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Electric Water Heater Modeling, DR Approaches Analysis and Study of Consumer Comfort for Demand Response

Md Tofael Ahmed, Pedro Faria, Zita Vale

IPP – Polytechnic of Porto, Porto, Portugal

Abstract

With the smart energy management system household residential appliances is able to participate in the demand response events. To reduce peak load demand and complexities in the local infrastructure DR can play an important role now a days. This paper presents a study and analysis of several papers on residential EWH DR modeling and implementation. It shows an overview of analysis of the most used and recent DR models for EWH. It also shows the analysis of the used methods to model this and the used approach in several papers. Additionally, the discussed consumer comforts and obtainable benefits in several papers by participating in DR events is also shown here. The study and analysis in this paper will contribute to the future research and encourage the end users to participate in households DR events.

Keywords: comfort analysis, demand response; model analysis

1. Introduction

Smart grid (SG) technology is used to develop the modern energy management system. Now a days the focus has been shifted to demand side management (DSM) as the main focus of this is to manage the demand load curve by peak shaving, peak shifting and valley filling [1]. In SG, the efficiency and reliability can be improved also by delivering energy from the suppliers to the customers with the help of modern digital technology [2]. Sufficient grid flexibility and energy efficiency can be provided by the integration of SG technology in the building energy management system (BEMS). It is the main motivation to provide an efficient and reliable energy system of climate and energy targets 2020 namely “20-20-20” [3].

DSM is the potential most solution to solve the problems during peak load consumption. For the purpose of covering all concepts and methods for energy management system in demand side is covered by DSM [4]. There are different types of DSM strategies in controlling domestic EWH.

In the SG, demand response (DR) mechanism is an important feature for the electricity management. The capacity of DR is stated as “the potential for flexible response from end-use appliances across the commercial, industrial and residential sectors” [5]. To reduce both total energy consumption and peak demand, DR is used as a basic tool by the Independent System Operators (ISOs) in the recent modern electricity infrastructure. It has an important contribution by managing electricity demand in response to supply conditions in the smart grid technologies. Time-based rates and incentive-based programs are the important features of DR [6].

EWH is the largest single consumer of electricity so it is the most suitable appliance to be considered for DR events. In the modern grid a significant source of energy consumption is represented by the EWH. In the form of a water storage tank it has also built-in thermal storage system inside of it. It has also higher nominal power ratings combined with large thermal buffer capacitance that make it well suited for demand management. It does not need reactive power support from the grid because the heating element is actually a resistor. This special feature makes the heater very flexible and convenient to control the switching actions.

Additionally, the water heating in the heater is easily shiftable in time as it does not impact significantly on the user's comfort. The considerable temperature inside a heater range from very low to a very high value (e.g., 40 – 85 ºC). So, it does not interrupt the consumer's comfort level due to this higher range of temperature [7].

The rest of the paper is organized as follow. Section 2 represents the different model analysis from several papers. Modelling approach or DR approach is described in Section 3. Section 4 discusses the consumer comfort analysis from different papers. Finally, the main conclusions of the paper are discussed in Section 5.

2. Different Model Analysis

There are several models existing in the current electricity management system for demand response of EWH. Overall 100 papers were analyzed and studied for this purpose. An Excel work sheet was made to analyze the overall models. From the study it is found that Load Model [8], [9], [10] is the most used model in the EWH management system. This model discusses the electrical heater load characteristics and behaviour in according to the appliance elements. Then the second most used model found in the study is the Thermal Model [11], [12], [13]. Thermal model discusses the thermal behaviour of the heater.

After a brief analysis it is found that Mathematical Model [14], Simulation Model [15], Aggregate model [16] and so on comes sequentially after this in the most used model. An overview of the analysed and studied model from several papers is shown in the Table 1 below.

Table 2: An overview of the studied model with reference.

Reference Paper No.	Used Approach
2.	Black-Box Model
17.	Linear Model
18.	Dual Element Model
19.	Dynamic Model
20.	Predictive Model
21.	User Comfort Model
22.	Physical Model
23.	Transient Model
24.	Boiler Profiling Model
25.	Statistical Model

There are several other interesting models also analysed in our study. For example, Average Illumination model, Metrics Model, Stochastic model Non-invasive model and so on.

3. DR Approach/Modeling Approach Analysis

The studied models are analysed by using different DR approach to be implemented in the smart energy management system. In this section, it was discussed about the studied DR approaches for the DR implementation based on the several papers analysis.

A group of approaches were gathered from several papers and studied in order analyse. From the analysis it is found that the most used approach is to Follow Water Temperature [26], [27], [28] of the heater. In this approach, the solution is taken based on the water temperature of the heater as it is considered as the main parameter to solve. Then, the second most used approach is Load Control [29], [13], [15]. This approach is used to solve for DR of the appliance by controlling the load during peak load or high demand time.

Then it comes sequentially Load Shifting [30], Load Curtailment [29], Direct Load Control [31] etc is in the list of used approach for DR in the studied papers. Load Shifting is used to shift the EWH load, Load Curtailment is used to curtail the EWH load and Direct Load Control is used to control the heater remotely during the peak demand period. An overview of the analysed and studied approaches from several papers is shown in the Table 2 below.

Table 2: An overview of the analyzed approaches with reference.

Reference Paper No.	Used Approach
10.	Cluster Analysis Method
32.	Linear Optimization
16.	Monte-Carlo
2.	Machine Learning Algorithm
33.	Smart Metering Solution
34.	Artificial Neural Network
35.	Load Scheduling
36.	Dynamic Pricing
37.	Peak Shaving
14.	Parameter Analysis

There are many other existing DR approaches also studied during this work. Among them the interesting approaches are Heuristic Algorithm, Water Temperature Assessment, Mixed-Integer Non Linear Programming.

4. Consumer Comfort Analysis

This section describes the analysis of consumer comforts based on the study of the used model and DR approach from the papers. It also discusses the consumers benefit or convenience for the proposed analysis. Water Temperature Profiling [8], [11], [38] is the most found user convenience situation in the studied paper. The term means that user can have a clear profile of the water inside the heater. This will help them to use the heater according to their needs.

The second most convenience found from the analysis is Peak Load Reduction [30], [39], [40]. This term means that by using the proposed method in the referenced paper, peak load can be reduced so that it can fulfill the DR conditions. The other comforts and user convenient terms are found like Low Computational Complexity [15], Performance Analysis [41] and Pricing Knowledge [30]. An overview of the analysed and studied user comfort from several papers is shown in the Table 3 below.

Table 3: An overview of the analyzed user comforts and benefits with reference.

Reference Paper No.	User Comforts/Benefits
13.	Usage Prediction
42.	Power Management
28.	Cost Minimization
30.	Financial Benefit
12.	Energy Consumption Reduction
18.	Thermal Comfort
43.	Optimal Control
21.	Payback Effect Decreasing
22.	Parameters Identification
24.	Efficient Energy

With the above mentioned user comforts and benefits there are other benefits and comforts for end users found during the analysis also. Among those the most important options are Load Extraction, Smart Interface, Energy calculation, Energy savings etc.

5. Conclusions

The main challenge in the traditional electrical infrastructure and management system is to balance demand and supply during peak demand time. The complexity is also growing because of the increasing penetration and uncertainties of the renewable and distributed energy resources. Residential household appliances have a great influence in the peak load increase among the local grid. To solve this issue smart energy management system and demand response can take part in the electricity management.

Among the several residential appliances, electrical water heater is considered to analysis in this paper. It includes the study of the used models in several papers, the approach to model this is for DR purpose and at the end the benefits or comforts analysis for the users.

This study reveals that there are several models are very convenient to use, implement and execute to perform DR for residential heater. This will show a pathway for the researchers to work on EWH in future and choose the right models for their work. Also, it discusses the used convenient approaches to solve this and model this. An overview of the user comfort and benefit analysis is also shown which will encourage the consumers to make participation in households demand response.

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