OPTIMAL COST BENEFIT OF THE ETOU ELECTRICITY TARIFF FOR MANUFACTURING OPERATION BY USING OPTIMIZATION ALGORITHMS

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in partial fulfillment of the requirements for the degree of
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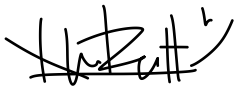
DECLARATION

I declare that this thesis entitled "OPTIMAL COST BENEFIT OF THE ETOU ELECTRICITY TARIFF FOR MANUFACTURING OPERATION BY USING OPTIMIZATION ALGORITHMS" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidate of any other degree.

Signature : 

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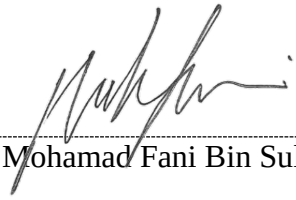
APPROVAL

I hereby declare that I have checked this report entitled "OPTIMAL COST BENEFIT OF THE ETOU ELECTRICITY TARIFF FOR MANUFACTURING OPERATION BY USING OPTIMIZATION ALGORITHMS" and in my opinion, this thesis complies the partial fulfilment for awarding the award of degree of Bachelor of Electrical Engineering with Honours.

Signature : 

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DEDICATION

To my beloved mom and dad

Sharifah Binti Sudin

Late Alias Bin Mat Isa

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ABSTRACT

Since the electricity market are getting more attention due to the electricity demand, there are many options of tariff can be chosen thus making it harder for consumers to make decisions. The consumers looking for an affordable tariff rate that able to give the benefit in reducing the total electricity cost. In regard to the issue, Tenaga Nasional Berhad (TNB) has introduced a more advanced tariff under Demand Side Management (DSM) programs namely Enhanced Time of Use (EToU) tariff as an advanced version of the Time of Use (ToU) tariff for generation and demand side benefits. However, the number of participants joining the programs are less that the expected due to the lack of awareness and knowledge about energy conservation and demand side management strategy. Thus, in this study, simultaneous DSM strategies are proposed for energy consumption cost reduction for manufacturing energy load profiles. Optimization algorithm namely Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) are implemented and compared in order to optimize the load profile. The significant test has been done to four types of industrial consumers from low, medium and high voltages segment. The proposed method had shown reduction in electricity cost at all time zones. The case for this study has been split into six cases that involve the baseline cases using flat and ToU tariff, using normal EToU and using the DSM strategies load adjustment of both algorithms. The end results have shown reduction in total electricity consumptions for industrial D and E1 which is 12% (D) and 2% (E1). Meanwhile, for E2 and E3, there is an increment in the electricity consumptions but it still in the permissible range, but the peak consumptions have able to be shift to mid-peak and off-peak. The electricity bills also have been reduced for all cases that involves load adjustment and the most reduction has been recorded in 30% load adjustment. For 30% load adjustment using ACO optimization, the electricity costs have been decreasing by 19% (D), 16% (E1), 9% (E2) and 1.13% (E3). Meanwhile, for PSO algorithm, the costs have decrease by 40% (D), 47% (E1), 15% (E2) and 3% (E3). The findings of this study hoped to help industrial consumers in managing their tariff selection while enhance the demand side management programs in Malaysia.

ABSTRAK

Oleh kerana market elektrik makin mendapat perhatian disebabkan oleh peningkatan elektrik, terdapat banyak pilihan tarif yang boleh dipilih membuatkan pengguna susah untuk membuat pilihan. Pengguna mencari tarif yang murah yang mampu memberi faedah dalam mengurangkan jumlah kos elektrik. Berdasarkan masalah ini, Tenaga Nasional Berhad (TNB) telah memperkenalkan satu tarif dibawah program strategi pengurusan tenaga (DSM) iaitu 'Enhanced Time of Use '(EToU) tarif versi yang lebih baik kepada 'Time of Use' (ToU) tarif untuk generasi dan faedah berdasarkan permintaan. Walau bagaimanapun, jumlah peserta yang mengikuti program ini adalah sedikit dari yang dijangka kerana kurangnya pengetahuan dalam pemeliharaan tenaga dan strategi pengurusan berdasarkan permintaan. Disebabkan itu, beberapa strategi pengurusan berdasarkan permintaan telah dicadangkan untuk mengurangkan kos penggunann tenaga untuk profil tenaga industry pembuatan. Algoritma pengoptimuman iaitu Pengoptimuman Koloni Semut (ACO) dan Pengoptimuman Kawanan Partikel (PSO) telah dilaksanakan dan dibandingkan untuk mengoptimumkan profil tenaga. Cara yang dicadangkan telah menunjukkan pengurangan kos elektrik untuk semua zon masa. Kes untuk projek ini telah dibahagikan kepada enam kes yang melibatkan kes asas menggunakan tarif mendatar dan tariff ToU, menggunakan tariff normal EToU dan menggunakan strategi pelarasan beban untuk kedua-dua algoritma. Hasil akhir telah menunjukkan pengurangan dalam jumlah penggunaan elektrik untuk industri D dan E1 iaitu sebanyak 12% (D) dan 2% (E1). Manakala, bagi E2 dan E3, terdapat peningkatan dalam jumlah penggunaan tenaga tetapi masih dalam angka yang dibenarkan dan penggunaan tenaga ketika puncak telah berjaya dipindahkan ke puncak tengah dan keluar puncak. Bil elektrik juga telah berkurang untuk semua kes yang melibatkan pelarasan beban dan pengurangan paling banyak telah direkodkan untuk 30% pelarasan beban. Untuk 30% pelarasan beban menggunakan pengoptimuman ACO, kos elektrik telah berkurang sebanyak 19% (D), 16% (E1), 9% (E2) dan 1.13% (E3). Manakala untuk PSO, kos telah berkurang sebanyak 40% (D), 47% (E1), 15% (E2) dan 3% (E3). Pencarian projek ini diharapkan dapat membantu pengguna industri dalam pengurusan tarif pilihan mereka serta mengembangkan program pengurusan berdasarkan permintaan di Malaysia.

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LIST OF ABBBREAVIATIONS

ACO	Ant Colony Optimization
AFD	Adaptive Fast Dynamic
BFO	Bacterial Foraging Optimization
CLC	Connected Load Charge
DC	Direct Current
DR	Demand Response
DSM	Demand Side Management
EE	Energy Efficiency
EMD	Empirical Mode Decomposition
EMS	Energy Management System
EToU	Enhanced Time of Use
GA	Genetic Algorithm
IBP	Incentive Based Program
IRR	Internal Rate of Return
LF	Load Factor
LFI	Load Factor Index
LMS	Load Management System
LS	Load Shifting
MACO	Multi-layer Ant Colony Optimization
MG	Microgrid
NPV	Net Present Value
PBP	Price Based Program
PC	Peak Clipping

PID	Proportional Integral Derivative
PSO	Particle Swarm Optimization
SVR	Support Vector Regression
ROI	Return of Investment
RJO	Rechargeable Job Order
TNB	Tenaga Nasional Berhad
ToU	Time of Use
UAV	Unmanned Aerial Vehicle
VF	Valley Filling

CHAPTER 1

INTRODUCTION

1.1 Research background

Electricity plays important role in people's daily life. Electricity makes everything much simpler thus leading to increasing demand of electricity from every part of the world. The continuous increment in energy consumptions are involved with the widespread of the modern home appliances such as refrigerators and air-conditioner [1]. The increasing in electricity consumption are gathering concern due to the continuous energy generation from burning fossil fuel that has led to the increasing of CO_2emission [2]. It is reported that 84% of CO2 emissions are because of manufacturing activities [3]. Not only in Malaysia, the industrial activities has consume electricity for about 41.5% in Singapore [4], 24% in Europe and 32% in USA [5].

Demand-side management (DSM) programs has been introduced in order to provide solutions to these issues and to promote and regulate energy efficiency in Malaysia. DSM is to improve the energy system at the side of consumption. DSM can be categorized as in Figure 1. Demand response (DR) is a program to drive the DSM program to become successful. DR is described as the changes in the electricity consumption by customers based on their normal daily consumption patterns in reference with the changes of electricity price over time [6]. Demand response program are separated into two parts and one of them is Price Based Program (PBP) [7]. Under PBP, Time of Used (ToU) tariff scheme has been introduced by Tenaga Nasional Berhad (TNB) in 2014. ToU tariff scheme implemented to encourage customers to use electricity efficiently by using less energy using peak hours as well as to mitigate electricity expenses. It has two different time frames for electricity consumption consists of Peak and Off-Peak energy rates.

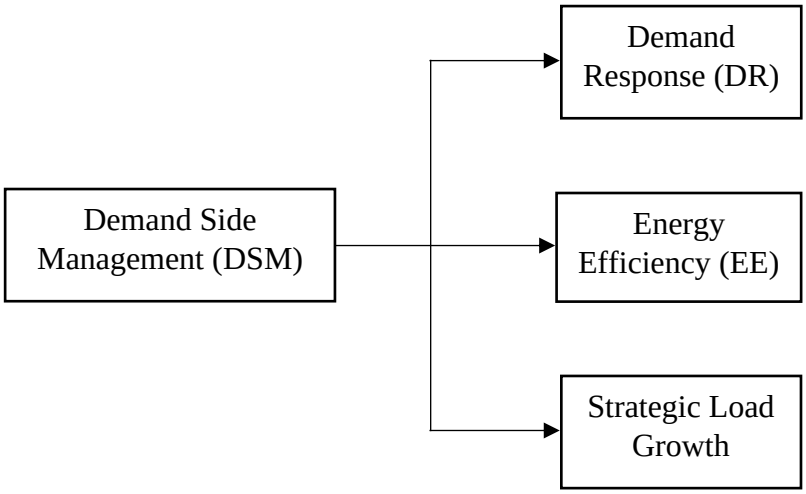

Figure 1 Categories of DSM

After the implementation of the tariff, there have been an upsurge in electricity price. To overcome this issue, TNB has introduces a new tariff scheme known as Enhanced Time of Use (EToU) for industrial consumer in 2016. This new tariff has one more time frame added which is Mid-peak energy rates. It also has different price rate for weekday and weekend. Figure 2 and 3 is the time zones for ToU and EToU accordingly. EToU tariff main objective is to promote demand side management through peak load reduction that can leads to electricity expenses reduction. However, it is reported that only 1% of commercial and industrial consumers join the program [8].The lack of knowledge on how to manage their load profile might be one the biggest factor why consumers are reluctant to join this scheme.

To manage the load profile, consumers need to know the impact of every machinery or appliances they buy and use to the consumption of energy. Knowing where and how the energy are used in factories can help to reshape the manufacturing operations to a better system. This study focuses on analyzing the types of machinery and their energy breakdown in order to know their respective electricity consumption, managing the load profile of industrial consumers by using load management strategy. The validation of the cost whether it is decreasing or increasing after the load management strategy and optimization algorithm have been applied in reflecting the EToU price accordingly.

TOU Time Zones	
Time Zone	Hours
Peak	08:00 – 22:00 hours
Off-peak	22:00 – 08:00 hours

Figure 2 ToU Time Zones

Enhanced Time of Use Time Zones	
Time Zone	Hours
Mid-Peak	08:00 – 11:00 hours
Peak	11:00 – 12:00 hours
Mid-Peak	12:00 – 14:00 hours
Peak	14:00 – 17:00 hours
Mid-Peak	17:00 – 22:00 hours
Off-Peak	22:00 – 08:00 hours

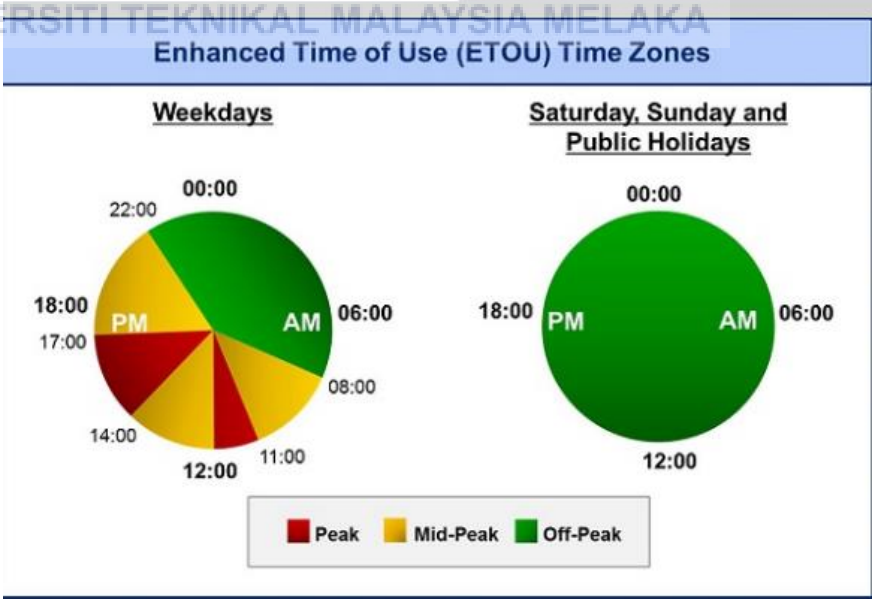

Figure 3 EToU Time Zones

1.2 Problem statement

1) The consumptions of electricity in industrial are much larger than in residential especially in production type manufacturing factory. The types of machinery in the factory and the energy consumption of each machinery are the important factors that contribute to the costs of electricity bills. Wrong ways in managing the machinery may lead to a big waste of electricity [9].

2) High electricity usage during peak hours can lead to high electricity expenses [10]. Consumers need a suitable load profile that can help them reducing the electricity usage during peak hours by using load management strategies such as valley filling, load clipping and load shifting in addition of the implementation of optimization algorithms.

3) A certain amount of investments are needed to be paid by customers in order to change from one tariff to another such as the charge from the supplier and digital meter for monitoring the electricity usage [11]. The load profiles that have been analyze can help customers to wisely chose either to stay using the old tariff or change to the new one.

1.3 Objectives

1) To investigate the energy load profile in manufacturing reflecting to normal ToU and EToU price.

2) To analyze the performance of the load management strategy in reflecting EToU price using ACO and PSO algorithms.

3) To validate the energy cost benefit of the proposed load management strategy under EToU tariff structure.

1.4 Scope

Scope of this case study has been limited to industrial customers in Malaysia. In this project, four different load profiles of manufacturing company which are D, E1, E2 and E3 are used as the case study.

Load management strategy methods used in this project is to minimize the electricity expenses by applying the simultaneous valley filling, load clipping and load shifting.

The optimization algorithm used in this study is Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO). These algorithms will be run in MATLAB software.

Time of use (ToU) and Enhanced Time of Use (EToU) tariff scheme are used in this study to analyze the load profile and their corresponding electricity usage and costs. The result of these two tariffs will be compared to validate the cost whether it is increasing or decreasing after the load management strategy and the optimization algorithm have been carried out to help customers choose wisely which tariff will be suitable for them.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discussed each topic that are involved in doing this study. Section 2.2 and 2.3 discussed the definition and purpose of Demand Side Management (DSM) and Demand Response (DR) in electricity market. Section 2.4 discussed the Price Based Programs (PBP) that exist in our country. The tariff scheme introduced under this tariff namely ToU tariff and EToU tariff also will be discussed under this section. In 2.5, the machinery management strategies are discussed. In this section, the breakdown of energy from each machinery is monitored, and the DSM strategies such as load shifting, load clipping and valley filling are applied to make a suitable load profile that later will be optimized by optimization algorithms. the optimization algorithms that will be used in this study are Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO). Lastly, in 2.6, the cost-benefit analysis is discussed by differentiating the two tariff, ToU and EToU tariff.

2.2 Demand Side Management (DSM)

Demand side management (DSM) programmes have been useful in managing the demand of electricity in most countries. The programmes contain energy efficiency (EE) policies and demand response (DR). From electricity consumers view, DSM is a helping tool that helps them adapt to the price signals coming from the electricity market. Many previous research has been conducted in order to improve DSM programmes. Figure 4 shows the energy efficiency and demand response classification [12].

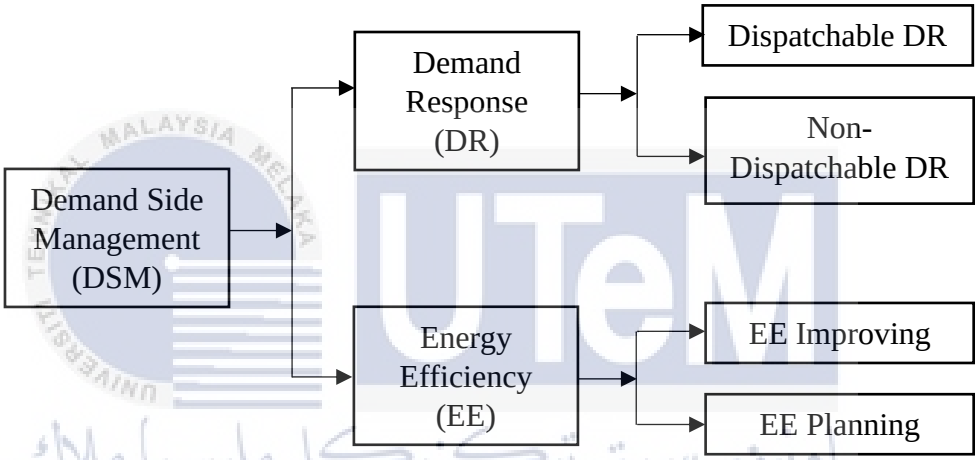

Figure 4 Classification of DR and EE

2.3 Demand Response (DR)

DR refers to load adjustment strategy that was implemented under DSM. DR aims to motivate consumers to change their power consumptions habit in regards to the changes of the price of electricity in order to have a smooth demand curve [13] by using any strategy such as load demand strategy. DR programs often use mechanisms to persuade consumers to reduce demand during peak hour to have lower peak demand. Since DR may induce discomfort in consumer, they would actually limit the time exposed to those discomfort [14]. DR is split into two parts which are dispatchable DR and non-dispatchable DR as shown in Figure 4. Dispatchable DR is usually known as Incentive-Based Program (IBP), and non-dispatchable DR is known as Price Based Program (PBP) [15].

2.4 Industrial Price Based Program (PBP)

PBP has programs under it which are Critical Peak Pricing, Real-Time Pricing, Time of Use and Enhanced Time of Use Tariffs [16]. Figure 5 shows the classification of PBP and IBP.

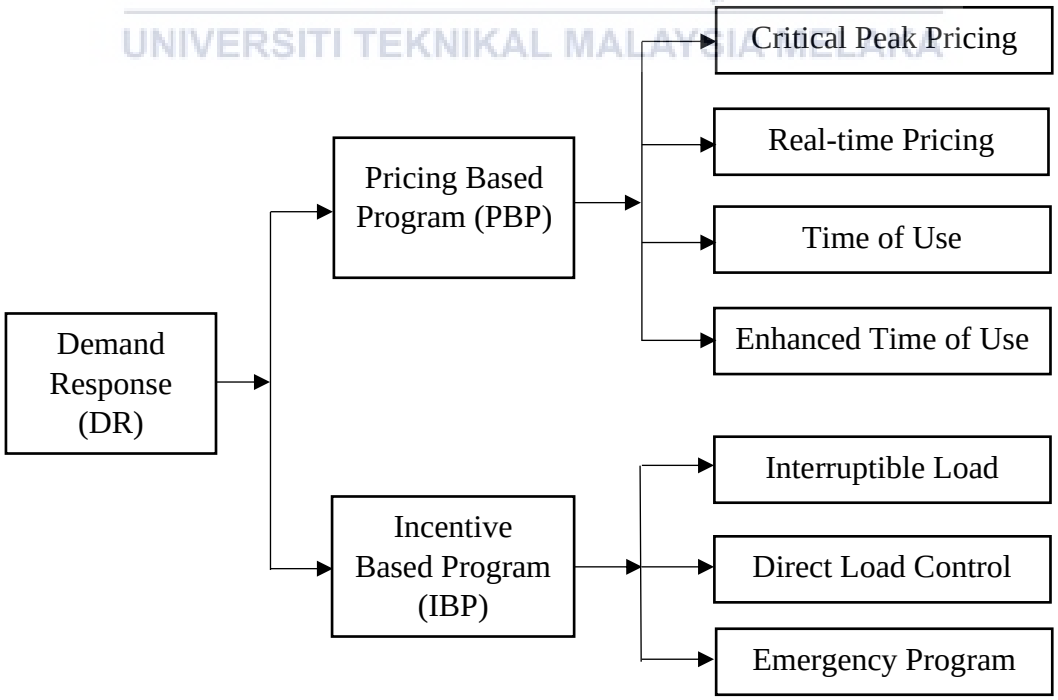

Figure 5 Classification of PBP and IBP

2.4.1 Time of Use (ToU) Tariff in Malaysia

ToU tariff was introduced by TNB under PBP. ToU is known as a pricing method that have different prices for peak hour and off-peak hour. Peak hour has higher pricing than the off-peak hour. Thus, the aim of ToU tariff is to persuade customers to shift their consumption from peak hour to off-peak hour as the rates depend on the two time zones and their daily power consumption. For residential customers, smart metering system is implemented at their place to enable them tracking the usage of electricity and also the electricity bills [17]. The role of this smart metering is to help customers plan their electricity consumption wisely. ToU tariff is offered to commercial and industrial customers (Industrial D, Industrial E1, Industrial E2, Industrial E3) and each of them is offered different price rates. Table 1 shows the Flat for industrial D and E1 and TOU tariff rates for E2 and E3 industrial customers from 2014 until now [11].

Many past studies have been conducted on ToU tariff. In [18], the effect of ToU tariff and maximum demand on the power exchange of power grid is analyzed. The sensitivity of the load profile towards the MD rates is also discussed in this study. In [19], a ToU tariff design has been developed from a flat tariff to save electricity cost by using DSM strategies, but the study is focusing on designing the new tariff. The ToU tariff rate was designed by using a clustering technique, namely Gaussian Mixture Model. Authors in [20] used a stochastic-based decision-making framework to optimize the electricity portfolio and ToU pricing as well as to maximize the profit and minimizing the risk for retailers. Authors in [21] use a model namely emergency demand response program (EDRP) that can affect the maximum demand and it price based on ToU tariff. The benefits that will be obtained by the consumers are also calculated by the authors.

Table 1 Flat and ToU tariff rate for industrial customers in Malaysia

Tariff	Industrial D	Industrial E1	Industrial E2	Industrial E3
MD (RM/kW)	Not available	29.60	37.00	35.50
Peak (sen/kW)	38.00<(200 kWh)<44.10	33.70	35.50	33.70
Off-Peak (sen/kW)	Not available	Not available	21.90	20.20

2.4.2 Enhanced Time of Use (EToU) Tariff in Malaysia

EToU tariff was introduced in 2015 and was implemented on 2016 as an extension to the ToU tariff by Tenaga Nasional Berhad (TNB). EToU tariff is offered to two types of consumers, commercial and industrial consumers. The pricing rates for these two consumers are different regarding the different time zones. As EToU has one more added rate which is mid-peak, consumers can have less concern about when to shift their electricity consumption periods. Besides, from the six segmentation of times that EToU tariff has, customers can decrease the consumption of electricity by applying DSM strategies. Table 2 presents the EToU tariff rate pricing offered to industrial consumers starting from 2015 until now [11]. Table 3 list the tariff categories that are offered EToU tariff [22].

Although EToU tariff has been introduced for about five years already, there are not many consumers that are choosing this tariff. Because of that, some previous studies have been carried out to manage the problems. In [10], the impact of the EToU tariff scheme has been analyzed by analyzing two different industrial consumers load profile to come out with the advantages of EToU tariff in order to help customers choosing between ToU and EToU tariff scheme. Meanwhile, in [23] and [2], optimization algorithm (ACO algorithm) and optimal EToU tariff formulation have been used to optimize the uptight load profile of a DSM strategy to reduce the electricity cost based on EToU tariff. Authors in [24] use EToU tariff and ToU tariff pricing for a chiller plant operation. The aim of the study is to reduce the electricity