

Time of use Period Determination for Residential Customers in Peninsular Malaysia



N. Khamis, C.S. Tan

Abstract: Time of Use (TOU) is basically one of the demand response programs which enable the end-user consumers to adjust their energy use in response to changes in electricity prices over a period of time with an incentives. Generally, Time-of-Use implementation help to reduce system's maximum demand by transferring some of the demand into different hours. Time-of-Use also is a cost reflective electricity pricing scheme in which days are commonly split into multiple periods such as peak, mid-peak and off-peak. The residential sector is expected to have the highest growth as compared to commercial and industrial sectors. This is due to an increase in population and increasing living standards which increase the number of households and the electrical electricity consumption per household as more households and individuals choose to buy more electrical appliances. This paper presented a new clustering method called Jenks Natural Breaks in order to segmentize the Time of Use period for the residential customers in Peninsular Malaysia. A comparison of K-Means clustering method and the proposed Jenks Natural Breaks method is presented in this paper. The time of use determination are performed using these two methods based on the average of six actual residential customer's load profiles. In this paper, two-part periods (zones) segmentation of TOU are considered for analysis and discussions. The results shows the TOU Peak period using the K-Means clustering method is between 10.00am and 8.00pm while for a new proposed Jenks Natural Breaks method the TOU Peak period is between 9.00am and 8.00pm.

Keywords: Time of Use, Residential, Jenks Natural Breaks, k-Means clustering

I. INTRODUCTION

Time-of-Use (TOU) electricity pricing are widely spread in developed countries such as in Australia, America and Europe. Meanwhile in ASEAN, several countries such as Malaysia, Thailand, Singapore and Philippines have begun to implement TOU pricing to provide better tariff options to their customers while other ASEAN countries such as Indonesia, Vietnam, Brunei, Myanmar, Laos and Cambodia are still offering inclining block tariff to their customers [1]. For those countries that have a seasonal weather, time of use may vary based on their seasonal variation.

At present, many utilities have offered TOU rates typically as default service to large commercial and industrial customers [2]. Introducing TOU for residential, commercial and industrial customers are tricky since each customer has own unique load profile. Therefore, adopting TOU period for residential customers similar to the commercial and industrial customers TOU period should not be the same. This is because residential electrical electricity consumption during day time is low while commercial and industrial are high. Generally, TOU period design must benefit both utilities and customers. It was reported that implementing TOU will benefit utility through reduction of peak demand and electricity generation cost while customers benefit through electricity bill reduction [3]. One of the important aspects of Time-of-Use design is the determination of the period such as Peak and Off-peak hours of the day [4]. Generally, clustering analysis is a technique used to group the hours that having a similar consumption of the day into clusters to be used in time of-use rate design. Clustering analysis has been widely used in a number of fields including Science, Medicine, and Engineering. Numerous clustering techniques exist and the selection of the clustering techniques depends on the context and intent of the analysis. There are also variety methods of clustering techniques that have been applied to power systems applications. A recent study conducted by [5] has introduced a new segmentation technique called Jenks Natural Breaks for the residential customers by segmenting customers load profile into two-part periods namely peak and off-peak periods. Most of the literature reviews from the previous studies used Hierarchical clustering, K-Means clustering, Fuzzy K-Means clustering and Self-Organizing Map (SOM) clustering [6-8]. A previous study conducted by [9], has introduced and analyzed the difference between the clustering methods which includes Hierarchical clustering, K-Means clustering, Follow the leader, Fuzzy K-Means and Fuzzy Classification. The study indicates, a good clustering method will help to produce high quality clusters in which the intra-cluster similarity is high and the inter-class similarity is low as well the ability to discover some or all of the hidden patterns. However, the quality of a clustering result will also depends on the similarity of the measures used and the implementation of the method. Self-Organizing Maps (SOM) and K-Means clustering method have been used in a previous study by [10] and [11] to identify the customers load patterns and to describe a characterization framework for the electricity customers.

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Two methods for performing electricity customer classification based on their electrical behavior were presented in their studies. The number of clusters shall be determined by the researchers as it cannot be directly fixed. The desired number of clusters may require successive executions of the algorithm by adjusting the threshold value. A two-stage recognition of load curves based on different clustering methods is described by [12] including K-Means clustering. Self-Organizing Maps (SOM) clustering method has been done by [13] based on the database measurements to achieve the classification of clustering and demand pattern of the customers. K-means is a commonly used clustering method with the simplest principle and fast speed of convergence[14]. Other than that, K-Means also has been used to analyze the large scale datasets[15]. Each of the clustering method has its own advantages and disadvantages. Table 1 below shows the advantages and disadvantages of each clustering method.

Table. 1 Advantages and disadvantages of each clustering method [9, 10-15]

Clustering Method	Advantages	Disadvantages
Hierarchical	<ul style="list-style-type: none"> Useful and good result for small dataset Number of clusters can be determined using dendrogram Easy to implement Original Data kept unchanged 	<ul style="list-style-type: none"> No necessarily scalable for large datasets Slow speed convergence Time complexity is not suitable for large datasets
K-Means	<ul style="list-style-type: none"> Fast speed convergence Good for large dataset Data point exclusively group in cluster 	<ul style="list-style-type: none"> K-Means algorithm shows less quality Difficult to predict the number of clusters (K-Value)
Fuzzy K-Means	<ul style="list-style-type: none"> Data point is assigned and may belong to more than one cluster center 	<ul style="list-style-type: none"> Longer computational time Require initial guess Sensitive to outliers and low (or even no) membership degree for outliers.
Self-Organizing Maps (SOM)	<ul style="list-style-type: none"> Easy to implement Provide good visualization New data can be added easily 	<ul style="list-style-type: none"> Output space topology is predefined Convergence of clustering depending on

Clustering Method	Advantages	Disadvantages
		initialization and learning rate
Jenks Natural Breaks	<ul style="list-style-type: none"> Suitable for Mapping values that are not evenly distributed in the histogram 	<ul style="list-style-type: none"> Class ranges are targeted to a single dataset Hard to compare maps of different data sets Difficult to choose the optimum number of classes, especially when data are evenly distributed

Another clustering method that involve iterative process is Jenk Natural Breaks. This method can also be used to segregate data into classes. Historically, Jenks Natural Breaks was developed and introduced in 1977 for optimal data classification. The design of this method is based primarily upon Fischer’s Optimization method that was developed in 1958 [16]. Jenks algorithm was developed for the use of geographic data analysis, and has been prominently used as a standard geographic classification algorithm in the commercial software package such asAeronautical Reconnaissance Coverage Geographical Information System (ArcGIS). Therefore, in this paper, a continuation study and works from [5] using Jenks Natural Breaks is introduced and presented to determine the two-part periods TOU from the average of actual six residential customers load profile. A comparison of two-part periods TOU between K-Means Clustering method and Jenks Natural Breaks are presented in this paper.

II.METHODOLOGY

In this study, the Jenks Natural Breaks analysis and K-Means clustering method which are available in the Microsoft Office Excel Real Statistics Resource Pack Add-In Tools are used to analyse and determine the TOU period based on the average six (6) actual customers load profiles. Two classes of periods are chosen for the load profile segmentation which are Peak and Off-Peak periods. This is because the more classes utilized, more complex and time consuming the algorithm will be.

Six (6) residential customers load profiles in a particular billing period in Melaka were collected and shared by the utility. The residential customers load profiles were collated between 20th of August 2017 and 20th of September 2017 (31 days) with antimeinterval of 30 minutes. Total dataset points for load profile clustering of 6 residential customers for 31 days are 8928 datasets.



The segregation will be conducted using both proposed methods with a two-part period namely Peak and Off-Peak periods. The steps taken to perform the segmentation of TOU period for the six (6) residential customers using Jenks Natural Breaks method and K-Means Clustering method are described as below.

2.1 K-Means Clustering

This method groups the load profile data by first identify number of clusters and a center point for each cluster. After determining the center point of each cluster, each data set will be assigned to the nearest center point and recalculation of the new center point will be done iteratively until the position of the center point is converged[7]. K-means clustering uses actual observations of objects or individual data and therefore it is more suitable to cluster large amounts of data. The steps of the K-means algorithm are discussed as below:

- Step 1: Initialization – Identify number of clusters, K
- Step 2: Searching - Determine the value of the center point of each cluster identified. Calculate the distance between dataset and center point. Based on this calculation, the nearest distant to the center point of each cluster will be assigned to the corresponding cluster.
- Step 3: Updation - The cluster center points will be updated in each cluster and step 2 is repeated
- Step 4: Continuation – Step 2 and Step 3 are repeated until no more change in the value of the center points of each cluster.

2.2 Jenks Natural Breaks

This method is performed by minimizing each class average deviation from the class while maximizing each class’s deviation from the means of the other groups. In other words, this method seeks to reduce the variance within classes and maximize the variance between classes. Similar to K-Means clustering method, this method requires an iterative process which means the calculation must be repeated using different breaks in the dataset.

This is to determine which set of breaks has the smallest in-class variance. The process is started by dividing the ordered data into groups. There are six steps that must be repeated until the goodness of variance fit (GVF) is maximized as follows [17]:

- Step 1: Compute sum of Squared Deviations Between Classes (SDBC)
- Step 2: Compute sum of Squared Deviations from the Array Mean (SDAM)
- Step 3: Calculate sum of Squared Deviations from the Class Means (i.e., within classes) (SDCM) by subtracting SDBC from SDAM (SDAM - SDBC).
- Step 4: After inspecting each of the SDBC, a decision is made to move one unit from the class with the largest SDBC toward the class with the lowest SDBC
- Step 5: Calculate new class deviations, then the process is repeated until the sum of the within class deviations reaches a minimal value.
- Step 6: Calculate Goodness Variance Fit (GVF) as (SDAM - SDCM) / SDAM. GVF ranges from 0 (worst fit) to 1 (perfect fit).

The method is achieved when the quantity GVF is

maximized. Figure 1 depicts the flowcharts for both K-Means Method and Jenks Natural Break Method.

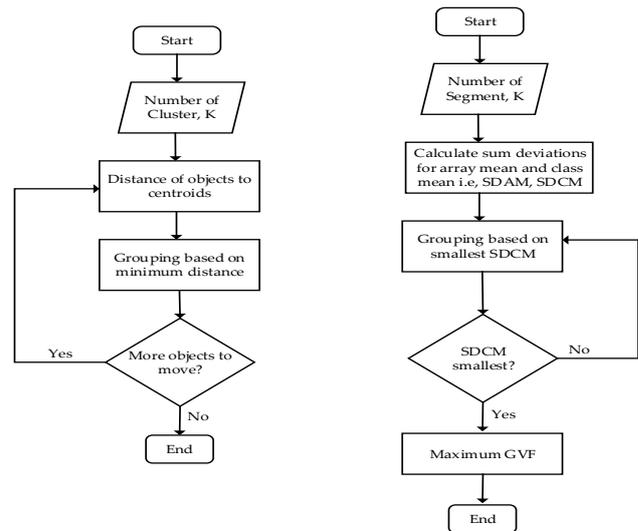


Fig. 1 Flowchart of the K-Means (Left) and Jenks Natural Breaks (Right) clustering methods

III. ANALYSIS AND DISCUSSION

In this research study, peak period is defined as the system generation peak hours where the system demand is peaking hence the cost of generation is higher and vice versa. Based on the data analysis in Table 2, all the data elements in the range of 0.0445kWh to 0.7850kWh are considered as peak period. Meanwhile, for the off-peak period, the data elements are from 0.7855kWh the lower data to 4.5530kWh the upper data. The lower data in Jenks Natural Breaks is defined as a minimum data element while the upper data is defined as maximum data element. From the analysis, the six customers load profile using Jenks Natural Breaks gives the SDCM equals to 727.604 while the SDAM of the input data is 1987.53. Hence Goodness Variance Fit (GVF) is 63.39% or 0.6339 which is close to 1. This indicates that the Jenks Natural Breaks method is reasonably acceptable.

Table. 2 Actual six residential customers results using Jenks Natural Breaks

Period	Min Load (kWh)	Max Load (kWh)	No. of Point
Peak	0.0445	0.7850	6793
Off-Peak	0.7855	4.5530	2135
GVF	727.604	1987.53	0.6339

Table 3 below shows the comparison of TOU period for peak and off-peak for both methods using Jenks Natural Breaks and K-Means clustering methods. The results using Jenks Natural Breaks indicates that the peak period is from 9.00am to 8.00pm (11 hours) while off-peak period is from 8.00pm to 9.00am (13 hours). This TOU period analysis is from Monday to Sunday.



Meanwhile, for K-Means analysis results, it indicates that the peak and off-peak periods are from 10.00am-8.00pm (10 hours) and 8.00pm-10.00am (14 hours) respectively from Monday to Sunday.

Table. 3 TOU Peak and Off-Peak period withboth methods

Period	K-Means Clustering	Jenks Natural Breaks
Peak	10.00am-8.00pm (10 hours)	9.00am-8.00pm (11 hours)
Off-Peak	8.00pm-10.00am (14 hours)	8.00pm-9.00am (13 hours)

The results tabulated in Table 3 can be depicted as in Figure 2 for the Peak and Off-Peak clusters between K-Means clustering and Jenks Natural Breaks methods. Cluster 1 indicates the Peak period while Cluster 2 indicates Off-Peak period. Based on the data collated, the K-Means clustering method and Jenks Natural Breaks method show TOU time different of one hour in the Peak Period. This indicates that Jenks Natural Breaks method can be used to cluster the customer load profile that having similar consumption to segregate customer load profile into Peak and Off-Peak periods.

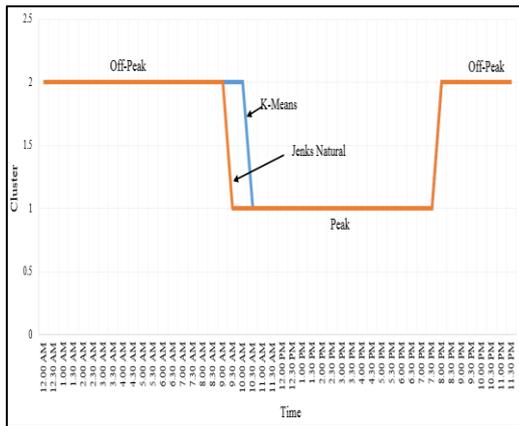


Fig. 2 K-Means Clustering versus Jenks Natural Breaks

IV.CONCLUSION

Jenks Natural Breaks method is introduced to segregate customers load profile into two periods which is Peak and Off-Peak periods based on the electrical energy consumption of residential customers. The results shows that the TOU Peak period based on the Jenks Natural Breaks is between 9.00am and 8.00pm (11 hours) while the Off-Peak period is between 8.00pm and 9.00am (13 hours). The segmentation of load profiles using K-means clustering method indicates that the Peak period is between 10.00am and 8.00pm (10 hours) and Off-Peak period is between 8.00pm and 10.00am (14 hours). From this result, it indicates that Jenks Natural Breaks method can be used to cluster load profile data in order to determine TOU period for the residential customers. The comparison between Jenks Natural Breaks and K-Means shows a difference of 1 hour. However, detail analysis such as impact of load variations on the segmenation of the TOU period is not

discussed in this paper. Further analysis is required to determine the benefits of the TOU period and the rates offered to the customers.

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