A Load Shifting Technique for the Residential Sector of Lesvos

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1 Business Context

In recent years, the Mediterranean islands face severe issues in terms of electricity supply due to population growth and intense tourist activity. In particular, demand fluctuates widely during the day, with peaks occurring mainly at midday and evening. The existing obsolete infrastructures are often unable to cover these fluctuations, leading sometimes to a total or periodic power outages. The accurate and immediate monitoring of energy consumption can contribute substantially in achieving significant energy saving rates and optimising the function of energy systems.

In an effort to upgrade the infrastructure in 2018, the Hellenic Electricity Distribution Network Operator (HEDNO), which is responsible for the normal operation of power networks, installed smart meters in thousands of homes in various islands. Smart meters is a cutting edge technology of smart networks enabling the recording, analysing and transmission of metrics in real time which can be deployed by network operators, energy suppliers and consumers to gather detailed information on energy consumption, usage patterns and make decisions based on their energy profiles. Apart from the recordings of total consumption, smart meters are able to keep track of the consumption of each device that operates at any time in a home during a day.

One of HEDNO's main goals is to reduce peak demand and, therefore, reduce operational costs of the system and increase its sustainability. Having secured the consumption trends of 613 houses (located in Lesvos island) measured by smart meters in 28/10/2018 (Figure 1), our purpose is to suggest an alternative schedule of using the flexible household electrical appliances without affecting the convenience of residents. Considering the different rate tariff which depends on the time of day (Figure 2) and the recorded consumption trends we try to re-schedule optimally the use of flexible devices of each house reducing that way both the total load peaks and consumers' bill. In other words, our perspective is to flatten the load curve by shifting devices to lower tariff rates giving an economic incentive to consumers to follow the suggested schedule. Tariff rates for each day are set the night before and communicated to customers. Aditionally, HEDNO examines the idea of communicating a proposed schedule.

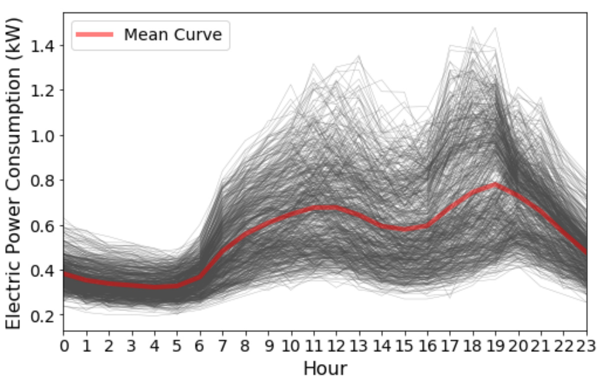

Figure 1: Load Curves From 613 Houses

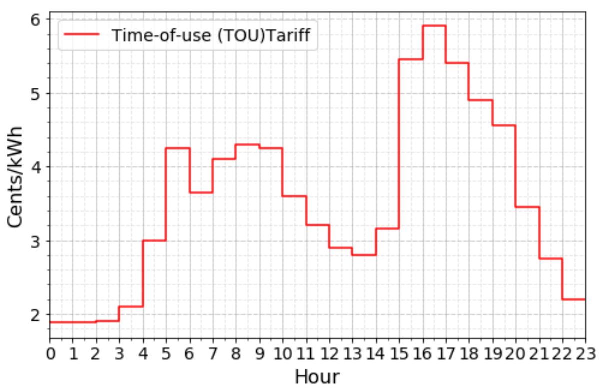

Figure 2: Electricity Price of a Day

2 Methodology

The proposed algorithm is a constrained optimisation technique that aims to bring the load curve of a house as close as possible to an objective curve which is determined by the operator of the network. It takes as an input the past schedule of flexible devices for a day, recorded by smart meters, and shifts the loads according to the desired objective function, taking into account a flexible displacement time so that the customers' comfort level is not affected. For each device, we have determined an interval of flexibility which penalises our algorithm from shifting a device beyond this interval. For simplicity, in this report, we present the results of the proposed algorithm implemented to only one house with high activity in 28/10/2018 and give a very brief description of the mathematical formulation. In Table 1 the schedule of flexible devices for the considered house is presented.

Table 1: Initial Schedule of Household Appliances

Appliance	Initial Schedule	Flexibility
Dryer	17:00-18:00	6
Electric Heating	19:00-20:00	2
Water Heater	20:00-21:00	2
Microwave	11:00-12:00,17:00-18:00	2
Coffee Maker	08:00-09:00	1
Hair Dryer	08:00-09:00	1
Electric Stove	12:00-13:000	3
Toaster	08:00-09:00	5
Kettle	21:00-22:00	5
Vacuum Cleaner	10:00-11:00	6
Iron	18:00-19:00	3
Oven	11:00-12:00,17:00-18:00	3
Washing machine	15:00-16:00	6
Dishwasher	13:00-14:00	5

Formulation of Optimisation Algorithm

The objective curve is determined taking into account the Time of Use Tariff (TOU), as defined in Figure 2. Shifting household appliances in low-demand hours will have an economic impact on consumers' electricity bills, as the price of electricity billing is lower at these times. For this reason, the objective curve is inversely proportional to energy prices, as shown in the equation below.

$$Objective = \frac{C_{PriceAVG}}{C_t^{Price}} \cdot \frac{1}{T} \cdot \sum_{t=1}^{T=24} P_t^{Load}$$

The technique is a binary programming problem and the optimisation equation can be mathematically formulated as shown below.

$$\underset{\beta_{tn}}{\text{minimise}} \quad \sum_{t=1}^{T=24} \left(P_t^{fixed} + \sum_{n=1}^{N=14} \beta_{tn} P_n - Obj_t \right)^2$$

The instantaneous electrical power (in Watts) due to the flexible device is expressed as $\beta_{tn} P_n$ where P_n is the maximum possible power demand of the device n according to its manufacturer specifications and β_{tn}, with values 0 and 1, is a binary factor indicating whether the flexible device is in operation at time t and is defined based on the schedule given from the smart meters.

The variables of the minimisation function are the elements of a table B. The problem determines the new elements β_{tn} (0 or 1), ultimately suggesting a new schedule for the flexible appliances.

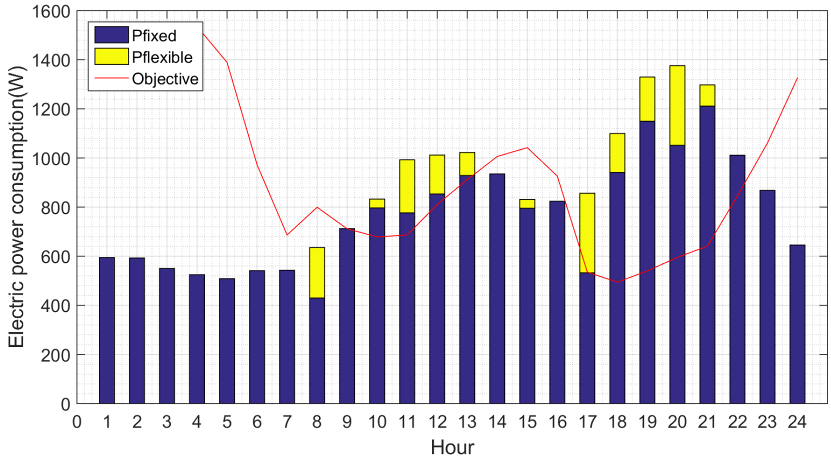

Figure 3: Flexible and Fixed Load Demand on 28/10/2018

Constraints

The optimisation problem also incorporates the constraints relating to the margins of displacement of appliances from their initial schedule. For each device there is a time range that can be shifted and specified in column 3 of Table 1. For example, based on the initial schedule, the dishwasher is switched on at 13:00 and has a flexibility of shifting of ± 5 hours, as shown in the table below.

$$B = \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} & \cdots & \beta_{1N} \\ \beta_{21} & \beta_{22} & \beta_{23} & \cdots & \beta_{2N} \\ \beta_{31} & \beta_{32} & \beta_{33} & \cdots & \beta_{3N} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ \beta_{241} & \beta_{242} & \beta_{243} & \cdots & \beta_{3N} \end{bmatrix} =$$

	Dryer	Dishwasher	WashingMachine	Oven(2nd hour)	Oven(1st hour)	Iron	VacuumCleaner	Kettle	Toaster	Electric stove	Hair Dryer	Coffe Maker	Microwave(2nd	Microwave(1 st	Water Heater	Electric Heating
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	**1**	0	**1**	**1**	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0	0	0
11	0	0	0	**1**	0	0	0	0	0	0	0	0	0	**1**	0	0
12	0	0	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0
13	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	**1**	0	0	0	**1**	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	**1**	0	0	0	0	0	0	**1**	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**	0
21	0	0	0	0	0	0	0	**1**	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

3 Results

Figures 4 and 5 indicate how the shifted load curve is formed after the proposed algorithm is implemented, while Figure 6 shows the proposed schedule for the use of household appliances in the tested house.

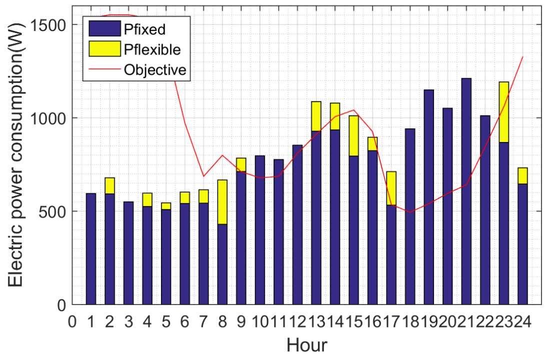

Figure 4: Shifted Loads

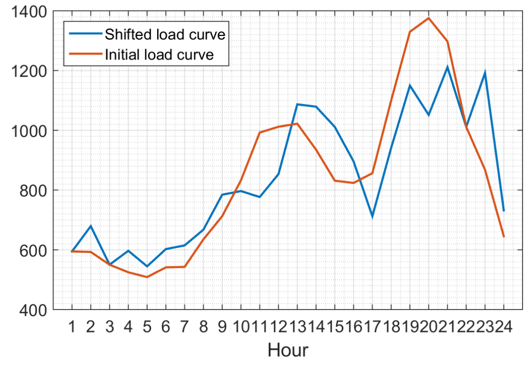

Figure 5: Initial and Shifted Load Curves

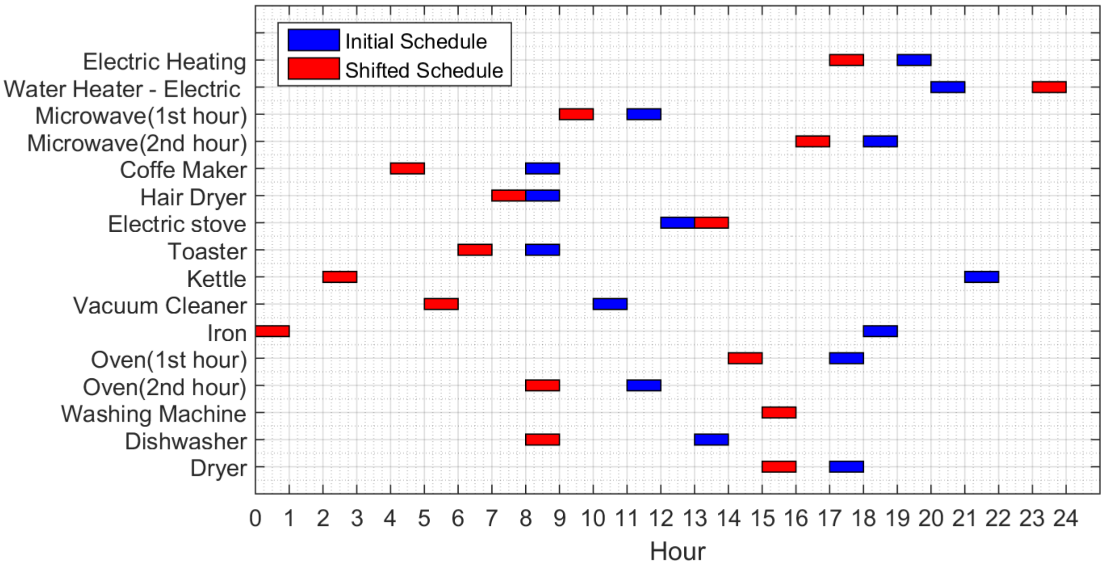

Figure 6: Initial and Shifted Schedule of Household Appliances

Finally, it is reasonable to examine the reduction in customers' bills if the proposed schedule is followed. This is achieved by multiplying the demand (Watt) by the Tariff rate at the specific time. The tested house paid €7.5 on 28/10/2018 for the actual schedule as measured by the smart meter. If the suggested schedule was followed, it would reduce its bill to €7. Apparently, this is not a substantial reduction, however, the reduction is highly related to the range of flexibility we define to the devices. Therefore, the more we increase the interval of flexibility, the more we reduce the total cost.

Stakeholders should bear in mind that even we have incorporated a flexible interval of each appliance, this differs widely from house to house as it depends on the habits of each consumer. Therefore, the level of comfort of customers may be affected by the implementation of such a program.

4 Retrospective

Being the only participant in this project, the following review is more a technical review of the above project rather than a critique on a team's performance.

What went well?

In this project, a constrained optimisation technique was implemented to propose a new schedule for the household appliances operation, taking into account the past operating schedules as measured by the smart meters. Looking at the results, this technique serves both operators and consumers by reducing peak loads and saving money from consumer bills. The targeted curve was created taking into account the variable tariff imposed by HEDNO which follows the variability of the load curve.

I familiarised more myself with Python and Matlab as these tools were used for the development of the algorithm. Also, I exposed myself deeper to the theory of oprtimisation problems.

What could have gone better?

An important limitation that was encountered is that, as shown in Table 1, the hours of household appliances operation are all rounded without minutes. The reason is that in the existing problem the proposed algorithm minimises an array with dimensionality 24XN where 24 correspond to the hours of a day, and N is the number of the flexible appliances in a house. Increasing the timetable interval, for example, to quarters then the dimensionality of the array becomes 96XN. To minimise such an array, a more powerful machine and resources than what is available are required.

The work process was divided into two sprints, mathematical formulation and algorithm development. Due to the time limit, there has been no major review in the existing literature in the first sprint. Due to bad management of time, work process until sprint 2 was a stressful process.

Bad communication with the manager. Late responses to my emails, affecting my schedule. After presenting the results to the stakeholders, I was told that less should be mentioned in the mathematical formulation, as the majority of them may not have the mathematical background to understand the concept and also, they may not care at all.

Much effort has been invested in finding the proper solver that can solve the binary problem as it was formulated. Trying out a lot of available solvers, I ended up with IBM's solver (CPLEX) which is free for students only. Perhaps a closer review of the existing literature would save a lot of time in this part.

What do we want to try next?

It is worth mentioning, that a larger project runs at this time, which aims to predict the operation of household appliances for each day in every home, exploiting the data from smart meters. The proposed algorithm will be implemented to the schedule arising from the prediction. However, because the particular project is still in progress, the proposed algorithm presented above was implemented to past data to examine its effectiveness.

The algorithm can be upgraded to approach closer to actual data. This involves increasing the time intervals by increasing the dimensions of Table B.