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Demand Side Management by controlling refrigerators and its effects on consumers

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ABSTRACT

Demand Side Management in power grids has become more and more important in recent years. Continuously growing energy demand both increases the need for distributed generation from renewable energy sources and brings out the topic of Demand Side Management. One of the major application areas of Demand Side Management in smart grids is cooling systems. In this paper, Demand Side Management with control of a refrigerator and its economic effects on consumers are analyzed. With a refrigerator model based on real measurements, several cooling schedules are simulated and annual energy fees for different pricing methods in use in Turkey are calculated and discussed. The results revealed that, 37.9% of refrigerator's demand in peak period can be shifted to other periods and annual electricity bills for customers can be reduced by 11.4%.

1. Introduction

In today's power grids, two major problems are being discussed. The first is continuously increasing energy demand. It is predictable that this trend will continue in the following years. International Energy Agency's expectation for demand growth until 2020 is 12% compared to 2010 [1]. In Turkey, until 2018, increase in annual electric energy demand is predicted to be between 6.6% and 7.4% [2]. Generation to balance this demand highly depends on fossil sources with the risk of extinction, and it may not be enough in the future. The risk of a possible energy crisis requires finding alternative methods for both generation and demand.

The second problem is inefficient use of backup generators because of total energy consumption trends. In a power grid, generation and demand should always be balanced. Energy demand reaches a peak, which is higher than average demand for a little time, and several generators are established to meet this, but stay inactive during the remaining time. New investments are also planned to meet future peak demands.

Various solutions for these issues can be explained under the topic of "Smart Grid". With distributed generation, the dependence on fossil fuel is aimed to be decreased by increasing the number of dispersed small generators which use renewable energies.

Two way power flow and unpredictable generation sourced by distributed generation requires finding additional solutions against high grid management costs and power system contingencies [3].

Another subtopic of smart grid for the solution of the problems explained above is named as "Demand Side Management" (DSM). Demand Side Management is the process of managing the consumption of energy to optimize available and planned generation resources. The most widely accepted definition of DSM is the following: "Demand Side Management is the planning, implementation, and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility's load shape, i.e., changes in the time pattern and magnitude of a utility's load" [4].

Load profiles describe the variation of electricity demand with time. Hourly load profiles provide crucial information on how electricity is used, and thus which DSM strategies could be potentially effective on where. There are six generic load shape objectives that can be considered during DSM planning, namely peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible load shape [4]. These applications can be categorized in two ways such as indirect load control and direct load control [5].

Indirect load control can be done by the use of incentive policies, different tariffs, discounts, bonus payments and advertisements, etc. These methods aim to constrain consumption at peak demand times and make customers shift their loads to off-peak times. Pricing methods depending on the time of use or peak consumption, are also being used as indirect load control methods to limit consumption during desired time periods. The major advantages of these methods are fast application opportunity and low investment need. The common disadvantage of all indirect load control methods is the uncertainty of customer's usage behavior. The results of a method on customers may vary from time to time and the desired changes in load shape may not be successful.

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Nomenclature

C_{th}	thermal mass (J/°C)
T	temperature (°C)
t	time (min)
Subscripts	
A	insulation
q	cooler's power (W)
Greek letters	
ε	system inertia
η	efficiency (%)
τ	time span (min)

Direct load control is the name given to the method about controlling flexible loads directly with a device. The controller device can be either a simple circuit that applies a preprogrammed schedule for a single load or a more complex device which communicates with house automation system and smart meter and controls various types of loads. There are various ways for management of loads such as controlling the power of the appliance or changing thermostat's temperature set points [6]. Direct load control methods require technological development and additional costs for infrastructure; on the other hand, they provide more accurate control. Performances of these methods can be improved, if they are supported with indirect load control methods [5].

The cost of controlling loads with a device is less than the construction of a new power plant or the set up and use of an energy storage system [7].

The selection of the load for controlling is one of the most important stages of Demand Side Management applications. Times of use for the load which is going to be controlled must be changeable and this change should not affect its customer. Moreover, the selected load's power consumption must be a considerable value in total consumption. Many loads may be flexible, but if they are being used infrequently and their power consumption is not of considerable value, they will not provide effective results in DSM projects. Taking this into account, thermostatic loads are commonly being preferred for DSM and between these, refrigerators are good candidates.

Most of the DSM projects focus on increasing the benefits of distribution network operators (DNO) and grids. Supply side companies can reduce average losses of their system, which will result in improved efficiency and increased revenues [8]. On the other hand, these applications will succeed, if they are accepted and commonly used by customers [9,10]. For this reason, customer benefits should also be considered during the development stages in DSM studies [7].

DSM studies have mostly been held in industrial sector, because of sector's high percentage in total energy demand. However recent increase in residential electricity demand receives attention of researchers [3,11]. Industrial consumers have the option of participation through bids, while commercial and residential consumers can participate as aggregated manageable resources [12,13].

In this paper, Demand Side Management with control of a refrigerator and its effects on customers are studied. In the second part DSM in cooling systems is explained. While the third part is about modeling a refrigerator, the fourth part includes simulation process and in the last part simulation results are discussed.

2. DSM in cooling systems

The energy consumption of cooling systems is a big part of total energy consumption. In Germany annual consumption of refrigerators and freezers is approximately 16 TWH. This is more than the total consumption of other household appliances like washing machine, clothes drier, etc. Moreover, the total DSM capacity of refrigerators is more than 800 MW. This value is close to the generation capacity of a large power plant [14]. In Turkey, refrigerators have the biggest ratio in residential end users' electricity consumption [15].

Cooling systems mostly have similar working schedules. Their primary mission is to keep the inner temperature at acceptable limits. To achieve this, cooler works to chill its temperature until it reaches the minimum, and then stops working and do not operate again until the inner temperature rises up to the maximum [16]. Time spans of cooling and warming depend on the thermal mass of the appliance and its isolation from outside. While keeping the inner temperature in accepted limits, the cooler's working schedule can be modified (by adjusting for precooling or delayed cooling) without disturbing its customer [17].

Cooling systems seem to be very suitable for DSM applications [18]. According to a study done in Austrian residential sector, the percentage of DSM-ready cooling systems is estimated to be more than 14% by 2020 [9].

Building cooling systems' and refrigerated warehouses' performances vary frequently depending on the outside temperature. Because they are always interacting with the outside, cooling and warming times of systems change continuously. While working with this type of systems, many characteristics of the place that they are implemented should be considered with also adding weather conditions of that area into calculations. On the contrary to building cooling systems, indoor appliances like refrigerators have close and predetermined isolation values and working schedules. They are usually being used inside the buildings where temperatures rarely change (around 25 °C). Their behavior in control applications can be estimated more accurately.

In control applications of devices for DSM, refrigerators have the highest priority of keeping the temperature in acceptable limits because of including perishable goods [19]. For this reason, their control needs more attention.

3. Modeling a refrigerator

For a DSM application with control of a refrigerator, firstly a model of a refrigerator is needed. There are several studies using various calculation methods to model a refrigerator. While studies about thermal homogeneity and refrigerator design focused on inner temperature variation for different compartments, studies for energy consumption use more basic calculations simulating temperature behavior [20–22]. Many studies that have been done for energy consumption use inner temperature and power consumption measurements taken from various models with different characteristics [16,23]. By using the data gathered from real devices, a virtual model can be used with mathematical equations to simulate power consumption (Fig. 1). Virtual model has a linear characteristic that uses the average of measurements of power demand which will result in same energy consumption value in a period. The advantages of using average value rather than dynamic variables are faster computation and smaller memory need for programming.