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Active demand side management operator tool (SGCLOS) and new communications architecture in the XXI century electrical grid.

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SUMMARY

The progressive energy demand increment in the Spanish power system, leads the Transport System Operator (TSO) to consider the development of new tools and methodologies to actively participate in the electrical demand management.

Currently, the major action that has been performed is related to changes in power generation, or the execution of contracts of interrumpibility with industrial consumers (the most common action to manage the demand). The demand management in residential and services sectors will allow flattening the demand curve, as well as a more detailed control per local areas.

With this purpose, the GAD [1] (Active Demand Management) project is defined under the CENIT collaborative Spanish R&D projects, to reinforce the 2020 Strategy in the Electrical Sector and the smart grids concept. In this project, different system actors (TSO, DSO and Power Marketer) interact by reducing domestic demand through intelligent devices installed at the customers-side, which have joined a GAD contract of power limitation.

In order to carry out this active demand side management, a customer management system has been developed and has been distributed according to the functions of each agent involved. The part of the system corresponding to the Spanish TSO is called SGCLOS (in Spanish, Sistema de Gestión de Clientes del Operador del Sistema), and thanks to the monitoring and analysis of the electrical grid in real time, this system will allow the TSO to send the DSO actuation orders, so that domestic demand can be reduced according to predefined GAD contracts.
Described below are the algorithms, the graphic interface and the communications architecture developed for this application:

- **ALGORITHMS:** a first demand forecasting algorithm has been designed to allow the estimation of the available GAD potential, that is to say, the amount of demand that is likely to be managed. Based on GAD potential, a second algorithm has been developed to oversee the grid status and to detect overloads and under-voltages that are likely to be

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solved through a possible reduction order, which has to be calculated and transmitted from the TSO to the DSO.

- **NEW TSO GRAPHIC INTERFACE**: in order to provide SGCLOS with an intuitive and user-friendly interface, the TSO has developed a unique screen that supports all the integrated information (characteristics and components of the electrical grid), without going in and out from this interactive graphic interface.

- **NEW COMMUNICATIONS ARCHITECTURE:** in order to send the reduction orders from the TSO and received in the intelligent devices at end users premises, GAD consortium is proposing a new communications standard under the Electrical Demand Management concept. This standard defines a new communications network within the electrical network. It models a new communications architecture from the lowest physical layers till the protocol and applications, to ensure a correct and safe transmission of the information from the till last mile.

Thanks to this new developments, the GAD project will set up a new residential electrical demand management, providing an additional and valuable resource for the operation of the National Grid, both in normal operation (by reducing demand peaks), and in voltage collapse critical situations (avoiding unwanted load shedding). This will lead into a new status in safety and efficiency of the electrical grid in our XXI century.

KEYWORDS

Active Demand Management (GAD), Smart Grid, Communications architecture in the Electrical Sector, Demand prediction, Active demand side management operator tool (SGCLOS), Transport System Operator (TSO), Distribution System Operator (DSO), Commercial Agent.

1. OVERALL SGCLOS SYSTEM DESCRIPTION

The SGCLOS system design starts with the implementation of an agreed set of functions with the other participants in the GAD project. On this specification has developed a complete hardware and software system, which serves the TSO as a tool to support Operation.

Related to the software layers used to meet the original specifications mentioned in the introduction, the system has been programmed as a web application (or standard e-business server-based application):

- **Data layer.** This layer has been implemented as a relational database. It stores any information associated with the GAD project and all necessary data to carry out the functionality of SGCL-OS.
- **Logic layer.** This layer refers to any internal implementation required for the operation and development of the Network Analysis Application.
- **Presentation Layer.** It has been designed as a web application and is responsible for displaying information and interacting with the user (TSO).
- **Communication with other agents**. In the current scope of GAD project there only exists direct communication between the TSO and the DSO. To provide the communication between both agents has been used Web Services technology.

Each of these layers is described in deeper detail in subsequent sections.

1.1. Data Layer

The GAD database stores all necessary information generated by and for the demand prediction algorithm, information from the Network Analysis Application, as well as other data derived from the GAD's context.

It has particular emphasis on mechanisms that preserve the integrity of data associated with network problems, identified and characterized by the Network Analysis Application, because they are linked to the changing conditions of the transport network. Also, very flexible mechanisms have been established for updating data due the multiplicity and the disparity between the different data sources. This entails loss of performance in data access, but bigger stability for them.

Any impact identified during data reception is recorded and stored in the application logs.

1.2. Logic layer

First of all, a demand forecasting algorithm has been designed, based on the historical consumption values of GAD customers, the working days calendar and the meteorology. This algorithm makes demand predictions with hourly resolution, both in the short term, scope of operation in real time, and in the long term, scope of power system planning. The above-mentioned prediction allows the estimation of the available GAD potential, that is to say, the amount of demand that is likely to be managed. This algorithm is described in detail in point 2, Demand prediction models.

Based on GAD potential, a second algorithm has been developed to overview the grid status continuously - both in normal situation, as in contingency situation –and to detect overloads and under-voltages that are likely to be solved through a possible reduction order, which has to be calculated and transmitted from the TSO to the DSO.

1.3. Presentation Layer

The purpose of the web application is to present to the end user, TSO, any information that is helpful to operate with the tool GAD, and the interface to perform this operation.
The web application takes from the database all the necessary information to properly submit all the functionality available.

The implementation core is primarily in the server. The main functions performed by the web application are: (1) Briefing geo-referenced of GAD databases: results of network analysis, results of the demand prediction algorithm and GAD potential technically available. (2) External interface with the DSO. It refers to GAD orders sending and GAD clients consumption request. (3) Internal interface of the network analysis on demand.

A main screen with a map has been developed (Figure 1 Results of network analysis), where the problems in the different grid elements, which have been previously identified, are represented by their geographical coordinates. By use of this map, it is also possible to access different screens that display more detailed information and, from there, the TSO is able to send actuation orders.

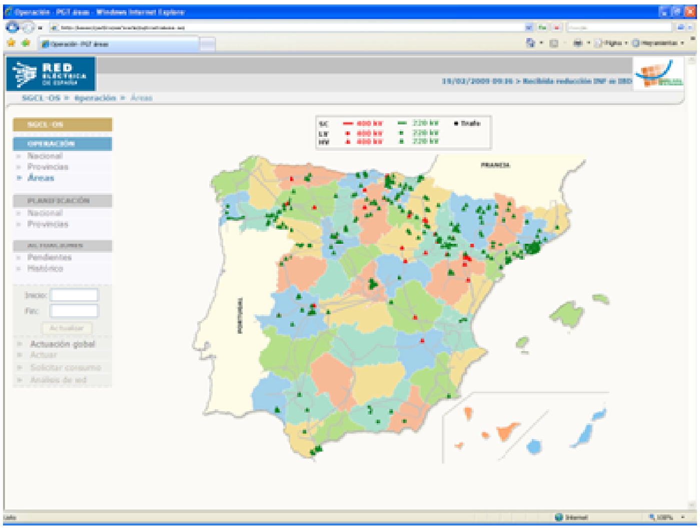

Figure 1 Results of network analysis

Before send limitations to the DSO, the system operator can see the demand prediction curve with planned actuation orders, the real demand curve until the current moment, the contracts of GAD clients and the available GAD potential (Figure 2 GAD Potential). The results of the network analysis are shown in tables, with more detail.

Figure 2 GAD Potential

The communication interfaces included in this server are integrated directly into the web application. It does not need any additional deployment of resources to those required by the application.

These interfaces include: (1) ASP module for SOAP requests by HTTP to communicate with DSO's Web Services. (2) ASP module to load files and invoke application on the server.

1.4. Communication

In the current scope of GAD project there only exists direct communication between the TSO and the DSO. Therefore, no direct communication exists with CM.
The communications between the TSO and the DSO have been implemented using a Service Oriented Architecture (SOA) due to the features that SOA offers.
SOA has been built using Web Services. They allow exchanging data between different software applications developed in different programming languages and executed on any platform. They also allow that software and services of different companies located in different geographic places can be easily combined to provide integrated services. Thus,

communication between TSO and DSO can be done easily and efficiently, ensuring interoperability.

Web Services is a technology based on standards: (1) HTTP and SOAP for communication.(2) XML and WSDL to describe and define the service. (3) UDDI to make public, discover and recover the service.
SOAP is a protocol specification relies on XML as its message format, so that the messages exchanged between the two agents are XML files.
The information to be exchanged between the agents is:
(1) Estimated burden per node/province.
(2) To reduce demand per province.
(3) Aggregate consumption.
(4) Technical limitation.
(5) Order cancellation.

To provide and consume Web Services has been used Apache Axis2/C, a Web Services engine implemented in the C programming language and which is based on Axis2 architecture. This enables using C in SOA implementations.
Apache Axis2/C supports several versions in SOAP, which makes it ideal for use.

DEMAND PREDICTION MODELS

One TSO GAD goal is to flatten the customer demand curve in the long-term during the global planning that means a stable situation not only from the consumption point of view but also from the generation. Other goal is to improve the local optimization of demand peaks due to for example air conditioning in the Spanish east coast in summer [2].

So, TSO must be able to predict contingencies or grid inefficiency situations, to avoid grid overcharge and the subsequent malfunction. Thus, the demand behaviour prediction becomes necessary.

In order to achieve such goal, the TSO implements a *demand prediction* algorithm ([3], [4]) that is able to predict the demand on both a short and a long term, which is implemented by using a linear regression. This algorithm is able to perform electrical demand forecast under a known set of circumstances, such as historical demand values (see the following picture), the working days calendar and the meteorology.

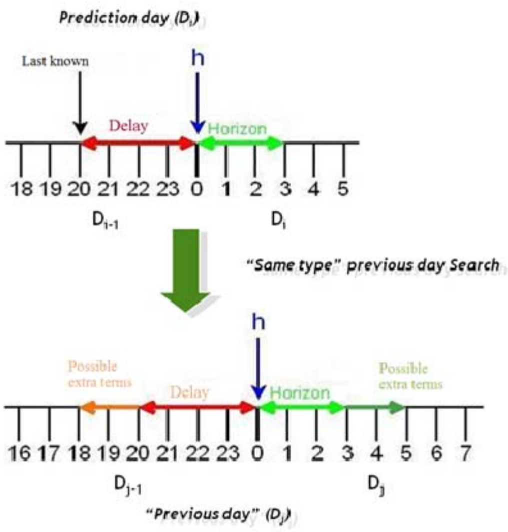

Figure 3 Demand prediction algorithm diagram

This prediction algorithm's goals are twofold: to be a useful tool not only for the operation in real time but also to help grid planning for mid and long term. Therefore two different variants exist: the first one obtains predictions with hourly resolution, extendable to daily or even weekly and the second has a longer resolution such as a three months period or even a year.

Conclusions of the SGCLOS proposal.

Due the current scope of GAD project, the following paragraphs refer only to the demand prediction algorithm in the short term, within the transaction in real time.

The algorithm design is done following two steps: (1) Historical data preparation that involves demand differences calculation, hourly temperature data interpolation, etc. in order to obtain the model data inputs; (2) Algorithm execution, modeling and executing the regression in order to obtain the final prediction.
Using three years of data corresponding to demand and temperature, and calculating daily predictions for a whole year, the timing obtained is:

Historical Data Preparation (three years): 1m 23.757s
Algorithm execution (one year): 5.090s
Real time execution: 1.022s.

The formula that has been used in the algorithm is:

$$[D_{i,h+x} - D_{i,h-R}] = \alpha_0 + \sum_{z=1}^{Z-1+TD} \alpha_z \times [D_{j,h+z} - D_{j,h+(z-1)}] + \sum_{r=0}^{R-1+TA} \beta_r \times [D_{j,h-r} - D_{j,h-(r+1)}] + \sum_{z=0}^{Z-1} \delta_z \times T_{j,h+z}$$

$$x \in [0, Z-1]$$

Figure 4 Demand prediction algorithm formulas

Where:

i = day to predict
j = the day before i
$D_{i,j}$ = demand of the day *i* and the hour *j*
α_i, β_i, δ_i = regresion coeficients
α_0 = constant term
Z = hourly prediction horizon
R = hours after the last available real data
TD = forward extra terms
TA = backward extra terms
$D_{i,h-R}$ = last known real data
$T_{i,j}$ = prediction of the day *i* and the hour *j*

Below it is described the scenario tests and the errors obtained with the best model:

(1) 1 hour delay: prediction time lapse starts at 0 hours, taking demand data of the last hour.
(2) Horizon: hourly predictions are issued for the following 24 hours.
(3) Regression terms: 29 differences in demand hourly of day earlier; 24 temperature estimations a day to predict; one constant term.
(4) Modelling period: 01/01/2004 - 30/06/2006.
(5) Prediction period: 01/07/2006 - 30/06/2007.

Validation methodology

In order to measure the models implemented, we have used the relative linear error (**RLE**), absolute linear error (**ALE**), Pearson's correlation coefficients (**PCC**) and mean quadratic error (**MQE**). In order, we show the Global Mean (**G**), Monday (**M**), Tuesday-Wednesday-Thursday (**T**), Friday (**F**), Saturday (**S**), Sunday - Vacations (**V**).

Table 1 shows the errors of the demand prediction algorithm that have been obtained as a result of applying the above scenario.

	G	M	T	F	S	V
RLE	2.03	2.46	1.96	1.98	1.64	2.21
ALE	603	744	624	634	445	544
PCC	98.55	98.07	98.12	98.21	98.24	97.62
MQE	884.7	1085.7	940.6	858.7	619.2	765.5

Table 1. Demand prediction algorithm errors

2. NEW COMMUNICATIONS ARCHITECTURE

In order to make the reduction orders sent from the TSO and received to the intelligent devices in the end users, it has been developed a new communications standard under the Electrical Demand Management concept. This standard defines a new communications network within the electrical network ([5],[6],[7], [8]. It models a new communications architecture from the lowest physical layers till the protocol and applications, in order to ensure a correct and safe transmission of the information till last mile.

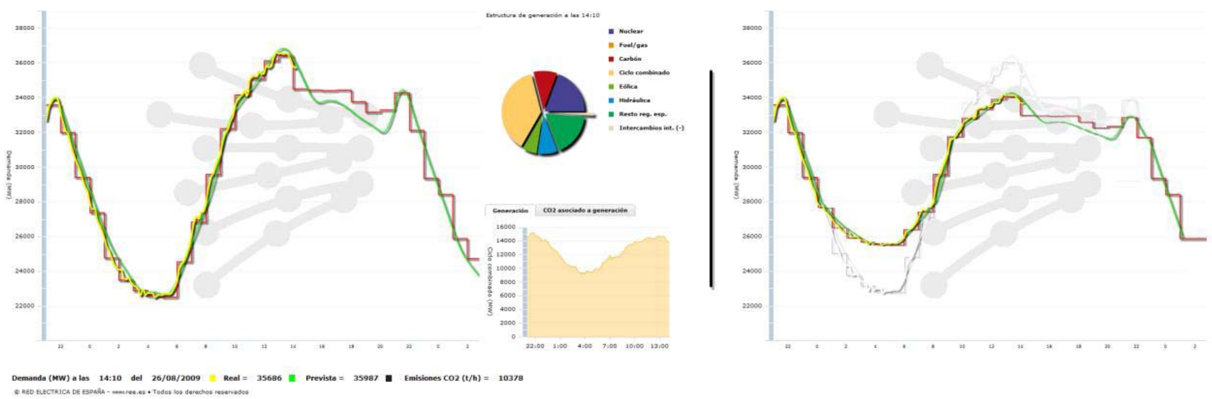

Figure 5 **:** Electricity Demand Curve tracking in real time [9] vs. Electrical Demand Curve flattening improves electricity generation efficiency. Demand Curve: The effect of these contributions is that a powerful network working system is needed to estimate, control and integrate all sources. Demand Management (curve flattening): Spain variation is from 42 GW to 24 GW from daily peaks to night valleys. Demand management tools should be design and put in place in order to reduce of utility loads during periods of peak demand, while at the same time building load in off-peak periods. Interrumpibility is already in place for industries, Smart Grids Demand Management tools for user segment are the target of the GAD project.

According to the defined business model, there are five main agents that support the Active Demand Management: end users, distributed energy generators, DSO, the Power Marketers and the TSO. These agents operate different segments of the electrical network structure, and these criteria will be used to define the new areas in the communications network:

- **Control Area:** physical and logical resources to guarantee the Communications between the TSO, the DSO and the Power Marketers.
- **WAN Area:** physical and logical resources to enable the Communications between DSO and the user devices at the buildings (counters, residential bridges, load controllers) ([10], [11]).
- **LAN Area:** physical and logical resources to enable the Communications between Load Controller and different devices at home (loads), with enough capacity to support intelligence and remote Management.

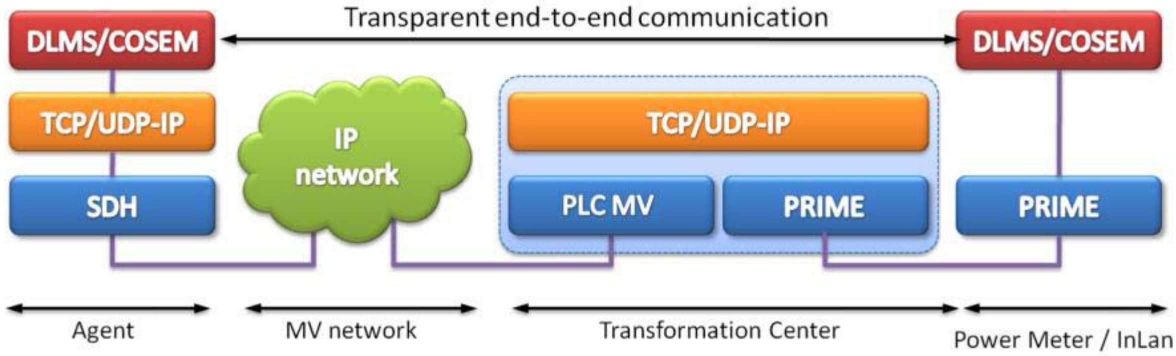

Figure 6 : Agent (TSO / DSO / Commercial) will use the DSO facility to reach end-user devices, thanks to this new concept in communication protocols. The electrical network is divided into several segments, with a differentiated physical layer (horizontal axis criteria: Control Centers at the Agents, High/Medium Voltage infrastructure (cables and substations), LV segment (cables and transformation centers, home installations). Use the OSI model to define the vertical layers and to define a final electrical communication model. In each matrix position, define the most suitable and status-of-the-art protocol to fit the end to end solution for residential segment. *Source: GAD project.*

Due to the complex status of the current electrical networks to imbricate a communications network, the GAD consortium has developed a simulation phase in which some areas of the national grid will be emulated with clusters. The physical stress test of the devices will be performed separately from the communications architecture concepts and business models, to minimize the technical risk and cost impact.

CEDETEL – SIEMENS have developed a communication simulator to support this features: the WAN of the GAD Project requires careful design and planning, together with a robust interface integration with the Agents algorithms and procedures, which makes simulation a critical decision tool.

REE is able to perform a Quality Assurance test thanks to the new algorithms and SGCLOS in their facilities to ensure the critical operation of the national transport network, as described above. The Communications simulator will interface with the data coming from REE via the

Iberdrola GAD system, and also the Commercial systems, thanks to the GTD development that is also linked to the Distributor system: the GAD Project is performing a full set of simulations over realistic scenarios using the OMNeT++ ([12], [13]) network simulation framework. OMNeT++ is open source and provides a full set of internet based protocols ready to use by means of the INET Framework [14] extension, as IPv4, IPv6, TCP, UDP, Ethernet, and many others.

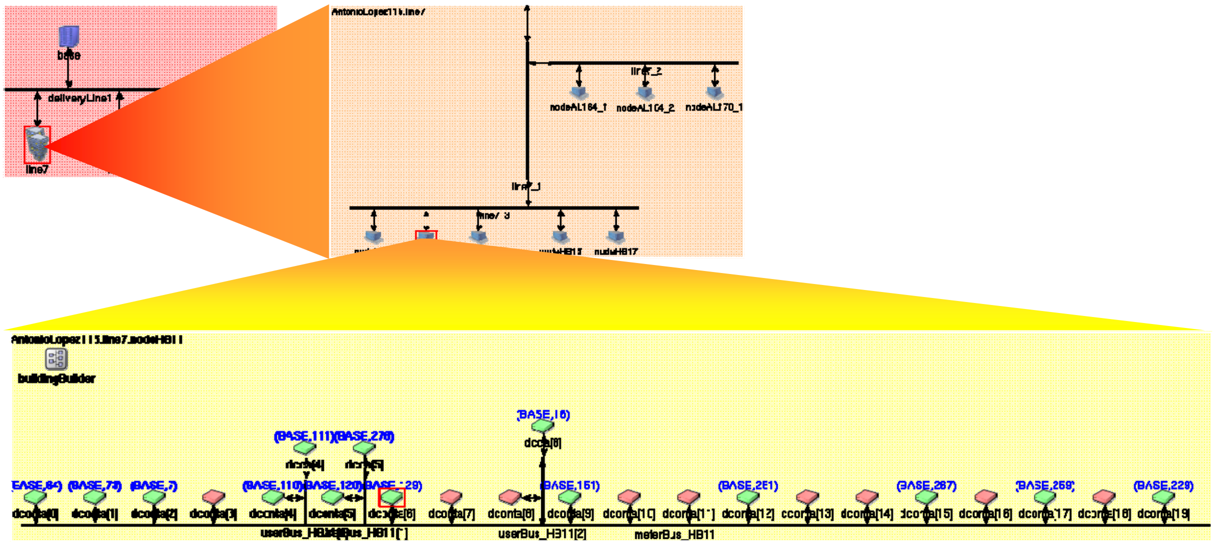

Figure 7: Last mile model in the simulator developed by CEDETEL – SIEMENS.

Simulations will characterize: the medium access performance under heavy concurrency conditions, the Access WAN mean transmission rate, end-to-end latency and system scalability among other figures of merit. Theoretical channel and algorithms simulation results are already available, and checks against real field stress test are expected to be available at the end of 2010, this are key to determine potential network performance and service quality of the GAD Project, scalability of the system to other national grids and business expectations with the selected PLC technology.

CONCLUSIONS

Thanks to this new developments, the GAD project will set up a new residential electrical demand management, providing an additional and valuable resource for the operation of the National Grid, both in normal operation (by reducing demand peaks), and in voltage collapse critical situations (avoiding unwanted load shedding). This will lead into a new status in safety and efficiency of the electrical grid in our XXI century.

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