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Interoperability Framework for Data Exchange between Legacy and Advanced Metering Infrastructure

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Abstract

Performance of Advanced Metering Infrastructure (A MI) is improving due to the introduction of International Electrotechnical Commission's (IEC) 61850 standard based smart meters and Intelligent Electronic Devices (IEDs). Whereas, legacy metering infrastructure and devices can not be ignored due to their wide spread use and substantial capital investment, but at the same time advance technology based smart meters are forcing utilities to adopt new technology in metering. Middle path, before complete transformation takes place, seems to be to make legacy and AMI interoperable. This paper proposes a solution where applications from different manufacturers can access a standard interoperable metered data. A novel solution is also provided for accessing the meter metadata without manually inputting the address parameters of a particular meter to reduce the development time involved in deploying the AMI head-ends.

Keywords: AMI, AMI Head-end, IEC 61850, Interoperability, Metadata, Smart Grid, XML Database

1. Introduction

Smart Grid is becoming popular day by day where utilities, manufacturers, and solution providers are exploring ways and means to improve and implement the technology for leveraging the existing power generation, transmission, distribution and metering infrastructure. A number of smart-grid advances in distribution management are expected where integration means, protocol standards, open systems, standard databases and data exchange interfaces will allow flexibility in the implementation of the head-end applications [1]. Further critical technologies like advanced visualization capabilities, measurement based stability analysis etc. are needed to achieve the vision of smart control center for providing reliable, economical, and sustainable delivery of electricity [2], [3]. To achieve the vision, utilities and solution providers have to develop and integrate the necessary technologies. Javier described the concept, characteristics, and benefits of implementing a smart grid [4]. Considering multi-manufacturer devices in an infrastructure, utilities have limited capabilities for enabling the integration across the applications to perform functions like system planning, power delivery and customer operations. In most of the cases, users of one department can not access the applications or data of other departments because of integration and interoperability issues. It is estimated that the utilities allocates programming budget of 35-40% for developing, maintaining and updating the programs especially for exchanging the information between legacy systems and databases [4]. In some cases, it was found that the lack of acceptable standards has delayed or stopped the deployment of smart grid technologies [5]. Thus smart grid society should be aware of guidelines and best practices that the electric utility is using in integration of energy infrastructure. Smart grid solutions suite using industry standards such as IEC61850, IEC61968, IEC61970, Common Information Model (CIM), and web services can help in data exchange amongst different applications [6]. IEC 61850 is a standard that provides an ability to achieve interoperability between multi-vendors IEDs installed in a substation [7]. IEC 61850 provides a comprehensive model that organizes data in a manner that is consistent across all types and brands of IED's.

Javier pointed out that the brand of one manufacturer does not always work with the brand of another manufacturer and identified this as a problem of flying monkeys [4]. Various strategies adopted by the utilities to overcome this problem are described by Steven in [8], where utilities try to give tender to a single manufacturer, who can complete the job from designing to erection and commissioning with proper documentation and training. With this solution, still, the utilities are dependent on the solution providers to carry out an integration task. Dependency on a particular solution provider is not a wise decision when the utilities look it from future perspectives.

Interoperability is a property which enables heterogeneous systems and organizations to work together for exchanging or sharing the information. Thus interoperability enables seamless end-to-end integration of hardware and software components in a system. Infrastructure or systems providing interoperability will be more productive through automation and enable smooth data and information exchange. Interoperability also enables users to choose between features and vendors rather than technologies. A checklist is provided by Alison et al. that help utilities to determine whether they have the characteristics or capabilities to contribute to the interoperability [9].

2. AMI and Smart Grid

Grid is not a single entity but a combination of multiple networks comprising of varying levels of devices, the communications and co-ordination among them are mostly manually controlled. By adding digital intelligence to the existing grid infrastructure, the grid can be made smarter. Automatic meter reading (AMR) is the technology of automatically polling the electricity usage reading from electric meters and transferring the readings to a central station for billing purposes. AMR technologies reduced the cost of reading the power meters by eliminating the involvement of man power. Thus AMR help utilities to overcome the challenges involved in meter-reading. Due to one way communication, AMR alone can not satisfy the objectives of today's environment. AMI comprising smart meters with two-way communication is becoming an emerging technology growing from AMR where meter readings are gathered intelligently at reduced cost [10]. AMI as a subset of smart grid acts as a solid interface between the grid and the consumers. Earlier, the electricity outages in a particular area were identified via the customer calls. By utilizing an AMI, the utilities can identify when, where, and why an outage occurs. Leveraging AMI infrastructure is an emerging research area where suitable strategies need to be adopted for realizing the smart grid. To know the load profile, power consumption or demand of a particular area, AMI plays a critical role in delivering the electricity usage. AMI with two way communication enables time stamping of metered data, outage detection and other functions like real-time pricing, load profile detection, on-off switching of registered home appliances etc. A cost effective and flexible GSM based AMI system is described by Huibin et al. where distributed structure of the AMI system makes it easy to be adopted in different sizes of utility systems [10].

In AMI systems, most of the time, there exist heterogeneous software/hardware components in the same network. Moreover, they are tightly coupled with each other and make interaction and integration job tedious for a system integrator or a solution provider. A service oriented AMI is discussed by Shudong et al. where smart meter reading is performed by calling the distributed meter reading services on the smart meters but the solution does not incorporate the digital meters having one way communication called as legacy meters installed in the network [11]. Ronald, in [12], described a software package using Open Database Connectivity (ODBC) and Dynamic Data Exchange (DDE) protocol for exchanging the data with the power systems, which is generic with Microsoft technologies only. Considering a scenario of TCP/IP Modbus networks in smart grid, various applications like SCADA, Energy Management system (EMS), and AMI creates their own proprietary databases and some of the databases are not in the standard format. For example, Schneider Electric SCADA Vijeo Citect 6.0 stores the tag values in .hst files whose format is not a standard format [18]. Therefore, without using translating or converting mechanisms, applications of different vendors can not access these .hst files or proprietary databases. Keeping heterogeneous nature of application's databases in mind, the domain of data engineering is under extensive research [13-15].

It is observed that by incorporating the IEC 61850 based smart meters and IEDs, web services, CIM, and Service-Oriented Architecture (SOA) technologies, interoperability can be achieved. But the problem arises when legacy infrastructure is integrated with the advanced infrastructure. This paper is an attempt to provide a mechanism for integrating the plurality of TCP/IP Modbus metering networks.

While developing the AMI head-ends, users or system integrators have to refer power meter manual for knowing the parameters address called as metadata. This is a manual task which becomes cumbersome when there are varieties of multi-vendor meter models installed in an AMI network. Referring power meter manuals involves human intervention which increases the overall development time of AMI head-end applications. This paper provides a novel mechanism of automatically extracting the metadata from a power meter and thus eliminates the need of inputting the parameters address manually.

Further the paper is organized as follows. Section 3 describes the current scenario of data exchange in a traditional metering infrastructure. Section 4 describes the proposed methodology for interoperable framework for data exchange between legacy and advanced metering infrastructure. An interoperable framework for metering infrastructure and its advantages are described in Section 5, whereas conclusions are given in section 6.

3. Data Exchange in Traditional AMI Network

Figure 1 illustrates the two AMI networks, comprising multi-vendor meters, where Application2 is required to fetch the data from a Database1 existing in Network1. Because of the different database architecture, i.e. schema and data types, translating or converting software components need to be incorporated as an interface between Database1 and Application2 to help Application2 for accessing the data from Database1 [12]. Application developers have to spend more time in understanding the architecture of database and modify the application accordingly. This problem becomes tedious to handle if a large number of AMI network databases need to be integrated. Therefore, a new methodology is proposed in this paper by which any of the AMI applications can access the database without requiring any translation or conversion of data.

4. Modified AMI Network Architecture

The architecture, as shown in Figure 2, consists of multiple AMI networks, each comprising at least one or more digital Modbus TCP/IP power meters, having one way communication means and smart meters having two way communication means at level1 as depicted M1, M2…, Mn. AMI head-end, AMI proprietary database, and XML database in parallel with proprietary database at level2, whereas Level3 is the higher level comprising applications like ERP system, and SCADA historian server, running on a remote station or local station. In the modified architecture, XML database running in parallel not only helps in achieving the interoperability but also provides redundancy in case of failure of AMI proprietary database. Thus by creating a XML database in each AMI network help applications, running at level2 or level3, for exchanging the metered data. Working of the proposed methodology for the modified AMI network architecture, as shown in Figure 2, is depicted in Figure 3.

"Parameter Extraction Routine" accepts two inputs named as "Meter Model Make" and "Meter Slave ID" and sends a read request for finding the address of parameters from a central repository. After extracting the parameters address, "Meter Polling Routine" polls the meters for extracting the metered values which are further used by the "Data Storage Routine" for storing the metered data in XML format.

In the modified architecture, ModSim32 tool is used to virtualize the functionality of a physical power meter installed at level1. ModSim32, as shown in Figure 4, simulates data from one or more Modbus slave devices instead of having the physical meters or slave devices [16]. ModSim32 can be connected to a Modbus TCP/IP master application via TCP/IP protocol. ModSim32 supports multiple simultaneous communications with master application and the data is accessed via any connected COM port or TCP/IP network connection. Figure 4 shows the screenshot for configured parameters (i.e. voltage, current, frequency, kW, kVA, kVAR, and kWhr) in ModSim32 for which data is scanned in AMI head-end. Thus effectively, a test setup is created where head-end application is shown in Figure 5 and a virtual physical meter with which this head-end application exchanges data is shown in Figure 4.

The created AMI head-end, as shown in Figure 5, is different from the existing meter head-ends, e.g. System Manager Software (SMS) from Schneider [17] or any other SCADA systems, because it does not need manual entry of the parameters addresses because the parameters are extracted automatically. The framework of achieving interoperability for data exchange in the AMI networks and parameter extraction from digital meters are described in the next section.

5. Interoperable Framework Implementation for AMI Network

For fetching the parameters value from a power meter, AMI head-end application needs to be configured with addresses of those parameters. Configuring the head-end application with parameter address, discussed in [17], or any other SCADA system is a manual task. This requires a user to enter the addresses of the parameters for each meter connected with AMI head-end application. Moreover, user has to refer a specific power meter manual for looking the address parameters.

5.1 Automatic extraction of parameter address

In the proposed methodology, the manual user intervention is eliminated by providing an XML file (i.e. called as "Rule File") containing the metadata, or parameter address information, for a particular meter. The XML rule file is required to be stored in the name of meter's model in a shared repository. For example, this paper has considered a virtual Win-tech meter, whose XML rule file called as "ModSim32-Sim.xml", is stored in the repository representing Win-tech meter model "ModSim32-Sim". Once all the XML rule files by different meter manufacturers for all the meter models are placed in one repository, the head-end application, as shown in Figure 5, scans each XML rule file for extracting the addresses of the parameters. For example, for finding the address of parameters like voltage, current etc. of Win-tech meter model ModSim32-Sim, the head-end application first searches an XML file "ModSim32-Sim.xml" placed in the repository. On the identification of "ModSim32-Sim.xml" file, a file handle is created, which extracts the address of the parameter (i.e. voltage, current, frequency, kW, kVA, kVAR, and kWhr) from the "ModSim32-Sim.xml" file. The mechanism for searching the XML rule files and extracting the addresses of parameters from the XML rule file is made automatic and one time process, which is executed at the time of initialization of the head-end application. The implemented AMI head-end application, as shown in Figure 5, consists of two windows. Left side window is called as "Meter Parameter Values", displaying the meter readings, and right side window is called as "Meter Connection Settings", in which configuration settings for a meter model are entered.

In "Meter Connection Settings", only "Slave Node ID" and "Slave Meter Make" fields are entered by the user and rest of the process for searching the XML rule file and parameter address extraction is performed by the head-end application automatically. "Slave Node ID" is the slave identifier assigned to a particular power meter installed in a metering network at level1 of Figure 2.

The value assigned to the "Slave Node ID" field needs to be a unique integer value for each power meter in the same network. "Slave Meter Make" field provides the information about the make of a meter model to the head-end application. This information enables the head-end application to refer to a particular XML rule file for extracting the addresses of parameters. The workflow of the head-end application is shown in Figure 6.

5.2 XML Data Storage

AMI is a network of heterogeneous systems comprising of multi-vendor meter head-end applications and databases. The data offered by these applications is not always compatible when exchanging the data with other vendor's applications. The proposed methodology uses an XML format to overcome the problem of data incompatibility so that any of the vendor's application can access it. XML data is stored in plain text format. Data extracted from a meter is wrapped into tags, which is software or hardware independent.

Data Storage Routine, as depicted in Figure 3, stores the meter readings in the XML format. Figure 7 displays the part of the stored data in XML form, where data is stored with the following information (i) Date, (ii) time stamp, (iii) meter model, (iv) location of the installed meter, and (v) parameter's value. Date and time stamping along with the parameter's value are used for tracking the historical values of any parameter of interest. Thus the history record of logged parameters enables the utilities to generate bills or do analysis for taking certain actions.

In case of a faulty situation, meter model and location information, stored in the XML file, enables the user to easily track the location of the installed meter. XML format storage thus enables the head-end applications interoperable and allows any meter manufacturer's application to access the XML databases without the need of any driver or protocol translator/converter. Moreover, using the XML data makes it easier to upgrade and integrate with new applications and systems without the cooperation from different vendors. Hence, leveraging the existing AMI becomes possible.

5.3 Rules

"Rule File" stores the metadata in XML format for a particular meter model. For example Figure 8 displays one of the rule file and provides the information related to the meter's manufacturer name, meter model, meter serial number, parameters addresses (i.e. voltage, current, power etc.), bytes required to store the parameter's value.

Advantages of creating the XML rules and database are as follows:

i) Automatic Address Extraction:

The automatic parameter address extraction eliminates the need of referring the meter manual for finding the address of the parameters.

ii) Fast AMI Deployment:

In case of hundreds of thousands of meters installed in an AMI network, proposed methodology makes the AMI head-end deployment faster due to its automatic address extraction property.

iii) User Friendly:

Users can customize the XML rule file as per their requirements to create their own tags as per the power meter specifications without taking technical help from solution provider.

iv) Adaptable:

In any of the monitoring applications, data storage plays an important role. If data is easily available or accessible, third-party applications can easily work on this data without wasting the time and efforts in knowing how to extract the data from proprietary data storage. Thus the use of storing the data in XML format enables third party applications adaptable to the storage means.

v) High Availability:

As the XML data storage is redundant to existing AMI database, any failure or corruption of AMI database will not hamper the work of other applications as XML database is still available. Thus redundant database makes the data available at any time. Moreover, queries for extracting the data will be executed on XML database instead of executing on AMI proprietary database.

Methodology, proposed in this paper, intends to relieve the utilities of worrying too much on integration issues and thus provides a solution for leveraging the legacy metering infrastructure by integrating it with the AMI. Once the AMI infrastructure is integrated, the overall system can provide much improved information of electricity usage and grid status seamlessly, that further enables utilities to make better decisions about system improvements and service offerings. The proposed architecture is not limited to only electric meters rather it can be used for water and gas digital meters as well.

5. Conclusion

Paper has proposed the XML format based interoperability framework for data exchange between legacy and AMI infrastructure and successfully demonstrates the implementation of the two important aspects, automatic parameter address extraction and data storage in XML format, related to interoperability and for integrating the legacy and AMI infrastructure

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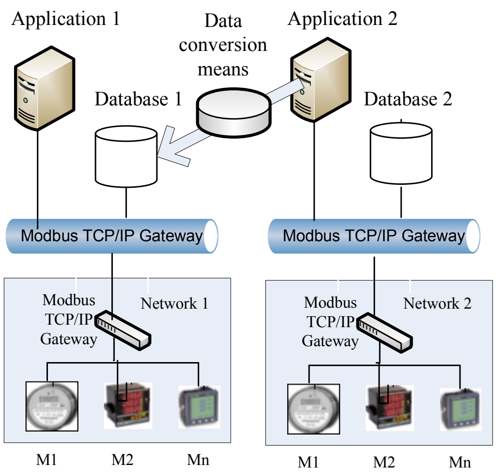

Figure 1. Two Different AMI Network Trying to Exchange the Meter Database

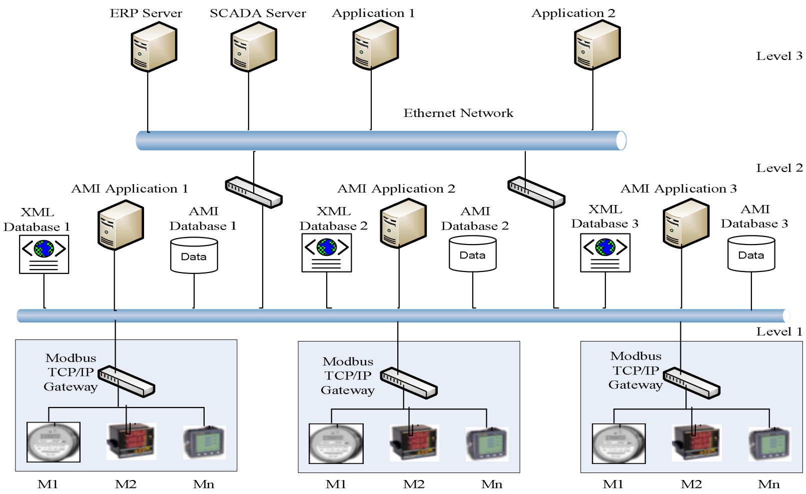

Figure 2. Modified AMI Architecture

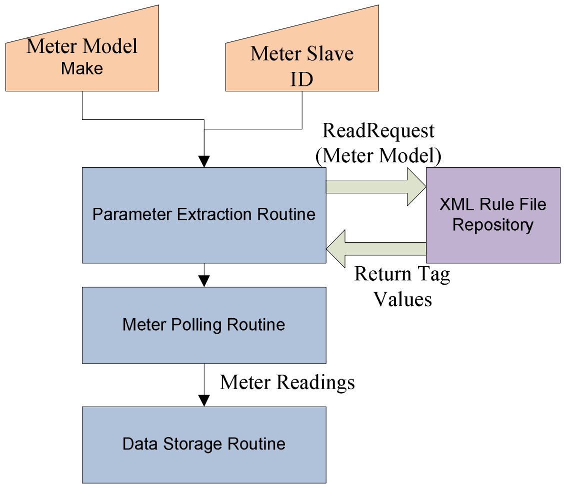

Figure 3. Modified Architecture Internals

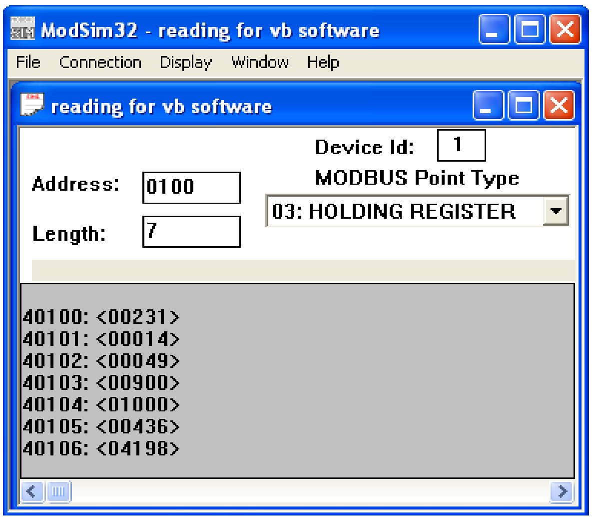

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Figure 4. ModSim32 Software Virtualizing a Physical Meter

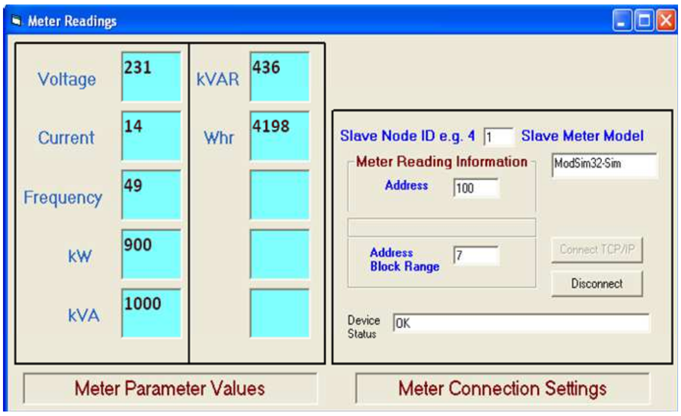

Figure 5. AMI Head-End User Interface

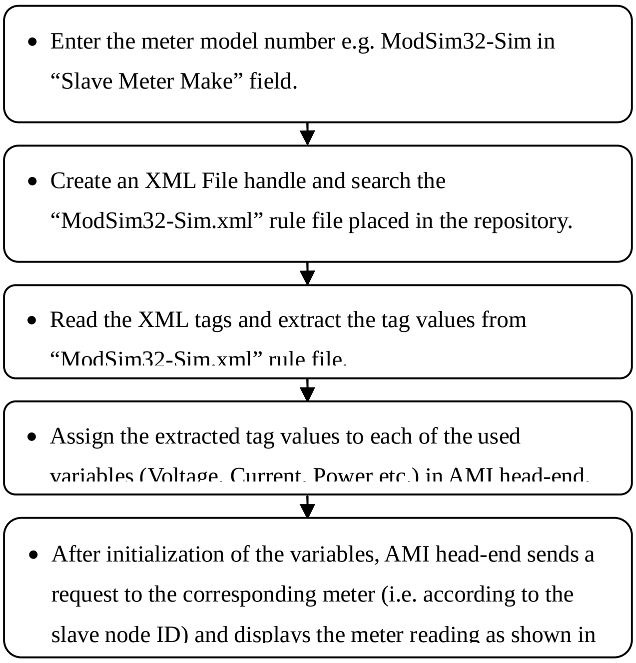

Figure 6. AMI Head-end Framework Steps

```
  <?xml version="1.0" encoding="UTF-8" ?>
- <Meter_Database>
  - <Meter_Reading>
      <Date>9/12/2011</Date>
      <Time>10:43:07 PM</Time>
      <Meter_ID>M1-ModSim32-Sim</Meter_ID>
      <Meter_Location>Loc1</Meter_Location>
      <Meter_Voltage>231</Meter_Voltage>
      <Meter_Current>14</Meter_Current>
      <Meter_Frequency>49</Meter_Frequency>
       •    •
       •    •
       •    •
       •    •
    </Meter_Reading>
  </Meter_Database>
```


Figure7. Data Storage in XML Form


```
  <?xml version="1.0" encoding="utf-8" ?>
- <Policy>
  - <Meter_Parameters>
      <Meter_Make>Win-tech</Meter_Make>
      <Meter_Model>ModSim32-Sim</Meter_Model>
      <Meter_SrNo>12345</Meter_SrNo>
      <Meter_Voltage>100</Meter_Voltage>
      <Meter_Voltage_Byte>1</Meter_Voltage_Byte>
      <Meter_Current>101</Meter_Current>
      <Meter_Current_Byte>1</Meter_Current_Byte>
      <Meter_Frequency>102</Meter_Frequency>
      <Meter_Frequency_Byte>1</Meter_Frequency_Byte>
      <Meter_KW>103</Meter_KW>
      <Meter_KW_Byte>1</Meter_KW_Byte>
      <Meter_KVA>104</Meter_KVA>
      <Meter_KVA_Byte>1</Meter_KVA_Byte>
      <Meter_KVAR>105</Meter_KVAR>
      <Meter_KVAR_Byte>1</Meter_KVAR_Byte>
      <Meter_WH>106</Meter_WH>
      <Meter_WH_Byte>1</Meter_WH_Byte>
    </Meter_Parameters>
  </Policy>
```


Figure 8. XML Rule File

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