Production and demand management

Demand Side Management (DSM) is usually considered as a process of shifting of energy consumption from peak hours to off-peak times. DSM doesn't always reduce total energy consumption, but it helps to meet energy demand and supply. For example, it balances variable generation from renewables (such as solar and wind) when energy demand differs from renewable generation [24].
One of limitation of electricity power is that generally, electrical energy cannot be stored because of a large number of economic or physical feasibility limits. Thus, it must be produced in the quantity needed. It is exactly the main objective of DSM – to equilibrate production and consumption of energy.

DSM originated after oil crisis in the 1970s. Then, energy demand was met relying on forecasts, which were often made with a ruler and double-log paper. In other words, demand side was largely disconnected from the market. Consumers were mostly simple users of energy sources. They received electricity from energy grid and paid for it. Gradually, situation is changing. After petrol shock in 1973, Demand Side Optimization has become more important. Most countries tried to develop programs to reduce dependence on oil and to promote energy efficiency and alternative energy sources. Nowadays, energy consumers are more proactive. They want to optimize electricity consumption so as to reduce their expenses.

The process of DSM activities usually follows the integrated approach. DSM sends signals to end-use systems to shed load depending on system conditions. This allows for very precise tuning of demand to ensure that it matches supply at every period, reduces capital expenditures for the utility. Critical system conditions could be peak times, or in areas with levels of variable renewable energy, during times when demand must be adjusted upward to avoid over generation or downward to help with high needs. Consequently, the analysis and optimization on the demand side focuses on the involvement of the customer and fits to the vision of a customer centric energy grid.

According to literature [25], DSM can be divided into 3 categories:
Energy efficiency means usage of less power due to more efficient load-intensive appliances such as water heaters, refrigerators, or washing machines.
Strategic Load Growth refers to a general increase in energy consumption. Load growth may involve increased market share of loads which can be served by fuel switching from fuels to electricity such as heat pumps, induction cooker and microwave oven.
Demand Response (DR) identifies the short-term relationship between price and quantity when the actions and interactions of substitutes and complements are considered. Currently, the term DR is used in a broad sense, in relation to electricity end-use, and is attributed to a wide range of control signals such as prices, resources availability and network security [26].
Fig. 1 sums up DSM categories (based upon [25]).

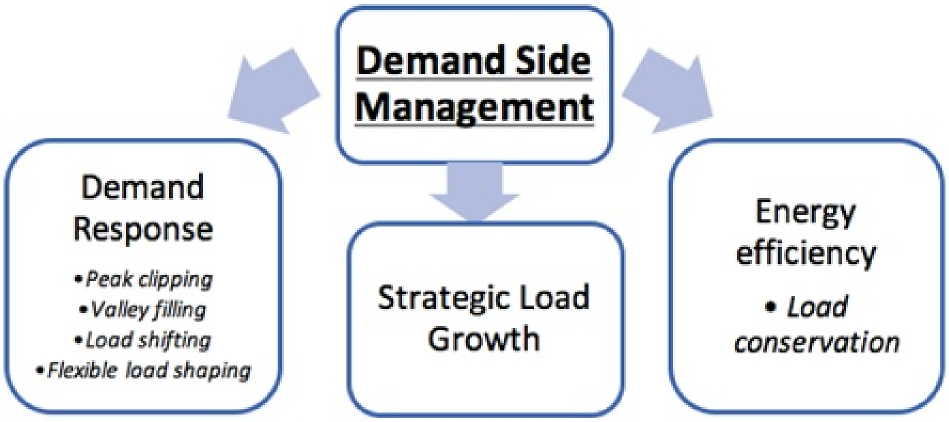

Figure 1: Categorization of Demand Side Management (based upon [26])

Demand Side Management and Demand Response
We define DR as part of DSM similar to [1] and [2], as the "voluntary changes by end-consumers or producers or at storages of their usual electricity/gas flow patterns in response to market signals such as time-variable prices, incentive payments" or beforehand given agreements between customers and third parties. Such pattern changes are possible due to flexibility on the demand side. Such flexibility might be provided for example through electrical or thermal storages where demand is decoupled from generation, but also from other flexible loads, such as EVs.

In electricity markets, traditional DSM programs are slowly getting replaced with DR programs. A good example of demand response implication and reducing electricity peak demand is the introduction of "Time of Use Tariffs" in France. Its aim was to apply a fixed rate with different time units depending on hours and seasons. "Time of Use Tariffs" in France included 3 parts:

- «Green tariffs» (1956) for large firms or buildings (La Defense): Many prices options according to season/hour and localisation/use.
- «Off-peak hours» (1965) tariffs for residential market and business– special tariffs from 10 PM to 6AM week days and on Sundays.
- «Peak day step back» (EJP) (1982) for residential market was introduced to decrease consumption at critical times (22 days of 18 hours between 1st November and 31th March). It established high price during this period and low price the rest of the year. Currently, EJP replaced by TEMPO (6 price's levels according to hour and season).

This program showed high results: «off-peak hours» tariffs reduce peak consumption by about 20% and customers with «Peak day stepping back» tariffs reduce their consumption by 50% during peak period (4% of total residential consumption) [28].

Direct Load Control vs. Indirect Load Control

In general DSM and DR concepts can be distinguished between direct and indirect load control. Indirect load control implies an incentive, such as a price signal. Such signal might motivate the consumer to shift its consumption into times of lower prices. Direct load control rather means an agreement between the customer and a third party that allows the party to directly control the loads of the customer based upon the beforehand made agreement [3].

For field installations the most promising solution which finds well acceptance in research and industry is the automated demand response (OpenADR) protocol which is now a de-facto standard for DR concepts [4].

Several recent research activities that use mathematical optimization techniques for DR refer both to direct and indirect load control. These research topics are related to the optimization and coordination of the operation supply and demand units throughout a time horizon, e.g. an offline day-ahead scheduling under consideration of flexibility. The flexibility is achieved through temporal shifts over a Horizon T. Such problems are very generally known as the Portfolio Balancing problem.

Demand Side Management in different time horizons (short to long term)

The classic unit commitment problem is mainly short term but can be solved also for medium and long term problems. As shown in fig. 2, similarly as presented in [1], we can distinguish Demand Side Management according to its time line.

Spinning Reserve in this context refers to primary and secondary and even tertiary control, which is usually done by power plants. However, in DSM, loads can be virtually aggregated and act as negative spinning reserve for frequency control. The time horizon is in between seconds and minutes.

Figure 2: Different time horizon in DSM, based upon [1]

Integrated Demand Side Management

Nowadays, DSM technologies become increasingly feasible due to the integration of information and communications technology and the power system, new terms such as Integrated Demand Side Management (IDSM), or smart grid.

Smart grid gives new opportunity of remote control services that allow the network operator to switch off high electricity consumption devices (for example, air conditioners, hot water tanks, heat pumps) for a limited period during peak demand without causing major failure for the consumer.

For example, French company Voltalis offers to residential customers, the ‘Bluepod’ box, a device which switches off electrical heating and space conditioning appliances.

If demand exceeds electricity production, transmission network operator (Reseau de Transport d'Electricite, RTE) contacts Voltalis, which can withdraw demand in real time by modulating electricity consumption in many households via ‘Bluepod’ [27].

Challenges and Requirements for Demand Side Management and Demand Response in Optimization

The above mentioned general description of the portfolio balancing problem for city districts and neighborhoods incorporate several challenges both for the mathematical method and the overall approach. First, there is usually a high heterogeneity of participants and devices that must be taken into account. Residential buildings, but also industrial consumers might take part of the portfolio balancing. The load and flexibility of such units diversify within their granularity of time, their amplitude and their criticalness. Second, a city district contains in general a high number of participants and devices which lead to a computational intensive problem with an increasing portfolio size. Consequently, a mathematical optimization must be able to handle a large amount of heterogeneous participants. Third, referring to the concept of demand response and in particular to direct load control, it is an important requirement for the method to ensure data privacy. Fourth, the coordination within city districts usually needs to integrate both local (customer) and global (system) level objectives. In respect to this challenge the method requires an approach for both satisfying global and local objectives. Fifth, depending on the kind of installed devices on the demand side the mathematical optimization method might have to be able to take care of on/off devices leading to an Integer related problem formulation.

Research Paper and Solver

Indirect load control on the demand side is for example studied in [5] and [6]. In particular [6] is a very recent example for showing the operation scheduling of Plug-in electric vehicles coordinated by an aggregator agent. The MILP is solved within GAMS Build 21.1.2. using the CPLEX 12.5.1 solver [7].

This research satisfies all of the mentioned requirements. As mentioned in the challenges above a central optimization becomes hard to solve with an increasing portfolio size. Indirect and direct load control for scheduling loads on the demand side by using a distributed algorithm is hence an active field of research. Consequently many research papers, such as [3, 5, 8–13] propose distributed optimization demand response techniques for (residential) energy demand side management. Decomposition methods such as in [13] or [14] use dual decomposition (DD) or the alternating direction method of multipliers (ADMM) such as in [3, 12]. For both DD and ADMM in particular challenges and requirements 1) – 4) are taken into account. [10]

The residential demand side energy management in [14] for example used the matlab environment in combination with ILOG CPLEX 12.2 to solve the optimization problems. The ADMM problems were solved using CVX, a package for specifying and solving convex programs [15], [16]. Looking into integer related problem formulations authors in [17] propose a column generation approach for direct load control which is solved using the object-oriented Python Interface of Gurobi [18]. Research in [10] performs a decentralized robust ILP optimization for balancing a portfolio within a microgrid. The optimization uses the CPLEX package within Java. Both [17] and [10] are other examples for satisfying all mentioned challenges 1) - 5) and the resulting requirements. [19] uses a MILP formulation for the optimal control of a residential microgrid using the Gurobi solver as well through the object-oriented interface for Java. Further, authors in [20] perform a distributed optimization via a multi-agent system using the Java agent development framework (JADE) [21]. However, each local agent solves its own local MILP optimization using MOSEK [22].

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