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Analysis of Residential Load Data and Its Applications for Smart Grids

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Analysis of Residential Load Data and Its Applications for Smart Grids

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Certificate of Original Authorship

I, Amin Rajabi, declare that this thesis is submitted in fulfilment of the requirements for the award of PhD degree, in the school of Electrical and Data Engineering, faculty of Engineering and Information Technology at the University of Technology Sydney. This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program Scholarship.

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Publications

The following publications are part of the thesis.

Journal publications

[1] A. Rajabi, M. Eskandari, M. Jabbari Ghadi, S. Ghavidel, L. Li, J. Zhang, P. Siano, "A pattern recognition methodology for analyzing residential customers load data and targeting demand response applications," *Energy and Buildings*, vol. 203, p. 109455, 2019.

- **This paper is incorporated in Chapter 4.**

[2] A. Rajabi, M. Eskandari, M. Jabbari Ghadi, L. Li, J. Zhang, P. Siano, "A Comparative Study of Clustering Techniques for Electrical Load Pattern Segmentation," *Renewable and Sustainable Energy Reviews*, vol. 120, p.109628, 2020.

- **This paper is incorporated mainly in Chapter 3 and partially in Chapter 4.**

[3] A. Rajabi, M. Eskandari, L. Li, J. Zhang, "Trends in Applications of Load Data Clustering in Smart Grid Enviornment," (Under review, *IEEE Systems Journal*)

- **This paper is incorporated in Chapter 2.**

[4] A. Rajabi, L. Li, J. Zhang, K. Muttaqi, “A Feature-Based Data Mining Approach for Characterizing Residential Consumption Behavior in Smart Electricity Grids,” (Under review, *Energy Research and Social Sciences*)

- **This paper is incorporated in Chapter 5.**

[5] A. Rajabi, M. Jabbari Ghadi, S. Ghavidel, L. Li, J. Zhang, “A Clustering-Based Framework for Development of Time of Use Tariffs for Residential Electricity Customers,” (To be submitted)

- **This paper is incorporated in Chapter 6.**

Conference publications

[6] A. Rajabi, L. Li, J. Zhang, and J. Zhu, "Aggregation of small loads for demand response programs—Implementation and challenges: A review," in *Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), 2017 IEEE International Conference on*, 2017, pp. 1-6

- **This paper is incorporated in Chapter 2.**

[7] A. Rajabi, L. Li, J. Zhang, J. Zhu, S. Ghavidel, and M. J. Ghadi, "A review on clustering of residential electricity customers and its applications," in *2017 20th International Conference on Electrical Machines and Systems (ICEMS)*, 2017, pp. 1-6.

- **This paper is incorporated in Chapter 2.**

Abstract

Smart grids are equipped with advanced smart metering infrastructures that enable the two-way communication between end-users and utilities and record the consumption data of electricity customers. The gathered smart meter data have opened up possibilities for analyzing the consumption behavior of customers and understanding the underlying factors affecting it. However, the dimensionality of recorded data necessitates the use of data analysis techniques to extract valuable information from the load profiles. In this regard, this thesis utilizes various methods to analyze the consumption and survey data of residential electricity customers.

In the first two chapters, the concepts of smart metering, residential customers' load patterns, and clustering of load data are extensively discussed, and a comprehensive discussion of the extant literature is presented.

Chapter 3 presents a comparative study of five main clustering approaches including K-means, fuzzy c-means, hierarchical, self-organizing map, and Gaussian mixture models for load pattern segmentation. Various parameters of each of these methods are explained in detail and their performances are compared using six cluster validity indexes. The obtained results are analyzed to find out the characteristic load shapes among the load curves of customers and to identify the main consumption patterns.

The problems of data deluge and residential DR establishment are addressed in Chapter 4 using a combination of symbolic aggregate approximation (SAX), as a suitable dimensionality reduction technique, a clustering algorithm, and the entropy concept. The use of SAX can assist in the clustering of residential load patterns, which usually display

high variability. Moreover, the results are utilized for ranking the customers based on their stability in usage patterns over time which is beneficial for different DR programs.

In Chapter 5, both the consumption data and survey data of residential electricity customers are used to find out the effects of the households' socio-demographic attributes and building characteristics on load patterns.

In Chapter 6, a combination of clustering algorithms and optimization models are used to design TOU tariffs for electricity customers. The problem is modeled as a mixed-integer linear programming problem with the objective of maximizing the profits of an electricity retailer that participates in different market settlements. The stochastic programming technique is used to address the uncertainties in future load and price.

Finally, in the last chapter, future directions in the analysis of smart meter data and the clustering of load patterns are briefly reported. Furthermore, the proposals for future work are elaborated in this chapter.

Keywords: Residential Load Data; Data Mining; Clustering; Demand Response; Data Size Reduction; Time of Use Tariffs

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List of Abbreviations

AIC	Akaike's information criterion
AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
ARMA	Auto Regressive with Moving Average
BI	Business Intelligence
BIC	Bayesian Information Criterion
CER	Commission for Energy Regulation
CFL	Compact Fluorescent Lamp
CFSFDP	Fast Search and Find of Density Peaks
CVI	Clustering Validity Index
DBI	Davies-Bouldin Indicator
D^2R	Dynamic Demand Response
DFT	Discrete Fourier Transform
DLC	Direct Load Control
DR	Demand Response
DMS	Data Management System
DTW	Dynamic Time Warping
DWT	Discrete Wavelet Transform
EM	Expectation-Maximization
FCM	Fuzzy C-Means
GMM	Gaussian mixture model

HMM	Hidden Markov Model
HDF	Household and Dwelling Features
I/C	Interruptible/Curtailable load
ISODATA	Iterative Self-Organizing Data Analysis Technique Algorithm
KEPCO	Korea Electric Power Corporation
KNN	K-Nearest Neighbor
LR	Logistic Regression
MAPE	Mean Absolute Percentage Error
MIA	Mean Index Adequacy
MSE	Mean Square Error
NTL	Non-Technical Losses
OPF	Optimum-Path Forest
PAA	Piecewise Aggregate Approximation
PAM	Partitioning Around Medoids
PG&E	Pacific Gas and Energy Company
PCA	Principal Component Analysis
RLP	Representative Load Pattern
SAX	Symbolic Aggregate approXimation
SIL	Silhouette index
SOM	Self-Organizing Maps
SVM	Support Vector Machines
SVR	Support Vector Regression
TLP	Typical Load Profile
TOU	Time of Use
WCBCR	The ratio of within-cluster sum of squares to between-cluster variation