ENEL EXPERIENCE IN REVENUE PROTECTION: AMI SOLUTION DELIVERED BENEFITS AND SHAPE, BUSINESS ANALYTICS PLATFORM, PREPARING FOR NEXT YEARS' CHALLENGES

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ABSTRACT

This paper intends to present the main benefits that the Enel AMI solution is delivering to distribution companies of the group and to other utilities. One of the advantages in operating an AMI is provided by the availability of data concerning the consumption and the energy flows. Since 2005 Enel has been working to design and develop the proper tools to support the revenue protection everyday operations. Data alone are not enough to increase operations efficient and deliver better results in terms of revenue protection. Therefore the data are analyzed by systems and presented to the final users in form of reports. The track record in revenue protection can be considered really satisfactory, both for Enel group distribution companies and customer utilities. Nevertheless Enel continues to test new solution; in the paper we would like to provide some insights on the new trend in data analysis and pattern recognition. SHAPE (Statistical Hybrid Analysis for load ProfilE) is an innovative Web software platform for Business Analytics applied to the load patterns sourced from the Enel network's smart meters. The SHAPE platform enables the Data Analyst to solve tasks such as hourly energy analysis, customer classification, load prediction, and non-technical losses detection.

INTRODUCTION

The transition from *product-centric* to *customer-centric* framework carried out by Enel after the liberalization of the electricity market needs not only an efficient and effective smart metering system, but also requires new business strategies and innovative services.

After 13 years from the first smart meter installed, Enel is today the utility with the largest Automated Meter Reading/Management infrastructure (AMI) in the world consisting of more than 34 millions smart meters installed in Italy. The energy market has been subject to significant changes, including EU corporate unbundling of the energy sector. The players are now facing new challenges, such as better customer services provision and tariff definition, energy quality supply enhancement, technical and non-technical losses reduction, medium- and low-voltage network update to deal with renewable energy producers (two-way active energy flows), as well as rationalization of the network investment costs [5]. Each market participants needs new business strategies and supporting tools in order to meet stringent requirements. With the introduction in the recent years of AMR/AMM systems in many countries, there has been a growing interest in developing applications based on load pattern data, mainly due to the ability of the underlying electronic meters technology to record data at a relative low cost at 1-60 minutes resolution, rather than monthly.

The optimization of electricity flows over the network and the contrast of consumer frauds are problems faced by all power utilities worldwide.

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In 2009 Enel presented its experience by using a Distribution Management System (DMS) in order to obtain precise results in network calculations and, consequently, real improvements in the reduction of power losses. The project allowed Enel to study the effect of the "Optimal switching" strategy on the technical losses reduction. [2]

In 2010 the implementation of a platform to integrate the data gathered from AMI with data collected by medium voltage SCADA (STAmi),allowed the development of several software application. Important results have been obtained during this first year in operation in the frauds detection field, thanks to the friendly access to the energy consumption and to the load curves [3]. In 2011-2013 Enel supplied an AMI solution consisting of 175.000 smart meters to Montenegrin utility EPCG, After the implementation of the solution, EPCG achieved remarkable results. [4]

Thanks to the AMI system called "Telegestore", Enel is today able to measure and collect remotely a large amounts of consumption patterns recorded on a 15 minutes basis. The extraction of knowledge from this huge amount of data requires state-of the-art technologies based on Data Mining and Machine learning and approaches on Big Data [1].

Enel has finally launched the SHAPE project, a new approach towards Non-Technical Loss (NTL) detection in power utilities using a combination of data mining and artificial intelligence (AI) based techniques [5].

THE ENEL AMI INFRASTRUCTURE

Enel's AMI solution is made of :

- the head-end system to remotely manage the billing information, monitor the quality of service and provide support to the roll-out;
- the low voltage concentrators (LV-C), installed in the secondary substations, to aggregate data recorded by the meters;
- the meters to remotely read the consumptions and manage the customers' supply contracts.

The AMI field devices by ENEL are the low voltage concentrators (LV-C) and the smart meters.

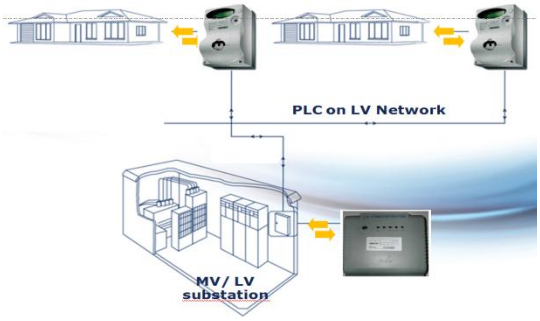


Figure 1 - Load pattern coverage near Milan in a given time period (a) and details per day (b)

The LV-C is a key element of the overall system architecture, able to manage communications in two directions, towards the smart meters via powerline in Cenelec Band A, according to EN50065-1, and towards the head-end system via public GPRS communication network, not only acting as a mere aggregator of information and/or gateway for communication purposes.

Remarkably, the LV-C operates as an intelligent device allowing local metering operation and the optimization of the costs of communication with head-end system.

DMS OPTIMAL SWITCHING

DMS is a powerful system. It includes several tools improving the overall efficiency of the medium and low voltage distribution network, providing what/if analysis, methods for the optimization of network resources, cost/benefit analysis, education/training facilities for the operators, planning facilities, etc. However, accurate network data are crucial to obtain good performances and results very close to the reality. In fact, to perform network calculations, such as "State estimation" or "Load Flow", many inputs are needed; for example it is important to have:

- the precise Network Topology, updated in real time together with the real connection status of each branch;
- the electrical characteristics of elements (transformers, conductors, switches, ….),
- some basic measures from the field;
- reliable evaluation of customers' load and generation.

Taking into account only the "Optimal Switching" function, it is possible to minimize the technical losses, reconfiguring the network during the year from season to season. The function identifies a list of network reconfiguration maneuvers alongside the expected losses reduction.

Of course, the execution of all the suggested actions was not viable due to the cost of the operation and therefore, only about one hundred of them was performed, choosing:

- all the remote controlled switches;
- the most effective of the list

These first actions led to a saving of about 6.5% of the technical losses. It was possible to maintain the result all the year round, and, after the first optimizing process, the losses reduction on the involved MV feeders was about 4%. [2]

STAMI INTEGRATION PLATFORM

STami is an innovative application for LV network monitoring, just a first step towards LV network management. It opens new possibilities to prevent and solve problems in the LV distribution network and to obtain further savings in the operational costs, supporting new business objectives and providing several benefits to different stakeholder. STami makes the load curves and the customer readings easily available to the distribution operations managers and team leaders. Special tools allow the comparison of aggregated sets of customers and balancing meters data,

Therefore the workforce receives support to identify the frauds and the unauthorized use of electricity. For instance, the customers consumption is compared with the energy flown through the same transformer and the same bus-bar, driving the analysis towards cluster of customers. In order to further select possible frauds the load curves are analyzed and critical deviation from medium consumption are identified. The use of advanced information allowed Enel to increase its performance in field verification effectiveness.

EPCG PROJECT

The Montenegrin power sector is representative of many West Balkan energy sectors: it is characterised by several decades of under-investment, a capacity deficit and high levels of energy inefficiency and carbon intensity. Generation is dominated by hydropower and lignite fired thermal capacity, but the country is heavily dependent on imports to meet total consumption. Energy intensity and carbon intensity are 73% and 100% higher respectively than OECD averages.

The largest company in the sector is Elektroprivreda Crne Gore AD Nikšić (EPCG) which is, in practice, the sole electricity generation, distribution and Supply Company in Montenegro. EPCG is distributing electricity to over 600.000 people through 360.000 meters.

One of the major challenges facing EPCG and its shareholders is addressing the high level of losses and bad debts in the distribution network. Losses were 23%

in 2009 compared to best international practice of 6-8%, while the collection rate was less than 90%, compared to best international practice of over 99%. In addition to contributing to Montenegro's high energy intensity this issue is an obstacle to the on-going development of the Company, reducing its cash flow and so constraining its ability to carry out necessary investments, particularly in its ageing generation assets. Recognising the importance of this issue, and the role of metering in addressing it, one of the targets set for EPCG in 2011 has been the installation of at least 175,000 smart meters within four years. ENEL supplied the smart meters and data concentrators supporting the deployment of EPCG AMI solution. After the first year of massive deployment, more than 70.000 meters are in operation and first measures of the project KPIs indicate that results are very encouraging:

- average losses reduction of 30%,
- percentage of successful bill collection increased

from 24.4% in previous year to current 75.5% [4]

SHAPE ANALYTICS PLATFORM

After a first phase of learning and understanding the value and the possible uses of the information available through the AMI solution, Enel has recently started a project to apply a systematic and structured approach to the analysis of data and suspicious pattern identification. Taking the results of the Applied Research phase, the final objective of the project is the development of a Business Analytics Web platform as a flexible and extensible Data Mining suite tailored for the electrical domain, allowing Analysts build their own analytics workflow in a user-friendly Rich Internet Application (RIA).
The platform consists of the modules :

1. Datawarehouse management
2. Basic load analysis
3. Customer load classification
4. Load prediction
5. Non-technical losses detection support

Each module, in turn, is divided into sub-modules. At the moment of the paper submission, the development of modules 4 and 5 is ongoing and will be described in a next work. Currently the SHAPE datawarehouse (DW) stores information from about 100,000 Low Voltage (LV) smart meters, gathered starting from January 2011 and currently in progress, including about 2,500 balance measurement points installed within MV/LV substations. All information are treated for statistical purposes, in aggregate and anonymous form.
In the SHAPE framework, a daily load pattern is a 96-point time series in which each point represents the energy in the last 15-minute interval. The patterns refer to active power consumption, active power production, and reactive power. Therefore, each year, for each customer's measurement point, SHAPE stores 3*96*365=105,120 measured data. Table 1 represents the amount of required storage space and number of points to be stored for a year-long load data.

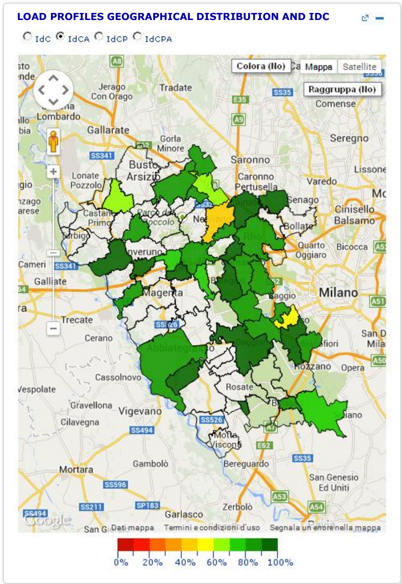
Time Interval	#Smart Meters	Daily Load data	Amount of Data	Amount of Measures
1 Day	100K	1 KB	98MB	29Mln
1 Month	100K	1 KB	3GB	864Mln
1 Year	100K	1 KB	36GB	10.4Bln

Table 1 – Amount of Load data

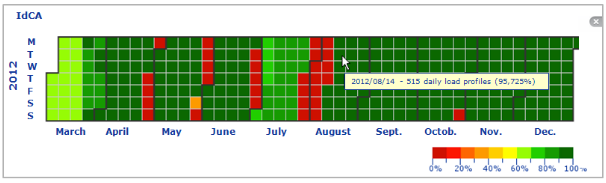
Data cleaning operations on load patterns are carried out during periodic DW update, whereas missing values are handled by means of the "Load prediction" module. No data dimensionality reduction is performed at this stage. At the end of each load patterns update (typically monthly), the application reports the details about the data quality stored in the DW and the errors detected and automatically corrected. By means of local storage support, SHAPE also enables the user to upload "spot" load patterns, to analyze them in a private area, without compromise the main DW.
One of the most important basic functionalities planned during the design of the platform has been to ensure the operator to obtain knowledge about geographical load pattern coverage, jointly with some related indexes. By proper interface, the user is able to visualize colored territorial nodes, as a function of amount of daily load patterns stored in the DW among the theoretical value in a given time period, defined as the product *measurement points*days* (IdCA index, Figure 2.a). In a different matrix component interface, the user can visualize details about daily patterns coverage (Figure 2.b). Suitable ad hoc coverage indexes have been developed.
Further basic analysis refers to these sub-modules:

- Load geographical aggregator
- Load pattern viewer (Figure 3)
- Time-of-use energy geographical analysis
- MV/LV substation energy balance assessment

In SHAPE, customer segmentation indicates the process of "classes discovery" which is generally carried out through clustering; customer classification instead is the process in which, given a previous customers' classes partition, a classification model is induced through a supervised training phase based on classes labels. New customers, for which the outcome class is unknown, are presented to the model and scored accordingly.
Customer segmentation is the process of dividing customers into distinct, meaningful and homogeneous subgroups based on various attributes and characteristics. The type of segmentation used depends on the specific business objective. For the SHAPE's objectives one of the first task implemented was to reveal, for the first time in Italy, the customers' consumption classes at the National level based on consumption behavior.



a) spatial coverage



b) daily coverage

Figure 2 - Load pattern coverage near Milan in a given time period (a) and details per day (b)

Figure 3 – Load pattern viewer

The Enel's Italian LV customer base was sampled taking into account the characteristic variable *annual energy*. Through a pre-sampling test we had established that the *annual energy* was quite heterogeneous. The consumption points (customers) have been grouped in $H = 10$ macro-categories (strata) according to their commercial categories, as follows:

1. Residential Households
2. Transport
3. Agriculture
4. Industry
5. Commercial
6. Public Lighting
7. General Building Services
8. Heat Pumps
9. Non-Residential Households
10. Generation (Producer/Prosumer)

Customer Segmentation and Classification is a task repeatable by means of the SHAPE Workflow interfaces. Customers can be segmented by choosing active consumption, active production or reactive energy. Enel currently knows the topology and the electrical characteristics of the low voltage network branches, nodes and transformers. The information are stored in a GIS system. Combining and integrating these information with the customers load profile, SHAPE is able to estimate the total technical losses load profile considering the low voltage network under each MV/LV substation, with a 15 minutes granularity. The module is currently under testing and the results in terms of saving will be available in 2015.

Machine Learning and clustering techniques algorithms are implemented in SHAPE in order to analyze the suspicious patterns to identify the sources of non technical losses

The concept is based on feeding the machine learning algorithm (based both on neural networks and classification tree) with load profile of customers found guilty of energy stealing. Another approach in SHAPE deals with identification of outliers, consisting in several tailored indicators implemented starting from load patterns clustering. Further results will be available in 2015.

CONCLUSIONS

Since the AMI solution implementation, Enel has been working on the use of business analytics to support operations and improve the network performance. Notwithstanding the good performance level already achieved, the research and development activities continue to work on the data analysis.

The results delivered by the SHAPE project are of strategic importance, as they will provide decision support to current business processes and identification of new ones. The knowledge of the typical patterns of the aggregated energy consumption/production brings new understanding, directly available in SHAPE, on how the loads should be estimated in network applications. The economic benefit of understanding and predict customer loads will decrease investment costs by better matching long-term planning needs, will assist technical losses evaluation and allow better estimation of the economic losses resulting from service interruptions. The Non-technical losses module will support the verification of energy frauds and metering anomalies..

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