400 WebServices);
- Being able to add/remove/exchange/update algorithm;
- Performing both of the above operations without service interruption.

Fulfilment of these requirements allows the SSN to service a wide variety of business cases pertaining to the decentralization of intelligence in the low-voltage grid. Automation data from a SS is held in a centralized data base within the SSN, separating the base automation hardware from user algorithms. The advantages of this approach lies in the total abstraction of hardware from the user implementation and the possibility of access control.

Implementation

Two manufacturers developed the SSN prototypes in their own facilities, with different approaches to fulfill the common specifications. Siemens based his approach on the use of an industrial PC with Ubuntu as operating system and specialized modules for metering and grid automation. On the other hand, Nucleo's approach is based on a unique embedded Linux CPU. In both cases, the local automation functionality and external devices from the own companies have been integrated. Regarding the PRIME PLC communication, different technologies were selected as well. Nucleo chose an Atmel solution and Siemens a ST solution. Smart meters from five different manufacturers, with different PRIME PLC technologies, were integrated successfully.

Figure 3: The two SSN physical prototypes

After their development, the SSNs and the MW went through a phase of integration in order to harmonize the interactions between the devices before the utility tests started.

Thanks to the open specification both manufacturers achieved SSN prototypes using different technological approaches. Both solutions are fully valid and operative, and show how different technologies can be used to fulfill the specification.

ASSESSMENT OF THE SYSTEM AND OUTLOOKS

Once the prototypes had been developed and the integration phase between the SSNs and the MW was over, the prototypes underwent a testing phase, in order to assess the system developed by the project and draw conclusions from the implementation choices and in particular the ability of the system to perform the required operations. This validation phase by the utilities focused on the functionalities described in the operational scenarios from the use cases.

Testing process

A. Test process

Two different types of tests were specified:

- The functional tests to be run first consist in dividing up the scenarios into elementary tests, focusing on the prototypes' individual behaviour. During these tests, each OpenNode prototype (SSN or MW) is tested independently using protocol emulators. The use of protocol emulators also validates the prototypes' conformance to the communication standards used.
- The complete scenarios can be run once the prototypes are validated, testing the coordination of the different elements and assessing the system's end-to-end operational capabilities. These scenario tests also prove the interoperability of the system, the MW being able to manage SSNs from different manufacturers.

B. Validation of the tests

Assessment criteria had been determined to evaluate both functional validation and performance. The functional criteria identified the important steps to be assessed in each test. Time constraints based on real operational DSO requirements had also been defined for scenarios in order to make sure that the global system answered to the operating needs of a utility.

C. Feedback loop

A feedback loop had been agreed on with the manufacturers for them to be able to update their prototypes in regard to the malfunctions revealed by the initial tests. After each upgrade, the concerned tests were run again. This feedback loop proved to be very fruitful, as in several cases it helped reach the correct implementation.

D. Laboratory tests

The equipment was first tested in laboratory. This ensured a safe behaviour of the system, as no risk could be taken on the field in regard to the customers. It also allowed tests on more advanced functions and the use of future-oriented standards.

The laboratory tests started with the functional tests to ensure the correct implementation of the prototypes, after what the complete scenarios were verified, giving the go-ahead for the field tests.

E. Field tests

Once the system had been validated through laboratory testing, the field tests directly addressed the complete scenarios. They took place in a SS in Madrid, assessing the scalability, efficiency and reliability of the system, thanks to real-life conditions:

- Real deployment of smart meters at customer premises;
- Real network behaviour: noise, couplings, poor signal quality, contingencies, etc.;
- Real distances between components of the system;
- Two power transformers with two SSNs from different manufactures working at the same time;
- Number of managed signals used in any SS;
- Real environment for the tests: underground room, heat, humidity, electrical disturbances, real incidents, etc.

F. Conformance tests

In parallel to the utility tests, mainly focusing on functionality, conformance tests were run to certify the compliance of the data models and protocols used by the prototypes to communicate.

Results and outlooks

The OpenNode project results can be classified in two categories: theoretical and practical. First, a complete list of Use Cases (20 in total) for metering/grid automation and an open architecture for Smart Grids were published [1][2]. Secondly, laboratory (no security ties, no client limitations, optimal conditions...) and field (scalability, real grid conditions...) tests were performed [3][4]. Laboratory tests over fast prototypes have revealed that the system would allow utilities to install most short-term monitoring and controllability functions on the grid, offering the possibility to implement new functions thanks to the architecture's modularity. SM readings have been performed correctly by the SSNs and stored in the MW. SMs have been disconnected and connected remotely successfully. Regarding grid automation, the system enables the SCADA system, via the MW, to receive on demand and periodic measurements, monitor inputs and control outputs. SSNs can perform calculations and monitor the alarms in case of abnormal values or threshold crossing. The ability of the OpenNode architecture to add configurable automation in the SSNs paves the way for future developments on advanced Smart Grid features such as DSM, DER, EV...

In field, most of the SMs and both SSNs were discovered, registered and synchronized properly by the system (MW). The SSNs have showed sensibility to noise which has limited the metering test performance. Grid automation signals (measurements, signal status and commands) were received, sent, displayed and updated periodically at the MW Console. It has been observed no interferences between both SSNs from two different manufacturers working simultaneously at the same SS on two power transformers. The SSNs were flexible enough to follow a modular architecture to be adapted to different SS requirements. The remote control access to the units by the manufacturers' own premises demonstrated the system's easy deployment.

Moreover, the CIM interface in the MW holding the metering data available in IEC 61968 data model allows the OpenNode architecture to be integrated and exchange information with other utility information systems through an Enterprise Service Bus (ESB).

Recommendations can be drawn from the OpenNode experience:

- The scalability of the system is an important factor to choose appropriate components.
- Optimization of communication between equipment would be advisable to reinforce architectures since not all SS are equipped with the same communication infrastructures.
- It is very important not underestimate the time that the deployment and interconnectivity phases can take.
- A step by step approach to implement functionalities is important in this kind of project.
- Equipment size and weight are key variables to adapt them to different SS layouts.

CONCLUSIONS

The OpenNode project has developed a flexible, modular and open architecture to cope with the upcoming grid evolution, taking into account current and future needs, for both metering and automation functionalities.

The distributed SSN is the main component of the system and provides innovative software architecture approach, modular and extensible, allowing the inclusion of third-party applications. The MW system is the orchestrator of all OpenNode subsystems, facilitating the integration between the Utility systems and other stakeholders. The system is held together thanks to a modular communication architecture based on Smart Grid standards.

The system was successfully assessed in laboratory and in the field and has provided public deliverables specifying the requirements and architecture of the system. The new transport methods and standard extensions developed in the project have been proposed to the corresponding standardisation bodies.

REFERENCES

[1] OpenNode, 2011, D1.3. Functional Use cases

[2] OpenNode, 2011, D4.2 Specification of data models, protocols and communication interfaces

[3] OpenNode, 2012, D5.3 Functional and Interoperability tests

[4] OpenNode, 2012, D5.4 Test scenarios