TABEDE: A NEW SOLUTION FOR DEMAND RESPONSE, CLEAN ENERGY & COST SAVINGS

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Abstract

In this paper, authors share preliminary findings from TABEDE (Towards Buildings Ready for Demand Response), an innovative, 3-year Horizon 2020 R&D program that aims to scale Demand Response (DR) across all building types. The key element to TABEDE is a Building Management System-Extender (BMS-E) that can either connect remotely to a site's existing BMS to deliver DR capabilities or be installed on site. It will control and optimize building loads directly in response to grid signals. TABEDE includes components that forecast and optimize energy consumption, incorporate DR requests, and control loads across a range of communication protocols.

A distinguishing feature of TABEDE is that the solution is being tested in real-world settings at three pilot sites (two residential and one tertiary building), and one simulated district environment. This paper shares preliminary results from the project that show, under certain conditions, energy cost savings of between 6% and 8% are possible at the two residential test sites with TABEDE installed, while widespread implementation of TABEDE at the neighborhood level could increase self-consumption of solar photovoltaic (PV) and mitigate the risk of renewables curtailment.

1 Introduction

Electricity systems are changing rapidly, throughout the world and especially in Europe. The old model of centralized, fossil-based generation is giving way to a cleaner and more distributed future with greater reliance on Renewable Electricity Sources (RES). While this shift is reducing carbon dioxide (CO_2) emissions, increased penetration of RES, due to its variability, poses new challenges to grid operators as they seek to balance electricity supply and demand.

DR is a strategy that can lower energy bills for building owners and occupants, reduce periods of peak demand and lead to greater integration of RES. Through DR, a building will modify some portion of its electricity consumption at the request of a grid operator in order to better balance supply and demand. DR programs can be categorised into price-based and incentive-based (1). Price-based programs provide customers with time-varying energy tariffs. Incentive-based programs offer direct payments to customers to change their consumption patterns upon request. In practice, a price-based program could offer consumers lower electricity tariffs during times of peak RES availability (2). This incentivizes end-users to shift their consumption to these periods to take advantage of abundant clean energy supplies. Alternatively, direct payments could be made to consumers to reduce consumption during times of peak demand to avoid congestion problems.

While DR programs are gradually taking hold throughout Europe, certain limitations continue to hamper progress (3). Focusing on the end-use level, some of the barriers include: lack of interoperability among communication technologies, protocols and data models used in building automation and energy management systems; high cost of adapting existing building management systems (BMS) to include DR capabilities; lack of standard DR protocols and the lack of market-ready BMSs that can support DR out of the box.

TABEDE is a 3-year Horizon 2020 R&D program that seeks to overcome these barriers and scale DR across all building types. The key element to TABEDE is a BMS-Extender (BMS-E) that can either connect remotely to a site's existing BMS to deliver DR capabilities, or be installed on site and control and optimize building loads directly in response to grid signals. The TABEDE project team is composed of the following partners: ENGIE Impact[1] (project coordinator), CEA (Le Commissariat à l'Energie Atomique et aux Energies Alternatives), Cardiff University, CSEM (Centre Suisse d'Electronique et Microtechnique), Schneider Electric, Schneider Electric Italy, and R2M Solution. Now in its final year, the TABEDE project is validating the BMS-E at three test sites and a neighborhood-scale simulation environment.

2. Methodology

In the first phase of the project, the TABEDE team built the BMS-E and supporting software components that together forecast energy loads, optimize device schedules, emulate electricity price signals and measure grid impacts.

2.1 The TABEDE System

TABEDE is an interlinked system of hardware and software components designed to seamlessly connect with one another to allow buildings to optimize energy consumption on the basis of grid signals, weather patterns, and occupant preferences. The BMS-E occupies a central role. It can be installed in a building as physical hardware or remotely, as a virtual extension in the cloud to a building's existing BMS. In either case, the BMS-E can accommodate most communication protocols available on the market, such as EnOCean, ModBus, WiFi, Bluetooth, Zigbee and Z-Wave, so it can be "plug and play" and quickly communicate with different devices/appliances, regardless of the manufacturer.

The BMS-E's interaction with the other project components to form the overall TABEDE system is illustrated in **Figure 1** below and described in more detail here (the components developed through the project are in bold). The **BMS-E** begins by collecting building-level appliance and equipment energy consumption data, user preferences entered by the building owner and/or occupant through the **End-User Interface**, and grid signals simulated by the **DR Automated Server (DRAS)**. The **Real-time Energy and Environmental Forecasting and Simulation (REEFS)** system receives the energy consumption data from the BMS-E and uses it to produce 24-hour, day-ahead forecasts at 15-minute intervals. **The Agent Based Optimizer (ABO)** (4) receives the forecasts from REEFS and combines it with the DR signals and user preferences it receives from the BMS-E to create optimized load profiles. These are then sent back to the BMS-E, which sends control signals to the appliances and equipment to match the optimization specified by ABO.

To test TABEDE's impact at the community and grid-scale, the project team is utilizing Smart Operation (SO), an existing tool from ENGIE Impact. SO assesses the optimal operation of an electrical distribution network in the presence of distributed energy resources such as PV, electric vehicles (EVs), and battery storage systems, while adhering to grid constraints such as voltage and current limits (5).

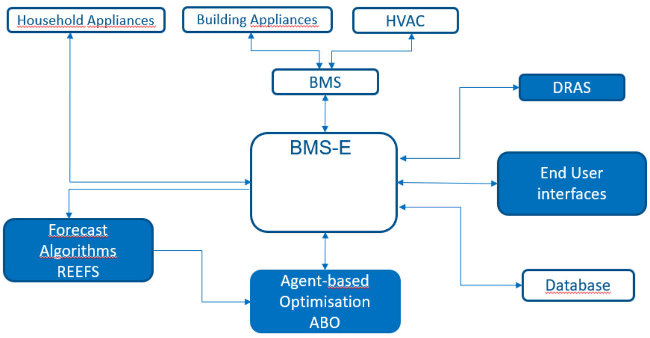

Figure 1: TABEDE Operating System

2.2 Validation

With the TABEDE system successfully built, the project team is now validating the solution at three test sites (two residential houses in UK and IT, one commercial building in FR) and a simulated district. The validation process seeks to demonstrate that the TABEDE system: 1) functions properly, with its constituent parts performing as expected and communicating with each other in an integrated manner; and 2) achieves an impact in terms of energy cost savings and increased RES utilization.

Objective 1 was accomplished through extensive system testing. Objective 2 is still being pursued, but preliminary results (which are described in more detail in section 3) show that at the residential test sites, TABEDE can drive energy cost savings between 6% and 8% by shifting flexible building energy consumption from periods of low to high on-site renewable generation, thereby displacing higher-cost grid-purchased electricity, all while respecting user preferences that building owners and occupants enter through a web-based system. To be clear, these results were achieved through off-site simulations—essentially optimization experiments using real test site data, but stopping short of controlling devices. Incorporating device control into the experiments and measuring impacts at the house level is one of the next steps for the project.

At the district level, preliminary results support the hypothesis that widespread implementation of TABEDE within a neighborhood can reduce grid-level congestion by adjusting consumption across multiple buildings and minimize the risk of RES curtailment by shifting aggregate consumption to better match peak RES generation.

3 Results

TABEDE is being validated at three test sites and in a simulation environment. Two of the test sites are residential

[1] ENGIE Impact is the new name for Tractebel's Advisory and Advanced Analytics team.

(in Cardiff, UK and Bergamo, Italy), the third is a commercial/industrial building (in Grenoble, France). In this paper, we share results from the two residential sites and simulation environment. Results are not yet available at the commercial/industrial site.

3.1 Cardiff, UK

The Cardiff, UK, test site, known as Tŷ Smart, is a recently-built prototype smart house, representative of new houses built in the UK. Energy efficiency of the house is rated A, the highest rating that can be achieved, while the average rating of dwellings in the UK is D (60). Four people occupy the house.

Based on preliminary results, TABEDE was shown to reduce energy costs by about 6% through load shifting. In this case, we selected a typical winter day in January in Cardiff and utilized a time of use pricing system similar to the real rates paid by the homeowner. To be more specific, we used a peak price of 0,20 €/kWh (covering the time period of 07:00 AM and 12:00 PM), off-peak of 0,13 €/kWh (for the rest of the hours), and an electricity export tariff of 0,04 €/kWh. The export tariff ends up being a key variable that effects the overall economic performance of the system. In Cardiff's case, excess PV can be sold to the grid, but at rates that are much lower than the retail rate (both peak and off-peak). As a result, there is an economic incentive to self-utilize as much PV generated on-site as possible.

In our tests, the TABEDE system successfully optimized consumption to take advantage of this dynamic. This movement is represented in **Figure 2** by the difference between the consumption of flexible loads in the baseline period (pre-TABEDE, red curve) and the optimized flexible loads (post-TABEDE, blue curve). The baseline is the forecast of the same day, provided by REEFS based on the consumption and production patterns of the building and other influencing variables. As shown in the figure, the optimized flexible loads have now been shifted to consume energy in the late morning, and mid-afternoon when solar PV is available (represented by the orange curve). In this experiment, flexible loads included were the washing machine, air purifier, and robotic vacuum cleaner.

The more specific energy consumption and cost data is shown in **Table 1** below. Cost savings are driven by the increase in self-utilization and corresponding decrease in electricity exports, rather than load shifting from periods of high-to-low energy prices. Note that with TABEDE, the Cardiff site achieves 100% self-utilization of solar PV, when fixed loads not shown in the graph are taken into account. This is due in part to the relatively small size of the PV system at the house as well as the limited amount of available solar radiation in Cardiff during the winter time. For context, without TABEDE, the site was utilizing a little more than 85% of the available solar.

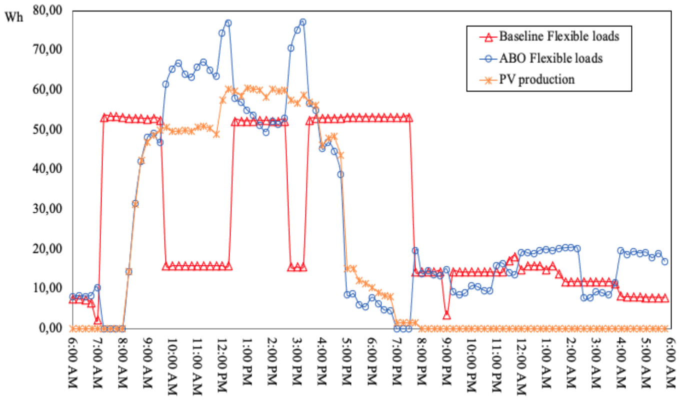

Figure 2: TABEDE Optimization Results at Cardiff, UK Site

	Pre-TABEDE	Post-TABEDE	Difference	%
Total consumption	5,73 kWh	5,73kWh	--	--
Energy import	4,06 kWh	3,81 kWh	0,24kWh	-6%
Energy export	0,24 kWh	0,00 kWh	0,24 kWh	-100%
Energy import cost	0,73 €	0,68 €	0,5 €	-8%
Export revenue	0,01 €	0 €	0,01 €	-100%
Total daily energy costs	0,72 €	0,68 €	0,04 €	-6%

Table 1: Energy Cost Savings at Cardiff, UK Site

Six percent is not a massive reduction in electricity costs—it represents a little less than 22 € saved over a year. Still, we consider it a respectable figure considering the experiment was done in a winter day with relatively limited flexibility. If we repeat this in summer, with more solar, the opportunities to take advantage of available on-site PV will increase, and with it, the cost savings [6]. In future experiments, we will add an electric radiator as a flexible device, which may present new opportunities for optimization and cost savings.

3.2 Bergamo, Italy

In Bergamo the demonstration site is a residential building, recently refurbished and with a basic BMS system installed. This type of building, with no or limited technological solutions for monitoring installed, is common for the Italian and European residential market, therefore an important focus of the TABEDE project to ensure replicability of outcomes.

Based on our preliminary results, TABEDE was shown to reduce energy costs by about 8% through load shifting. In this case, we used a typical autumn day in late October and utilized the following energy price scheme (which generally matches the real prices the resident pays): 0,17 €/kWh (from Monday to Friday 08:00 AM to 07:00 PM), off-peak of 0,14 €/kWh, and an electricity export tariff of 0,045 €/kWh.

Similar to the Cardiff site, the cost savings are driven by the shift in consumption of flexible loads to periods with available solar PV. **Figure 3** below shows how some flexible loads have moved from late afternoon/early evening in the baseline period (pre-TABEDE, represented by the red curve) to the morning in the optimized scenario (post-TABEDE, represented by the blue curve), to take advantage of the available solar resources (represented by the orange curve). Note that at some points the red and blue curves overlap, indicating no change in the behaviour of the flexible loads during those periods.

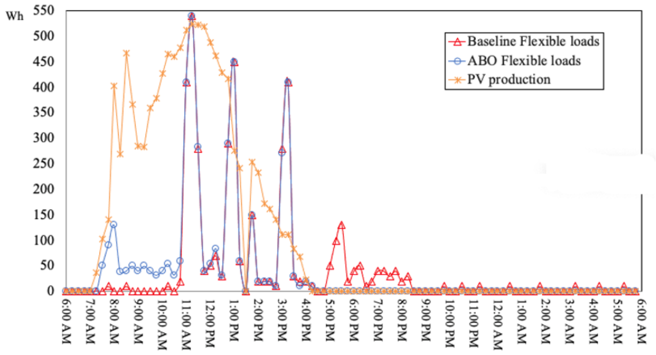

Figure 3: TABEDE Optimization Results at Bergamo Site

Table 2 provides a more detailed look at the consumption and cost savings experienced at the site. Similar to Cardiff, the savings are driven by the optimization of on-site solar. Unlike the Cardiff site, however, Bergamo never achieves 100% utilization of on-site generated PV. Even in the optimized scenario, the Bergamo site is still exporting 3,24 kWh to the grid, at a price substantially lower than the retail price. This is because the available PV is higher than the available flexibility, therefore there is still excess to be exported. Further cost optimizations would therefore be possible if some of the existing fixed loads could be made flexible to shift their consumption patterns to soak up some or all of the remaining on-site PV capacity, or energy storage mechanisms. As it stands, in this case, the 8% savings, extrapolated out, factor to about 62 € per year.

	Pre-TABEDE	Post-TABEDE	Difference	%
Total consumption	20,92 kWh	20,92 kWh	--	--
Energy import	14,3 kWh	12,77 kWh	1,53 kWh	-11%
Energy export	4,78 kWh	3,24 kWh	1,54 kWh	-32%
Energy import cost	2,29 €	2,04 €	0,25 €	-11%
Export revenue	0,22 €	0,15 €	0,07	-11%
Total daily energy costs	2,07 €	1,90 €	0,17 €	-8%

Table 2: Energy Cost Savings at Bergamo Site

The project team is preparing to introduce an energy storage mechanism in Bergamo through a combined electric heat pump-hot water system. The system is designed so that when available solar PV exceeds the home's electrical demands, the heat pump is instructed to increase the temperature of the water tank, with the heated water stored for future use. In this way, excess electric energy from the PV will be stored. As a result, we expect grid exports to be reduced significantly, perhaps to zero, leading to much greater cost savings.

3.3 Simulation Environment

The development and pilot-site validation of the TABEDE solution focuses on individual residential and tertiary buildings. Through the TABEDE Simulation Environment we also investigate the impact of TABEDE at the district level by simulating a community of managed buildings in a residential district in the UK. Through the Simulation Environment we can: simulate energy demand and generation at each building and the district level; estimate the flexibility of the district based on the generation of renewables, building energy consumption, and penetration of the TABEDE solution; and model the impacts of TABEDE on the district as a whole.

The district and its grid topology are modelled off the Penarth Heights neighbourhood in Vale of Glamorgan, Cardiff, UK. It is essentially a model of the neighbourhood that surrounds the Cardiff test site presented on page 3. Our simulated neighbourhood consists of 66 houses with a mean consumption of about 15kWh per day. Among the use cases explored through the project, we utilized the simulation environment to evaluate how TABEDE can increase on-site PV consumption, thereby reducing grid congestion and minimizing the risk of RES curtailment. Specifically, we model a situation in which the district generates aggregate PV that is both greater than its own needs and subsequently more than can be injected to the grid due to overvoltage issues.

In this simulation, we look at two broad scenarios—one that assumes half the homes have PV installed and the other that assumes all do. To capture the range of possibilities, we apply these scenarios to summer and winter conditions, using the best and worst days, respectively, for solar irradiation. All scenarios assume a level of PV penetration that is vastly higher than currently observed within the Cardiff Penarth neighbourhood, but the higher rates are assumed in this case for illustrative purposes to better understand TABEDE's impact. In our analysis, we define self-consumption as the percentage of total PV output consumed on-site.

As shown in **Figure 4** below, looking first at the bottom graph, PV self-consumption increases in all scenarios as TABEDE penetration increases. The most significant impacts are seen in the "Winter—100% PV Penetration" scenario, with self-consumption increasing from about 37% with no TABEDE installed in the neighbourhood, to a PV self-consumption rate of a little over 60% with TABEDE installed in all homes.

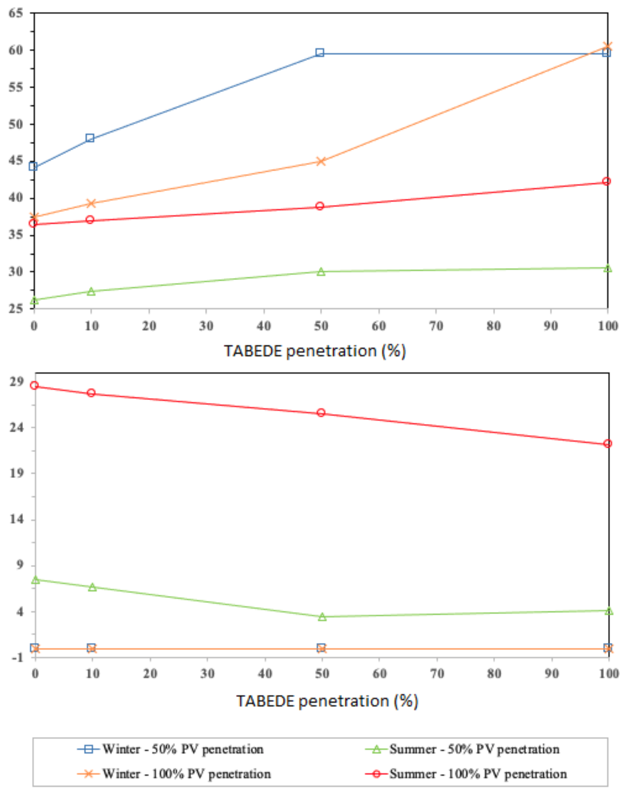

Figure 4: TABEDE Drives Increased Levels of PV Utilization

We then impose a set of grid constraints assuring the grid's quality according to nominal standards. Due to this limitation, excess PV that could ordinarily be injected back to the grid is constrained. This leads to curtailed, or wasted PV, as the renewable electricity can neither be used on site or sold to the grid. In our model, only the summer scenarios are relevant to the curtailment case as there is not enough PV in winter to produce the overvoltage problem. In summer, though, we can see that TABEDE can limit curtailment, as it shifts flexible loads to consume more PV on site and reduce aggregate exports. In our model, curtailment drops by about 45% in the 50% PV scenario and 22% in the 100% scenario when TABEDE increases from zero to full penetration.

4 Conclusion

In early experiments, TABEDE has demonstrated its effectiveness in driving energy savings at the residential sites and increasing utilization of self-generated PV within the simulation environment. This shows TABEDE can be effective in enabling flexibility at the building level and increasing the range of buildings able to participate in DR.

It is important to note, however, that TABEDE itself does not create flexibility. Therefore, the upper boundaries of the energy cost savings it can facilitate will be dictated by the flexibility inherent in the building. Energy cost savings driven by TABEDE can be expected to increase over time as behind the meter batteries, distributed RES, electric vehicles, and electric heating systems continue to take hold in the market. Increased rates of building electrification, RES penetration, and energy storage capacity are themselves being driven in part by policy developments at the European Commission and Member State level. Additional policy measures that could expand flexibility markets and increase uptake of DR, include: stronger financial incentives for end users to participate in DR schemes, and the establishment of clear data access and exchange protocols. Additionally, we foresee a positive role for traditional green building rating systems, such as the Leadership in Energy and Environmental Design to factor the ability of a building to activate flexibility as part of their ratings. Lastly, while TABEDE has largely succeeded in developing a system that is interoperable with a wide range of communication protocols at the device level, the establishment of an open standard that governs communication between buildings and the grid could help further speed adoption of DR solutions.

5 Acknowledgements

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6 References

[1] European Commission DG Energy "Impact Assessment Study on Downstream Flexibility, Price Flexibility, Demand Response & Smart Metering" ENER/B3/2015-641, July 2016

[2] IRENA (2019), "Innovation landscape brief: Time-of-use tariffs", International Renewable Energy Agency, Abu Dhabi

[3] "Final Report: Demand Side Flexibility - Perceived barriers and proposed recommendations" European Smart Grids Task Force, Expert Group 3 (2019)

[4] O. Kem and F. Ksontini, "A Multi-Agent Approach to Energy Optimisation for Demand-Response Ready Buildings," Artificial Intelligence Techniques for a Scalable Energy Transition, pp. 77-107, 2020

[5] Chittur Ramaswamy, Parvathy, et al. "A case study to assess data management and performance of optimal power flow algorithm-based tool in a DSO day-ahead operational planning platform." CIRED 2019 Conference

[7] Amin, A. Kem, O. Chervet, P., et al. "An Intelligent Infrastructure for Enabling Demand-Response Ready Buildings." International Conference on Applied Energy 2020, Bangkok/Virtual, December 2020