How Internet of Thing Makes the Energy Grid Smart

The rise of the Energy of Things

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Abstract—**The high penetration of intelligent appliances has turned whole buildings into effective and efficient prosumers. These distributed and autonomous intelligent Commercial Prosumer Hubs, constituted of Distributed Energy Resources (DER) clusters raising an actual decentralized Demand Side Management (DSM), behave like Smart Virtual Power Plants. An Aggregator manages the new Smart Virtual Power Plant enabling the electricity production and consumption to be measured, reported and controlled in real time. This new infrastructure maximizes the response capacity of the vast, small-commercial prosumer base (e.g., tertiary buildings, offices, etc.), presenting incentives and delivering benefits through their automated active participation in the energy market, aligning consumption by asking consumers to reduce their power usage rather than increasing the power generation facilities. Under this approach, prosumers that cooperate might receive incentive payments from the power company. In comparison, the Internet of Things (IoT) paradigm claims to solve this issue expanding Demand Response services based on the analysis of occupants historical interactions with the lighting, ventilation and air conditioning controls. In this respect, an overlay smart network for efficient grid control, running on top of the existing energy grid and incorporating high levels of distributed intelligence within autonomous and semantically enhanced Prosumer Hubs (local hub) will bring to the new concept of Internet Of Energy. This new smart network addresses the present structural inertia of the Distribution Grid by introducing more active elements combined with the necessary control and distributed coordination mechanisms, as well as Demand Side Management Operator.**

Keywords-Internet Of Things; Energy of Things; Smart Grid; Demand Side Management; Energy Flexibility;

I. INTRODUCTION

The great amount of intermittent renewable energy resources injected into electric power systems can significantly modify the net demand profile [1]. This recent phenomenon with the current rather inelastic nature of the demand curve can generate big issues on the electric grid, most important of which are frequency fluctuations and voltage imbalances [2].

These problems are found in the majority of current electric grids due to the large number of passive elements that constitutes today's electrical network.

Different approaches were proposed to overcome these problems [3].

The most common solutions are those that use the devices flexibility to balance the grid. Flexibility is the capability of shifting production or consumption of energy in time following an external signal, in order to provide a service within the energy system.

The problem with this approach is that flexibility is obtained compromising the final user comfort [4].

With this regard, the INERTIA project [5] has been thought to extend Demand Side Management strategies by incorporating a new entity: an enhanced Distributed Energy Resources. This new entity includes local generation and consumption capacity and will provide flexibility without impacting users comfort. Therefore, it addresses the present "structural inertia" of the grid by introducing more active elements combined with the necessary control and distributed coordination mechanisms.

This new kind of DER, semantically enhanced (generation, consumption and flexibility), is the core of our solution and will constitute an active and flexible knot equipped with local information based on environmental, occupancy, and historical data.

The adopted solution enables a mechanism that allows consumers to actively participate in the Demand Side Management without affecting the customer's comfort level, as well as turning the customer into an active and proactive *prosumer*. The entrance in the landscape of this new actor will lead to a most effective participation of all elements in the grid.

Of course, the best natural way to do this is following the *Internet of Thing Paradigm*.

According to this approach, every DER has a computational model and a communication part in embedded systems, that paves the way towards highly sophisticated networked devices that carry out a variety of tasks not in a standalone mode, as usually today, but taking into fully account dynamic and context specific information.

These DER "objects" are able to cooperate, share information, act as part of communities and generally be active elements of a more complex system. Our solution is a real instance of the so called Ubiquitous Computing: different systems and subsystems (each having its computational capacity) that are driven simultaneously to cooperate with each other as in Figure 1.

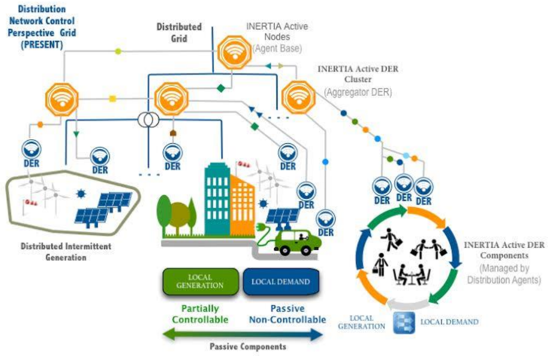

Figure 1. INERTIA framework

This paper learns from the progress of the existing efforts in demand side management that allows for intelligent demand aggregation and dynamic demand on much higher levels than those of individual appliances and is organized as follows. Section II describes the modeling devices that are the focus of INERTIA together with systems and subsystems, that are provided with different communication and integration protocols: DERs, Key Performance indicators, sensors, mobile devices with a specific user interface. Section III describes the approach followed to aggregate these device models in the whole system. Section IV describes the pilot DEMO implemented in Europe. At the end conclusions, close the article.

II. INTERNET OF THINGS REVOLUTION FOR ENERGY EFFICENCY IN SMART GRID

The Internet of Energy (IoE) is a new conception of the power grid that allows promoting a transition from the current energy system to a new modulated one. IoE provides an architecture with distributed embedded systems to implement a real-time interface between the smart grid (which depends of electrical generating energy sources but also of flexibility concept before explained) and a cloud of devices (electric vehicles, commercial and residential buildings, offices, electrical devices, appliances, etc.).

This provides the capacity to produce, store and use energy efficiently, balancing the supply and the demand using a cognitive Internet of Energy, which will harmonize the grid by processing data, information and knowledge through the Internet.

This innovation causes all network elements of a physical model to be instantly connected and able to contribute actively to the network to the purpose of DSM.

A. *DER flexibility modeling*

The DER models are aimed at simulating the individual and aggregated behaviour of the different devices/systems taking into account the complete operational context (environmental conditions, occupants, time, device operational characteristics, etc.). These will allow creation of multi-dimensional DER flexibility profiles reflecting the real-time load demand elasticity as a function of multiple parameters such as price and occupancy prediction.

To this purpose, DER modeling consists of two main parts:

- DER models: DER models contain the mathematical formulation defining the electric demand (consumption, generation and storage) of the DER in function of dynamic input parameters and static parameters (configuration) affecting DER's demand. For example: the DER model for a HVAC (Heating, Ventilating, and Air Conditioning) system contains the mathematical model that calculates the power consumption of the HVAC given the HVAC characteristics (rated power, efficiency, thermal characteristics of the building) and several inputs that change dynamically (temperature set point, outdoor temperature, occupancy, etc.).
- Control models: control models presented in this document refer to the local controllers associated to each controlled DER. The models described here represent the components that contain some local intelligence including the capability to simulate set point schedules provided by the centralized optimizer and by which of means it is possible to extract flexibility.

These models have the objective of simulating the final state of the device and are able to provide the forecasted flexibility. For example an HVAC DER model would have also as input the expected occupancy of a thermal zone and in case that this value is 0 it will tell us that all the energy forecasted will be available under the form of flexibility to the system. The main output of each DER model is the power consumption during the simulation time step.

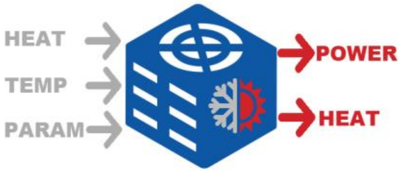

Figure 2. HVAC model

Other auxiliary outputs are also provided. These auxiliary outputs are needed in order to feed the model with input data for the next simulation step. Other key output of the models is the heat gains generated by the DER and the occupants. This heat gains are used together with the thermal models of building zone to calculate the power consumption of HVAC systems which are one of the main power consuming devices in buildings [6]. Inputs needed by each DER model are separated into configuration and dynamic type.

For the correct creation of a profile, we need to divide the DER models in four categories: local demand, generation, thermal zone and thermostatically controlled appliance [7]. While local demand and generation are models that simulate consumption and electricity production, a thermal zone model represents the thermal losses and gains of a building area, which is controlled by a thermostat.

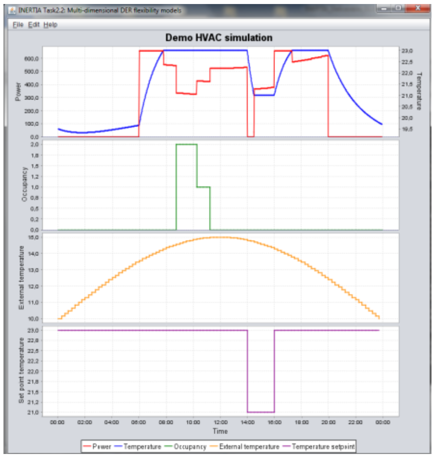

Figure 3. HVAC power consumption as parameter function

A thermal zone contains a set of construction elements describing how the heat is transferred from one area to another, also the loads and the occupants of the thermal zone need to be considered since they act as heat producing elements. All these elements together with the desired temperature set point in the thermal zone define the required parameters to obtain the heat demand that is used as input for the HVAC DER as in Figure 3.

At last, we have the thermostatically controlled appliances whose operations are driven by a temperature thermostat.

Thermostatically controlled appliances can be used to cool or heat a certain space or element. For a cooling appliance, when the temperature measured by the thermostat reaches the high temperature limit the appliance starts cooling and therefore consuming power and when the temperature reaches the lower limit the appliance stops cooling and stops consuming power. For a heating appliance,

the operation procedure is exactly the same but the consuming period is started at the low temperature limit and stops at the high temperature limit.

There are two main appliances operating as thermostatically controlled appliances

- Refrigerators/Freezers: their objective is to maintain the temperature between a certain temperature range where this temperature range is usually below the ambient temperature.

- Water Heaters: They are in charge of heating the water inside a tank maintaining it within a predefined temperature range.

To simulate a thermostatic device one important parameter to keep in mind is the percentage of consumption time (on time) with respect to the operating cycle (on + off times) that is called duty cycle and defines the power consumption profile of the appliance.

The shorter duty cycle time periods reflect low activity indicating that the appliance is only supplying the thermal losses through its shell. While the larger duty cycle time periods reflect increased heating/cooling demand indicating that the appliance is being used (hot water is being drawn from the water heater or food is being filled or removed from the fridge).

Depending on the usage of the appliance, the duty cycle is larger when the appliance is being used and shorter when the appliance is not being used.

This consideration leads to the approach that calculates energy consumption of the appliance, according to the usage patterns that may be inferred from occupancy data. This means that during time periods with higher usage of the appliance the on time periods will be larger than at times where the appliance is not used. Given therefore the energy consumption during the operating cycle, the duty cycle linked to different usage levels and the occupancy data is possible to model the appliance.

B. *Sensor and Occupancy*

The behavior of occupant has been shown to have large impact on building control and appliances consumption. Consequently, user activity and presence is considered as a key element and has been used for control of various devices. Innovative approach of INERTIA will consist on bring occupancy related information in the DER models. The most natural way to do this is through a sensor cloud that will provide the model for the real time occupancy extraction, along with the monitoring part related to the energy consumption and production. This kind of behavioral modelling approach is going to take occupancy related data, control actions of the users on the DER and the environmental conditions as parameters. Provided that an identification mechanism is installed in the building under consideration and some of the occupants are equipped with RFID cards, two types for the Occupancy and Flow Model are defined: the first one (Overall) refers to the occupants as a group, while the other one (Individual) refers to specific individuals. Using Radio Frequency Identification (RFID) equipment for some occupants will improve prediction accuracy and user profiling, as it will be possible to track occupants' location at any time having more specific information concerning their habits and schedules. With data provided from occupancy , INERTIA will provide short-term (near real time) and mid-term (next day) occupancy and flow prediction allowing for more efficient management of building's energy resources and providing the essential information for optimal local demand side management strategies. The estimate method will be based upon comfort parameter expressed as a discomfort probability, and based on an analysis of the past history of the user's interactions with DER.

C. *Key Performance Indicators*

Key performance indicators are becoming a common instrument in public and private organizations used to analyze and monitor performance, and finally to drive informed decisions. In general, measuring the total performance of a system is used to learn, improve and cover the goal settings while also to provide the tools for the extraction of the optimal policy. Thus, the importance of well-defined performance indicators is even higher when dealing with optimization frameworks as the one examined within the INERTIA Project. Since these different coexisting sub-systems pose different performance constraints (energy related constraints, users comfort related constraints, business & flexibility related constraints) which are most often conflicting, INERTIA will adopt a holistic approach that will equally address and balance those aspects within a single integrated performance framework.

D. *User Interface system in IoT context*

The User Interface system of an application based on IoT is the synthesis of the interconnection of active entities. It should represent in a human friendly mode the modeling behind these entities and these interconnections. So in IoT, we have a lot of active elements and the User Interface system should connect all these active elements with the last and probably most important active element one: the final user. For this reason, the User Interface system should not only merely shows entity's data but also especially gives to user the possibility of being an active actor of its IoT world.

For INERTIA project, being an active user means that the user should be involved in profiling and forecasting in order to address the "structural INERTIA" of the Distribution Grid. How? Sharing his habits, his preferences about devices and comfort and his activities. This surely leads to privacy issues that must be treated in a suitable way (e.g.,: with anonymous data collecting, *Privacy by Design* [8]). Furthermore, since we are talking about IoT, User Interface system must fit security and scalability requirements.

1) *Architecture*

Each "thing" feature in IoT is uniquely identifiable through its embedded computing system and is capable to interoperate within the existing Internet infrastructure in order to coexist actively with others entities. This means the User Interface system should be able to communicate, in scaling way, with all these things, by filtering and synthetizing their data and also routing user's inputs. The solution identified and explained in this paper uses the Model View Presenter design pattern in order to:

- Makes *View Model*-independent
- Moves application logic outside de *View*
- Fits best scaling and security policies

The three main roles (*Model*, *Presenter* and *View*) can be summarized as seen in Figure 4.:

- *Model*: all devices, entities and systems connected through the internet forming what we call Internet of Things; e.g., data base storing sensors data, devices, sensors, controller, etc.;
- *Presenter*: the "middle man" transforming all Model data into information. It also connects the user with others IoT entities – systems, devices, sensors – according to the idea of user as active element like all other "things";
- *View*: the graphical component that displays data and routes user commands to the presenter. It gives the user the chance to "touch with hands" the IoT entities;

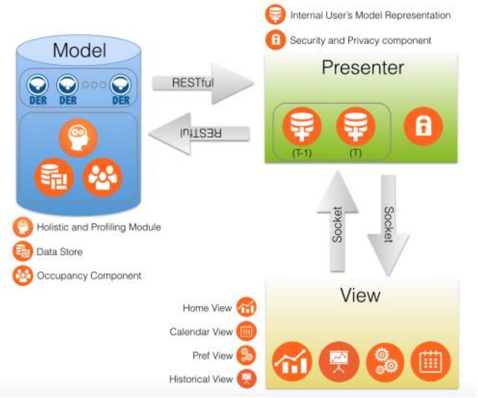

Figure 4. Model view presenter

2) *Presenter – a deeper analisys*

Presenter is the system's back end. It collects data from the *Model*, transforming these data into information and presents information to the *View*. Since we are talking about a system working in real time mode, the Presenter should fits this requirement. Anyway, an effective real time is not feasible, so it might be better talking about to call it "near-real time" flows of information.

How we do this? Essentially the Presenter builds an internal intermediate representation of user's model. This intermediate model stores information such as for example user's DERs, occupancy area, comfort values and consumptions. Periodically the Presenter queries the entities of IoT (or the store in which the IoT entities send data) to instantiate and populates the intermediate model. At each time (T) the Presenter compares this intermediate model with the previous one at time (T-1). All changed values of the intermediate model will be sent to the *View*. In this way the *Presenter* sends to *View* information changed only when they are changed, minimizing traffic, minimizing payload and diminish view's responsibility.

3) *View – functionalities*

Thanks to the *View*, the user is an active part of INERTIA world (see Figure 5). The View component of the design pattern is organized into different subcomponents:

a) HOME view: user monitors status and consumption of all DERs (personal and zonal), taking under control his comfort status. He also monitors his position in the building;

b) PREFERENCES view: user submits to INERTIA world his preferences about his devices, such as for example, HVAC winter or summer temperature, elettrical vehicle time-in and SoC, personal devices start and stop;

c) CALENDAR view: user submits to INERTIA world his habits and commitments such as for example “surgey in operating room from 11:00 am to 3:00 pm” or “training every Monday from 6:00 pm to 9:00 pm in the workout room”;

d) HISTORICAL view: user monitors the historical data about consumption at different time;

Figure 5. Personal user interface

E. *Communication technologies*

All the components of the user interface architecture must communicate with each other. The connection between Presenter and View uses a socket connection. A socket is an end-to-end link over a single TCP connection, having the following features:

- Full duplex
- Bidirectional
- Always on
- Rapid data transformation due to a header much smaller then HTTP header

These features fit very well with an application working in (near) real-time mode, in which the user is an active element that should be always connected with the INERTIA world, possible submitting inputs, examining status of DERs and devices frequently.

The issue with this communication architecture is the limit of the number of connections in relation with the message rate per second [9]. For these reason it’s important to have the possibility in scaling to multiple servers and minimizing the messages sent from server to client.

Communication between Inertia IoT Entities (*Model*) and the *Presenter* is made by the Linksmart [10]: this is an Open Source Middleware allowing developers to incorporate heterogeneous physical devices into their applications through easy-to-use web services for controlling any device. So for each entity we have a RESTful service that can be used to access data and control devices.

III. BOTTOM UP APPROACH

In the INERTIA concept, the DER will constitute active and flexible components carrying contextual knowledge of their local environment.

To deploy the INERTIA strength, DER will form dynamic clusters comprising self-organized networks of active nodes that will efficiently distribute and balance global and local intelligence. This aggregation is done in two steps. The first will be at the single building level and the second to the level of cluster of building.

A. *Local control and automation hub (Building Automation System)*

A whole tertiary building can be represented by a building automation system named Local Control Hub (LCH).

Thanks to *Building Automation Systems*, all individual building subsystems DER can become part of a single central system, also able to learn users’ needs and behavior, to anticipate solutions or provide recommendations. These systems make use of forecasting, optimization and evaluation algorithms that acquire real-time data from smart sensors and meters, placed in strategic points of the building, capable of detecting internal microclimate parameters, space and ICT infrastructure use, attendance, weather data and energy quality. Based on the input data analysis, the system suggests actions to support building management optimizing energy consumption; users, on the other hand, as an active part of the system can monitor consumption instant by instant, by tablet or smartphone, and improve their behavior accordingly, becoming agents of saving themselves.

In this respect, the objects become self-recognizable and acquire intelligence due to the ability to communicate information about them and gain access to aggregate information from any other devices, allowing these systems to operate in real time.

Some ambient user interfaces (UIs) continuously collect data resulting from the occupant’s interaction with existing traditional building hub devices and provide the necessary incentives through different interaction GUIs - e.g. through mobiles, monitors - , driving them to more energy- efficient choices.

B. *Aggregator Control Hub.*

The aggregator is an energy stakeholder that in a scale of aggregation following immediately the building and therefore manage different clusters of Local Control Hub using their portfolio, trading with the market stakeholders on behalf of small customers.

Aggregators gather, analyze and efficiently organize their customer load portfolio’s and define specific active demand (AD) strategies and services based on market needs. They act as an intermediary between suppliers and network operators and the different commercial and industrial (C&I) prosumers belonging to their portfolios.

IV. DEMO

Tests are underway to validate the proposed solution faced by INERTIA and the validation is done by means of simulations and laboratory tests. We have three field tests, which are a combination of actual field-testing and developed prototypes sited in Sweden, Greece and Spain.

It should be pointed that within the pilot we use one real Local Hub and a portfolio of simulated one that in their turn are two different kind of models.

The first kind is formed by simulated DERs, occupancy profiles, user preferences that all together constitute local hub set. This is a complex simulation approach since it implies deploying full LCH systems with all its components.

In light of this we made a second kind of building consumption profiles obtained from typical penetration in the pilot and based upon real DERs. Consequently it has been created a set of several building stereotypes.

The high level simulation then starts by obtaining a set of real consumption profile data (hourly or 15 minutes data) coming from building consumption measurements made in real pilot or from available typical building profiles. Then, the mix of controllable DERs is used together with the consumption profiles in order to calculate the flexibility made available at the simulated LCH. At the end by means of the portfolio of simulated LCHS it is created a mix of local control hub with different consumption and flexibility characteristics.

Then, we developed one test related to the network operation scenarios that involve the whole INERTIA chain stating form the DSO simulating some problem in the network seeding the corresponding DR signal to the aggregator, that deploying the needed control actions over the LCHs in its portfolio and finally the LCHs operating the final DERs that offer flexibility (Figure 6).

The test is considered successful under the fulfillment of the following conditions:

- The simulation of the congestion problem in the network provokes the calculation of DR signals (demand reduction) by the DSO Control Hub.
- These signals are sent to the Aggregator Control Hub that in turns sends the required control requests to the LCHs (real and simulated)
- The real LCH and micro-level simulated LCHs receive the control requests and operate the final DERs
- The demand at the MV supply level corresponds to the DR signals that were delivered
- The ACH generates demand forecasts updated according to the control actions taken
- The DSO Control Hub considers the updated demand forecasts and verifies that the congestion problem is solved

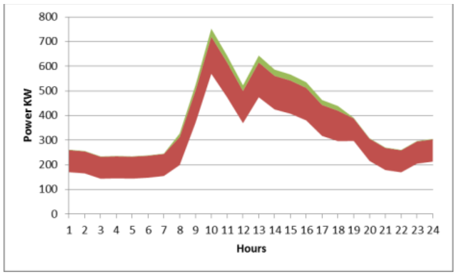

Figure 6. Flexibility requested

V. CONCLUSION

Demand side management has the capacity to overcome some of the major barriers of controlling and balancing supply and become a powerful tool at the hands of distribution grid. Moreover, as DERs continuously set an indispensable part of the EU Grids infrastructure, demand capacity and flexibility becomes a key performance factor with shared profit opportunities for all stakeholders involved. In addressing the "structural inertia" of existing Distribution Grids by introducing more active elements combined with the necessary control and distributed coordination mechanisms our project is an attempt in linking Internet of Things/Services principles to the Distribution Grid Control Operations.

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