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Decision Process to Manage Renewable Energy Production in Smart Grid Environment

João C. Ferreira[1,2,3], Vitor Monteiro[2], J. G. Pinto[2],
Ana Lúcia Martins[3], João L. Afonso[2]

[1] Instituto Universitário de Lisboa (ISCTE-IUL), Information Sciences, Technologies and Architecture Research Center (ISTAR-IUL)
[2] Centro ALGORITMI, University of Minho, 4800-058, Guimarães, Portugal
[3] Instituto Universitário de Lisboa (ISCTE-IUL), Business Research Unit (BRU-IUL)
{joao.carlos.ferreira, almartins}@iscte.pt,
{vmonteiro,gpinto,jla}@dei.uminho.pt

Abstract. This research work is related to the Electric Vehicle (EV) integration in the electricity market, using the OpenADR open protocol for demand response. The proposed solution integrates a local developed EV charging system and a cloud management system, to coordinate the available energy produced from renewable energy sources, taking into account its intermittent production and the requirements of the EV charging process at home. Considering the smart mobility paradigm, all transactions processes are available at mobile devices in real-time, where users can define their usual behavior, configure the energy consumption profile at home, establish new profiles for specific days according to the EV charging process, and consult the historical transactions.

Keywords: Electric Vehicle, EV Charging, OpenADR, Decision System, Demand Response, Renewable Energy, Smart Grid.

1 Introduction

Nowadays, the power grid operates under the hypothesis that the consumed energy is always available from the energy resources. This assumption requires a whole system with several layers synchronized in order to maintain stability from the production points until the final consumers. It is then mandatory to have energy production resources with low operation costs, full availability of energy production according to demand, and fast transaction between operating powers in full power operating range. Besides, it is expected to have reduced greenhouse gas emissions from the energy production resources.

In order to contribute to this scenario, renewable energy sources are introduced into the power grids in large scale, especially large solar photovoltaic and wind plants. However, these types of renewable energy sources have intermittency production problems, i.e., the sun and the wind are resources that cannot be controlled according the power demand. To fight this, energy storage systems are introduced to store the energy produced by renewables and to be able to deliver the energy according to the instantaneous power demand. An extended review about energy storage systems for mitigating the intermittency energy production from renewables is presented in [1]. Besides these traditional energy storage systems, through the vehicle-to-grid paradigm, the electric vehicle (EV) can also be used as an energy storage system, providing capability to store energy from renewables or to deliver energy to the power grid [2][3]. This is even more relevant if one takes into account that the EV can operate as distributed energy producer or consumer (prosumer) in different points along the power grid [4]. The contribution of plug-in EVs to smooth the natural intermittency of energy production from renewables and for cost and emission reduction is presented in [5]. For such purpose, smart charging strategies for the EV operation as a contributor to enhance the power grid performance and also to maximize renewables integration into the power grid are proposed in [6]. Energy management considering the EV and renewables integration in a micro-grid scenario is analyzed in [7], where strategies for the EV operation are identified to facilitate the integration of distributed energy resources. The analysis of the EV operation in a micro-grid office building scenario and also considering distributed energy resources is presented in [8].

2 OpenADR

Energy delivery needs a real-time perfect balance between supply and demand. The problems of intermittent production behavior of renewable energy sources and the change in power consumption can be overcome with a high investment in infrastructure or by the implementation of demand side (load) response. Demand Response (DR) is a new paradigm in electricity consumption by end-users where they change their consumption patterns in order to avoid consumption peaks and absorb the renewable production excess. This behavior change by the flexible consumers is promoted by lower electricity use at times of high wholesale market prices or when the system reliability is put at risk.

The fully automated DR illustrated in Figure 1 can be achieved by the implementation of a standard OpenADR and a Home Energy Management System (HEMS). An HEMS system is responsible for monitoring and managing the operation of in-home appliances, and providing load shifting and shedding according to a specified set of requirements defined by the user and controlled through a central system.

One of the goals of this research is to implement this protocol and a central cloud system to handle renewable production excess in an intelligent way, taking into account intermittent behavior of renewable energy sources, power limitation of the distribution network and energy prices. The EV charging process and the need of enough energy for user's daily mobility process are integrated in this approach.

The OpenADR protocol is based on a communication Internet Protocol (IP) network to handle energy consumption requests based on production availability and is a tool for the integration of renewable energy based on a centralized process that is able to turn on/off appliance. This protocol introduces the concepts of: Virtual End Node (VEN), client energy consumer appliance to turn on/off remote based Demand Request (DR) events announced by Virtual Top Node (VTN). This VTN performs the role of a

Virtual Power Plant (VPP) manager. A VPP consists of an aggregation of Distributed Energy Resources (DERs). The VPP Manager centralizes transitions from VEN with the loaded resources that they interact with and perform decisions about loads based on the distribution distance previously calculated in georeferenced graph. This VPP receives information about the available production resources and based on the Demand Response tries to fit the resources from the VEN aiming for minimization of power losses and non-supplied energy.

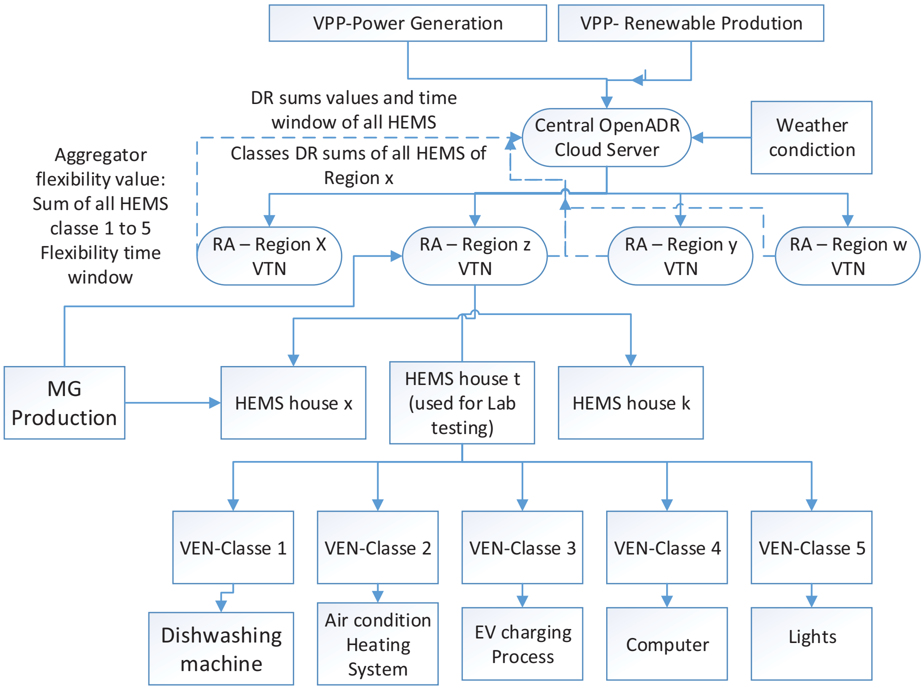

Fig. 1. General overview of the energy market stakeholders and their role on the OpenADR approach.

2.1 Micro Generation

In the proposed approach it is also possible to integrate all the local Micro Generation (MG) resources, which can be handled as a VEN with a report service based on a metric device. Taking into account local MG, this VTN can be created at a local substation considering the electrical distribution network (DN) to handle all the energy transactions from all the local MG. A new service to calculate the distribution distance was created. Its output is the distance of a VEN to another energy resource based on a georeferenced graph for the power grid DN. However, the main challenge of this approach is the georeferenced identification of each of these points on the DN. Once this information is collected any geographic database can easily handle the problem. The main idea for the decision process of electrical distribution is the real distance on the DN. The area with the distribution of the electrical network is manually transformed in a graph, where it is added geographic information and power limitations between the nodes, as described in [10]. Each node identifies the distance, which is calculated using the line distribution size of a VTN and VEN matching to these nodes. When a VEN is registered, a distance calculation is performed to other VEN. For that process it is necessary to have all the distribution nodes georeferenced.

2.2 Virtual End Node

The Virtual End Node (VEN) has operational control of a set of resources/processes and is able to control the electrical energy demand level of such systems in response to a set of received messages (i.e., DR signals). The VEN is able to communicate (2-way) with a VPP receiving and transmitting messages related with the power grid situations, e.g., events or stability conditions. Consumers define the number and type of electrical appliances of the house from a pre-defined list. Five main operation classes are defined based on the operation's responses needs (see Figure 1):

- Class 1: Scheduled-Based Appliances – Concerns with the electrical appliances time periods of operation. Since in the houses there are appliances with flexible operation time, like washing machines, dryers and dishwashers, users can define their operation time window according to the best options in terms of energy availability and energy cost optimization.
- Class 2: Range Temperature Based Appliances – For appliance with temperature range, like refrigerators, heating systems or air conditioners, for which the users can define the operation ranges, the VPP manager will try to fulfil such range based on energy availability and energy cost optimization.
- Class 3: Battery-Assisted Smart Appliances – The EV charging process can be scheduled and controlled to be adapted according to the energy availability and energy cost optimization, e.g., according to the operation of the other electrical appliances connected to the same electrical installation.
- Class 4: Home electrical appliances with prioritized energy supply (equivalent concept of Quality of Service (QoS) in computer communication [12]), due to the needed of a continuous energy supply when they are turned-on. However, according to the user acceptance they can be turned-off if there is no excess or a need in the distribution to take out this consumption. An example of these appliances could be a music player or a laptop because they have their own battery.
- Class 5: Home electrical appliances that the user do not accept turn-off, but they can take production excess, like the example of lights.

3 Decision System for OpenADR

Figure 1 shows the energy distribution with the associated players and the OpenADR functions. Class operation protocol is performed at the Regional Aggregator (RA) and at a central OpenADR system. The RA controls all the local electrical appliances with OpenADR interfaces. This RA based on regional flexibility capacity (total power with

OpenADR interfaces) exchanges information with a central OpenADR command center. This command center has the mission to divide the renewable production excess among the RAs. This division is based on the load capacity available from each RA and this load capacity changes from day period to day period based on client's performed appliance definition. RA also acts as an adviser for client towards the reduction of the energy invoice by providing suggestions to increase appliance aggregation with OpenADR, increase flexibility times, control heating/cooling systems based on the production availability. Therefore, all of these actions are registered through a local home energy management system, and can be accessed through a mobile device or a web interface. RA aggregates all load requests and shows to a central system its level of demand as a time function. The central system suggestion in a first approach (others could be implemented) to divide renewable production among RAs based on their individual level of demand. If the sum of all RA demand loads is not enough to handle excess energy production, traditional reserves (such as energy storage batteries) should be activated. When the excess of produced energy (offer) is lower than the sum of all loads (demand) a decision rationalizing process is activated. For this we implemented the proportional division among all RAs based on classes priority values. This division can be performed based on several approaches, e.g., queuing theory, market value, among others. Afterwards the RA has to divide the energy by the local electrical appliances. At this point several approaches can be implemented, such as: 1 - Energy price; 2 - Priority based on the defined classes; 3 - Stochastic process and; 4 - Distributed equal usage based on the created power profile. As example: user A has 20 kW (40% total power available), user B has 10 kW (20% total power available), user C has 15 kW (30% total power available) and user D has 5 kW (10% total power available). For a case of available power of 10 kW, RA gives 4 kW to user A, 2 kW to user B, 3 kW to user C and 1 kW to user D. The next step is performed internally at each house, which is the prioritization in the distribution of available power. Using the example of a user A, with an available power of 4 kW for a total of 20 kW requested, RA follows the diagram represented in Figure 2, where the first priority is for classes 1 and 3, which are appliances close to the end of their defined time windows. On the contrary, if there is a peak of energy consumption (less energy available), it is possible to turn-off appliances in the sequence defined in Figure 2.

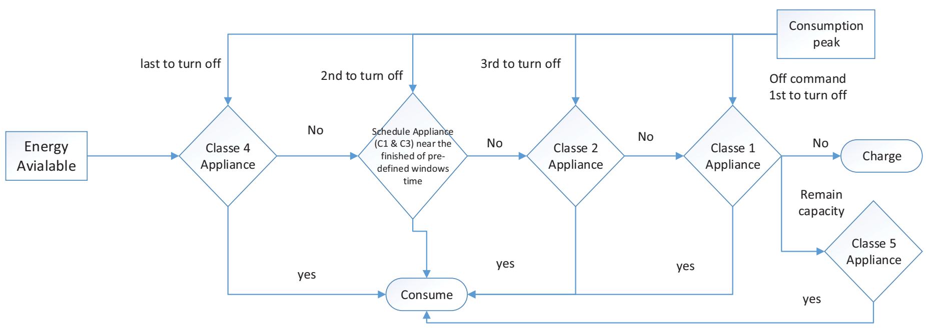

Fig. 2. Prioritization at RA, regarding the distribution of renewable production excess through OpenADR appliances.

For the same class, the home energy management system turns-off appliances taking into account the power consumption. This approach works based on the energy prices reduction, which changes from operation class to operation class. The price reduction would be achieved by the need for lower reserve levels because demand flexibility was introduced. These reserves (identified as spinning reserves) currently represent around 40% of electricity prices [2].

4 Case Study at University of Minho

The proposed solution was validated under a supervised laboratorial installation emulating a real residential pilot, considering a set of PV panels, a flexible remotely controlled energy storage system based on EVs, and remotely controllable residential loads (e.g., heating systems, electric boilers, washing machines, lights, etc.). A web/mobile application is used to handle all the information related with the pilot installation: 1 - Configure remote OpenADR appliance, e.g., heating systems, lights and other loads; 2- Remote control (e.g., turn-on or turn-off) of appliances such as heating systems; 3 - Check energy prices and historical data of consumptions/productions; 4 - Check online consumption when appropriate OpenADR interface is available to follow this remotely. In this laboratory test environment, we used also our developed App for Android (operating system) used to track user movements and interact with [11]. So, based on this app it is possible to identify user's returning home and tune starting time of heating or cooling systems. Besides, using real-time visualization it is possible to interact with OpenADR appliances and receive alerts from RA regarding energy prices and turned on/off appliances. The different appliances (PV panels, batteries and electrical appliances) installed in the experimental setup can be monitored in terms of energy transactions and constraints considering the DR flexibility control. As the implemented pilot was supervised in laboratory environment, the technologies were tested in critical situations (e.g., severe delays in communications, communications faults, and failures in appliances). The obtained data from the monitoring system was useful to evaluate the proposed technologies based on the DR flexibility control. Analysing such scenarios, it is possible to define several cases, as following described.

Case 1 - Time 17 h, with renewable power available of 5 kW. OpenADR appliances are (see Figure 3): washing machine (2 kW) with a window working-time from 14 h to 18 h (class 1), TV plasma 0.3 kW, WC heater 1.2 kW, oil radiator and heater with 2 kW. All of these appliances have a total power of 5.5 kW, but our renewable energy source only can produce power of 5 kW. As a consequence our approach consisted in establishing a time delay to the starting of the of washing machine, because the window working time only finishes at 24 h, and on Class 2 is injected less power. Case 2 - Time 20 h, with start of EV charging process (Class 3 of 3 kW). Together there is a tumble dryer (Class 1 of 3.5 kW), TV Plasma (Class 4 of 0.3 kW) and water heating (Class 2 of 1.5 kW). This represents a total power of 8.3 kW. Taking into account a renewable energy production of 4 kW, in this scenario, the central system decides to provide power to the TV plasma and tumble dryer, and the remaining 0.7 kW is delivered to the water heating. In such scenario, EV charging process is postponed. Case 3 - Time 8 h, with stereo system (Class 4 of 0.06 kW), air conditioner (Class 2 of 1.8 kW), heating water (Class 2 of 1.5 kW) and EV (Class 4), with an available renewable power of 2.5 kW. In this case, the stereo system works and the remaining power is divided by the two Class 2 appliances. EV is in the last charging period and, therefore, the system decides to charge at usual prices avoiding the savings of flexibility charging. An example taking into account laboratory scenario is presented at Figure 3, where we highlight the EV charging process with a maximization strategy to charge based on DR approach. We also simulated Spinning Reserve with an introduced battery, and since DR is implemented, this battery with 20% of renewable production capacity was able to handle also intermittent behaviour of renewable production and meet the production needs to serve the consumption demand.

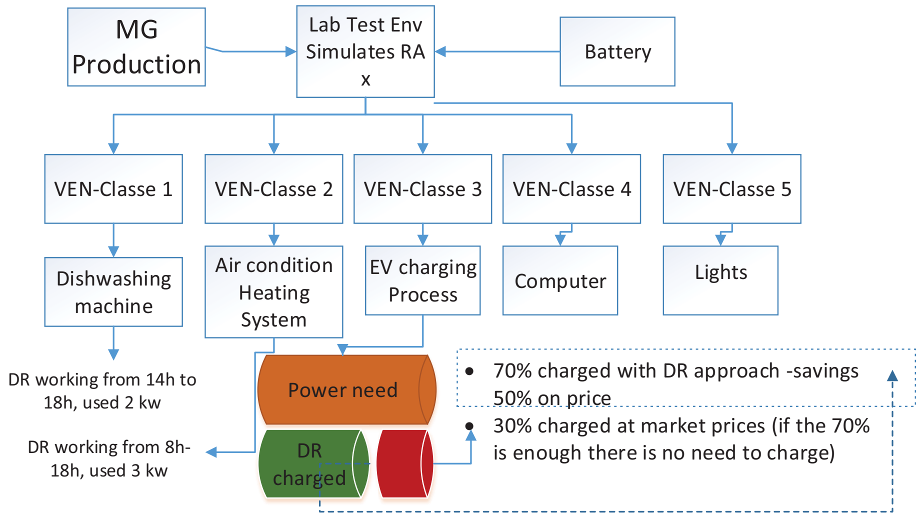

Fig. 3. EV charging process, divided by process priority, a centralization of EV charging profile.

5 Conclusions

This work proposes a new decision process with an approach to handle the Demand Response (DR) concept. Users are invited to participate in such concept by adopting energy consumption flexibility to use electricity at cheaper prices. Along the paper, it is shown the possibility of integrating the proposed decision-making process with the transactional energy market information system (e.g., OpenADR DR), so that energy DR transactions can be implemented automatically. As shown in this paper, a small-scale implementation utilizing variable real-time energy demand profiles was considered. If it is assumed a DR market with an average price around 50% of standard prices, this approach is able to save around 30% on energy invoice without user behavior change in energy consumption patterns.

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