# IEC60870 METER SMART SOA MANAGEMENT

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## Abstract

*The transition from distribution and transport power networks into the so-called smart grid paradigm must cope with many problems, one of them the high amount of related standard protocols. Achieving interoperability between them is the key this goal. We focus here on the IEC 60870, the Spanish standard for high-voltage meter control and management. We have designed and deployed a service-oriented architecture (SOA) that wrap all the functionality offered by the IEC 60870, enabling in this way an open, non protocol-dependent access to those functions. Moreover, we present two strategies to integrate the SOA, each one addressing different management needs, and illustrate both of them with the description of two proof-of-concept applications.*

## 1. Introduction

One of the challenges the so-called *smart grids* must face is the unification (when possible) and untangling of the related protocol mess. As accounted in [7], the NIST (National Institute of Standards and Technology) originally identified 16 key smart grid standard protocols [28] and in a report from the EPRI (Electric Power Research Institute) to the NIST, this list increased to 77 items [10]. This drawback aggravates when it comes to the management of high-voltage (HV) meters due to historical reasons. For instance, the ANSI C.12 [30] rules in the USA whereas COSEM (Companion Specification for Energy Metering) [21] is the standard Europa-wide and Spain, though, remains still loyal to the humble IEC 60870 [20]. Needless to say, these protocols are not interoperable.

With the emergence of the *semantic web*, the interoperability of protocols may be achieved in an easier and more feasible manner. To be more specific, one of the basic pillars of the semantic pyramid, namely *web services* or service-oriented architectures (SOA), facilitate and simplify this challenge since they have been especially conceived to allow communication among different applications and distinct sources of data. In a way, SOA sends and receives the information through standardised XML (eXtended Mark-up Language) envelopes (by means of the Simple Object Access Protocol, SOAP), achieving the desired interoperability, providing both easy service discovery and publication mechanisms (Universal Description Discovery and Integration, UDDI), and an efficient service description language (Web Service Description Language, WSDL). Hence, any (ad-hoc, non-proprietary or standard) data exchange protocol is susceptible to be wrapped into a SOA mediator in order to fulfil the same functionality but in an open, inter-operable fashion.

This approach is not new: it was for instance already applied in the late 90s to develop an *universal* gateway between several field-area networks and the Internet [36], or adding the self-description ability of XML, to exchange industrial data [46]. Similarly, lately there have been a number of high-level researches that have followed this spirit to, for instance, manage the connection between two heterogeneous semantic systems (i.e. two different *ontologies* [26, 41]). In order to achieve this goal, they use *ontology mappings* (say a list of equivalence definitions) that help connecting similar concepts in diverse domains.

We focus here on the IEC 60870, the high-voltage meter management standard only in Spain. This protocol allows remote reading and manipulation of the meter but is not interoperable with other wide-established protocols (e.g. DLMS/COSEM). Therefore, the management must be achieved by means of proprietary applications implementing the protocol.

Against this background, we advance the state of the art by designing a SOA wrapper for the IEC 60870 protocol mapping the services of the protocol to Web Services. We detail two possible architectures, one using a remote database to store meter measurements, and the other allowing real-time meter querying. Moreover, we describe two applications, one for each architecture, as proof of concept. The remainder of the paper is organised as follows. Section 2 gives an accurate introduction to the IEC 60870 protocol. Section 3 details the feasible alternatives for the architecture of the wrapper. Section 4 presents two applications based on those architectures. Section 5 accounts and discusses related work. Finally, Section 6 concludes and draws the avenues of future work.

## 2. IEC 60870

The IEC 60870 is the standard adopted by the Spanish Transmission System Operator (TSO) for the management of high-voltage meters. It provides two types of frames depending on its length (fixed or variable). The first group is used to transmit acknowledge messages or `ack` (i.e. operation successful), error codes or information on the status of the communication. The second group carries questions and answers along with the pertinent data. Fig. 1 shows the schema of fixed and variable length frames (each cell representing a single byte).

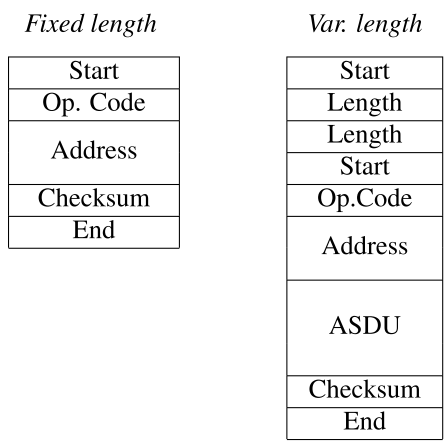


**Figure 1. Fixed and variable length frame content.**

The meaning of each field is explained next:

- **Start**: It indicates the head of the frame. In fixed length frames, this field is set to `0x10` whereas in variable length frames, it is assigned the value of `0x68`. In the latter case, this field appears twice in the frame due to security reasons.
- **Operation Code**: This field determines the objective of the frame.
- **Address**: It shows the MAC address of the target meter. This field comprises 2 bytes sent in *little endian* format.
- **Checksum**: Allows to check the integrity of the received data.
- **Length**: Specifies the amount of bytes of the frame. In variable length frames, this field appears twice due to security reasons.
- **ASDU** (Application Service Data Unit): It is a field whose length depends on the amount of data to be sent. It contains one byte specifying the type of ASDU (`cdt`), the address of the target (including `meter id` and an application layer address), and the data to be transferred.
- **End**: Similar to `Start`, this field marks the end of the frame. In both fixed and variable length frames its value is set to `0x16`.

The Spanish standard for meter management is, more accurately, an implementation based on the IEC 60870-5-102 that specifies the communication protocol between registers or accumulators and meters. It presents three layers, namely *physical*, *link*, and *application* (taking the OSI Model as reference).

- **Physical** layer: The IEC 60870 foresees three approaches to access the meters, one direct and the other two remote (via GSM modem or TCP/IP, depending on the device model and its features). We focus here on the remote GSM alternative since all meters have a GSM modem attached. Therefore, the physical connection is performed through AT-HAYES commands.
- **Link** layer: This layer is dedicated to establish a communication session between the meter and the external querier by the assignment of an unique `session id` that lasts until the communication is closed. The vehicle to exchange data in this layer is the frame. The IEC 60870 specifies their type and order, being usually grouped in question-answer pairs, except for the `session-open` and `session-close` frames that receive a fixed length frame with `Op.Code 0x10` (`ack`) in case the operation was successful. The connection in this layer is established as follows: the querier sends a fixed length frame with `Op.Code 0x40`, the meter responds with a `0x0B`, then the querier replies with an `Op.Code 0x40` and, if the connection is succesful, the querier receives an `ack` frame.
- **Application** layer: The protocol enables non-password protected operations (i.e. non critical) such as inquiring the meter and vendor id, reading current date and time, official work-schedule dates (holidays and vacations), contracted power, consumed active and reactive power (accumulated and stored since the last reading), and so on. Password protected functions include all meter configuration operations that could lead to an deceitful or defective data retrieval such as changing date and time, modifying contracted power, holidays, password, or reading the meter's configuration information (since this information contains the password).

Fig. 2 illustrates the frame flow issued when performing the following two operations: first, retrieving the meter vendor code (`Op.Code 0x100`) and, second, querying absolute integrated consumption readings (`Op.Code 0x189`). We assume that the connection is not yet established and that it will be closed after receiving the requested information.

Once the session is opened, we can already perform *open* functions such as the retrieval of the vendor id, which

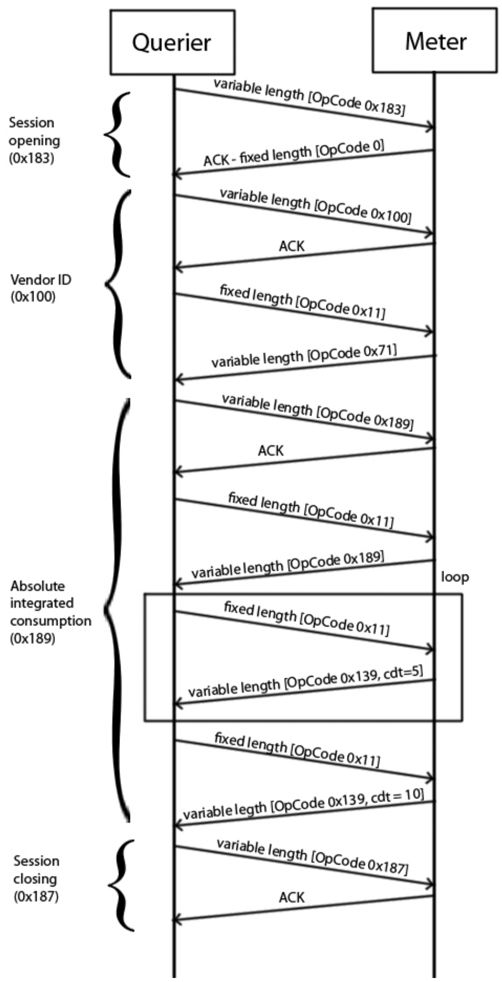


**Figure 2. Data flow with operations Ox100 and Ox189.**

always includes the same number of frames (one for the query, a fixed length frame, and a variable length one for the answer). We have also portrayed an operation whose amount of needed frames depends on the length of the information to be transmitted, for instance reading the absolute integrated consumption, as in Fig. 2. It starts with a fixed part (a request with `Op.Code 0x189`, an `ack` response), and then a loop that is repeated until all the information is transmitted. In this case, the querier issues an `Op.Code 0x11` frame to continue getting data, which is a variable length frame with `Op.Code 0x139` and whose ASDU shows ASDU type `cdt 0x05` (meaning answering request). The last of the frames sent by the meter in this operation has also `Op.Code 0x139` and `cdt 0x10` (meaning transmission end).

## 3. Architecture

The meter stores every fifteen minutes the load consumption data in a cyclic buffer (i.e. replacing older data by newer information) whose capacity depends on the vendor and model of the meter (the average is about three months worth of data). Taking into account the aforementioned connection variants (direct, via GSM, via TCP/IP), there are three different approaches for enabling SOA management on IEC 60870 meters, as follows:

- **Embedded SOA wrapper**: It implies the direct connection to the meter in order to enable the communication through SOA. This may be difficult due to the possibly hazardous environment, the requirement of investing on an embedded lightweight platform (which will have limited storage capacity as well), and may not be allowed by the Utility that owns the meter.
- **Remote SOA wrapper**: This alternative consists of a remote machine that, via GSM or TCP/IP, queries and stores the meter data in a database (avoiding in this way the problem of storage limit) and offers simultaneously decoupled access to that database through a SOA. The database could even be placed as a *cloud computing* service [45], if needed.
- **Remote real-time SOA wrapper**: In a similar vein to the previous one, the remote machine acts as a transmitter of the SOA requests, translating and delivering via GSM or TCP/IP to the meter and vice versa for the responses. This strategy still suffers from the limited storage problem (though it could be solved by querying the meter on a regular basis).

With these three alternatives in place, we have implemented the last two due to their obvious advantages. The three of them comprise the conceptual architecture depicted in Fig. 3.

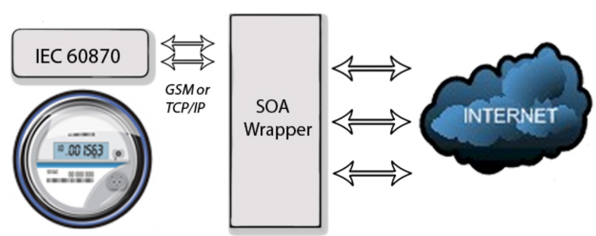


**Figure 3. Conceptual architecture.**

The second solution, the database-enabled remote SOA wrapper, shows the following architecture (please note that it is not the same as the real-time one since this later lacks of a storage mechanism such as the database), illustrated in Fig. 4.

The SOA layer offers the following services non-password protected (please note that the `db` prefix means that this service is offered only in the database-enabled architecture and the `rt` prefix in the real-time one):

- ***db*_read-active**: Allows retrieving the consumed active power of a given period (as long as that period exists in the database).

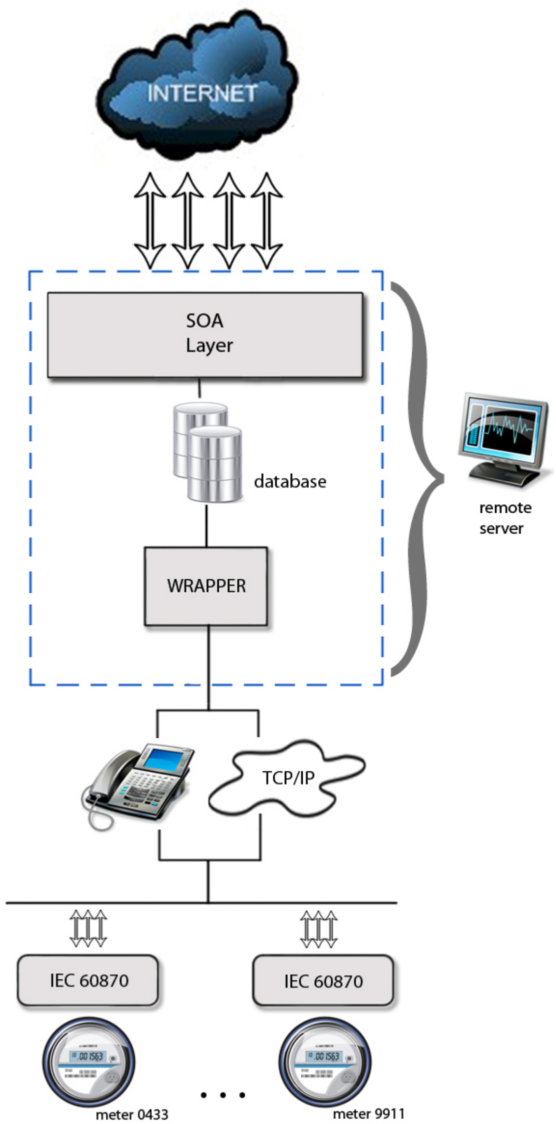


**Figure 4. Real architecture of the Remote SOA wrapper.**

- ***rt*_read-active**: Queries the accumulated information (stored each 15 minutes) on consumed active power (usually 3 months of data). Opposite to the previous service, this one does not allow to specify the period (it just retrieves all data of this type).

- ***rt*_read-integrated-active** : Queries the accumulated hourly information on consumed active power.

- ***db*_read-reactive**: Returns the consumed reactive power of a given period (as long as that period exists in the database).

- ***rt*_read-reactive**: Asks for the accumulated information (stored each 15 minutes) on consumed active power.

- ***rt*_read-integrated-reactive**: Queries the accumulated hourly information on consumed reactive power.

- **read-vendorId**: Reads the vendor Id of the device.

- **read-deviceId**: Retrieves the Id of the meter.

- **read-dateTime**: Queries the current date and time of the device.

- **read-dateChange**: Allows retrieving the days in which the hour is changed (in order to save energy).

- **read-holidays**: Asks for the vacation days.

Similarly, sending the password, it allows the accomplishment of the following password-protected services (common to both architectures):

- **read-parameters**: Reads the configuration parameters of the meter, including the password.

- **change-parameters**: Writes new values on the configuration parameters of the meter, including the password.

- **change-dateTime**: Allows changing the current date and time of the device.

- **change-dateChange**: Updates the days the hour is changed.

- **change-holidays**: Enables changing the vacation days.

- **read-contractedPower**: Retrieves the data on contracted power.

- **write-contractedPower**: Allows updating the contracted power to another amount.

- **read-tariffInfo**: Reads the tariff information stored in the meter.

- **write-tariffInfo**: Writes new tariff information.

## 4. Applications

Based on the service-oriented architecture devised on Section 3 and as a proof of concept, we have been able to develop several applications, two of which will be described next. One is based on the database-enabled remote approach while the other focuses on the real-time alternative.

- **Consumption Monitoring System**: This application queries every fifteen minutes the consumption data of a high-voltage meter and, together with the information published by the Spanish TSO on the national generation mix, calculates and shows the equivalent $CO_2$ emissions corresponding to the registered electricity consumption. In addition, it shows

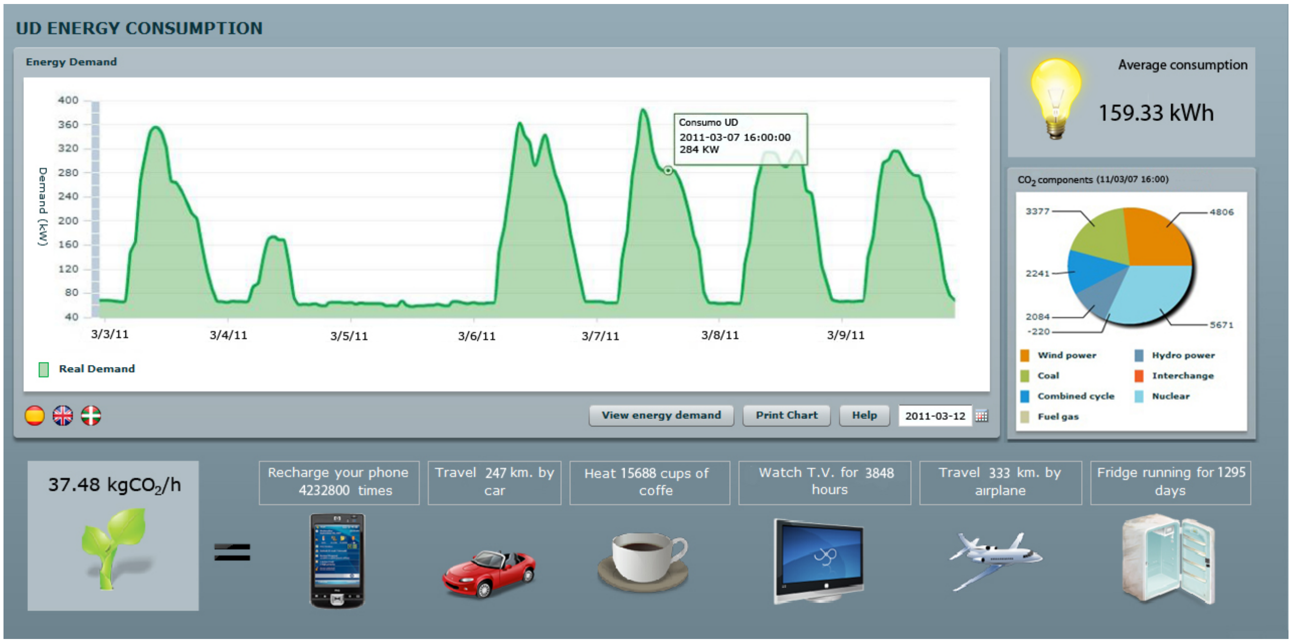


**Figure 5. Consumption monitoring system with $CO_2$ emissions chart.**

the daily demand curves in order to relate the energy demanded with the emissions its generation implies. We have developed this application with the purpose of bringing awareness on the impact our daily activities have on the environment. To do so, it has been installed and presented in several monitors at our main campus (University of Deusto, Bilbao, Basque Country). Fig. 5 shows the $CO_2$ emissions chart.

- **Short-time load forecasting system**: As presented in [33], we have developed and implemented several statistical and artificial intelligence algorithms to foresee the consumption based on a meter's historical records. Opposite to the previous application, we have used the database-enabled architecture since we need more than a year data to train the methods, issue the predictions and validate them. Fig. 6 shows the result of predicting a weekday's load with two different methods (AR, an auto-regressive statistical method, and NN, a Neural Network) compared to the actual demanded consumption.

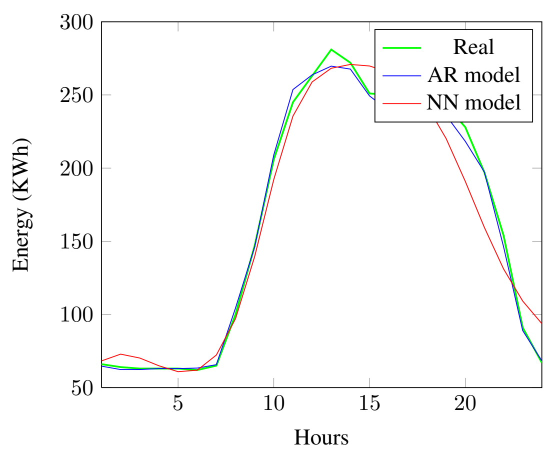


**Figure 6. Short-time load forecasting in a week day [33].**

## 5. Related Work

Since smart grids have become a fashionable term, there has been a hectic research around many of their compounding parts and particular or global requirements [43]: evolution from classical design [33], protocol interoperability [18], integration of renewable sources [8], control and monitoring [9], metering [32], modelling of both transmission [1] and distribution systems [17], energy production scheduling [42]... the list of issues grows yearly.

Communication protocols are not an exception; moreover, taking into account the huge amount of related specifications and their lack of interoperability, as we pointed out in the introduction. There have been some interesting new directions opened lately in this domain, especially focusing on the bidirectional integration of two smart grid protocols. Generally, all of these works intend to place one of the targeted protocols as the basis, and then, they map the functionalities of the other through some kind of middle-ware layer, similar to the *protocol tunneling* achieved in other network domains [2]. This verge of research has recently turned to semantic technologies in their search for tools to accomplish interoperability. For instance, the apparition of the UML model citeUML of the CIM standard [22] has highlighted it as the reference *ontology* [3, 31, 5] to be extended in order to include the rest of related protocols [16, 44, 7, 6, 34, 35, 32], also envisioned by the IEC [38] and the EPRI [12, 14, 13, 11, 15]. This methodology has been backed from the Technical Committees developing the, involved protocols, as in the case of DLMS/COSEM, where the DLMS Users Group itself has propelled a study to integrate this protocol into CIM [39].

Further from this integration issue, there is another research direction that foresees the smart grid as a constellation of domain ontologies that must be mapped and brought to collaboration [40]. The problem in this approach is not only overcoming smart-grid related drawbacks but also the ontology mapping challenge [25, 37, 26]: finding and expressing the equivalences between ontologies or their optimal alignment, achieving the actual communication, integrating diverse source of data [19, 27], etc. Worth mentioning are the special efforts invested on integrating the IEC 61850 and the CIM [24, 23, 29, 4], both of them main pillars of the smart grid vision [38].

In any case, the work described herewith is humbler in its ambitions or, say, presents another intention since we aim at an open, non domain or protocol-dependent meter management, in this case with the IEC 61870 as the targeted protocol. Still, the semantic alternative would be welcome if the application performing the meter management was to be integrated within a general smart grid framework. In that case, using the same context (say ontology), would be very beneficial in order to ease protocol interoperability but, anyway, half of the work would be already done as presented here.

## 6. Conclusions and Future Work

One of the most urgent challenges smart grids have to face is the harmonisation of the involved standard protocols. For instance, if we focus on high-voltage meter management, depending on the country we may find the supremacy of the ANSI C.12 (e.g. in the USA), or the DLMS/COSEM (e.g. almost all over Europe). We deal here with achieving interoperability with the IEC60870 protocol, the standard for this purpose in Spain.

We have proposed a SOA wrapper relying on a direct protocol service mapping that makes them accessible through a SOA. We have put forward two complementary architectures, one using a database for meter information storing and decoupled SOA access, and another with real-time direct meter management. Finally, we have described one application implementing each architecture type as a proof of concept.

Still, this solution does not achieve direct interoperability with other protocols. Further research will explore the possibility of integrating the IEC 60870 data model within an ontology. For this purpose, we foresee two alternatives. First, developing a novel, separate ontology for the protocol and then map it to other existing smart grid ontologies (such as the CIM [22], the Common Model Interface defined by the IEC, as in [32]). And, second, extending an existent smart grid ontology (again, this target ontology would be the CIM, similar to what presented in [39]). In both cases, since the IEC 60870 does not present an associated data model (as, for instance, DLMS/COSEM does), a functionality mapping similar to the one presented in this work, would suffice.

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