Flexibility Assessment Through Local Energy Consumer

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***Abstract*—The paper describes modelling experience in flexibility assessment for local energy consumer. Energy Management System strategies were carried out in order to facilitate price-based demand response for future implementation as consumer flexibility tool. The case studies were tested with the aim of providing and identifying the load flexibility potential through elaborated scenarios and innovative technology implementation at distribution level. The results of the study were summarized and analysed in the paper.**

***Index Terms*—Demand Response (DR), Demand Side Management (DSM), Flexibility, Energy Management System (EMS).**

I. INTRODUCTION

The climate targets and energy policy for 2020 to 2030+ binding on the EU Member States provide for the following: 1) cutting GHG emissions by at least 40% compared to 1990 levels; 2) increasing the share of renewable energy consumption by at least 27% of the total energy consumption; 3) increasing the energy efficiency goal by at least 27% compared to the estimated energy consumption in the future [1]. In practice, solutions supporting climate and energy targets result from the synergies between different innovations across different dimensions. A variety of innovative solutions and technologies are already contributing to *Decarbonisation*, but still need to be implemented at all power system levels. Furthermore, other global trends such as *Decentralization* and *Digitalization* are influencing the whole power system evolution.

Consumer loads are becoming more and more advanced; with the help of communication and more control they can be a potential provider of several different services to the grid. For most services and concepts, technical solution is already found and tested but it was hard to find the incentives that make the service competitive. The paper is discussing EMS contributions to local flexibility and system operation. The described approach can also contribute to market flexibility, as consumers would consume less electricity during the energy system peak times and more electricity in subsequent periods when there is enough electricity and capacity in the grid. In our understanding, flexibility can ensure an optimal use of the distribution grid as well as reduce the need for system operator to increase the grid capacity and hence tariffs.

II. DSM POTENTIAL

Planning and implementation of DSM incentives is designed to influence customer use of electricity in ways that will produce desired changes in the utility load shape, i.e., changes in the pattern and magnitude of a utility load. [2], [3]. DSM encompasses the entire range of management functions associated with directing demand-side activities, including program planning, evaluation, implementation and monitoring. [4], [5].

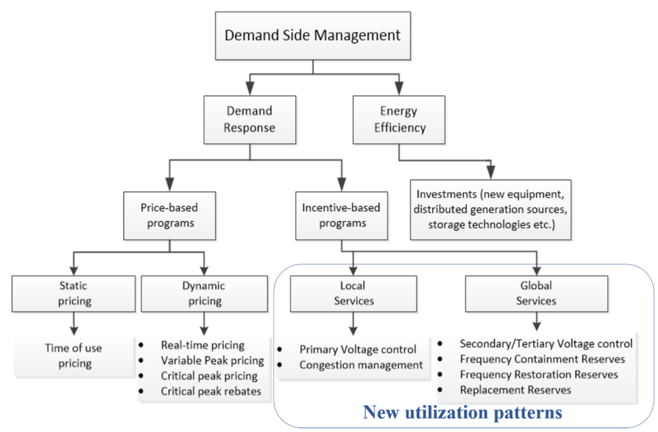

Figure 1: Core elements of Demand Side Management.

At the same time, DSM technology with key enabling factors, such as smart meters deployment, real-time monitoring, and with its playing field for aggregators, prosumers and other flexibility providers can also contribute to a new role of Distribution System Operators (DSOs). Then, based on the DSM opportunities, a DSO can boost grid flexibility and reduce network investments. Depending on the regulation, the new role of DSO would include network congestion and peak load

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management, reactive power and voltage support to TSOs, and define the standardized market products to effectively benefit from the available flexibility. In this research, we intend to encourage DSM through consumer rewarding, where in the price-based Demand Response (DR) program, users can create their own load response to hourly changes in electricity market prices by shifting hourly loads from higher prices periods to lower ones, resulting in user profit. DR programs can benefit not only the users, but also the grid itself, reducing the load in peaks to reduce the chance of outage. In the incentive-based DR programs, users are compensated for their consumption reduction. [6]

A. DSM incentives and contributions

A number of national and European projects have demonstrated the utilization of flexibility within individual categories of grid connected devices, such as various types of domestic load, EV charging, storage resources and VPPs with distributed generation. [6]

When creating incentives and strategies to influence energy behaviour, it is important to focus on the behaviours that can target several issues mentioned above. Further details of price-based and incentive-based programs are analysed from the Static Pricing and Dynamic Pricing point of view. Identifying flexibility potential, it is important to address the problem more holistically, allowing the comparison of flexibility resourced from different types of resource, not only demand and generation, but also storage, network automation and smart network devices. Figure 2. [7]

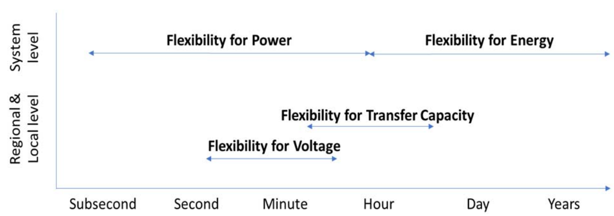

Figure 2. Flexibility needs in space and time.

The coordinated utilization of dispatch enables resources taking into account inherent fast-acting response of other devices, and the design of associated flexibility in control and protection schemes to adapt to the changing power system states. Such a scheme must take into account inherent dynamic response, local controls, centralized control actions, decentralized controls, as well as direct and price-driven control mechanisms.

B. DSM contribution to flexibility

Controlling (electrical) flexibility challenges includes these components and processes: scalable DSM with alternative and changing market/aggregator/VPP deployments, testing and accreditation of DSM functions, characterizing confidence in resource estimation for utility decision making, stochastic models and uncertainty, characterizing the V&f response of domestic devices in a flexible grid, domestic consumption/generation control through the voltage levels and interoperability between DMS-SCADA-AMR, as well as optimal exploitation of electric heating.

From power system operation, DR solution can contribute to system flexibility provision through Local and Global services. [8]. Local services provisions include primary voltage control and congestion management. Then, the Global services specifics are Secondary/Tertiary Voltage control, Frequency Containment Reserves, Frequency Restoration Reserves and Replacement Reserves.

DR has many types and can be beneficial, but it has many market and policy barriers for providing AS [7], [8], [11]. In [9], problems are acknowledged as a means of precautions to new DR users willing to participate in AS or aggregators that pursue creating adequate quotas as means of DR for AS by coupling together many residential loads. There are many barriers in the practical implementation of EMS, one of which is the amount of flexible load [10]. Although investigated and test-bed model is based on a commercial type (real) building data, its flexible load is quite small, but it can be increased by using a battery storage system. Furthermore, the repay length for EMS system implementation is based on how many appliances will be controlled based on meters used and their unique consumption; all factors must be taken into account.

III. Electricity Consumption Aggregation and Demand Flexibility Potential

The target market analysis indicated growing trends in all the above markets with the highest potential identified in the smart home sector where the market is expected to grow rapidly after 2020. Figure 3.

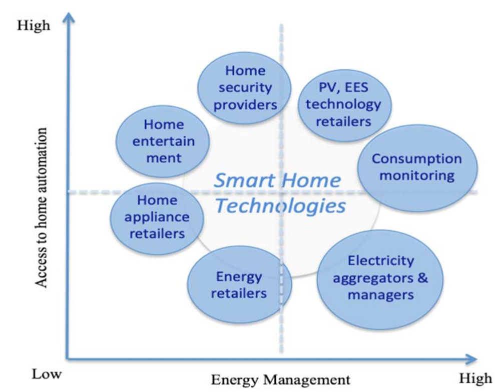

Figure 3. Market for energy consumption aggregation.

The provision of flexibility is not restricted to the loads, sources and storage elements connected at the extremities of the grid. The deployment of novel network technologies will contribute to the provision of flexibility through manipulating power flows and relaxing network constraints. Advances in distribution automation, sensing technology, monitoring schemes are also deployed for the reduction of customer interruptions and the deferral of network reinforcement. The opportunity exists for such schemes to be more effectively utilized at scale in the future to enhance system flexibility.

For the energy consumption data analysis and aggregation, the developed pilot technology is used, aimed at optimizing electricity consumption, reducing electricity bills for consumers and improving energy efficiency. [9] The given technology is capable of collecting data automatically and budgeting automated load management based on electricity market prices, carrying forward the functioning of the electric device to a later time, when the market price is lower. In practice, load management is affected through smart appliances, which use wireless radio signals for receiving load "on/off" commands, and the command executed by physically stopping the load supplied through the smart socket. A technology can be used to accommodate various load types, taking into account technical limitations of the connected load, which includes the maximum load off time and the minimum operation time, as well as takes into account the impact of sensors (such as temperature, humidity, etc.) on the load functioning. Load management and planning is structured considering the economic benefit (gain) arising if there is a price difference between two hours, i.e., the system carries out the above-mentioned activities, reducing the total cost of electricity of the user and providing flexibility to the system.

To fully harness the potential for flexibility, it is necessary to find a market model that would compensate and benefit energy consumers and power system in a transparent and predictive manner. [11], [12]. Effective control and equitable distribution of rewards requires the flexibility to be measurable. Control measures must take into account the confidence bands associated with these observations that arise without the issue of stability. Such flexibility must be able to be exercised under emergency and restorative conditions as well as normal operating conditions. It must be able to accommodate transitioning in grid operating modes, such as managed through the "traffic light concept[1]", for instance, built on SGAM architecture, and using flexibility available at smart grid connection points and in the network. Flexibility is provided by diverse group of actors – individual prosumers, large generators, network operators, aggregators, suppliers, traders etc. The following approach can be used here, Figure 4.

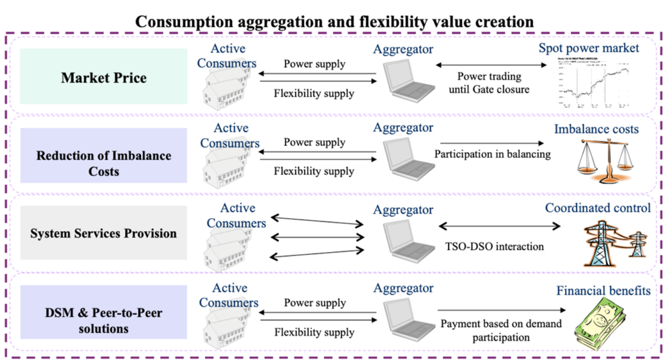

Figure . 4. Active consumer contribution to the flexibility.

Demand flexibility for network operation can be implemented in DSO services, such as:

- Real Time Congestion Management based on this criterion: below the overloaded lines, proportional to the available flexibility, and
- Control of Voltage Limit Violations based on this criterion: calculation of the impact of using one unit of flexibility in the problematic buses, proportional to the sensitivity factor.

The described framework provides demand flexibility assessment practices from (real) consumption data management.

IV. MODELLING EXPERIENCE

Flexible loads are a large part of DSM solutions; each flexible load usage has been selected in advance and modelled accordingly. Case study main settings for flexible load include working hours, from 9:00 to 17:00; within this timeframe flexible load, shifting operations can occur. This test is limited to 256-day limitation and uses price references from Nord Pool Day-ahead (LV area).

The experimental part of the research is focused on the load flexibility and its economic benefits assessment, where the OPAL-RT system was performed and four test cases were considered.

The flowchart of the algorithm is shown in Figure 5.

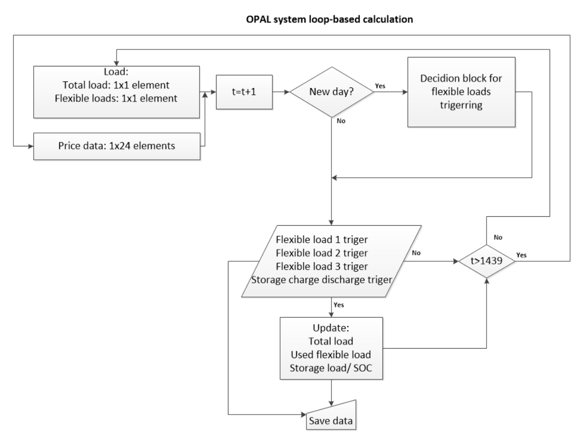

Figure 5. Algorithm with 1-second loading resolution.

Flexible loads are divided into three groups – boiler load, low loads with known working behaviour and low loads with unknown working behaviour. Although all groups base their actions on market price, the decisions are made differently. Decisions for each flexible load are made separately from one another and are limited by their own load controllability.

The developed case study consists of model building total consumption and three flexible load groups with electricity market price as the main shifting decider. In each case, total consumption is taken with appropriate electricity market price,

[1] A fundamental prerequisite for designing a flexibility traffic light concept is a reliable, predictive detection of congestion in the distribution grid.

but flexible loads are 10% of the average total consumption amount, Pr_{total} (1, 2).

$$Pr_{total} = Pr_{base\ load} + Pr_a + Pr_b + Pr_c \quad (1)$$

where:

Pr_a - flexible loads, boilers.

Pr_b - low loads with known behaviours; their consumption and market price is known for the day; load shifting is based on the total cost before and after shifting.

Pr_c - low loads with unknown behaviours; this group is shifted purely based on market price. This load type is similar to boiler type in its decision, but shifts for individual hour can be performed up to 3-hour horizons with a limitation of no additional shifts until previous hour has completed shifting.

Flexible loads provide more diverse shift potential, and their potential in DSM is highly based on the controlled load and user interactions. Furthermore, to flexible loads, Electric Vehicles (EVs) pose a large benefit in DSM shifting, because of their constantly high charging rates for distribution network. EV behaviour and setup within building EMS model is given below.

Table 1 shows the shifted load amount per flexible load, compared to the total building load in the case study.

The shifted load amount from total load in % Table1.

10x Boiler	10x Fridge	10x Water boiler	10x Air C	10x Server (low)	10x Server (high)	5x Electric Vehicle
0.176	0.036	0.084	0.2827	0.024	0.149	2.05
≈ 2.8% in total						
The shifted flexible load is only 0.75% of the total load						

Although this amount is quite small, it is highly based on flexible load settings with more loads; in general, with a different and more interactive user interaction the amount shifted can be a lot larger. With the combination of EVs, which represent 2.0491% of the total building load, the combined shifted load amount of these units reaches 2.8% of the total building load.

The variety of the ES (Electric Storage) test modes provide a look into different charge/discharge cycles effect on *costs savings provided*[2], while also comparing the difference in the shifted load to achieve this added benefit. An optimal scenario of PV and ES combination for the model was achieved when PV generation was set to 50 kW and ES storage capacity at 56 kWh. The optimal combination of PV and ES provides a total of 1497.39 EUR. Total savings are divided into three parts – savings provided by ES, by PV and added benefit from the combined work of the two elements. The results are shown in Figure 6, ES (in blue) with 16.37% and 245.18 EUR, PV (red) with 83.29% and 1,247.21 EUR, and added benefit is represented in green with 0.33%, which is 5 EUR.

[2] Hereafter is used as savings in the mining of saving electricity and lowering electricity bill.

The values are calculated using PV and EES individual combined savings compared to combined element operation provided savings. The benefit of 5 EUR is achieved by PV + ES scenario.

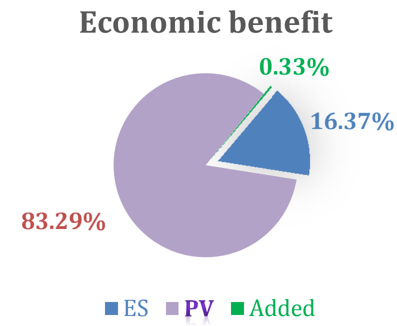

Figure 6: Economic benefit.

Consumption from PV generation is divided into building load, EES charge and part of generation that can be given back to the network, Figure 7. Most of the generation is consumed by the building 98.53% (1230,855.29 kW), because the generation does not always serve the total building load. Only 1.47% (18,412.87 kW) of PV generation amount of which 1.37% (17,148.30 kW) is used to charge ES; 0.10% (1264.57 kW) is over the needs and can be given back to the network (Loss) for the benefit of consumer.

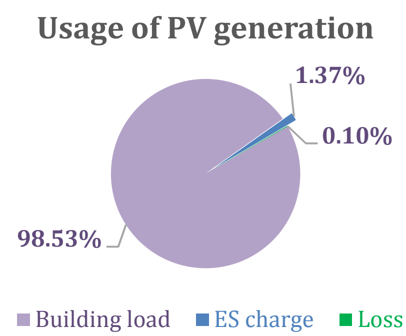

Figure 7: Usage of PV generation.

EES can be charged from two sources – the grid or PV. In Figure 8, both sources are representing their contribution to the total EES charging process. Here, charging is mostly provided by the grid 97.13% (579,352.4 kW), due to the lack of PV generation in this scenario. The PV generation has charged 2.87% of EES charging processes, and represents 1.37% of the total PV generation amount.

However, unlike these matching values, the added benefit of 0.33% (5 EUR) in Figure 6 does not represent all stored PV generation. It only shows the charges that have occurred in non-EES discharge hours.

If a charge from PV generation occurs in EES discharge hour, its price reference is zero, because the EES is expected to be fully charged until discharge hour.

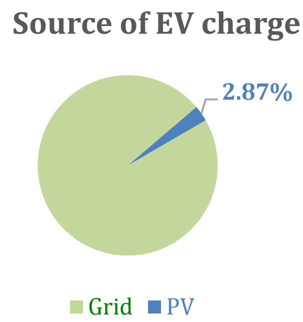

Figure 8: Source of EV charge.

It means, it could not have been charged during the night, so charging is possible since EES has discharged some of its capacity during the occurring discharge hour. For that reason, not all PV generation provided savings are included in the added benefit in Figure 6, because this charge would occur only the next day when market prices for the model are yet unknown.

The described experience and technology provide a kind of flexibility assessment tool that can be easily replicated for different types of buildings and individual consumers (smart homes). Flexible load shifting is a great way to benefit on appliance use. The results obtained have provided evidence that flexible load shifting can yield positive results, but benefit is tightly based on flexible load availability and price fluctuations. Price fluctuation impact can be seen comparing the test results. The last two test cases reflect summer situation, where prices have a large difference between them and are, in general, high, creating good opportunities for flexible load shifting.

V. CONCLUSIONS AND FURTHER WORK

The demand control algorithm was developed in the form of office building EMS model that was successfully created using measurements collected by the developed smart sockets. The collected data were used to model flexible load models, which simulated appliance functionality.

Various tests were carried out to find the most optimal building EMS setup based on the real data. Building EMS model proved that flexible loads do provide constant savings, but the amount saved is very closely based on user interaction. In the provided test range, the three resulting PV and EES combinations were deemed optimal for the building.

The model can be used to determine general building energy improvements based on provided source data. Improvements to the model such as implementing wind generation, adding forecasting solution for solar radiation, wind speed and building load, and expanding available flexible load list and features will increase model applicability and accuracy.

The provided case study is validated in the lab with real-time buildings and market data, and also contributing to:

- User profiling for the extraction of comfort preferences;
- DER and RES business models for obtaining the available flexibility and impact in comfort;
- Aggregation system exploiting the flexibility of the tertiary buildings;
- Data analytics tool for the potential Demand Aggregator to manage its portfolio;
- Tool enabling the DSO and TSO to use Demand Flexibility for network operation.

Further work can be focused on the technology constraints treatments, tailored retail pricing strategy and innovative solution development, as monetary and contractual transactions over peer-to-peer private and public networks by satisfying the cyber security concerns.

REFERENCES

[1] ISGAN and the Swedish Smart Grid Forum, "Opportunities to Accelerate Smart Grid Deployment through Innovative Market Design," 2018. http://www.iea-isgan.org/isgan-side-event-during-cem9-intelligent-market-designboosting-global-smart-grid-deployment/.

[2] D. G. Berkowitz, C. W. Gellings: "Glossary of Terms Related to Load Management, Part I of II Parts". IEEE Transactions on Power Apparatus and Systems, Volume PAS-104, Issue 9, 1985. Page(s): 2381-2386.

[3] NERC, "Data Collection for Demand-Side Management for Quantifying its Influence on Reliability", Available: http://www.nerc.com/files/demand-response.pdf

[4] M. Ifland, N. Exner, D. Westermann: "Appliance of Direct and Indirect Demand Side Management". Energytech, 2011 IEEE.

[5] A. Ahmad, N. Javaid, U. Qasim, Z. A. Khan: "Demand Response: From Classification to Optimization Techniques is Smart Grid," IEEE 29th International Conference on Advanced Information Networking and Application Workshops, 2015. Page(s): 229-235.

[6] I.Oleinikova, A. Mutule, A. Obushevs, N.Antoskovs. Smart Grid Development: Multinational Demo Project Analysis. //Latvian Journal of Physics and Technical Sciences, ISSN 0868-8257, 2016, NR 6 (Vol.53): lpp.3-11. DOI: 10/1515/lpts-2016-0038.

[7] E. Hillberg et al., Flexibility needs in the future power system. 2019. *https://www.iea-isgan.org/wp-content/uploads/2019/03/ISGAN_DiscussionPaper_Flexibility_Needs_In_Future_Power_Systems_2019.pdf*

[8] A. Ahmad, N. Javaid, U. Qasim, Z. A. Khan: "Demand Response: From Classification to Optimization Techniques is Smart Grid," IEEE 29th International Conference on Advanced Information Networking and Application Workshops, 2015. Page(s): 229-235.

[9] A. Obushevs, I. Oleinikova, A. Mutule: "Demand side management platform for HAN flexibility estimation with agent control". European Energy Market (EEM), 13th International Conference, 2016.

[10] I. Oleinikova, A. Mutule, I.Zikmanis, E Grbeshs. Energy Management Modelling Under Real-time Approach. PowerTech 2019 International Conference, 2016., Milan. Italy, (Accepted).

[11] The Nordic Balancing Concept. Statnett and Svenska Kraftnat June 2017. *https://www.statnett.no/globalassets/om-statnett/nyheter-og-pressemeldinger/nyhetsarkiv-2017/the-nordic-balancing-concept.pdf*

[12] Bobinaite,V., Obushevs, A., Oleinikova, I., Morch, A. Economically Efficient Design of Market for System Services under the Web-of-Cells Architecture. Energies 2018, 11, 729; DOI:10.3390/en11040729.