ASSESSMENT OF FLEXIBLE DEMAND RESPONSE BUSINESS CASES IN THE SMART GRID

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ABSTRACT

The purpose of this work is to assess three selected business cases in a smart grid environment that have been designed by project members of the EU co-funded SmartHouse/SmartGrid project. These cases cover balancing services, demand side management and micro grid operations. Each business case and its individual technology architecture are evaluated with respect to expected costs and revenue. Results suggest that in the modeled reference scenario, there are profitable business cases and also cases which are not yet profitable under current conditions.

INTRODUCTION

In a conjoint approach, the European governments have decided to face the threats of an ongoing climate change and its possible consequences by commonly acting in energy related policies. The goals of the EU wide efforts, often referred to as the 20-20-20 goals, include a rise in the share of renewables in the energy mix to 20%, an efficiency gain in overall energy generation by 20% and a cut of greenhouse gas emissions (GHG) by 20 % until 2020 [1]. These goals entail consequences that impose challenges particularly for the European power grids. Especially the integration of a higher amount of (fluctuating) renewables imposes a serious challenge to power grids because of their distributed and volatile output. Volatile power generation forces a higher amount of balancing power standing by; distributed generation is currently not designed for central grid balancing actions [2]. By giving the opportunity and also the responsibility to actively manage his electricity consumption, the passive end consumer can change into a more active system participant who can help to level out some of the fluctuations from renewable generation. Economic assessments of imbalance reduction in the grid, of demand side management and of microgrids that rely on flexible household demand can be found in the literature [3, 4, 5]. In contrast, studies about emerging business opportunities for single players given by the deployment of smart grid and smart house technologies are less frequent. This paper presents such analyses for three different investment scenarios of smart grid approaches.

TECHNOLOGIES AND SCENARIOS

Three business cases for flexible demand response have been assessed in detail for the present work. Case 1 and its outcomes will be described in more detail while Case 2 and 3 will be summarized briefly.

Case 1: Real-Time Imbalance Reduction in a Balancing Area

At the core of Case 1 is the balancing responsible party (BRP) and its standard load profile (SLP) customers, i.e.: households within its balancing area that deliver flexibility services to the BRP via the PowerMatcher technology and thus minimize the costs for balancing power.

The PowerMatcher (PM) as the key technology was developed by the Energy research Centre of the Netherlands (ECN) and is also part of a current field trial in Hoogkerk (Netherlands) that is embedded in the SmartHouse/SmartGrid project. The PM system offers an automated demand and supply balancing mechanism via a multi-agent system technology on the end consumer level; a more detailed description of the technology can be found in [6].

As a first step to estimate the possible savings by avoided balancing power, data from three German distribution system operators (DSO) and their balancing areas for SLP customers were analyzed: Stadtwerke Karlsruhe Netze GmbH, Vattenfall Distribution Berlin GmbH and Vattenfall Distribution Hamburg GmbH. These DSOs represent medium and large utilities in the German context. The costs for balancing power induced by the load deviation of SLP customers are assessed under the following most relevant setting: The price for balancing power is positive and there is a shortage in the balancing area – the BRP pays money for balancing power. That is, by avoiding shortages in the balancing area, the BRP reduces the costs of balancing power.

In a second step, the load and power generation potential available for balancing purposes on the household level is calculated. For the reference scenario, the following values have been derived.

An artificial representative medium scale balancing area with a yearly power consumption of 267,379 SLP customers of 1,000 GWh is considered. The average load deviation per 15 min interval in a shortage situation induced by all the SLP customers is 8,021 kW based on the balancing area deviations of the three DSOs during the time of May to December 2009. This leads to yearly costs for balancing power of 6.75 €/SLP customer with an average deviation of 0.030 kW/SLP customer. 10,000 households are supposed to be equipped with the PM technology. As devices for balancing purposes on the household level, state of charge (SOC) appliances and micro-CHPs are considered. Each of the households is supposed to have a freezer and a refrigerator installed. We assume that 0.5 % of households are equipped with a micro-CHP unit that runs heat led with electricity as a by-product, with load profiles following [7]. Combining the controllable load of the SOC appliances and the controllable generation capacity of the CHPs, we derive an average potential for balancing actions of 5,070 kW. That allows for avoiding 63% of load deviations in a shortage situation [8, 9].

PowerMatcher Investment Costs			**Yearly Savings**	
Component	Costs per component	Total costs	Number of SLP customers	267,379
Substation	1,500 €	100,500 €	Costs per SLP	6.75 €
Aggregator	75 €	750,000 €	Total costs for balancing power	1,805,000 €
Controlling chips	1 €	50,000 €	Balancing potential/avoided costs	63%
IT integration	500,000 €	500,000 €		
Labour costs	368 €	3,680,000 €		
Investment		**5,080,500 €**	**Yearly savings**	**1,137,150 €**

Table 1: Investment and savings data for scenario 1

To finally calculate the NPV for the investment, we chose a ten years investment horizon with a flat interest rate of 5%. Tax effects and possible debt services are neglected. Discounting by the standard NPV formula, the resulting NPV for the reference scenario is:

$$C_0 = -I + \sum_{t=1}^{T} R_t * (1+i)^{-t} = 3.700.770{,}87\ €$$

where I, i, R_t, $t = 1,\ldots,10$ denote the initial investment costs, the interest rate, the savings per year, and the year, respectively.

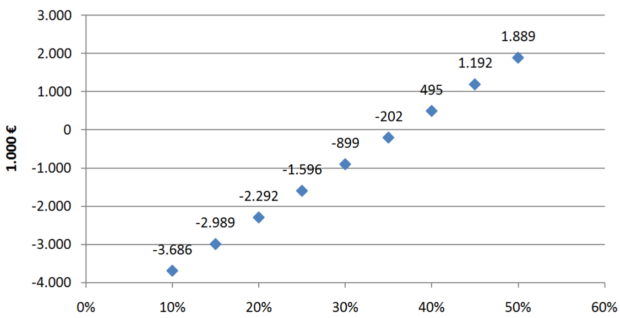

Fig. 1: Impact of Balancing Power Coverage on the NPV of Scenario 1

In a sensitivity analysis, the average costs for balancing power and the potential of avoiding imbalances were altered. In the whole interval which has been considered for the variation of the price level (between 80 % and 120 % of the reference case) and holding 63% potential for avoiding balancing power, the investment remains with a positive NPV. In contrast, the needed coverage for balancing capacity must be higher than 40 % of the load deviations in order to allow for a positive NPV of the investment. This result is demonstrated in Figure 1.

As a further variable in the sensitivity analysis, the variation of hardware failure rates of the PM components showed major effects on the profitability only if increased tenfold as compared to the reference case (to 10 % per year on the substation and 25 % per year on the appliance level) which appears to be a rather unrealistic setting for a mass rollout.

Case 2: Procurement Cost Minimization via Variable Tariff-Based Load Shifting

Time variable electricity tariffs and their effects on demand response (DR) have been analyzed and discussed intensely [e.g. 10, 11]. One motivation for variable tariffs is to lower electricity procurement costs for the energy supplier [12]. The mass rollout of smart metering on a household level and the increasing deployment of volatile DG enables the introduction of more complex tariff schemes on a large scale, thus making cost-based load shifting an interesting option for cost minimization in energy procurement.

The key technology for this case is the bi-directional energy management interface (BEMI), which has been developed by the Fraunhofer Institute for Wind Energy and Energy System Technology. The BEMI is a home energy management gateway that receives tariff information from the energy supplier, and controls shiftable devices according to a cost-optimized operating schedule [13]. It is assumed that smart meters are installed in all households that are equipped with a BEMI device. The energy supplier is assumed to be the owner of the BEMI components and operates the BEMI system. He sets the price schedule such that his forecasted procurement costs at the wholesale market are minimized given the load shifting potential offered by the flexible smart houses.

A quantitative financial analysis of this business case must include power procurement costs resulting for a load curve under a flat tariff in comparison with the load under the optimized variable tariff. Data from wholesale power markets such as the German EEX are suitable for this purpose. The load shifting potential of the households, however, is more difficult to assess, as hardly any structured experiments are available that measure the price elasticities of different household appliances. Some simulations estimate the load shifting potential from variable tariffs [14, 15, 16] for the German market.

As an indication, the typical household assumed in [16] has an average electricity consumption of 3,635 kWh per year and is equipped with a freezer (running 8 hours/day with 106 W) and a refrigerator (running 8 hours/day with 140 W) as SOC appliances and with a washing machine (890 Wh per cycle; 141-245 cycles per year), a dryer (2,460 Wh per cycle; 102 cycles per year) and a dish washer (1,190 Wh per cycle; 203 cycles per year) as fixed program schedule appliances. Consumer electronics, ICT and cooking appliances are out of scope for load shifting, because it is improbable that for example the TV consumption behavior may change through variable electricity tariffs. Households with electric space heating with heat storage have an average daily consumption of 59 kWh; in Germany 4% of all households apply this heating type. Less than 1% of German households are equipped with a micro CHP unit for residential heating. Micro CHP units can be integrated into optimized control schedules; a reasonable power to assume for a household is 5 kW of electrical output.

Simulation results of the overall load shifting potential for an average household vary in different studies. If only the savings from lower procurement costs are considered, these are in the range of a few Euros [calculations based on 16] and 13-15 Euro per household and year [14, 15].

On the investment side, the system installed in the households consists of a multi-utility communication gateway, the BEMI device, a sensor system controlling the smart appliances and one Pool BEMI, which is the central control processor for all BEMIs. Estimated costs for all hardware and installation are roughly in the same order of magnitude as those listed for case 1. The development goal is to bring hardware and integration costs down to a level of around 100 Euro per household.

Resulting from the potential savings and the investment costs related to the given business case, it must be stated that with current wholesale price spreads, it is hardly possible to refinance the necessary investments into the technical infrastructure. However, if additional applications such as peak load reduction and balancing power provision can be provided with the same hardware, as proposed in [15], then positive business cases can be realized with higher probability.

Case 3: Distribution Grid Cell Islanding in Case of Higher-System Instability

In areas of unstable grid operation, demand and supply side flexibility can contribute to restoring operation in critical situations and can deliver black start support. These features can be seen more frequently in island grids, as they exist manifold in Greece. On many of these islands the potential for solar and wind energy is quite high, and the generation capacity will be increased significantly in the next 15 to 20 years. The business case analysis therefore takes the perspective of the year 2030.

One technology that can make demand flexible in order to avoid blackouts and brownouts in such environments is the MAGIC system. Its components and functioning has been described e.g. in [17]. It is a Multi Agent System (MAS) specifically designed to cope with the complicated and diverse problems faced in the control of microgrids. The MAGIC equipment can be operated by a commercial aggregator who manages a grid segment and helps the DSO to ensure stable grid operation, including setting segments to islanding mode or reconnecting them to the grid. The system consists of a core controller for every customer (~200 €) and separate controller units per electric device within a household or commercial building (~50 € each). For residential customers, three separate controllers are necessary on average, for small/medium/large commercial users we can assume five/seven/ten separate units. Installation costs per household can be assumed to be 35 € and 58/82/117 € for small/medium/large commercial users. One main server (~700 €) is needed for every 1,000 core controllers.

As a reference case, we take a grid segment behind two average 10 MW feeders at the 20 kV level with the following sums of consumers:

- 4,800 residential, total load: 12,000 kW
- 300 small commercial, total load: 3,000 kW
- 150 medium-sized commercial, total load: 3,000 kW
- Ten large commercial, total load: 2,000 kW

Average interruption costs, normalized by the annual peak demand (kW) and a four hour outage have been estimated for the above mentioned groups [18, 19]:

- Residential: 1.5 €/kW
- Small and medium-sized commercial: 5.4 €/kW
- Large commercial: 14.5 €/kW

Average interruption times in Greece are above four hours (~4.8 hours per year), so the interruption costs of a four hours outage represents the lower bound for the willingness to pay of the customers.

Based on data from [17], we can assume that roughly the installed peak PV capacity is available in critical grid situations. As for wind energy, an average power output of the installed wind turbines of 4.42 MW. With this, a total load of 9.62 MW can be held up on average by renewable generation during islanding mode, if flexible demand and supply via the MAGIC system ensures stability. Multiplied with their respective interruption costs, this would lead to ~64,000 € savings allocated to the given customer categories:

- 2,430 € for 648 residential customers (load: 1.62 MW)
- 16,200 € for 300 small commercial customers (3 MW)
- 16,200 € for 150 medium-sized commercial (3 MW)
- 29,000 € for ten large commercial customers (2 MW)

If overall savings are put into the context of the necessary investments into the technical infrastructure for the given scenario, then the NPV turns out to be negative. However, hardware cost reductions in a mass roll-out scenario are probable. Further sensitivity analyses with unchanged hardware costs show that an above average interruption time per year (>12 hours) would yield a positive NPV for the installation of the system.

CONCLUSION AND OUTLOOK

The business cases presented in this paper give a first insight into the economic feasibility of demand side management. The scenarios and their parameters were filled with values that represent the actual and likely development of the underlying ICT infrastructure and its cost in the German and Greek power markets.

In the first case, it was shown that the PM infrastructure can be successfully employed to lower the balancing costs of a medium sized DSO with more than 267,000 customers in a profitable way. The sensitivity analysis illustrates that capacity for at least 40 % of the load deviations has to be available on average in order to allow for a profit in the analyzed scenario. The variation in the balancing power price does not have such a high impact on the profitability of the investment and neither does the reliability rate of the components.

In the second case, the profitability of the BEMI system used for variable tariff based demand response is analyzed. For the given scenario, this case proves not to be financially viable. One important parameter that influences profitability is the price variance at wholesale markets. The investment into the BEMI technology can only be profitable if additional applications, such as peak load reduction and balancing power provision, can be provided with the same hardware.

The third case framed in the Greek context of 2030 shows that the MAGIC system can provide a microgrid control infrastructure that can assure the supply of at least the commercial customers in the modeled region. From the results, one can conclude that for areas in which the grid reliability is below average, the MAGIC system could be a viable measure to ensure supply security, partnered by the continuous construction of new generation units.

This paper implemented a first approach to analyze possible savings and profits gained from the mass deployment of smart grid technology at the end customer level. It shows that there are viable business cases; in a next step, these findings have to be validated against the outcomes of field trials in which the technologies and concepts are deployed with real customers.

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