Performance Results from 100,000+ PRIME Smart Meters Deployment in Spain

Alberto Sendin
Iberdrola
Bilbao, Spain
asendin@iberdrola.es

Inigo Berganza
Iberdrola
Bilbao, Spain
iberganza@iberdrola.es

Aitor Arzuaga
ZIV
Zamudio, Spain
a.arzuaga@ziv.es

Anssi Pulkkinen
Current Technologies
Mägenwil, Switzerland
apulkkinen@currentgrid.com

Il Han Kim
Texas Instruments
Dallas, USA
il-han-kim@ti.com

Abstract— **PRIME (PoweRline Intelligent Metering Evolution) is a narrowband Power Line Communications (PLC) technology targeted for use in smart metering applications. It is standardized as part of international Recommendations ITU-T G.9955 and G.9956, and there are currently a number of deployments by utilities in different markets which use it for a cost-effective, technically proven solution.**

This paper is a continuation of two previous ones presented in the first and second SmartGridComm Conferences, in which PRIME background and status were discussed, including interoperability tests and first results in multi-vendor deployments.

This final article describes the network architecture which has been thoroughly tested and is currently being used by Iberdrola for its Smart Grid deployment, PRIME network deployment selections, a proposed classification for secondary substations based on experience, and finally the tools which are being used for analysis and acceptance tests, along with performance results.

I. INTRODUCTION

Due to significant interest in Smart Grid and Smart Metering, PLC is being considered and used by multiple electric utilities around the world [1]. In parallel with recent standardization efforts for PRIME for Smart Grid purposes, PRIME field tests have been focused on interoperability and on-field performance over the years ([2] focused on interoperability and prototypes test results, and [3] on first multivendor controlled field results). PRIME has been extensively and successfully installed in Spanish electricity grids. Results from multi-vendor, interoperable PRIME systems have proven its feasibility for large scale deployments.

In this paper, we describe in depth PRIME features collected from field. First we show the PRIME system deployed configuration. We also discuss channel aspects, which affect PRIME performance and condition the classification of Secondary Substations (SS's). Then we outline necessary tools and methods to monitor and analyze PRIME system performance. We also report on representative results from analyzed SS's.

This paper is organized in sections. Section II describes communications architecture for Smart Grid and Smart Metering deployment. Section III discusses channel impairments, deployment decisions and a classification for SS's. Section IV focuses on the description of the tools used in the deployment, and section V provides performance data and lesson learnt. Section VI concludes the paper.

II. COMMUNICATIONS ARCHITECTURE FOR SMART METERING AND SMART GRID DEPLOYMENT

In Smart Grid and Smart Metering networks, all premises including substations and meters need telecommunication services. The specific requirements for the telecommunications networks are dependent on each utility interest, regulatory constraints and strategy.

The architecture used by Iberdrola defines the SS as one main nodal element. The network is then divided into two sections: from the SS to the central offices and from the SS to the meters. The latter is where PRIME subnetworks are being used at each SS. The former is covered with a mix of telecommunication networks based on Ethernet/IP technology, and as such the devices in the SS incorporate Ethernet/IP technology, guaranteeing stability, scalability and security for the whole system.

SS's are very diverse in their nature and location. Thus, for efficiency reasons Smart Grid deployments often use a mix of public and utility-private telecommunication means. A group of different technology options are available and are being used on field. These technologies include Medium Voltage (MV) PLC (so-called Broadband over Power Line or BPL), cellular (GPRS and 3G), xDSL, fiber optics, point to multipoint radio, hybrid fiber-coaxial and some others. The architecture is based on groups of layer-2 network domains which use BPL, and connect to the network core with layer 3 technologies.

III. PRIME PLC DEPLOYMENT STRATEGIES

PRIME is a plug&play technology so there is no need for manual intervention on the system once Base Nodes and Service Nodes have been installed [4]. However, some aspects need to be controlled on how PRIME PLC signals are injected and progress through the grid.

A. PRIME devices deployment strategy

There are different strategies when deploying PRIME, from the perspective of coupling PLC signals into Low Voltage (LV) grids at SS's. Coupling is made at LV bus bars on the secondary of the transformer.

There are two options available. First one is single-phase injection. The signal is coupled only into one phase, and the meters connected to other phases are able to register to the PRIME subnetwork either by signal cross-coupling among phases, or by means of other Service Nodes behaving as repeaters. The second option is three-phase injection, either with additive coupling (1 front-end channel with 3 passive couplers), or with separate coupling (3 front-end channels with a separate coupler each). The former is more cost-effective.

For Iberdrola PRIME field deployments, single-phase coupling has been used [5], and it has demonstrated to provide excellent performance.

As for smart meter deployment strategy, it is highly recommended to populate as many meters of the SS's as possible. Iberdrola considers, based on field results, that when less than 85% of meters in a SS have been substituted for PRIME smart meters the situation is not representative of how a PRIME subnetwork is going to perform once it is fully populated. Since every meter (Service Node) can behave as a repeater ("switch"), missing nodes mean missing repeating opportunities for the subnetwork to achieve its maximum performance.

B. Factors affecting performance of PRIME systems

There are several kinds of factors that impair performance of PLC systems. At physical level, there are three major disturbances: noise, impedance, and frequency selective channels. At system level the number of nodes in a subnetwork, distribution of elements in different locations and length of the LV lines have to be considered.

1. Factors impairing physical performance

Noise has been traditionally the most studied factor in PLC systems. In power lines, because electric devices are connected to one single shared medium, there is significant noise that affects the system performance. The two prevalent noises are periodic impulsive noise synchronous to 50 Hz or 60 Hz mains frequency and narrowband interference. Time domain noise taken from field in Spain grid is shown in Figure 1. We can see noise bursts every 10 ms (=1/100Hz). Special care needs to be taken to handle this kind of impulse noise with forward error correction, interleaving, etc. ([6][7][8] provide detailed spectro-temporal noise characterization over a frequency range 0 - 500 kHz).
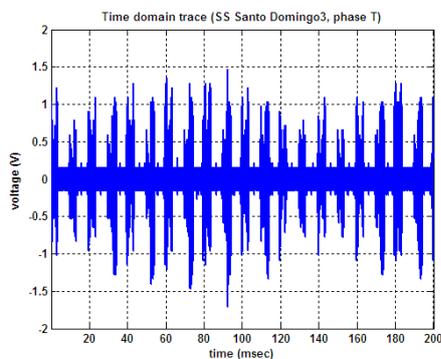

Figure 1. Time domain noise trace (8 bit ADC) at SS in the Spanish LV grid.

Line impedance is another challenge in LV grids. LV PLC communication faces low and time-variant impedance. PRIME Alliance TWG [9] has been doing impedance measurements over various places in Spanish electricity grid. Figure 2 shows one of the LV impedances measured at certain SS for PRIME band. Impedance changes from 0.1 ohm to 1.5 ohm with frequency. This is because of a multiplicity of devices connected in parallel, which lower line impedance significantly. Different colors in the graph mean that impedance is changing across the AC mains cycle. It is also shown that line impedance is increasing across the frequency band.

PRIME specifications define a Line Impedance Stabilization Network (LISN) by modifying the original LISN defined in CENELEC EN 50065-1 [10] to reflect real low line impedance conditions. The effective impedance is 2 ohm and PRIME specifies 1 Vrms (120 dBuV) injection over 2 ohm load.
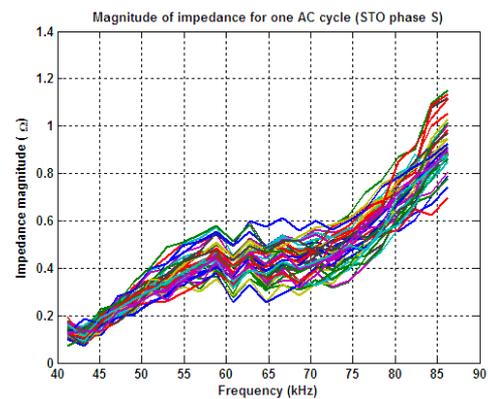

Figure 2. Impedance at the SS in the Spanish electricity grid.

Frequency selective channels are another typical feature of PLC. Power line channels are normally frequency selective because of line impedance and channel delay due to distance and others. Modeling of PLC channel using ABCD parameter and transmission line theory has often been addressed [11]. If properly designed, OFDM systems should be able to support large delay spreads by means of cyclic prefix (CP). PRIME CP length is 192 us, to handle large delay spreads [6].

2. Factors affecting system performance

From MAC and application layer perspective, some factors clearly influence performance of PRIME PLC systems. These factors have been used by Iberdrola to classify its SS base:

- Number of Subnetwork elements. Since power line is a shared medium, available resources will be shared among the number of elements trying to communicate.

- Distribution of elements in different locations. The concentration of PLC elements (i.e. meters) in a certain location where devices share a collision domain will create a competition for the resources, and collisions will increase with the concentration of elements in the same physical location.

- Length of LV lines. Distance between subnetwork elements affects both factors above and should be considered in any performance analysis.

C. Classification of SS's for a controlled PRIME deployment

One of the defining characteristics of PRIME is its MAC layer. It takes inspiration from meshed systems for limited bandwidth systems. It uses CSMA/CA for access and the concept of "switch" as a functional state for a Service Node so that every meter can dynamically configure itself to help the Base Node extend its reach to hidden parts of the subnetwork. No manual configuration or intervention is needed, so PRIME deployment is easier than with similar technologies.

However, PLC technology is so dependent on the electricity grid that any Smart Metering deployment strategy must consider the different grid characteristics that influence PRIME performance.

This paper provides the classification used for the preparation of Iberdrola PRIME deployment, based on the categorization of the different SS's, regarding relevant system parameters mentioned in section III.B. Specifically the concepts of Point of electricity Supply (PoS –number of elements in the subnetwork as one PoS equals one meter-) and density of PoS (DPoS -level of concentration of subnetwork elements at the same physical location-) will be used. Distance parameter will be disregarded since the correlation of PoS and distance is high (i.e. usually SS's with large numbers of PoS's also show larger total lengths of LV lines). The advantage of using just these two parameters is that their values can always be found in utility databases. It has been seen on field that classification in terms of PoS and DPoS relate to actual common trends in performance.

TABLE I.   CATEGORIES OF SS'S FOR DEPLOYMENT CONSIDERATIONS

		Density of Points of Supply (DPoS)		
		0<DPoS <= 6	6 <DPoS <=12	12<DPoS
Points of Supply (PoS)	0<PoS <=100	Category G 151 SS's 5,380 PoS's	Category A 26 SS's 1,562 PoS's	Category B 21 SS's 1,247 PoS's
	100<PoS <=300	Category H 76 SS's 13,752 PoS's	Category C 61 SS's 11,596 PoS's	Category D 74 SS's 13,990 PoS's
	300<PoS	Category I 51 SS's 22,615 PoS's	Category E 36 SS's 15,441 PoS's	Category F 35 SS's 15,096 PoS's

According to Table I, categories A to F include SS's with high levels of smart meter concentration in specific locations (i.e. meter rooms), and G to I include SS's with mainly distributed meters. For G to I scenarios a further differentiation can be made between rural and industrial environments (G), and urban environments with non-concentrated meters (H and I). Performance results obtained in each of the three categories present different trends.

IV.   TOOLS FOR PERFORMANCE ASSESSMENT AND TROUBLESHOOOTING

In any network deployment it is essential to have software administrative tools for management, monitoring and validation of network traffic, quality and performance. PLC networks are particularly challenging because the medium is not designed for data communications.

Two currently available tools, i.e., PRIME Examiner and PRIME Manager [12][13] are discussed. Both of them are sniffers associated to general or specialized hardware, which have been used for troubleshooting purposes in Iberdrola deployment. A third tool (developed and used by Iberdrola in the global performance monitoring) is also presented.

A. Low level analysis tools. PHY layer

PRIME Examiner has been used to view traffic in real time, or to store packet data locally to be analyzed later. Information analyzed and displayed includes PRIME PHY information. Sniffed packets are tagged with additional information like exact time in the MAC Frame, where the packet was sent (i.e. Beacon slot, SCP or CFP) and PHY level information like received power, modulation, PHY time and SNR.

PRIME Manager also presents PHY layer data, such as real time CENELEC A-band frequency spectrum graphics for received signal. This is helpful e.g. to locate noises, interferences etc. Additionally EVM and amplitude results per frame are obtained for further on-field analysis.

B. Low level analysis tools. MAC layer

PRIME Examiner's user interface uses open source Wireshark packet analyzer through a plug-in; in terms of MAC layer this allows for sniffing of PRIME MAC data including ARQ headers, PRIME convergence layer data (CPCS header, IEC 61334-4-32 SSCS header…), and PRIME Management plane data including Firmware Upgrade protocol.

PRIME Examiner also tracks opened connections to be able to display correct convergence layer and management application information. One typical usage scenario is validation of various fields in captured packets. Figure 3 shows how PRIME Examiner displays detailed header information of a MAC PDU containing IEC 61334-4-32 SSCS data. Both MAC and convergence layer headers are broken into individual fields and device behavior can be verified. Actual application payload can be easily extracted and further analyzed.
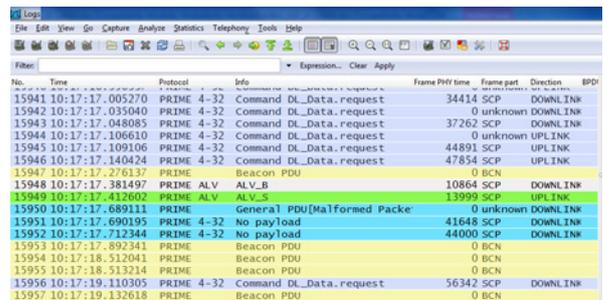

Figure 3.   Wireshark with PRIME Examiner plugin. PRIME traffic.

PRIME Manager deciphers MAC PDU's and provides a timeline of interchanged PRIME MAC Frames, identifying the nodes which are generating packets. It is able to perform certain operations in a subnetwork such as promotion, demotion or unregistering of a node on demand. Additionally it is able to save traces and network captures for offline analysis (see Figure 4).
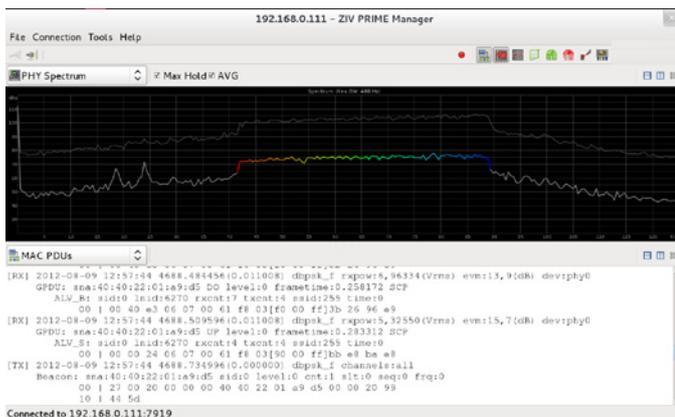

Figure 4.   PRIME network management tool.

C.   Subnetwork monitoring and topology

Live network monitoring using graphs is a powerful resource to visualize and understand network behavior. Figure 5 displays live graphing from PRIME Examiner: the number of data and control packets per minute is monitored during performance tests for a small PRIME subnetwork. Both the initial subnetwork convergence during the first 10 minutes and the actual performance test start after 40 minutes are visible.
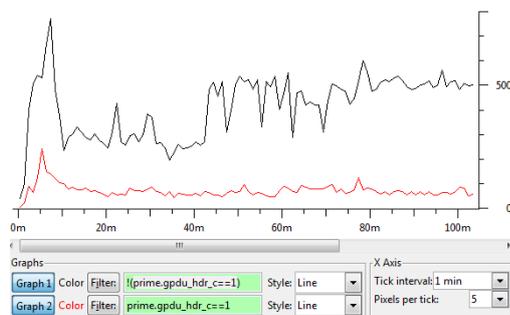

Figure 5.   Number of data (upper line) and control (lower line) packets in small subnetwork during network start up and performance tests.

PRIME Manager shows real time topology and coverage statistics in graphical format (see Figure 6). Since PRIME builds a mesh network, it is extremely helpful to trace the correspondence between logical topology and real physical node location. This helps gain understanding of the field behavior of the subnetwork. Additionally, topology and event logs along with historical records for registration, coverage and signal quality are available for every node.
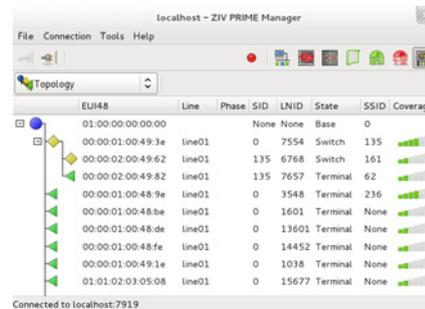

Figure 6.   Real time graphical topology of a PRIME subnetwork.

D.   Monitoring and Analysis tool for SS's and meter performance assessment

PRIME allows for acceptance testing after on-field installation, so that deployed smart meters can be safely delivered to production environment in the MDM system.

For statistical analysis to be useful, deployment results should be analyzed making abstraction of specific technology details and implementation specifics for each manufacturer, and at the same time allowing for identification of issues.

A procedure and a tool have been developed for Iberdrola deployment, which performs an intensive monitoring of PRIME subnetworks at SS level, compiling all information gathered for a seven-day period where both communications and application-level data are collected. After automated analysis, the information is arranged in a report that summarizes the performance of the SS's, in order to validate performance, compared to average results obtained in the same SS category group, and to identify potential problems in the PRIME subnetwork in order to solve them (e.g. smart meter hardware failures).

Performance assessment considers two main concepts: availability and stability. PRIME availability is defined as the accumulated time (relative to total time) for which a Service Node has been registered in the subnetwork; if applicable to application data, it is the ratio of successful to total transactions. When referred to the whole subnetwork, availability is the average of all Service Nodes in it. Stability is a measure of the ability of a Service Node to consistently remain in a non-disconnected functional state. When referred to a subnetwork it is defined as the ability to maintain a constant number of registered Service Nodes.

The procedure consists of two parts. The first part (monitoring phase) collects data and elaborates results to obtain the performance of a subnetwork, both from communications (PLC) and application (metering) perspective. The second part (analysis phase) analyzes parameters (PLC and metering) and relates them to existing electricity grid data. It is only considered that the analysis is complete once performance results are correlated with LV grid data: SS transformers, LV feeders and physical location of each individual meter.

1.   Monitoring phase

It is understood that for Smart Metering networks the main target is to be able to remotely access any meter at any time.

The methodology on the monitoring phase is based on intensive communications stress over the subnetwork. As PLC is the technology being analyzed, the monitoring period has to last one week as a minimum.

The monitoring phase controls two aspects of system behavior. First, it monitors the PLC technology itself. So, it provides information on how the subnetwork topology evolves over time. Aspects such as Service Node dependencies, Service Node functional states (Switch, Terminal, etc) and time stamps associated to changes on the above are recorded. Second, it forces a constant flow of application data to analyze metering behavior of the complete system. Data Concentrators at the SS's are programmed with cycles querying all Service Nodes registered to them in constant loops for a period of two days for low-load application data transactions (Short Cycles), and two more days for high-load application data transactions (Long Cycles).

2. Analysis phase

Once the results are collected, the behavior of each individual meter (application level) and Service Node (PRIME level) is analyzed.

The correlation of recorded values with the associated electricity grid characteristics is fundamental to understand the behavior of each specific meter concentration, LV feeder and transformer. Hence the global performance of the SS is obtained and also automatic identification and location is given on underperforming elements (individual smart meters, meter concentrations, LV feeders or complete SS's).

V. PERFORMANCE RESULTS

Castellon is the city in Spain where over 100,000 multi-vendor smart meters (1% of the total installed Iberdrola base in Spain) have been installed, as part of a larger Smart Grid deployment which also supports remote control, automation, and MV - LV supervision. Smart meters where connected to a total of 531 SS's in locations which are representative of the different environments and installation scenarios which most utilities find in their electricity grids: urban, suburban and rural; dense and disperse; industrial and residential areas.

All of the SS's have been monitored and analyzed before entering production environment, although at the time of analysis only around 45% of these could be considered representative of the final situation (i.e. more than 85% of the smart meters already deployed when monitored). Reasons for this are the constraints on the deployment, mainly safety issues which prevent immediate meter substitution (as of today still 4% of all meters are pending substitution), and the fact that adjacent SS's were not deployed at the time of analysis so e.g. some Data Concentrators had meters registered to them which were actually connected to a different SS's still without Data Concentrators installed.

Figures 7, 8 and 9 show a summary of the performance (including availability and stability data) for each typical SS scenario, where smart meters from three vendors with different PRIME implementations interoperate with Data Concentrators from two vendors.

Code	Concept	Average Values	Smart Meter Manufact. 1	Smart Meter Manufact. 2	Smart Meter Manufact. 3
DB1	SS Name	STA. CRUZ TENERIFE			
DB2	SS Code	501000383			
DB3	Category-Number of Transformers	C-1			
DB4	DB Meters for SS 501000383:	188			
DB4a	+ PRIME Meters, found in SS SN	182			
DB4b	+ PRIME Meters, NOT found in SS SN	1			
DB4c	+ NON-PRIME Meters, in SS SN	5			
DB5	SS PRIME SN:	189	154	11	24
DB5a	+ PRIME SN Meters, found in DB for this SS	182			
DB5b	+ PRIME SN Meters, found in DB under OTHER SS	7			
DB5c	+ PRIME SN Meters, NOT found in DB	0			
PT1	Number of Connected Service Nodes	180.45			
PT2	Number of Switches	17.75	-	-	-
PT3	Availability	99.54%	99.61%	98.29%	99.73%
PT4	Changes in the number of Connected Nodes per Minute	0.76	-	-	-
PT5	Meters with PRIME availability = 0%	0	0	0	0
PT6	Monitoring Start Date - End Date	10/10/2011 14:19 - 17/10/2011 12:34			
SC1	Number of Connected Meters	186.32	-	-	-
SC2	Availability	98.05%	98.06%	97.27%	98.33%
SC3	Duration of a Transaction per Meter (seconds)	5.38	-	-	-
SC4	Meters with application level availability 0%	1	0	0	0
SC5	Monitoring Start Date - End Date	11/10/2011 13:29 - 13/10/2011 12:52			
LC1	Number of Connected Meters	182,78	-	-	-
LC2	Availability	96.18%	97.26%	79.45%	96.92%
LC3	Duration of a Transaction per Meter (seconds)	21.51	-	-	-
LC4	Meters with application level availability 0%	1	1	0	0
LC5	Monitoring Start Date - End Date	13/10/2011 13:03 - 15/10/2011 15:18			
NOTES: DB = Database; SS = Secondary Substation; SN = Subnetwork; PT = PRIME Topology; SC = Short Cycle; LC = Long Cycle					

Figure 7. Typical performace of a dense scenario SS in Castellon.

Code	Concept	Average Values (single manufacturer)	
DB1	SS Name	JOAQUIN COSTA 2	
DB2	SS Code		501000249
DB3	Category-Number of Transformers	I-1	
DB4	DB Meters for SS 501000383:		301
DB4a	+ PRIME Meters, found in SS SN		259
DB4b	+ PRIME Meters, NOT found in SS SN		4
DB4c	+ NON-PRIME Meters, in SS SN		38
DB5	SS PRIME SN:		262
DB5a	+ PRIME SN Meters, found in DB for this SS		259
DB5b	+ PRIME SN Meters, found in DB under OTHER SS		0
DB5c	+ PRIME SN Meters, NOT found in DB		3
PT1	Number of Connected Service Nodes		240.97
PT2	Number of Switches		25.98
PT3	Availability		99.48%
PT4	Changes in the number of Connected Nodes per Minute		0.52
PT5	Meters with PRIME availability = 0%		0
PT6	Monitoring Start Date - End Date	01/08/2011 9:14 - 08/08/2011 8:48	
SC1	Number of Connected Meters		257.00
SC2	Availability		97.71%
SC3	Duration of a Transaction per Meter (seconds)		5.63
SC4	Meters with application level availability 0%		3
SC5	Monitoring Start Date - End Date	02/08/2011 8:49 - 04/08/2011 9:05	
LC1	Number of Connected Meters		257.32
LC2	Availability		97.83%
LC3	Duration of a Transaction per Meter (seconds)		19.70
LC4	Meters with application level availability 0%		3
LC5	Monitoring Start Date - End Date	04/08/2011 11:01 - 06/08/2011 10:53	
NOTES: DB = Database; SS = Secondary Substation; SN = Subnetwork; PT = PRIME Topology; SC = Short Cycle; LC = Long Cycle			

Figure 8. Typical performace of a disperse urban SS in Castellon.

Code	Concept	Value	Smart Meter Manufact. 1	Smart Meter Manufact. 2
DB1	SS Name	PI GROS-SATRA		
DB2	SS Code	501000307		
DB3	Category-Number of Transformers	G-1		
DB4	DB Meters for SS 501000383:	5		
DB4a	+ PRIME Meters, found in SS SN	4		
DB4b	+ PRIME Meters, NOT found in SS SN	0		
DB4c	+ NON-PRIME Meters, in SS SN	1		
DB5	SS PRIME SN:	4	2	2
DB5a	+ PRIME SN Meters, found in DB for this SS	4		
DB5b	+ PRIME SN Meters, found in DB under OTHER SS	0		
DB5c	+ PRIME SN Meters, NOT found in DB	0		
PT1	Number of Connected Service Nodes	2.86		
PT2	Number of Switches	1,00		
PT3	Availability	99.72%	99.45%	100,00%
PT4	Changes in the number of Connected Nodes per Minute	0,00		
PT5	Meters with PRIME availability = 0%	0	0	0
PT6	Monitoring Start Date - End Date	11/07/2011 12:02 - 20/07/2011 7:54		
SC1	Number of Connected Meters	3.99		
SC2	Availability	99.77%	99.56%	99.98%
SC3	Duration of a Transaction per Meter (seconds)	3.39		
SC4	Meters with application level availability 0%	0	0	0
SC5	Monitoring Start Date - End Date	14/07/2011 12:34 - 16/07/2011 12:19		
LC1	Number of Connected Meters	3.93		
LC2	Availability	98.36%	96.82%	99.90%
LC3	Duration of a Transaction per Meter (seconds)	7.18		
LC4	Meters with application level availability 0%	0	0	0
LC5	Monitoring Start Date - End Date	18/07/2011 8:03 - 20/07/2011 7:54		
NOTES: DB = Database; SS = Secondary Substation; SN = Subnetwork; PT = PRIME Topology; SC = Short Cycle; LC = Long Cycle				

Figure 9. Typical performace of a disperse, rural/industrial SS in Castellon.

Parameters for codes DB are both information extracted from utility databases, and correlation of this information with PRIME communications on-field. DB4 is the number of meters that should be found connected to each SS according to information in databases, and DB4a, DB4b and DB4c represent installed meters which actually register in the PRIME subnetwork, PRIME meters which did not register in the PRIME subnetwork and smart meters not yet installed, respectively. Parameter DB5 represents the number of Service Nodes (meters) in the PRIME subnetwork, classifying the different meters in DB5a, DB5b and DB5c as meters well identified in databases, meters which are wrongly identified as connected to other SS, and meters not yet recorded in databases, respectively. These values are fundamental to understand how representative the performance data in PT, SC and LC codes, are.

Performance figures for PRIME availability (PT3) represent the percentage of time the average Service Node is registered to the PRIME subnetwork in the SS. Performance figures for application data availability (SC2 and LC2) have to be understood as a measure of the percentage of polls the average meter has successfully answered over a period of several days (e.g. intensive monitoring in figure 9 produces 8,504 polls for Short Cycles, and 4,452 polls for Long Cycles over a period of two days each). Short Cycles and Long Cycles involve DLMS/COSEM Application Association establishment and release for each transaction with individual meters. Short cycles read the 'value' attribute of OBIS code 1.0.1.8.10.255 (Active energy import) and afterwards the 'buffer' attribute of OBIS code 0.0.21.0.6.255 (Instantaneous Energy Values). Long Cycles read the 'time' attribute of OBIS code 0.0.1.0.0.255 (Clock) and afterwards the 'buffer' attribute of OBIS code 1.0.99.1.0.255 (Load profile with hourly period) which represents 13 arrays of 8 fields each.

As it can be seen also noticed in figures 7, 8 and 9, some meters showed underperforming behavior (see codes DB4b, SC4 and LC4). All troubles with meters in these SS's, and exhaustively for the complete Castellon deployment, have been analyzed in more detail, and all of them have been solved. The reasons behind these solved issues can be almost completely summarized in broken meters (either from PRIME or metering side), wrong configuration of meters or Data Concentrators, wrong data in databases (which recorded incorrect SS-meter connections), SS's with not all PRIME meters deployed and non-permanent noise levels which were found to be significantly higher than maximum limits allowed for intended transmitters [10].

Operationally Castellon deployment has also taught some helpful lessons. PRIME meters from different vendors do not all show the same performance: an average difference of 6% in availability has been found among the three most representative meter vendors. The maximum possible percentage of smart meters has to be deployed before monitoring. PRIME signal has to be coupled [5] to all transformers in the SS. Meters and SS's should be deployed in a succession of contiguous locations to both minimize inaccuracies coming from errors in databases, and maximize PRIME repetition capabilities. The last fundamental lesson learned for a PRIME deployment is the need to implement a performance acceptance process before moving SS's to production environment, in order to identify, locate and solve issues around underperforming elements.

VI. CONCLUSIONS

A successful PRIME deployment has been demonstrated by Iberdrola with over 100,000 smart meters in a municipality which is representative of a typical electricity grid.

Along with the deployment, knowledge has been developed in the form of a set of tools and lessons learned that are applicable for any Smart Metering deployment. This body of knowledge may be of help for any utility engaged in Smart Grid and Smart Metering deployments.

The model deployed in Castellon will be extended to other grids all over the world. Iberdrola continues the deployment of 1 million additional smart meters in 2012.

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