Open and Interoperable ICT Solution for Integrating Distributed Energy Resources into Smart Grids

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***Abstract*—The ever increasing integration of renewable energy resources into the electric energy system gives rise to new challenges on a large scale. New and extended information technology is necessary for controlling the corresponding power grids and their components. The need for advanced control functions and ancillary services provided by distributed energy resources is also increasing. As a response to this trend, this paper addresses the concept of an open and interoperable information technology solution specifically designed for the integration of renewable energy sources into smart grid systems. The concept addresses remote programmable and flexible functions used in resource constrained, distributed energy resources controllers. A generic communication infrastructure as well as an accompanying formal modeling and engineering method for distributed energy applications are introduced. The usage of the proposed concept is illustrated via a representative example.**

I. Introduction

The massive deployment of Distributed Energy Resources (DER) in recent years has led to a paradigm change for the planning and operation of the electric power system. The concept of smart grids facilitates the usage of the existing power grid infrastructure in a more efficient way, thus allowing higher penetration levels of DER [1]. Such approaches also require new information and communication solutions, automation architectures, and control strategies [1].

DER components with their fast and flexible internal control mechanisms can implement many functions for supporting a stable grid operation. Such functions help to prevent grid problems like outages and profit cuts. However, to date, no common engineering approach for the implementation of DER functions exists that covers both DER manufacturer and system operator requirements. A formal modeling approach and an open engineering concept for energy applications and DER components in smart grids are still missing [2].

In the OpenNES research project, these shortcomings are addressed. Through the development of a concept for an open and interoperable information and automation solution, the integration of renewable energy sources can be improved. The approach is characterized by remote programmable control functions, a generic communication infrastructure, security-by-design (covering issues such as access management for different user roles), and a corresponding formal application modeling method applied to resource constrained controllers. This paper provides an overview of the proposed OpenNES Information and Communication Technology (ICT) system architecture and includes an illustrative example.

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II. Reference Architecture and Models

The Smart Grid Architecture Model (SGAM) presents a structured approach for modeling smart grid use cases [3]. SGAM is a result of the “European Commission M/490 Standardization Mandate to European Standardization Organizations (ESO)” [4] and it provides a layered approach for a smart grid architecture development, where the basis is a three-dimensional frame consisting of domains, zones, and layers. The component layer is the bottom layer of SGAM. On top of it, four interoperability layers are provided: the communication, information, function, and business layers. When SGAM is combined with the corresponding M/490 use case template, a powerful tool-set for the development of smart grid use cases and requirements is available [5].

Currently, architectural concepts defining a generic software layout for DER controllers are not very common in the domain of smart grids. Existing solutions like OGEMA, OpenMuc, IoTSys, and OpenHAB [6] mainly address energy management and home automation concepts. Concepts from other domains such as automation and automotive are of high interest interest and should be considered [7], [8]. Automation approaches like IEC 61131 or IEC 61499 provide useful concepts which have partly been adopted for smart grid systems [9], [10]. The AUTomotive Open System Architecture (AUTOSAR) introduced by the automotive industry also provides a very interesting and promising architecture for the development of DER control systems. It has been specified to create and establish an open and standardized software architecture for automotive electronic control units [11]. The generic approach defined in AUTOSAR is a candidate solution that should be considered for developing DER controllers.

Summarizing, there are many architectures, protocols, and standards available covering different topics in the domain of smart grids. However, very few of them are directly addressing the development of smart DER components. Domain-specific requirements and needs for the realization of such devices (e.g., limited computation demands, real-time execution behavior, security issues and SGAM-compliance) are often addressed insufficiently [6]. To address and cover the above mentioned issues and requirements, a corresponding software architecture and a modeling environment for smart DER components are being developed by the OpenNES project.

III. Proposed System Architecture

The proposed OpenNES ICT/automation solution consists of two parts: *(i)* a flexible system infrastructure for resource constrained DER controller components, and *(ii)* a corresponding use case and system modeling method based on SGAM. Moreover, efforts are focused on the specification of an access management for DER, taking into account different user roles. Fig. 1 provides a brief overview of the main project idea with the proposed open ICT solution used in smart grid systems.

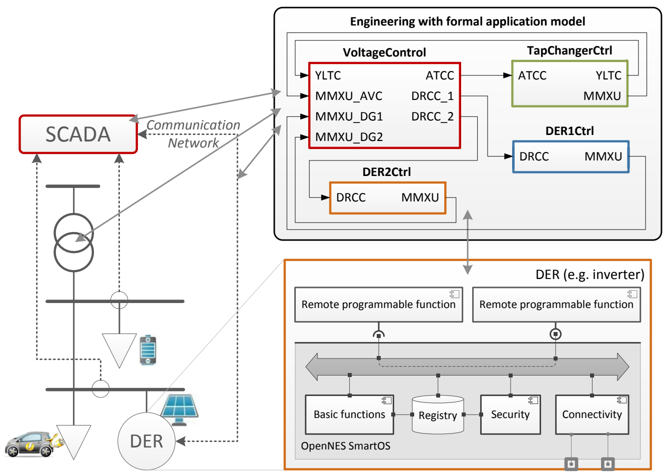

Fig. 1. Overview of the OpenNES system architecture concept.

In order to remotely program DER controller functions or Intelligent Electronic Devices (IEDs), an appropriate software architecture is needed on these components. For this purpose, the SmartOS has been conceptualized. It provides a flexible component-based architecture which allows remote programmability as well as comprehensive configuration possibilities. Fig. 1 shows the information flow of a possible smart grid communication network. As an introduction to the actual components of such a communication network, Fig. 2 gives a high level overview. A basic distinction between publicly available infrastructures (Internet, etc.) and private infrastructures (under control of stakeholders in the smart grid environment) has been made. As indicated by Fig. 2, the OpenNES approach is not only directed towards programming of DER controller functions, it also addresses networking controllers using a Software Defined Networking (SDN) scheme.

A. Generic Modeling Approach

A smart grid system can be considered as a complex system of systems, where many aspects must be considered when use cases are implemented. However, currently no design method exists that covers all these aspects. A holistic modeling approach integrating physical, communication, and control aspects is needed for optimized development and validation of smart grid applications [2].

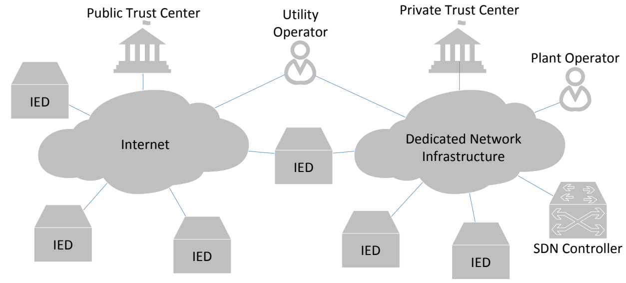

Fig. 2. Physical network architecture considered in the OpenNES context.

The design of smart grid use cases includes decisions on multiple layers. What kind of components (e.g., DER, transformers, switches) are involved in the use case, how do they communicate with each other, what information is exchanged, and what functions are running on each component are typical questions. All these aspects need to be taken into account by an integrated modeling approach [2].

The methodology defined in SGAM supports a structured description, as well as the visualization, of use cases. This allows the exchange of use case descriptions between different stakeholders. However, to fully take advantage of the information available in the use case description, a transformation into a machine-readable format is needed [12].

With the SGAM use case methodology in mind, in [13], the so-called SGAM Toolbox, a Unified Modeling Language (UML)-based extension to the Enterprise Architect software, has been developed. This design environment allows the modeling of ICT scenarios using UML constructs like use case, sequence, and activity diagrams. It can also be used to describe business objectives and functions represented in SGAM [5]. Although it is possible to use UML-tools to roughly describe functions and business objectives, these descriptions will not contain enough information to support automatic code generation. In order allow this, more detailed descriptions are needed.

This work suggests a software component model, a containment model that supports different levels of detail. The component model (see below) is designed with focus on the SGAM function layer rather than on the business layer. Each component can contain other components. This allows the function developer to pick the right level of detail that is necessary for realizing and implementing use cases. Furthermore, information exchange between software components can be modeled using an Interface Description Language (IDL).

B. SmartOS DER Controller Environment

The SmartOS is the conceptual software environment developed especially for resource constrained embedded systems in OpenNES. It is a platform dedicated for controllers on smart DER components with the main goal to incorporate flexibility, extensibility, and interoperability. Fig. 3 provides an overview of the proposed concept. It contains four main parts: *(i)* the SmartOS itself with basic DER functions as well as security and communication functionality, *(ii)* pluggable software components, and *(iii)* an engineering environment used for programming and configuration. The different parts are described in more detail below.

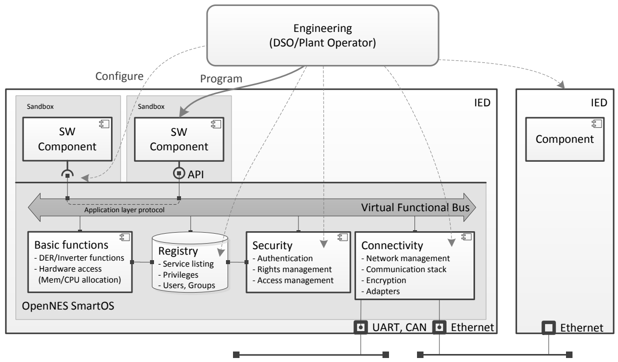

Fig. 3. General concept of the OpenNES SmartOS.

1) Software Components: Software components are pluggable modules in OpenNES which can be dynamically removed or added. They can either be developed and delivered by the DER manufacturer or developed by an external certified partner (plant operator, system integrator, etc.). Different types of components will be available. They may have fixed functionality or be programmable from an external engineering environment (e.g., using IEC 61131-3 or IEC 61499). "Programmable" in this case means that the component can be remotely programmed or updated during runtime. The updated application can contain new functionality (e.g., new monitoring or control functionality) as well as a reconfiguration of services provided/requested by the component.

Since the functionality of a component may change during runtime, its certification requires special consideration. One approach is to make sure that the application operates within specified constraints. Information about these constraints is stored in the local registry, against which all requests are checked for validity by the rights management functions within the security module. Furthermore, system critical applications (e.g., applications capable of setting permissions in the registry) are not allowed to be altered during runtime. Using the same mechanism, software components can be encapsulated in a safe compartment (i.e., through sandboxing).

2) Virtual Functional Bus: In order to allow communication between components in an organized and safe manner, a Virtual Functional Bus (VFB) is introduced in the SmartOS. Each software component can provide and request services through a service API provided by the SmartOS via the VFB. Services can be either public or private. A public service may also be accessed by external IEDs (e.g., other DER components or by a utility operator). Private services are only accessible from the same IED.

3) Basic Functions: In order to influence the behavior of DER components, a set of Basic Functions (BF) is defined. Power adjustment is a simple way to actively influence the local power grid. The power adjustment can be toggled between active (P) and reactive (Q) power management, whereas the management of the apparent power (S) is a result of adjusting P and/or Q. These mechanisms can be used to influence the local grid voltage as well as its frequency. With the term Advanced Grid Features (AGFs), we subsume several functions and behaviors. By providing only a simple set of BFs, the AGFs can be implemented by software components. Using this approach, it becomes easier to activate and configure certain AGFs. This is important, since different AGFs are mandatory in different countries.

4) Connectivity: The purpose of the Connectivity component shown in Fig. 4 is to provide a unified interface for external communication to all components via the VFB. Ideally, an application should require minimal to zero knowledge about the underlying network technologies, topologies, or protocols.

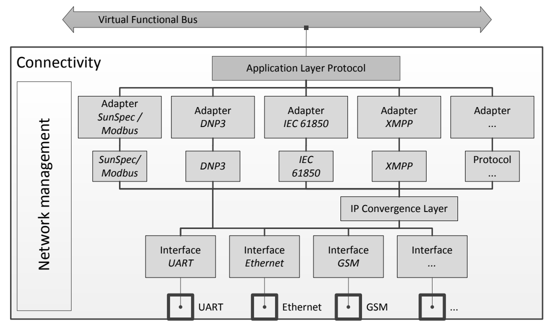

Fig. 4. Connectivity component of the SmartOS.

A modular approach using adapters for each protocol is intended to maximize flexibility and extensibility. These adapters (for protocols such as IEC 61850, Modbus/SunSpec, XMPP, etc.) are utilized to translate between the various external connection methods and the unified application layer protocol which is available to the various components. The adapters may also need to provide missing functions of the respective protocols (e.g., support for publish/subscribe, request/response and push messaging patterns). The configuration of the connectivity module is handled by a network management.

5) Security and Registry: Security is required across multiple layers in the overall OpenNES architecture. Communication between components, even within the same device, must be authorized by a Security Module. This module handles Role-Based Access Control (RBAC) and serves as the Policy Decision Point. For each access request it determines, whether or not the requester possesses the according access rights.

The Registry acts as a local permission store. It contains all users and groups/roles known to the IED, a mapping of the corresponding privileges, as well as data about the installed software components and their services.

The VFB acts as Policy Enforcement Point, only processing requests which have been permitted by the Security Module. Rights Management (in order to set the appropriate access rights to the corresponding roles in the Registry) is handled by a configuration component. For every request which passes through the VFB, the VFB first queries the Security Module, which in turn performs a lookup within the Registry in order to determine the validity of the request.

Access Management and Authentication are major tasks of the Security Module. For reliable Authentication and secure transmission of data, a Public Key Infrastructure (PKI) using certificates is proposed. This requires the Security Module to have access to a trust center, see Fig. 2.

IV. Engineering Example

In order to enable an engineer/developer to use the application modeling approach and to efficiently handle the flexible SmartOS, proper engineering support is needed. The example provided in Appendix B in [5] is intended to illustrate the use cases design and implementation process. It is titled *Reactive Power Control of DER*, which is a typical use case for power distribution management. In Fig. 5, the design approach of the use case is provided.

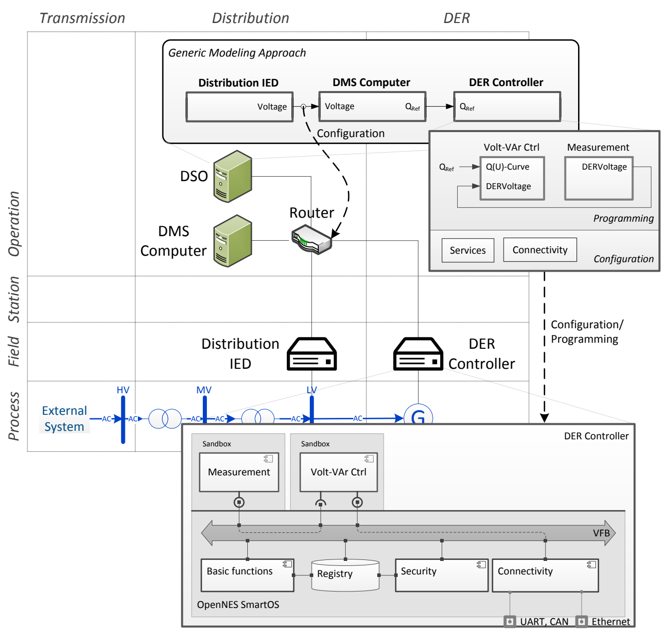

Fig. 5. Engineering approach applied to the reactive power control of DER.

The *Distribution IED* measures the voltage at the low-voltage bus to which the DER unit is connected. This measurement is sent to the *Distribution Management System (DMS) Computer*, where it is evaluated. In case the voltage violates any thresholds, a new Volt-VAr curve (Q_{Ref}) is calculated and sent to the *DER Controller*. Upon receiving a new curve, the *DER Controller* updates the operation parameters of the distributed generator.

The use case is modeled by the utility operator (i.e., Distribution System Operator (DSO)), using the proposed approach described above. For each component, a programming and a configuration model are provided. In Fig. 5, this is shown for the *DER Controller*. Two software components are defined in the programming model and a configuration is provided. In the configuration, the services of the software components are configured. The *Measurement* component provides a service that is requested by the *Volt-VAr Ctrl* component. Similarly, the *Volt-VAr Ctrl* component provides a service which is used by the *DSO Computer* to set Q_{Ref}. External access to this service is possible via the *Connectivity* component.

V. Conclusions and Future Work

The ever increasing penetration of DER requires new and intelligent ICT solutions. This change not only affects grid operators but also DER manufacturers, who need to implement more and more intelligent functions as ancillary support. This increase of new ICT solutions and functionality gives rise to new challenges in terms of engineering and operation.

In order to cope with these challenges, the OpenNES project suggests an open and interoperable approach for the integration of DER. Open (and remote), but limited, access for programming and configuration of DER is provided. Furthermore, interoperability is covered by providing both communication and functional interoperability. This is accompanied by a generic engineering and modeling approach.

Further research will have to bring the OpenNES approach from a concept stage to a prototypical implementation. An initial version of the OpenNES SmartOS will be developed and tested on a real photovoltaic inverter controller platform.

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