Analysis Potential Benefit of Energy Cost the Chiller Plant Operation Engaging with Tariff Scheme

SR Shaari1,3, Othman, M.L.1, Hizam, H.1, NY Dahlan2, Mohd Hanafiah Chik3, Mohamad Suhaimi Yahaya1, Hamzah Abu Bakar3, Suhaizuddin Zainal Anuar1 and Zulhelmi Amir3

1Department of Electrical & Electronic Engineering, Faculty of Engineering, Universiti Putra Malaysia (UPM), Serdang, Selangor, Malaysia
2Faculty of Electrical Engineering, Universiti Teknologi Mara (UiTM), Shah Alam, Selangor, Malaysia
3Malaysia Nuclear Agency, Bangi, Selangor, Malaysia

Abstract. Engagement with new tariff scheme, Enhanced Time of Use (EToU) after switching from old tariff scheme, Time of Use (ToU) for chiller plant operation may be not promising a significant benefit for consumer in term of techno-economic value or even getting worse. This uncertainty condition make consumers doubt to switch onto latter. Therefore this study is focusing to analyze and looking potential benefit of energy cost the chiller’s plant operation when engaging with the new tariff scheme EToU rather than ToU. Consumer’s potential benefit appear for this study when switching from ToU to EToU tariff scheme for chiller plant operation through shifting the chiller’s plant operation from peak to mid-peak hour while maintaining discharging operation of thermal energy storage (TES). This could benefit both consumer’s on demand and utility on supply side respectively. Consumer may experience lower energy cost charged by utility. While utility could minimize the investment cost to install and maintain power system infrastructure in order to meet energy demand as well. However, further comprehensive study on this paper is also discussed for looking the more significant benefit to reduce energy cost of chiller’s operation when engaging with EToU tariff scheme.

Keywords. Enhancement Time of Use (EToU); Time of Use (ToU), Tariff Scheme, Chiller’s Plant Operation

1. Introduction
Effort to reduce electricity bill and peak demand gain interest from both demand and supply side. Since January 2016, Malaysia government through Tenaga Nasional Berhad (TNB) as utility company introduced new tariff scheme, Enhanced Time of Use (EToU) [5]. Different with the previous one, Time of Use (ToU) are energy and demand charge for respective time zone. EToU has three (3) time zone which are Peak, Mid-peak and Off-peak hours. While ToU only has two (2) time zone which are Peak and Off-peak hours [1]. Purpose both of these tariff scheme were introduced are to encourage demand side management, through consumer’s effort to shift activity out of the peaks hours. This could minimize the investment cost to install and maintain power system infrastructure in order to meet energy demand sufficiently. This is because power consumption of a load in distribution and tariff charge function also may affect TNB revenue to some great extent [6].

EToU tariff scheme was introduced as extension from ToU tariff to enhance load shifting capability which is not limited only from peak to off-peak hours, but also to mid-peak hours as well.
However, switching from ToU to EToU tariff scheme make consumer doubt because of uncertain significant techno-economic benefit or even getting worse for them. This can be seen through related study on switching tariff scheme which was not giving significant techno-economic benefit for them. One of study reported that 93% of bill payers are less willing to switch to the time of use tariff [2]. This shows that most of consumers are not interested to switch their old tariff scheme onto the new one. This is because they could also stand to increase their bills if they are unable to shift their consumption away from peaks [2]. Another, they would also lose flexibility over the timing of their electricity use [2]. However, consumers might be interested to switch tariff scheme with the new one if they have potential to experience significant low on their electricity bill without compromising their comfort.

In commercial building like Malaysia Nuclear Agency, the regular working period is from 8.00am to 6.00pm. This period appear as peak hour for ToU time zone. Therefore, chiller plant should be operated during this peak hours to serve people. High energy charge will be charged for the consumers along that period of ten (10) hours. While EToU time zone limit peak hours only for four (4) hours out of ten (10) hours working period. This shows that EToU could benefit more than ToU tariff scheme for chiller plant operation. However, this must be ensured through detail study on that. Therefore, an analysis on energy cost of chiller plant operation is conducted through evaluation from both EToU and ToU tariff. Other than that, the potential benefit of that plant also discovered when engaging with EToU tariff scheme. This could be realized through shifting out chiller plant operation from peak to mid peak hours. In advance manner, this shifting strategy to schedule multiple cooling sources of chillers and thermal energy storage (TES) could be implemented through optimization technique such as genetic algorithm (GA), linear programming (LP) and other new or invented optimization technique from the GA and LP as well. A real scenario for domestic appliances in Czech Republic is scheduled by using an optimization technique, mixed-integer linear programming (MILP) proven that reducing the total energy price paid by consumer through reducing power peaks to achieve a balanced daily load schedule [7]. This is also possible to be implemented for chiller’s plant operation since there are multiple mechanism of cooling sources shiftable in order to meet optimal coordination mechanism scheduling of chiller’s plant operation. However, optimization technique is not covered for this study. This scope will be covered on further study to enhance techno-economic value of chiller plant operation.

Figure 1 shows chiller’s plant operation and main mechanism such as Chiller 1, Chiller 2, Chiller 3 and Thermal Energy Storage (TES) as cooling source to chill water in District Cooling System then supply to Air Handling Units (AHUs) for Main Complex, Malaysia Nuclear Agency. While Figure 2 shows the average thermal load of District Cooling System that presenting the cooling demand of conditioned space in buildings for this agency.
Basically, this paper consists of 4 sections. In this Section 1, introduction, mentioning scope of study about chiller’s plant operational status in Malaysia Nuclear Agency and other related study with tariff scheme. Then research methodology of how making analysis on energy cost of chiller plant operation when engaging with tariff scheme is discussed in Section 2. The result of analysis on energy cost of chiller plant operation with its related thing is detail explained in Section 3. Lastly, section 4 concludes this study for this paper.

2. Research Methodology
Implementation the analysis on energy cost of chiller’s plant operation based on a tariff scheme require the input such as energy charge of a tariff scheme, chiller’s plant operational hour and their power consumption and related calculation. The following item from 2.1 to 2.4 are described detail on this matter.
2.1. Gathering Information of Tariff Scheme
Since the Tariff Category of Main Complex, Malaysia Nuclear Agency is Commercial Tariff C2 [9], then this study discover that the energy charge for both ETou and ToU tariff scheme as mention detail Table 1 and Table 2 respectively. While Figure 3 and 4 mention time zone for both ETou and ToU tariff scheme respectively.

| Table 1: Commercial Tariff C2 ETou Energy Charge [1] |
|------------------------------------------------------|
| Time Zone   | Period(Hours) | Energy Charge (sen per kWh) |
| Off-peak hour | 10            | 22.4                       |
| Mid-peak hour | 10            | 33.9                       |
| Peak hour    | 4             | 63.6                       |

Table 1 shows energy charge of ETou tariff based on respective time zone Off-peak, Mid-peak and Peak hour as mention detailed on Figure 3. On weekday, Off-peak hour is starting from 0000 to 0800 and 2200 to 2400. While Mid-peak hour is starting from 0800 to 1100, 1200 to 1400 and 1700 to 2200. And Peak hour is starting from 1100 to 1200 and 1400 to 1700. However Off-peak hour is charged the whole day during weekend and public holiday.

| Table 2: Commercial Tariff C2 ToU Energy Charge [3] |
|------------------------------------------------------|
| Time Zone   | Period(Hours) | Energy Charge (sen per kWh) |
| Off-peak hour | 10            | 22.4                       |
| Peak hour    | 14            | 36.5                       |

While Table 2 shows energy charge of ToU tariff based on respective time zone Off-peak, Midpeak and Peak hour as mention detailed on Figure 4. On weekday, Off-peak hour is starting from 0000 to 0800 and 2200 to 2400. This is same with ETou tariff scheme in term of time zone ad their energy charge. And Peak hour is starting from 0800 to 2200. However Off-peak hour is charged the whole day during weekend and public holiday.
2.2. Gathering Information of Chiller Plant Operation

Table 3. Chiller Plant Mechanism Power Consumption Based on Operating Period [4]

| No. | Mechanism, i               | Operation Period (Hour) | Consumption, $P_i$(kW) |
|-----|----------------------------|-------------------------|------------------------|
|     |                            | Day | Night | Day | Night |                     |
| 1   | Chiller 1                  | 0   | 8     | 0   | 225.2 |
| 2   | Chiller 2                  | 10  | 8     | 219.2 | 218.2 |
| 3   | Chiller 3                  | 10  | 0     | 179.4 | 0     |
| 4   | Chilled Water Pump (CHWP)  | 10  | 8     | 45.1  | 70.9  |
| 5   | Storage of Latent Heat Pump (STLP) | 10 | 0     | 16.1  | 0     |
| 6   | Distribution Pump (DP)     | 10  | 0     | 63.3  | 0     |
| 7   | Condensed Water Pump (CWP) | 10  | 8     | 36    | 31.2  |
| 8   | Cooling Tower Fan (CTF)    | 10  | 8     | 26.7  | 29.5  |

Table 3 shows eight (8) mechanism, i of chiller’s plant shows their respective power consumption based on operating period.

2.3. Operating Hours of Chiller Plant in Main Complex, Malaysia Nuclear Agency

Table 4. Chiller’s Plant Mechanism Operational Hours

| No. | Mechanism, i               | Availability an Hour Daily Operation Hour, $b_i$ |
|-----|----------------------------|--------------------------------------------------|
|     |                            | 0000 0100 0200 0300 0400 0500 0600 0700 0800 0900 1000 1100 |
| 1   | Chiller 1                  | 0 0 0 0 0 0 0 0 0 0 0 0 | 0 0 0 0 0 |
| 2   | Chiller 2                  | 0 0 0 0 0 0 0 0 0 1 1 1 | 1 1 1 1 |
| 3   | Chiller 3                  | 0 0 0 0 0 0 0 0 0 1 1 1 | 1 1 1 1 |
| 4   | Chilled Water Pump (CHWP)  | 0 0 0 0 0 0 0 0 0 1 1 1 | 1 1 1 1 |
| 5   | Storage of Latent Heat Pump (STLP) | 0 0 0 0 0 0 0 0 0 1 1 1 | 1 1 1 1 |
2.4. Calculation and Analyze Energy Cost of Chiller Plant Operation

At \( n = 8 \) which refers to the number of chiller’s plant mechanism, \( i \), therefore the equation to calculate total energy cost, \( C_{Te} \) is mentioned as the following equation.

\[
C_{Te} = r \times \sum_{i=1}^{n} P_i \cdot b_i
\]

Where;

- \( P_i \): Power Consumption of chiller’s plant mechanism
- \( b_i \): Availability an hour daily operation of chiller’s plant mechanism
- \( r \): Set of 24 hours energy charge of tariff scheme

Power consumption and availability an hour daily operation of chiller’s plant mechanism are detail tabulated in Table 3 and 4 respectively. While the set of energy charge of tariff scheme is detail mentioned in the following Table 5.
| Hour’s Duration | Energy Charge, $r$ (sen per kWh) |
|-----------------|----------------------------------|
| From | To | EToU | ToU |
| 0:00 | 1:00 | 22.40 | 22.40 |
| 1:00 | 2:00 | 22.40 | 22.40 |
| 2:00 | 3:00 | 22.40 | 22.40 |
| 3:00 | 4:00 | 22.40 | 22.40 |
| 4:00 | 5:00 | 22.40 | 22.40 |
| 5:00 | 6:00 | 22.40 | 22.40 |
| 6:00 | 7:00 | 22.40 | 22.40 |
| 7:00 | 8:00 | 22.40 | 22.40 |
| 8:00 | 9:00 | 33.90 | 36.50 |
| 9:00 | 10:00 | 33.90 | 36.50 |
| 10:00 | 11:00 | 33.90 | 36.50 |
| 11:00 | 12:00 | 63.60 | 36.50 |
| 12:00 | 13:00 | 33.90 | 36.50 |
| 13:00 | 14:00 | 33.90 | 36.50 |
| 14:00 | 15:00 | 63.60 | 36.50 |
| 15:00 | 16:00 | 63.60 | 36.50 |
| 16:00 | 17:00 | 63.60 | 36.50 |
| 17:00 | 18:00 | 33.90 | 36.50 |
| 18:00 | 19:00 | 33.90 | 36.50 |
| 19:00 | 20:00 | 33.90 | 36.50 |
| 20:00 | 21:00 | 33.90 | 36.50 |
| 21:00 | 22:00 | 33.90 | 36.50 |
| 22:00 | 23:00 | 22.40 | 22.40 |
| 23:00 | 24:00 | 22.40 | 22.40 |
Then, this energy cost of chiller plant operation for both EToU and ToU tariff scheme are calculated and analysis based on the following condition.

a) Without shifting chiller plant operation based on EToU tariff scheme from peak to mid-peak hours.

b) With shifting chiller plant operation for all four (4) hours based on EToU tariff scheme from peak to mid-peak hours.

c) Chiller plant operation without shifting from a time zone to other particular time zone based ToU tariff scheme

3. Result & Analysis

3.1. Energy cost of EToU and ToU tariff scheme

Table 5 shows the energy cost for three (3) conditional of chiller’s plant operation. The two (2) conditional based on EToU tariff scheme, which are with and without shifting chiller’s plant operation. And the last condition is chiller’s plant operation based on ToU tariff scheme.

| No. | Chiller Plant Operational Condition | Energy Cost (MYR) |
|-----|-------------------------------------|-------------------|
| 1   | Without shifting chiller plant operation EToU based tariff scheme | 3,712.19 |
| 2   | With shifting chiller plant operation EToU based tariff scheme | 3,110.59 |
| 3   | Chiller plant operation ToU based tariff scheme | 3,168.57 |

Figure 5. Comparison the Energy Cost of Tariff Scheme

3.2. Analysis the Energy Cost of Tariff Scheme

Based on Figure 5 and Table 6, energy cost comparison of chiller plant operation based on both EToU and ToU tariff could be stated as the following condition.
3.2.1. Energy cost comparison between EToU (without shift) and ToU. Energy cost based on EToU is higher than ToU tariff scheme without shifting the plant operation from peak to mid-peak hour’s period.

3.2.2. Energy cost comparison between EToU (with shift) and ToU. Energy cost based on EToU is lower than ToU tariff scheme with shifting the plant operation four (4) hours period from peak to mid-peak hour’s period.

3.2.3. Energy cost comparison between EToU (without shift) and EToU (with shift). Energy cost of chiller plant operation with shifting the plant operation four (4) hours period from peak to mid-peak hour is lower than without shifting the plant operation based on ToU tariff scheme.

3.3. Discussion
ToU tariff scheme could offer consumers lower energy cost for chiller plant operation and possibly other non-shiftable loads operation as compared to EToU tariff scheme. This is because chiller’s plant operating for long hour’s period at lower energy charge during peak hour charged by utility based ToU as compared to EToU tariff scheme.

However, EToU tariff scheme also could offer lower energy cost for chiller plant operation and possibly other shiftable loads compared to ToU tariff scheme when they shift their operation from peak hours to mid-peak hours as. This because the lower energy charge charged by utility for EToU during mid-peak hours as comparing with the same time zone of peak hours period based on ToU tariff scheme.

4. Conclusion & Future Work

4.1. Getting benefit from both tariff scheme
The characteristic of nature operational of a load should be identified. If an operational load cannot be shifting out from peak hour’s period, the best way is to maintain with ToU tariff scheme. But if an operational load can be shifting out from peak hours to mid-peak hour’s period, it is better to switch onto EToU tariff scheme.

One of shiftable load is come from secondary based supply load with looping system. A chiller plant with other multiple chiller plant and thermal energy storage (TES) could be managed to be ON and OFF consecutively or parallel in looping distribution cooling supply to distribute chilled water to Air Handling Units (AHUs).

4.2. Enhance potential benefit for energy cost of chiller plant operation
Advanced load shifting strategy can be implemented through coordination the scheduling of each chiller’s plant operation with TES by using optimization technique such as genetic algorithm for further based study.

Acknowledgments
Authors gratefully acknowledge this assistance and academically encouragement by main and co-supervisor from Universiti Putra Malaysia (UPM) and Universiti Teknologi Mara (UiTM), special work and support by managerial and technical staff support from M&E Unit, Engineering Division in Malaysia Nuclear Agency.

References
[1] https://www.tnb.com.my/Faq/Etou
[2] Moira Nicolson, Gesche Huebner, David Shipworth, Are Consumers Willing to Switch to Smart Time of Use Electricity Tariff? The Importance of Loss-aversion and Electric Vehicle Ownership, Energy Research & Social Science 23 (2017) 82-96.
[3] https://www.tnb.com.my/commercial-industrial/pricing-tariffs1/

[4] Unit Kecekapan Tenaga Dan Tenaga Lestari, Seksyen Pembangunan Kepakaran Cawangan Kejuruteraan Mekanikal, Ibu Pejabat JKR, Laporan Audit Tenaga Bangunan Agensi Nuklear Malaysia, ID CKM.BPK.EE/AT/11/01, Versi 00, Page 22, 10 Mei 2011.

[5] Nur Azrina Mohd Azman, Md Pauzi Abdullah*, Mohammad Yusri Hassan, Dalila Mat Said, Faridah Hussin, Enhanced Time of Use Electricity Pricing for Industrial Customers in Malaysia, Indonesian Journal of Electrical Engineering and Computer Science, Vol. 6, No. 1, April 2017, pp. 155 – 160.

[6] W N R A Zainudin and N A Ramli, Modelling altered revenue function based on varying power consumption distribution and electricity tariff charge using data analytics framework, IOP Conf. Series: Journal of Physics: Conf. Series 890 (2017) 012099 doi :10.1088/1742-6596/890/1/012099

[7] Zdenek Bradac, Vaclav Kaczmarczyk* and Petr Fiedler, Optimal Scheduling of Domestic Appliances via MILP, ISSN 1996-1073, Energies 2015, 8, 217-232; doi:10.3390/en8010217

[8] Unit Kecekapan Tenaga Dan Tenaga Lestari, Seksyen Pembangunan Kepakaran Cawangan Kejuruteraan Mekanikal, Ibu Pejabat JKR, Laporan Audit Tenaga Bangunan Agensi Nuklear Malaysia, ID CKM.BPK.EE/AT/11/01, Versi 00, Page 24, 10 Mei 2011.

[9] Unit Kecekapan Tenaga Dan Tenaga Lestari, Seksyen Pembangunan Kepakaran Cawangan Kejuruteraan Mekanikal, Ibu Pejabat JKR, Laporan Audit Tenaga Bangunan Agensi Nuklear Malaysia, ID CKM.BPK.EE/AT/11/01, Versi 00, Page 11, 10 Mei 2011.