# LISCOOL – A DEMONSTRATION PROJECT OF AN AUTOMATED FAST DEMAND RESPONSE MANAGEMENT SYSTEM: MAIN OUTCOMES

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## *ABSTRACT*

*The increasing integration of Renewable Energy Resources (RES) in distribution systems with an inherent variable production along with the inclusion of new assets, such as Electric Vehicle Charging Stations, is leading to an increasingly challenging network management. These assets, besides having a volatile demand profile, may also require large amounts of energy from the grid in short periods, which a traditional electrical grid is not prepared to respond to. To address this growing issue, an Automated Demand Response System (ADRS) was developed under LISbon COOL (LISCOOL) energy project scope. This paper aims at presenting the project's main results and lessons learnt from the first year of operation, while briefly introducing the system's architecture. The results show the adequacy of the system to reduce the variability of the demand and to promote better standards of energy efficiency. In addition, the system is effective on helping grid operator tackling contingency situations in the network.*

## INTRODUCTION

In recent years, there have been significant changes on Distribution Networks, driven by the fast deployment of Distributed Energy Resources (DER) such as Electric Vehicles (EVs) and microgeneration units. Considering the inherently unpredictability of supply and demand associated with these resources, their integration poses several challenges to the efficient and safe operation of networks, i.e., within the technical limits (e.g. control voltage rise).

Although the simplest solution to tackle the technical operation problems would be the control of DER itself (e.g. disconnect a microgeneration from the grid), its scope is not efficient, as most of these units are private owned and thus, the control capabilities by the network operators are very limited.

There is a growing consensus among policy makers and market participants that demand side flexibility, empowered through Demand Response, is one critical resource for achieving low carbon, efficient electrical grid. Demand Response, in its basic form, is a change in the power consumption of end-users in response to financial incentives based on the operation requirements of the electrical grid. With the rise of interconnectivity and smart devices, Demand Response programs are progressively moving towards automation and the industry itself closer to the Smart Grid paradigm. The advances on integrating information and communication technologies (ICT) allow the system operator to interact and efficiently coordinate, in real time, a substantial number of distributed resources in an automated fashion.

Based on this premise, a demonstration project is being carried out in Lisbon, Portugal between November 2016 until December 2019, sponsored by New Energy and Industrial Technology Development Organization (NEDO) – a Japanese governmental agency.

One of the goals of LISbon COOL energy (LISCOOL) demonstration project is to implement an Automated Fast Demand Response Management Solution (AFDRMS). The AFDRMS system forwards Demand Response requests based on weather forecasts, renewables production and power grid status to the end-user, automatically managing its consumption for accepted events. Fundamentally, this system works as an energy services provider and can operate under two main modes:

i. **DER program** – The objective function is to maximize renewables auto-consumption on a micro-grid level, optimizing energy needs from the network on a daily basis. Demand Response Management System (DRMS) computes the optimal operation of consumers' flexible loads, in order to reduce reverse power flows, lines congestions and voltage rise on the Distribution Networks.
ii. **Direct Load Control (DLC) program** – The objective function is to resolve contingency situations on the network. In this case the DLC events are triggered by the network operator which inputs in the system the required flexibility. DRMS then forwards the requests to its assets. Due to the emergency character of this program, its command overrides the DER program operation.

For demonstration purposes on the end-user behaviour, two buildings were provided by the Lisbon City Council. In each one, PV microgeneration units and Air Conditioning (AC) systems with cold storage tanks units

were installed. Currently under development, tank units are being tested as an alternative to conventional energy storage systems. The consumption of the AC Systems, coupled with the tank units is adjusted according to the controls actions calculated by the Demand Response Management System (DRMS).
After an initial design and implementation stage of the system and equipment installation, the system went into preliminary operation between May 2018 and October 2018. Throughout this period, signal exchanges between servers and Demand Response events were tested, ensuring an error free operation. The comprehensive system deployment and fully automated operation is scheduled for summer, 2019.
This paper's aim is to present the main results and lessons learnt from the preliminary operation phase.

## SYSTEM OVERVIEW AND DESCRIPTION

The AFDRMS system is designed to operate in an automated fashion without the need of intervention from the users. The system architecture is depicted in Figure 1, where two main actors can be identified:

i. **DRMS –** is the central management system, working as an aggregator of energy services. It is responsible for managing the data from different users – which have subscribed the participation in the DR programs – and to generate controls to their controllable devices. This way, it simplifies complexity on customer side as it comprises embedded optimization and generation forecasts algorithms that can be applied on a centralized system for all the consumers. On the specific case of the project, the controllable devices are the AC systems.

ii. **AC ADR server** – is the cloud-based system responsible for collecting and aggregating the operational information from AC systems and managing the units upon receiving signals from the DRMS.

While running the DER program, the DRMS optimizes the AC consumption schedule of each end-user, in order to minimize the energy needs from the network, based on local energy generation. In order to do so, AC ADR server computes, on a first instance, a day ahead consumption forecast and respective flexibility limits on a 30-minutes period basis. It is also able, when required, to send an updated forecast report during an intraday operation mode. The intraday update allows to perform a more granular optimization as there might be significant differences between forecasts and real operation conditions.
Upon receiving the reports from the AC ADR server, the DRMS gathers information on weather forecasts and power consumption/production on each site through installed smart meters, using it to produce its own forecasts, such as PV generation. After processing all the information, the AC ADR server sends an optimized consumption schedule.
Lastly, the AC ADR server processes each Demand Response request and responds to the DRMS with Opt-in or Opt-out responses. Controlling signals are then sent to the locally installed AC Systems, in order to reach the power consumption setpoints of each accepted event.
On DLC program, which has an emergency character, the DRMS uses the last flexibility reports, to run an optimization for distributing Demand Response events for all the subscribers in order to quickly achieve the flexibility request from the grid operator.
The standard protocol OpenADR 2.0b [2] was used for the communications between the DRMS and the AC ADR server. Hence, the DRMS is also fully prepared to manage other end-devices such as Home Energy Management Systems (HEMS) that are compliant with the OpenADR 2.0b protocol data exchange. In such a way, a multitude of heterogeneous end-users and devices can be aggregated in the DRMS endowing this solution with a high scalability.

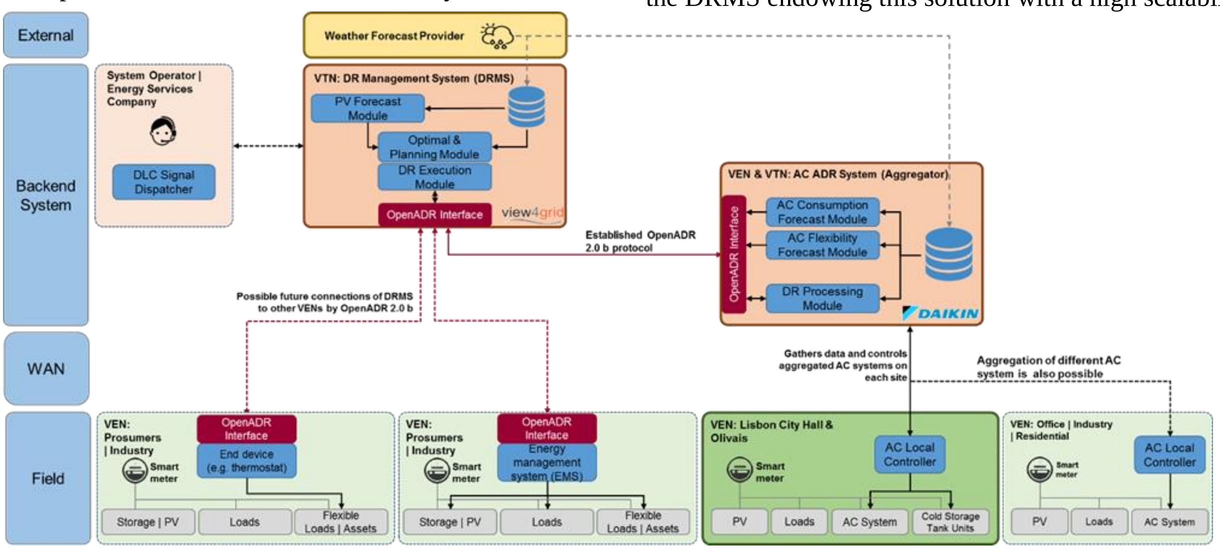


*Figure 1 – AFDRMS Architecture.*

## OPERATION RESULTS

Throughout the summer of 2018, the preliminary operation of the overall system was proceeded as scheduled. Throughout this phase, signal exchanges between servers and actual Demand Response events were tested. It was primarily focused on identifying and correcting errors in order to smoothly transition from manual to automated operation. After the necessary adjustments and adaptations to the logic and processes, all schedule exchanges and optimizations worked reliably and operational data was retrieved.

Through a high-level analysis on the operation data, represented on Table 1, out of 197 events sent for both buildings, 98 targeted Lisbon City Hall and 99 targeted Olivais Building. Also, roughly of the events got accepted by Daikin's AC ADR server - 56% and 45% opt-in events for City Hall and Olivais, respectively.

*Table 1 – Summary of the Fast DR events' results*

| Parameter | City Hall | Olivais |
|---|---|---|
| **Events with Opt-In response** | 54 | 44 |
| **Events with Opt-Out response** | 44 | 55 |
| **Percentage of Opt-In events** | 56% | 45% |

From the opt-in events, it is fundamental to assess the accuracy of the AC ADR server. Referring to the values presented in Table 2, there is a significant discrepancy from the minimum, average and maximum deviation. Whereas the minimum deviation is practically zero (precise response by the AC System), the maximum deviation reaches 12,02 kW (735%) and 42,02 kW (3066%) for City Hall and Olivais, respectively. Averagely, the absolute deviation observed is equal to 2,31 kW (63,0%) for City Hall and 3,33 kW (200,5%) for Olivais.

*Table 2 – Summary of the deviation analysis*

| Parameter | | City Hall | Olivais |
|---|---|---|---|
| **Abs. Min. Deviation** | [kW] | 0,06 | 0,00 |
| | [%] | 0,9% | 0,2% |
| **Abs. Avg. Deviation** | [kW] | 2,31 | 3,33 |
| | [%] | 63,0% | 200,5% |
| **Abs. Max. Deviation** | [kW] | 12,02 | 42,02 |
| | [%] | 735,0% | 3066,0% |

One of the main reasons for the significant maximum deviation for both sites is the high level of uncertainty associated to the AC System consumption and flexibility prediction. The forecast, due to the lack of operational data, still displays a low accuracy, which impacts the optimization algorithm on the DRMS system. Ergo, there are events with power consumption target, which during real time operation, are not feasible, eventually leading to exceptionally high deviations.

Other reason associated for such results was the interpretation conflict which was identified during the signal exchanges between servers. Throughout the preliminary operation, the AC System did not properly comply with the DR events due to minor discrepancies in interpretation of a few parameters between DRMS system and AC ADR server, which were identified and corrected. However, it is worth to pinpoint that these are punctual situations and do not represent in any case a typical event.

In Figure 2, a box plot chart is plotted based on the AC Setpoint deviation without considering the outlier values. In this case, the average deviation decreases to around 1kW for both sites

Comparing both sites, there is a slightly higher tendency in City Hall for positive deviations, i.e., real consumption above the setpoints is observed (around 66%), and the opposite for Olivais site (64% of negative deviations). The 25th percentile is -28,5% for City Hall and -48,7% for Olivais while the 75th percentile is around 29,1% and 10,3% respectively. Finally, the median of the AC setpoint deviation for City Hall is equal to 8,3% and -22,8% for Olivais site.

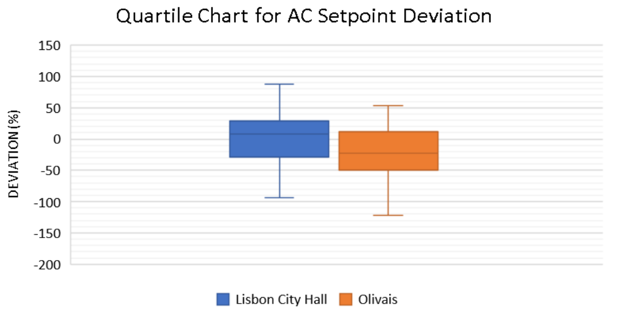


*Figure 2 – Box plot chart for both City Hall and Olivais: AC Setpoint Deviation.*

In the following subsections, an example for DER and DLC program is analysed in-depth.

### 1. DER Example

Regarding DER program, the DRMS computes and issues an optimized daily schedule divided into 30-minutes based on the available flexibility. The AC aggregating system, in turn is responsible for accepting or refusing the DR events based on any operational constraints.

In Figure 3, the daily consumption on October 19th 2018 for Lisbon City Hall is depicted. In total, throughout this day, eight DR events were received and accepted by the AC ADR server. Additionally, the forecast and the existing flexibility issued on a day-ahead from AC Aggregating system are also plotted.

Firstly, focusing on the events received and consequent response, the AC system showed a good compliance, as the deviation from the target was less than 1kW for most of the events.

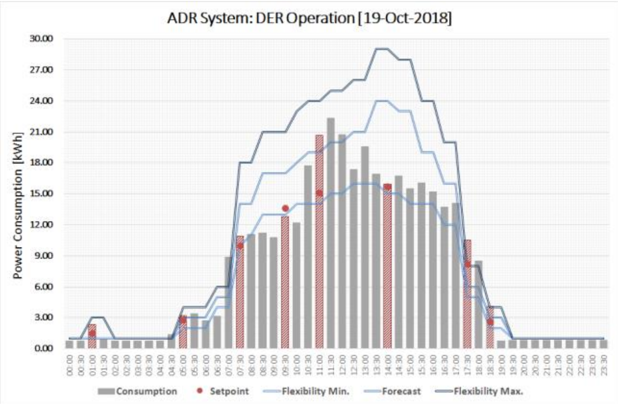


*Figure 3. ADR operation: DER Program (19/10/2018)*

There is one event, between 11:00am and 11:30am, that the AC System did not comply as expected and the actual consumption surpassed the setpoint in about 5,5kW. As mentioned above, the significant difference between the forecast algorithm and the actual consumption consequently impacts the optimized schedule sent by the DRMS.
The information related to the accepted DR events is presented on Table 3.

*Table 3. DER program events (19/10/2018)*

| Time [UTC] | Setpoint [kW] | Real [kW] | Deviation [kW] | Abs. Error |
|---|---|---|---|---|
| 01:00 – 01:30 | 1,50 | 2.35 | 0,85 | 56,7% |
| 05:00 – 05:30 | 2,80 | 3,23 | 0,43 | 15,3% |
| 07:30 – 08:00 | 10,02 | 10,87 | 0,85 | 8,5% |
| 09:30 – 10:00 | 13,62 | 12,80 | -0,82 | 6,0% |
| 11:00 – 11:30 | 15,12 | 20,65 | 5,53 | 36,6% |
| 14:00 – 14:30 | 15,70 | 15,92 | 0,22 | 1,4% |
| 17:30 – 18:00 | 8,25 | 10,50 | 2,25 | 27,2% |
| 18:30 – 19:00 | 2,60 | 4,16 | 1,56 | 60,1% |

## 2. <u>DLC Example</u>

On an earlier stage of the operation, the DLC program was also tested. The results on August 16th 2018 for Olivais building are presented in Figure 4.
In total 4 *negawatt* events – half of which had 1h duration - and 1 *posiwatt* event were opted-in by the AC aggregating system.
Contrary to the DER program, in which the optimization process is highly dependent on the accuracy of the forecasts, the DLC case relies solely on the available flexibility at the moment of the grid emergency. Hence, not only a substantial difference between the baseline consumption and the consumption during the Demand Response events is perceptible, but also the accuracy of the AC System is much higher.

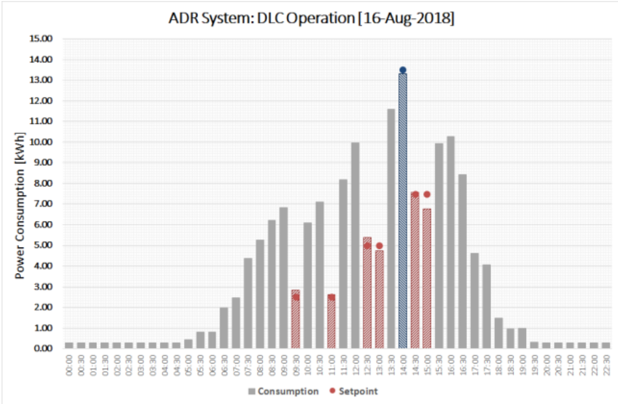


*Figure 4. ADR operation: DLC program (16/8/2018)*

Moreover, based on the Table 4 values, the AC System displays a great accuracy achieving the consumption target, with deviations below 1kWh for all events (the maximum absolute error is 13,4%)

*Table 4. DLC program events (16/08/2018)*

| Time [UTC] | Setpoint [kW] | Real [kW] | Deviation [kW] | Abs. Error |
|---|---|---|---|---|
| 09:00 – 09:30 | 2,50 | 2.84 | 0,34 | 13,4% |
| 11:00 – 11:30 | 2,50 | 2,62 | 0,12 | 4,7% |
| 12:30 – 13:00 | 5,00 | 5,38 | 0,38 | 7,6% |
| 13:00 – 13:30 | 5,00 | 4,74 | -0,76 | 5,1% |
| 14:00 – 14:30 | 13,50 | 13,33 | -0,17 | 1,3 |
| 14:30 – 15:00 | 7,50 | 7,57 | 0,07 | 0,9% |
| 15:00 – 15:30 | 7,50 | 6,77 | -0,83 | 9,8% |

## LESSONS LEARNT

Heretofore, one of the major lessons learnt from the LISCOOL project is related to the OpenADR 2.0b protocol implementation. It is used for the communications between the DRMS and the AC ADR server and presented several challenges. Since it has a wide comprehensiveness of features, adjustments were required according to the end devices capabilities, the DR framework and project scope.
Secondly, during the preliminary operation, the day-ahead AC consumption and available forecast is still not accurate due to the lack of operational data. Consequently, it impacted the definition of a baseline consumption, i.e. electricity that would have been consumed if a demand response event had not been accepted. The baseline, therefore, indicates the normal energy usage and allows to calculate the total amount of *negawatt* or *posiwatt* provided by the AC ADR server. Notwithstanding, on the results discussed above, the AC system's capacity to change its consumption according to the consumption targets received is clear. The forecast algorithm for the AC system is expected to be improved until the fully

automated operation in 2019.

On the other hand, the forecast uncertainty also impacts the optimization algorithm on the DRMS side. The uncertainty of forecasts leads to DR events with setpoints that are impracticable, since real time consumption greatly differs from the forecast, ultimately leading to the non-compliance of the AC ADR server to the event. It is evident that an intraday mode, responsible for continuously updating the forecasts based on real operation conditions is required. The intraday mode is particularly important for the system operator as it reduces the uncertainty and produces better technical and economical results.

Lastly, the use of AC system with cold storage tank units, presently under development, introduced additional challenges. It was required to create new models and respective control commands to characterize and optimize the flexibility provided by coupling the operation of the AC system with the tanks. It comprises a much more complex control dependent on different variables, opposite to conventional energy storage systems (batteries), in which the power output can be directly adjusted.

## FUTURE WORKS

As a preparation for the full system deployment, during the summer of 2019, the partners will focus on improving the reliability of exchanged signal values between different parties (i.e. forecasts, optimized schedules, among others) and on enhancing the robustness of the AFDRMS platforms for precise control and measurements.

Regarding the flexibles loads, further investigation and evaluation on the operational performance of AC system with cold storage tank units (e.g. efficiency improvement, controllability) will be required.

## CONCLUSIONS

The main differentiating aspect of LISCOOL refers to its capability for introducing consumers as a flexible and active participant in the network management, enabling among others, the increasing of the networks capacity to host new DER, to increase the penetration levels of renewable energy in the energy mix and the improvement of the quality of service and energy. In addition, it leverages the reduction of the greenhouse gas emissions and promotes better standards of energy efficiency.

Overall the results are very reasonable since a technical analysis of this global solution shows the effectiveness of the AC system to adapt its consumption according to the DRMS commands without compromising the thermal comfort of the building.

Finally, the first-year operation results show that this system can be effective on helping grid operator tackling contingency situations in the network and that DER program can contribute for flattening the load profiles.

In conclusion, LISCOOL project entails an aggregating platform promoting consumers as active participants on electricity markets by taking advantage of the flexible load of the AC systems.

## ACKNOWLEDGMENT

The LISCOOL project is sponsored by the Japanese governmental agency NEDO – New Energy and Industrial Technology Development Organization. We gratefully thank Lisbon Municipality for being committed with the project, for providing two demonstration sites and for all the support on the equipment installation. Finally, we also would like to thank to our colleagues from Daikin and Efacec, who provided insight and expertise that greatly assisted LISCOOL project implementation

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