# A STANDARD-BASED SOFTWARE INFRASTRUCTURE TO SUPPORT ENERGY STORAGE IN DISTRIBUTED ENERGY SYSTEMS

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Abstract: Efficient energy storage in distributed energy systems depends on the operation of a set of coordinated devices spread around the power system. These include not only storage devices, but also production and consumption devices. Usually these devices encompass some communication skills and are able to be operated by energy management systems, regarding the status of the power system. However, despite this interaction readiness, most of these devices rely on non-standard communication protocols and some interoperability issues still remain. This paper presents an innovative plug & play approach for the integration of energy storage devices, supported by a standard-based and service-oriented software infrastructure entitled NEtworked MOnitoring & COntrol, Diagnostic for Electrical Distribution (NEMO). This approach adopts the International Electrotechnical Commission's 61850 (IEC 61850) semantic information model and the Devices Profile for Web Services (DPWS) specific communication service mapping, to perform a seamless device integration and communication of energy storage devices.

## 1 INTRODUCTION

Energy industry has recently witnessed a growing interest and study on the smart grid concept. It is quite clear that the energy crisis has brought two interlinked actors to the stage, namely Information and Communication Technology (ICT) and Renewable Energy Sources (RES), triggering the development of smart tools for efficient energy monitoring and controlling, namely Energy Management Systems (EMSs), and advanced distributed energy systems with communication and electronic processing capable devices.

Major manufacturers are concentrating their efforts on the development of interoperable Intelligent Electronic Devices (IEDs) and applications, with smart features and remote access. However, current systems and platforms rely mostly on private or access restricted communication protocols and do not target legacy or multiple vendor installations, nor even ad-hoc systems.

Recently, energy storage, and its management regarding a holistic view of the power system has become a major research topic. In order to ensure the correct diagnosis and operation of the energy storage devices spread around the energy system, existing energy management systems must able to properly take acquaintance of the status of each of its players, and perform the adequate operations. This will improve not only the coordination of multiple storage devices (Lim and Nayar, 2010; Mendis et al., 2010) but also the coordination of storage devices with production (Figueiredo and Martins, 2010), protective (Lima et al., 2012) and consumption devices.

Therefore, it is imperative that energy storage devices are adequately monitored and operated to guarantee grid stability. Moreover, they can contribute with relevant information for the operational decision process.

The NEMO system, raised from the identified need at the energy sector for adequate complex distributed systems management and further described in (Lima et al., 2011a), aims to enable the seamless integration and communication of every device (related with distributed energy systems) plugged into the grid, despite its manufacturer or communication capabilities, using communication standards such as

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IEC 61850 and DPWS (Driscoll and Mensch, 2009).

This paper focuses on the development of a plug & play environment for the integration and operation of energy storage devices, using NEMO architecture. The next sections describe the several stages regarding device specification and communication, and the respective implementation, using the IEC 61850 data model allied to the DPWS service mapping, for the integration and operation of energy storage devices.

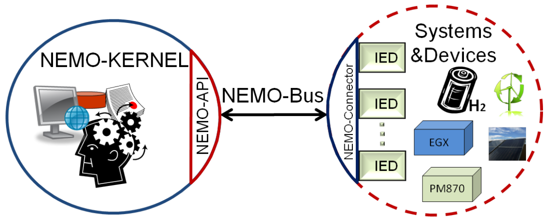


Figure 1: The main components of NEMO Software Network.

# 2 THE NEMO CONCEPTUAL ARCHITECTURE

## 2.1 Conceptual Vision

NEMO targets the development of a software infrastructure to help managing and controlling (from the energy efficiency perspective) complex energy systems where renewable sources are used in the production, distribution, and consumption of energy (Lima et al., 2011b).

The conceptual vision guiding NEMO is that networks of energy-related devices can be operated with the help of a (distributed) software infrastructure based on service oriented paradigm and standards.

Any instance of NEMO can use both new and legacy IEDs, which are required to have a minimum level of "intelligence" in order to be virtualised. In other words, they have to provide a software-enabled communication channel to be used in a communication process.

Two networks, namely energy and software networks compose each so-called NEMO system. The former is composed by systems and devices, which produce, distribute and consume energy. The is later used to monitor and control the energy network.

Two basic issues are addressed: IEDs recognition and communication with them. NEMO strategy to overcome them relies on two main pillars, namely Service-Oriented Architecture (SOA) and Standards. On the one hand, SOA architectural guidelines are followed for handling all IEDs as "service providers" and rely on DPWS profile for communication with and among those IEDs. On the other hand, IEDs are modeled, configured, and characterized into the System using the IEC 61850 standard. The role of both DPWS and IEC 61850 are described in detail in the next section.

The NEMO software network, shown in figure 1, relies on five main components, namely: NEMO-Kernel (NEMO-K), NEMO-Api (NEMO-A), NEMO-Bus (NEMO-B), NEMO-Connector (NEMO-C), and IEDs.

IEDs are at the nearest level regarding the devices and through them, commands are sent to the devices or data is gathered from them.

On the opposite side, there is the NEMO-K, which is the supervisor of the operation of Software Network. NEMO-K manages the services that can be provided by the system to the rest of the world. These services are named *External Services*, implemented as Web Services.

NEMO-B supports the interaction between the NEMO-K and all devices that are connected in the software network. Finally, NEMO-C is a wrapper that allows both integration and virtualization of IEDs into a given NEMO system.

Each of these components is further explained in (Lima et al., 2011a), and together they are essential for supporting the described conceptual approach.

## 2.2 Standard-based Approach

IEC 61850 is a worldwide-accepted standard for handling communication within substations. It integrates an information model, the so-called Abstract Communication Service Interface (ACSI), for substation description and the Substation Configuration Language (SCL), used to describe the ACSI information model.

ACSI allows describing an energy system and its respective components in a standard manner, independently from the respective individual manufacturers and with high level of detail. NEMO takes advantage of the intrinsic ACSI ability of virtualizing IEDs, by decomposing their respective physical properties and functionalities into a data model (Lima et al., 2011b). IED virtualization using the ACSI data model is further detailed in (Lima et al., 2011a).

Each standard compliant IED carries an XML-based SCL file, where the entire respective ACSI information is stored.

The physical features of each device may be enabled and disabled, or its information may be requested or changed, through the invocation ACSI services.

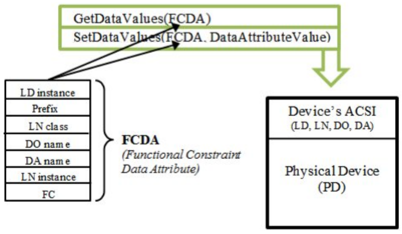


Figure 2: ACSI services invocation.

A shown in figure 2, two main ACSI service types are considered by NEMO: *GetDataValues* and *SetDataValues*. While the former is invoked for monitoring operations, when knowledge about the state of a physical feature is required, the later allows the physical control of a given device, replacing the older data attribute value by a new one.

Both require a reference that points to the required Data Attribute (DA) path with which the service is to be invoked. This reference is given by a Functional Constrained Data Attribute (FCDA) which includes, among others, the Logical Device (LD), Logical Node (LN), Data Object (DO), and DA that univocally characterise the physical operation (monitoring or control) to be performed (Lima et al., 2011a).

DPWS, the Web Service standard promoted by OASIS, was chosen to support the operation of the channel and really allow a seamlessly communication among all members of the network, supporting the inter-devices communication (Cândido et al., 2009b; Driscoll and Mensch, 2009). Web Services are the preferred mechanism for SOA implementation (Ribeiro et al., 2008; Cândido et al., 2009a) and the application of Web Services at device level will improve the operation of the system as well as the development process (Jammes and Smit, 2005). The service mapping between ACSI and DPWS allows supporting higher level heterogeneous platforms.

Similar to the Specific Communication Service Mapping (SCSM) based on Manufacturing Message Specification (MMS), described in IEC 61850 (Commission, 2003), NEMO uses a SCSM based on DPWS. The aforementioned ACSI Services - *GetDataValues(FCDA)* and *SetDataValues(FCDA, DataAttributeValue)* - are identified and mapped into the **GetIEC(FCDA)** and **PutIEC(FCDA, new_value)** Web Services (NEMO Internal Services), respectively. Therefore, each Web Service will be able to interact with single or multiple low level device physical features, through the invocation of NEMO Internal Services, each of them identified by its ACSI path.

Additionally to the services specified by the IEC 61850 data model, and in order to provide advanced features to the substation automation system not considered by the standard, NEMO defines a NEMO Communication Service Interface (NCSI) (Lima et al., 2011b). NCSI incorporates two NEMO Internal Services: **GetNonIEC(NemoIS)** and **PutNonIEC(NemoIS, new_value)**. These additional NEMO Services allow the integration and request of non-compliant services.

Since the majority of the IEDs do not understand DPWS, they usually need a mediator to make a bridge between DPWS and ACSI. This translation process is also performed by the NEMO-C who is responsible for offering device's features in the form of Web Services, performing all the necessary mapping between the device's ACSI and DPWS. This process is further described in (Lima et al., 2011b).

## 3 THE EXPERIMENTAL SETUP

An instance of NEMO System was implemented and evaluated in an experimental scenario, that covers the whole energy process (Lima et al., 2011a). For the sake of clarity, only the production and storage parts are explored and detailed here, which include:

- A set of photovoltaic panels, with a total installed capacity of 0.6 kW.
- A wind turbine with an installed capacity of 2 kW.
- A hydrogen fuel cell, installed capacity of 1.2 kW.
- An Active Front End (AFE) converter, attached to a set of batteries.

A electric vehicle are though to be integrated in order to store part of the electric energy generated, or too provide energy when the RES production is insufficient (figure 3).

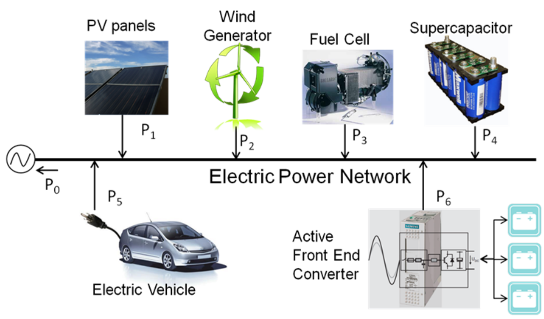


Figure 3: Energy Storage Devices Scenario.

The implemented fuel cell, photovoltaic panels, wind generator and the AFE do not comply with DPWS and IEC 61850 standards. For interacting with the devices, a proprietary communication protocol is required. For a better control of the fuel cell, its

NEMO-C interacts with the fuel cell itself and the respective inverter (Hydro Boy). The interaction with the fuel cell and the inverter is performed through a RS-232 channel, using both proprietary communication protocols. Fuel cell is always sending packages, so an initial synchronization is needed, while to interaction with the Hydro Boy is made by an event request.

The interaction with the AFE converter is performed through the USS Protocol, also by a RS-232 channel, reading and writing values. Several tests were executed in order to test the integration of the devices. Table 1 describes some of the executed tests.

## 4 CURRENT IMPLEMENTATION

As previously described, the scope of this work is to develop a plug & play approach for remotely monitoring and operating energy storage devices and, therefore, only the storage part of the experimental setup will be detailed. The production and consumption parts are further detailed in (Lima et al., 2011b; Lima et al., 2011a).

In figure 4 it is possible to behold how the NEMO-C of the fuel cell is implemented. As described in previous section the NEMO-C of the fuel cell is connected to two IEDs, interacting with each one in its specific communication protocol.

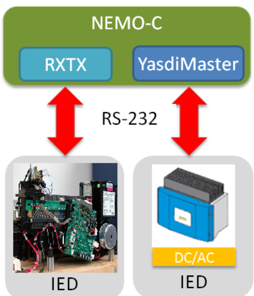


Figure 4: Fuel Cell Communication.

The interaction with AFE converter is made through a RS-232 connection, as shown in figure 5.

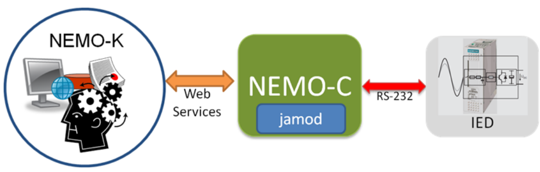


Figure 5: AFE Converter Communication.

As aforementioned, NEMO-C is responsible for the integration and virtualization of IEDs into the NEMO System, providing additional features through Web Services and enabling the interaction between NEMO System and the physical devices. Three different types of mappings are performed by the NEMO-C:

1. Between DPWS and IEC 61850, to allow the invocation of ACSI services using DPWS Web Services to both IEC 61850 compliant and non-compliant devices.
2. Between IEC 61850 and the IED's manufacturer communication protocol, to guarantee that IEC 61850 non-compliant devices understand ACSI services.
3. Between DPWS and the IED's manufacturers communication protocol, to allow the invocation of services not contemplated by the IEC 61850.

NEMO-C receives the DPWS service invocations of NEMO-K and through internal the mappings, it will be capable of performing the requested operations in the device. Regarding the energy storage area, and for the purpose of this work, there are two NEMO-Cs implemented: one virtualizing the fuel cell and one connected into the AFE converter.

The interaction between the NEMO-C and the fuel cell is made through a RS-232 converter. Equal converter is used to interact with Hydro Boy. Two different libraries are needed to interact with the devices: RXTX is a native library which provides serial and parallel communication for the Java Development Toolkit (JDK); YasdiMaster is a Dynamic Link Library (DLL) which allows communication with Hydro Boy via the proprietary protocol.

The connection with the AFE is performed through a RS-232 connector. The proprietary communication protocol to interact with the AFE converter is the USS Protocol. USS Protocol defines an access technique acordint to the master-slave principle for communication via a serial bus.

Both fuel cell and AFE are fully functional with all the possible services mapped to non-ACSI or to ACSI services. Examples of ACSI compliant services and of non-ACSI compliant services currently implemented in the fuel cell and AFE are shown in Table 2 and Table 3, respectively.

Lets consider that the NEMO-K requests an invocation of a non-ACSI service, for instance, a monitoring operation regarding a fuel cell hydrogen concentration. This operation starts with the invocation of the **GetNonIEC** Web Service having NEMO service identifier parameter with the value **HydrogenConcentration** (Table 3). This Web Service request will be received in the **NEMO.IS** component, and since it is identified as non-compliant service, it is

Table 1: Executed Tests for Integration Assessment.

| IEDs | | |
|---|---|---|
| FuelCell | HidroBoy | AFE |
| Read Air Temperature | Read Mode | Read Language Voltage |
| Read Stack Current | Read Storage | Read AFE current |
| Read Purge Cell Voltage | Read Frq Dif Max | Read Reactive Power |
| Read/Write DC Vtg Str | Read Hardware Version | Read/Write Operating Mode |
| Read Hydrogen Pressure | Read Time Stop | Read/Write Vd(set) Factor |

Table 2: Examples of ACSIs services currently implemented.

| IEDs | FCDA | | | | | | NEMO Internal Service |
|---|---|---|---|---|---|---|---|
| | LdInst | LnClass | LnInst | DoName | DaName | Fc | |
| HidroBoy | SB | MMXN | 1 | Vol | mag | MX | DC Vtg Str |
| FuelCell | FC | STMP | 1 | Tmp | mag | MX | Stack Temperature |
| FuelCell | FC | STMP | 2 | Tmp | mag | MX | Air Temperature |
| FuelCell | FC | MMXN | 2 | Vol | mag | MX | Purge Cell Voltage |
| AFE | AF | MMXN | 1 | Vol | mag | MX | Vd(act) |
| AFE | AF | MMXU | 1 | Hz | mag | MX | Line Frequency |
| AFE | AF | AVCO | 1 | LocSta | ctlNum | MX | Access Level |



Table 3: Non-ACSIs services currently implemented.

| IEDs | Type of Service | NEMO Service Identificer | Input Units | Output Units |
|---|---|---|---|---|
| HydroBoy | Get | SerialNumber | n/A | n/A |
| HydroBoy | GetPut | EnOp | n/A | n/A |
| FuelCell | Get | HydrogenPressure | n/A | barg |
| FuelCell | Get | HydrogenConcentration | n/A | % |
| AFE | Put | OperatingStatus () | n/A | n/A |
| AFE | GetPut | LineVolts () | V | V |

forwarded to **NEMO.IS.to.NonACSI**, where its accomplishment is verified. If NEMO-C is able to execute the requested service, this is dispatched to the **NonACSI.to.IED** component, which will perform the requested operation through the Communicator component, according to the NEMO-C internal mapping. Otherwise the service will be denied.

Lets consider now an IEC 61850 compliant monitoring operation, regarding the **Air Temperature** of the environment where the fuel cell is located. A **GetIEC** service is invoked (ACSI compliant), introducing the reference STMP.Tmp.mag[MX] to the FCDA parameter (Table 2). NEMO-K invokes the **NEMO.IS**, and this time the request is dispatched to the **NEMO.IS.to.ACSI** component, which verifies if the FCDA is correct, i.e., if it is defined in the IED's SCL file. If this is verified and the IED is IEC 61850 compliant, the operation is performed according to the IEC 61850 protocol. Otherwise, if the IED is not IEC 61850 compliant, the **ACSI.wrapper** component acts and the service is performed according to the FCDA internal mapping.

# 5 CONCLUSIONS AND OPEN POINTS

The intermittency characteristic of RES must be mitigate, for attaining a higher energy efficient management. A holistic view regarding the continuous and remotely management of energy storage devices is, therefore, a must. By integrating two communication standards and a standard data model, NEMO provides the seamless integration and interoperability of energy storage devices, required for a real effective operational architecture for the integration of energy storage devices.

As future work, new devices as super-capacitors are planed to be integrated, as well as the study of the effects in the electric power network of different control functions, where all the production devices will be managed to fulfil the demands.

Some studies to measure the delay added by the Web Services layer in RS-232 communications have to be performed. In a small system like the one described it may not be a problem, but in a large scale system this have to be taken into account.

The mapping between the DPWS Eventing feature (Driscoll and Mensch, 2009) and the Report ACSI service (Commission, 2003), is planned to be developed, in order to have a more efficient monitoring operation. With this features the devices will be able to inform the NEMO-K, about a system malfunction or a overrated value.

## ACKNOWLEDGEMENTS

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