Home Appliance Load Scheduling with SEMIAH

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***Abstract*—The European research project SEMIAH aims at designing a scalable infrastructure for residential demand response. This paper presents the progress towards a centralized load scheduling algorithm for controlling home appliances taking power grid constraints and satisfaction of consumers into account.**

***Keywords*–Smart grids, demand response, load scheduling**

I. INTRODUCTION

Demand Response (DR) is in its nascent stage in Europe. DR programs allow Distribution System Operators (DSOs) to reduce electricity peak demand by incentivizing consumers to adapt their usage to variations in the electricity generation [1]. Existing DR programs aim at large industrial consumers, who can be managed as one large client, representing an aggregated demand of hundreds of residential households. Despite the fact that households constitute 27% of the total energy consumption in Europe and are responsible for 10% of the CO_2 emissions, no automated DR programs have been implemented for European households. The European FP7 research project *SEMIAH* (Scalable Energy Management Infrastructure for Aggregation of Households) strives for developing an Information Communication Technology (ICT) infrastructure for DR [2]. SEMIAH enables shifting of energy consumption to periods with high electricity generation from Renewable Energy Sources (RESs) which helps DSOs to flatten the peak electricity demand.

SEMIAH undertakes three different approaches to address the home appliance load scheduling optimization problem as follows: 1) scheduling of non-critical power-intensive loads using a residential Home Energy Controlling Hub (HECH) system, 2) two-stage linear stochastic programming for scheduling of domestic loads, and 3) load scheduling with multi-objective optimization techniques. This paper introduces a single-objective load scheduling optimization as a precursor for the latter multi-objective optimization approach.

II. THE SEMIAH SYSTEM

The SEMIAH system employs a centralized approach for aggregation and scheduling of load demands of appliances. It relies on the flexibilities provided by households who decide to join a DR program. The *flexibility* concept of SEMIAH aligns with the European mandate M/490 [3]: "The flexibility [offering] concept assumes that parties connected to the grid produce offerings of flexibility in load and (distributed) generation. Thereby, so-called flex-offers are issued indicating these power profile flexibilities, e.g., shifting in time or changing the energy amount. In the flex-offer approach, consumers and producers directly specify their demand and supply power profile flexibility in a fine-grained manner (household and SME level)." In SEMIAH, flexibility from home appliances are aggregated in a coherent way to produce flex-offers that can be traded in the electricity markets.

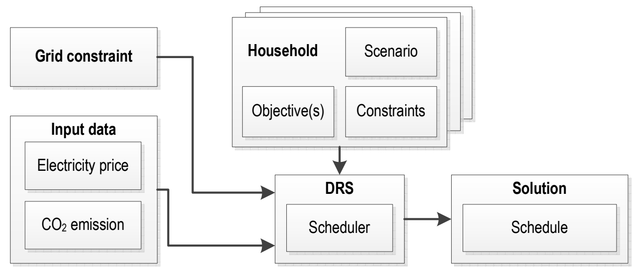

Figure 1. Conceptual diagram of the demand response serving subsystem.

Load demands of appliances can be categorized based on the *shiftability* feature [4]. Shiftability means to authorize a DR System (DRS) to shift load requests of *shiftable* appliances to a future time interval. Some appliances cannot be shifted, for instance the refrigerator. Hence, these become members of the category of *non-shiftable* appliances. Shiftable appliances can be further divided into groups based on the *interruptibility* feature. As an example, the DRS can both shift and interrupt the charging cycle of an electric vehicle. However, it should continue operation of the *uninterruptible* appliances until completion when these are started, e.g., a washing machine. Each household presents a scenario including the usage schedule of appliances. The household applies a *deadline flexibility* constraint, which sets a contract when a given appliance must complete its operation at latest. Subsequently, the DRS produces a schedule for the aggregated set of appliances, i.e., a solution. The deadline constraint imposes a non-trivial optimization problem for the scheduling of electricity loads.

Fig. 1 illustrates a conceptual diagram of the load scheduling subsystem. The DRS applies input data from the electricity market and the bulk generation side to establish an objective function used by the scheduling algorithm. In the household, a HECH is installed to manage loads of appliances. The HECH connects to sensors and actuators of the household by using ZigBee communication. It receives control information from the DRS and runs the scheduled appliances accordingly.

III. LOAD SCHEDULING

The DRS schedules and manages appliances based on desired scenarios of households. When consumers provide their appliances in the "DR Ready" mode to the DRS, they authorize the DRS to schedule appliances in a 24-hour period. The DRS receives load requests from all presented scenarios in each time interval of 5 minutes. Consecutively, it runs the scheduling algorithm on load requests taking the shiftability and interruptibility features of appliances into account. Three constraints are assumed by the scheduler: 1) keeping the total power consumption below a specific *Electricity Consumption Threshold (ECT)*, 2) satisfying the deadline flexibility of appliances, and 3) satisfying the *dependencies* between appliances, e.g., the laundry washing is completed before drying can start. The first constraint relates to the grid stability. The second and third constraints impact on satisfaction of consumers.

The scheduling algorithm allows non-shiftable loads to start or to continue their operation. If there are uninterruptible loads running in the previous time interval, they are permitted to continue. When there are loads which cannot be shifted without violating the deadline constraint, they must start or continue. Afterwards, the algorithm utilizes a Knapsack approach [5] on the remaining load requests to calculate the fitness of subsets. It returns a subset of remaining load requests to start or to continue in the current time interval. Loads, which cannot be started, are shifted to the next time interval.

IV. Preliminary Results

Table I offers an example of a scenario from a household with a consumer returning home at 18:00 and commencing to operate his appliances. The corresponding scheduled load demands of the household is demonstrated in Fig. 2 using two different *ECTs*. The maximum demand occurs at 18:25 and equals to 8,940 W. It comprises the electric vehicle, lighting, washing machine, oven, and stove. The day-ahead market is utilized for electricity price data (www.nordpoolspot.com). The CO_2 emission rate is derived from the electricity generation mix (www.energinet.dk) using the Danish power grid as the case study. To arrive at a *cost metric*, combining electricity price and CO_2 emission cost, an average cost of CO_2 emission of 171.78 DKK/1,000 kg is used. No shifting occurs when *ECT* is 9 kW which is higher that the peak demand of the household. When the threshold is lowered to 3 kW, load shifting takes place. The DRS decides to shift the charging of the electric vehicle by 200 minutes, and operations of the stove and oven by 100 and 20 minutes, respectively. It is beneficial to note that the threshold cannot be fully satisfied due to non-shiftable appliances that must run. This implies a "softness" of *ECT*.

TABLE I. An example of a household scenario.

Start	End	Activity description	DF	P_p [W]
18:00	23:00	Turning the **lights** on.	23:00	100
18:00	20:00	Plugging the **electric vehicle** in its station.	23:00	3,600
18:05	19:50	Running the **washing machine**.	23:00	2,000
18:10	18:50	Preparing food and turning the **oven** on.	22:15	2,350
18:20	18:50	Starting and using the **stove**.	22:15	840
19:00	19:45	Eating the food while watching **TV**.	23:00	55
21:30	23:00	Preparing the **laundry dryer**.	23:00	2,000

DF and P_p are the the deadline flexibility and the peak power consumption of appliances (marked with **bold** type face) , respectively.

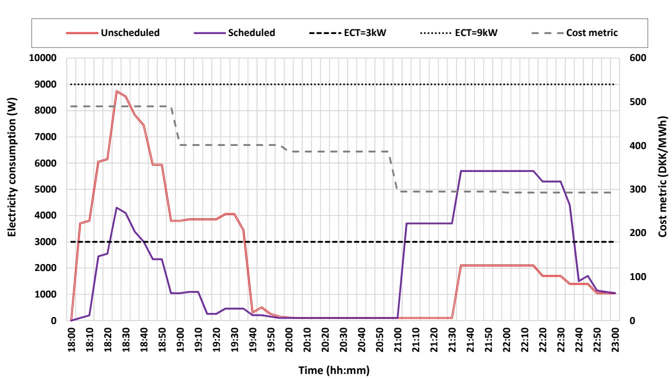

Figure 2. Peak demand shifting of home appliances due to *ECT* constraint. The cost metric (from 4 Nov. 2014 data) indicates a decreasing trend.

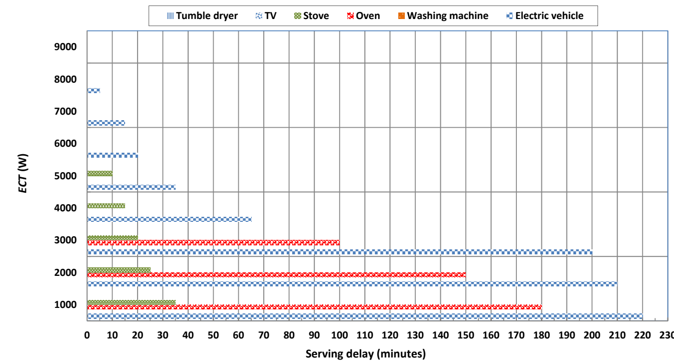

Figure 3. As *ECT* decreases, the serving delay of appliances increases.

To study consumer satisfaction, Fig. 3 examines the deviation between the starting and the serving times of appliances. Obviously, consumers prefer minimal deviation between the provided scenario and the offered schedule. As *ECT* increases, the consumer gets closer to the desired scenario. In the example, the electric vehicle is the best candidate to be shifted to later time intervals due to its higher peak power consumption.

V. Conclusions and Future Work

The SEMIAH project aims at developing an infrastructure for DR enabling aggregation and scheduling of electricity loads of home appliances. A scheduling algorithm based on a single-objective optimization approach has been developed. It allows the shifting of loads according to flexibilities provided by consumers. As future work, the scheduling algorithm will support multi-objective optimization techniques coupling with the divergent priorities of consumers and the DSO. SEMIAH targets a solution that scales to 200,000 households to produce aggregated flex-offers tradable in the electricity markets.

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