Simultaneous Load Management Strategy for Electronic Manufacturing Facilities by using EPSO Algorithm

*M.F. Sulaima**
Faculty of Electrical Engineering,
Universiti Teknikal Malaysia Melaka (UTeM),
76100, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia
**fani@utem.edu.my*

N.Y. Dahlan
Faculty of Electrical Engineering, Universiti Teknologi Mara (UiTM),
40450, Shah Alam, Selangor, Malaysia

Z.H. Bohari, M.N.M. Nasir
Faculty of Electrical and Electronic Engineering Technology,
Universiti Teknikal Malaysia Melaka (UTeM),
76100, Hang Tuah Jaya, Durian Tunggal, Melaka, Malaysia

R.F. Mustafa
Faculty of Electrical Engineering, Universiti Teknologi Mara (UiTM)
Johor Branch, Pasir Gudang Campus, 81750, Masai, Johor, Malaysia

Duc Luong Nguyen
Faculty of Environmental Engineering,
National University of Civil Engineering (NUCE),
55 Giai Phong, Hanoi, Vietnam

ABSTRACT

Increased power demand has contributed to the power generation tension. Thus, there were critical needs for a better Price Based Program (PBP) policy for the consumers. In Peninsular Malaysia, through the development of a policy for the regulated market plan, the Enhanced Time of Use (ETOU) tariff was introduced by the utility to promote better price signals to the industrial

ISSN 1823-5514, eISSN 2550-164X

Received for review: 2020-09-10
Accepted for publication: 2021-06-01
Published: 2021-09-15

consumers who contribute to the most massive energy consumption every year. However, fewer industrial consumers join the program due to a lack of Load Management (LM) knowledge while not confident in the price rate signal compared to the previous tariffs. Due to that reason, this study proposed simultaneous LM strategies for the selected power consumption profile in the electronic manufacturing facilities. Meanwhile, the Evolutionary Particle Swarm Optimization (EPSO) was adopted to search for the upright power consumption profiles of those average 11 locations of the manufacturing. The analysis of the results has compared to the baseline existing flat and Time of Use (TOU) tariffs. The results show an improvement in the energy consumption and maximum demand costs reduction of ~14-16% when load management was applied correctly. It is hoped that this study's results could help companies' management of developing a strategic plan for the successful load management program.

Keywords: *Demand response; Price-based program; Manufacturing facility; Optimization algorithm; Enhanced time of use tariff*

Introduction

Due to the global temperature surge, the disaster has led to collective knowledge in the environment and energy study. It was reported that 95% of countries in the world contributed to the increase of 1.5 degrees of the earth's temperature [1]. Thus, this situation has to upsurge the CO_2 emission and contribute to global warming that impacts the ecosystem of human activities [2]. The factor of energy consumption from the demand side, such as manufacturing facilities, has a significant effect on this global issue. In Malaysia, ~80% of the energy consumption from the electricity source has been demanded by industrial consumers, which was ~60% of them are from the electronic related manufacturer [3], [4], [5]. Thus, to balance the energy supply, the government through the energy commission of Malaysia has approved the utility's new PBP policy to the commercial and industrial consumers who are using the ETOU tariff scheme. The purpose of the tariff was to mitigate the peak demand on the generation side while promoting the electricity bill reduction among participants. The impact of the TOU tariff in the regulated market was determined by changing the price in the consumers' TOU tariff has contributed to the significant impact on the cost of generation [6]. The details disaggregated the appliance on the consumers' side, promoting a better effect on the TOU and ETOU tariff load management strategy [7]. A study on the ETOU tariff by promoting the load shifting strategy for an industrial power consumption profile results in electricity cost savings with 50% of the load changing from peak to mid-peak and off-peak zone as presented in [8].

Nevertheless, no appropriate formulation that reflects the industry's group and does not involve any optimization technique. The authors in [9] have promoted the bubble chart solution to identify the appropriate percentage of the load to be transferred in peak and mid-peak zones. Meanwhile, the application of the optimization algorithm proposed by [10] only focuses on the load shifting strategy for the manufacturing operation. On the other hand, the application of the optimization algorithm in the perspective of the price-based program for the demand-side was divided into three purposes: i) for the tariff design, ii) for the operation schedule, and iii) for the load management [11]. Since this study focuses on load management, the art of the literature has scrolled down to that particular issue accordingly. Thus, in supporting this program, the optimization algorithms have been effectively applied in dealing with load management, such as studies of PSO [12], improve PSO [13],[14], Evolutionary Algorithm (EA) [15], [16] and Genetic Algorithm (GA) [17], [18]. Most of the references presented the single application of the load management strategy, either load shifting, peak clipping, and valley filling, separately. The simultaneous integration of the strategies was proposed by authors in [19]. However, the study did not involve any optimization algorithm during the load management strategies available only in a single load profile under a similar bus system.

Regarding the EPSO algorithm, there were colossal applications in power system studies where few related to the demand response application. As in [20], [21], the use of the distribution network reduces the power network losses while improving the voltage factor. The related study of EPSO on the demand response program was concentrating on load forecasting, such as presented in [22]–[24]. Compared to the other optimization method, EPSO has produced improved RMS percentage value on the various load types forecasting. Meanwhile, the convergence time of EPSO was identified as fasters among heuristic algorithms. There is no application of the EPSO available in the past literature for the proposed of tariff PBP program in Malaysia to the best of our knowledge. The EPSO has not yet been considered in dealing with load management as well. Thus, this study proposes the EPSO algorithm to solve the optimal ETOU tariff program's objectives, reducing energy consumption and maximum demand costs, respectively.

The paper's arrangement is as follows: Section 2 presents problem formulation of the optimal ETOU tariff; Section 3 discusses the implementation of the EPSO algorithm; Section 4 explains the case of study while results and analysis of the finding have been written in Section 5 accordingly. The last Section 6 concludes the overall paper arrangement and contribution.

Problem Formulation

Optimal total electricity cost

The general optimal total ETOU electricity cost (MYR/kWh+kW) has been presented in Equation (1) where the formulation has referred [25]:

$$ETOU_{eCost} + MD_{Optimum}^{Cost} \quad (1)$$

Optimal energy consumption cost

$ETOU_{eCost}$, is the electricity cost of the desired load curve after load management strategies are applied, which reflects the six-time segmentation of ETOU tariff price zones according to Equation (2).

$$ETOU_{eCost} = \left(\sum_{t}^{N=10} \Delta P_{op} \times TP_{op}\right) + \left(\sum_{t}^{N=3} \Delta P_{mp1} \times TP_{mp}\right) + \left(\sum_{t}^{N=1} \Delta P_{p1} \times TP_{p}\right) + \left(\sum_{t}^{N=2} \Delta P_{mp2} \times TP_{mp}\right) + \left(\sum_{t}^{N=3} \Delta P_{p2} \times TP_{p}\right) + \left(\sum_{t}^{N=5} \Delta P_{mp3} \times TP_{mp}\right) \quad (2)$$

where,

ΔP_{op} : changing of off-peak desired load curve with changing of time, $N=10$; ΔP_{mp1}, ΔP_{mp2}, ΔP_{mp3}= changing of mid-peak wanted load curve with the different time change, $N=3$, $N=2$, and $N=5$, respectively; ΔP_{p1}, ΔP_{p2} = changing of peak wanted load curve at a time changing $N=1$ and $N=3$ separately

TP_{op} : tariff price for off-peak zone

TP_{mp} : tariff price for mid-peak zone

TP_{p} : tariff price for peak zone

Optimal maximum demand cost

Optimal MD cost reduction has been written Equation (3). Meanwhile, Equations (4) and Equation (5) summarize the MD power load selection to separate MD charges congruently.

$$MD_{P}^{cost} \geq MD_{Optimum}^{Cost} = MD_{MP}^{cost} \quad (3)$$

$$MD_{MP}^{cost} = Max[L_{T2};\ L_{T4};\ L_{T6}] \times MD_{MP}^{TP} \quad (4)$$

$$MD_{P}^{cost} = Max[L_{T3}; L_{T5}] \times MD_{P}^{TP} \quad (5)$$

where,
MD_{MP}^{cost} : Optimum power load selection at Mid-Peak area;
MD_{P}^{cost} : Optimum power load selection at Peak area;
L_{Tn} : Selected power load for n number at particular time segmentation (ts);
MD_{MP}^{TP}, and MD_{P}^{TP}: the MD charge for different mid-peak and peak

Simultaneous load management strategies

The concurrent Load Management (LM) strategies can be written as in Equation (6). The demand-side strategy that had been proposed was Valley Filling (VF), Peak Clipping (PC), and Load Shifting (LS).

$$\Delta P_{OP,MP1,P1,MP2,P2,MP3}^{General} = \sum_{ts,i}^{V\,F}\left(\Delta P_{ts,i}^{VF} \times W_{VF}\right) + \left(\Delta P_{ts,i}^{PC} \times W_{PC}\right) + \left(\Delta P_{ts,i}^{LS} \times W_{LS}\right) \tag{6}$$

where, $\Delta P_{ts,i}^{VF}$, is the changing amount of the desired load based on VF strategy by LM at random load (i) in time segmentation (ts). $\Delta P_{ts,i}^{PC}$ and $\Delta P_{ts,i}^{LS}$ are the changing amount of the desired load based on PC and LS strategies by LM at random load (i) in time segmentation (ts), respectively. Temporarily, W_{VF}, W_{PC}, and W_{LS} are the weightage of LM strategies to be implemented in load profile concurrently, which is set 50% as referred to [8].

Constraints

The constraints of the simultaneous LM strategies to achieve satisfying performance had been decided as follows:

Constraint for VF

$\Delta P_{ts,i}^{VF}$, will be selected during time segmentation with a minimum value of baseload price. The (ts) adjustment of VF selection must be as:

$$Average\ load\ price > \Delta P_{ts,i}^{VF} \geq baseload\ price \tag{7}$$

Constraint for PC

$\Delta P_{ts,i}^{PC}$, will be selected during the two highest prices of time segmentation loads as well as where the maximum demand is located, where (ts) adjustment of PC selection must be as:

$$Average\ load\ price\ < \Delta P_{ts,i}^{PC} \leq baseload\ price \tag{8}$$

Constraint for LS

LS in the LM program shall lead to perform at randomly selected three-time segmentations. Thus, the best way to put LS is after VF and PC selection, while the rest of the time segmentations will be the location for LS to perform randomly. The process of the proposed LS procedure is written as in Equations (9), (10), and (11) accordingly.

$$\Delta P_{ts,i}^{LS} \cong \Delta Z_{ts,i}^{shift} \tag{9}$$

$$\Delta Z_{ts,i}^{shift\ down} = \left(\Delta Z_{up}^{shift} - \left(\left(\Delta Z_{up}^{shift} - \Delta Z_{down}^{shift}\right) \times \omega\right)\right) \tag{10}$$

$$\Delta Z_{ts,i}^{shift\ up} = \left(\Delta Z_{up}^{shift} - \left(\left(\Delta Z_{up}^{shift} + \Delta Z_{down}^{shift}\right) \times \omega\right)\right) \tag{11}$$

where,

ΔZ_{down}^{shift} : changing of load decrease at certain time segmentation (ts) for the load, i;

ΔZ_{up}^{shift} : changing of load increase at certain time segmentation (ts) for the load, i;

Ω : The random weightage of load decrease and increase at lower bound and upper bound load setting.

Constraints for total energy consumption

Total energy before and after the optimization throughout the process of LM strategies should not be more than $\pm 5\%$ [26]. Equation (12) describes the constraints for total energy consumption (kWh) before and after optimization.

$$\sum E_T \cong \sum E_T^{'} \tag{12}$$

EPSO algorithm implementation

EPSO is essentially a hybrid of PSO and evolutionary programming. EPSO is a modified version of the PSO algorithm, which involves additional combination and selection processes.

This step is implemented after P_{best} and G_{best} are determined and after the new position and velocity of the particles are updated. Figure 1 shows the combination and selection processes (tournament) incorporated into the PSO algorithm (inspired from evolutionary programming), resulting in the EPSO algorithm. The EPSO implementation steps are followed.

Initialization

The EPSO algorithm begins with initializing the number of particles *D* and the number of populations *NP*. In this study, *NP* was set as 20. The initial number of particles *D* was determined by calling the load profile that represents the daily average 24-h energy consumption, which was randomly generalized. Equation (13) shows the initial condition of the load arrangement. The constant parameters such as the social and cognitive coefficients were set at 1.0, and the initial weight coefficient was set at 0.2. The maximum inertia, minimum inertia, and the number of iterations were set at 0.9, 0.1, and 1000.

$$j = [j_{x1}, j_{x2}, j_{x3} \dots \dots \dots \dots \dots j_{xn}] \tag{13}$$

Velocity and position update

The initializing number of Equations (14) and (15) were used to update the position and velocity of the particles, respectively.

$$x_i(t+1) = x_i(t) + v_i(t+1) \tag{14}$$

$$v_i(t+1) = v_i(t) + C_1(\overrightarrow{P_i}(t) - \overrightarrow{x_i}(t)) + C_2\,(G(t) - \overrightarrow{x_i}(t)) \tag{15}$$

The modified velocity and inertia weightage proposed by [27] has been applied in immense power and energy study such as integrated demand response [14], home energy management [28], power network reconfiguration [29], and load scheduling in manufacturing [30]. The modified velocity and inertia weightage of PSO was used to improve the optimal solution for the complex problem. Equation (16) represents the inertia weightage. The value for ω was set between 0 and 1, and it is the so-called friction factor. The inertia weightage is used to ensure that the particles remain in the original course. The particles do not affect the motion of other particles (by pulling other particles into their path) and preventing oscillations around the optimal value.

$$\omega(n) = \omega_{max} - \left(\frac{\omega_{max} - \omega_{min}}{iter_{\max}}\right) \times n \tag{16}$$

Equation (17) is used to update the velocity of the particles in the standard PSO algorithm, and Figure 1 shows the vector movement of the particles. In this study, the particles' velocity and position were updated according to Equation (18) and Equation (19); respectively, the local and global best were allocated to produce a clear presentation.

$$v_{ij}(t+1) = \omega v_{ij}(t) + r_1 C_1 \left(\left(P_{ij}(t) - \; x_{ij}(t) \right) + r_1 C_2 \left(G_j(t) x_{ij}(t) \right) \right) \tag{17}$$

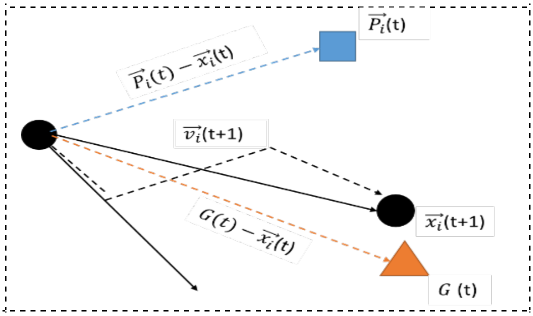

Figure 1: Updating the velocity and position of the particles in the standard PSO algorithm to determine the optimal solution.

$$V_j^{k+1} = (\omega \times V_j^k) + \left(C_1 r_1 (P_{best\,j}^k - X_j^k)\right) + \left(C_2 r_2 (G_{best\,j}^k - X_j^k)\right) \quad (18)$$

$$X_j^{k+1} = X_j^k + V_j^{k+1} \quad (19)$$

where,

V_j^k	: Velocity of Particle j in Iteration k
X_j^k	: Position of Particle j in Iteration k
ω	: Inertia weightage
$P_{best\,j}^k$	: Best value by Particle j in Iteration k
$G_{best\,j}^k$	: Best value among the fitness values
C_1 , C_2	: Constants weightage factor [0, 1]
V_j^{k+1}	: New velocity
X_j^{k+1}	: New position

Determine P_{best} and G_{best} and update the new velocity and position of the particles

During the searching process, the two best values were updated and recorded. The P_{best} and G_{best} represent the best energy consumption cost and optimum MD cost generated during the execution of the algorithm, respectively. In this step, the particle's current fitness value was compared with the particle's P_{best}. If the current fitness value was better than the P_{best} value, the P_{best} position was adjusted to the current best position. The same procedure was performed for G_{best}, where the G_{best} value was reset to the current fitness value, representing the optimal daily energy consumption cost and the minimum MD charge. The new velocity and new position were updated in each iteration according to Equation (18) and Equation (19).

Combination and selection (tournament)

Since EPSO is a hybrid of PSO and evolutionary programming, it has combination and selection (tournament) processes. After the second fitness function calculation, the old and new particles' fitness values were combined, which was not available in the original PSO algorithm. In this manner, the potential optimal particles can be selected, considering the randomly produced particles at the old and new positions. After the combination, the selection process was carried out, where all of the particles (each with its position number) were contested in the tournament. The percentage of contestants in the tournament was set using simple numbers of the particles' positions selected to the percentage of challengers.

Figure 2 shows an example of the combination and selection processes. If 10 positions are chosen, and the percentage of contestants was set at 40%, this means that four other random contestants challenge all of the particles. Each position has its weightage, which is based on the number of wins obtained so far. Only the particles with the higher scores remain during the selection process. These particles are sorted and ranked to determine P_{best} and G_{best} in the next iteration. With the combination and selection processes, the EPSO algorithm can determine the optimal solution quickly and accurately compared with the PSO algorithm.

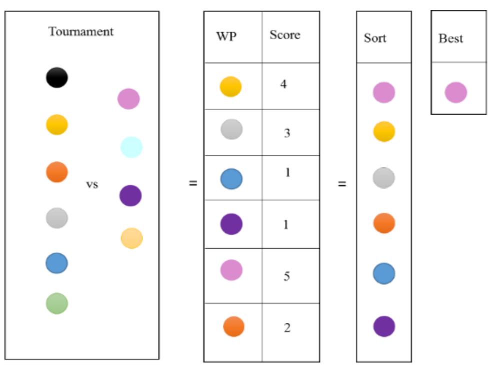

Figure 2: Example of the combination and selection (tournament) processes in the EPSO algorithm.

Convergence test

The convergence criterion was set as follows:

$$ft_{max} - ft_{min} \leq 0.0001 \tag{20}$$

This termination criterion was used to determine if the desired optimal solution was achieved. The searching process will be repeated until the values converge to the optimal load curve with the minimum energy consumption cost and minimum MD cost. Figure 3 presents the EPSO flow summary to find the optimal results while the combination and selection technique is involved.

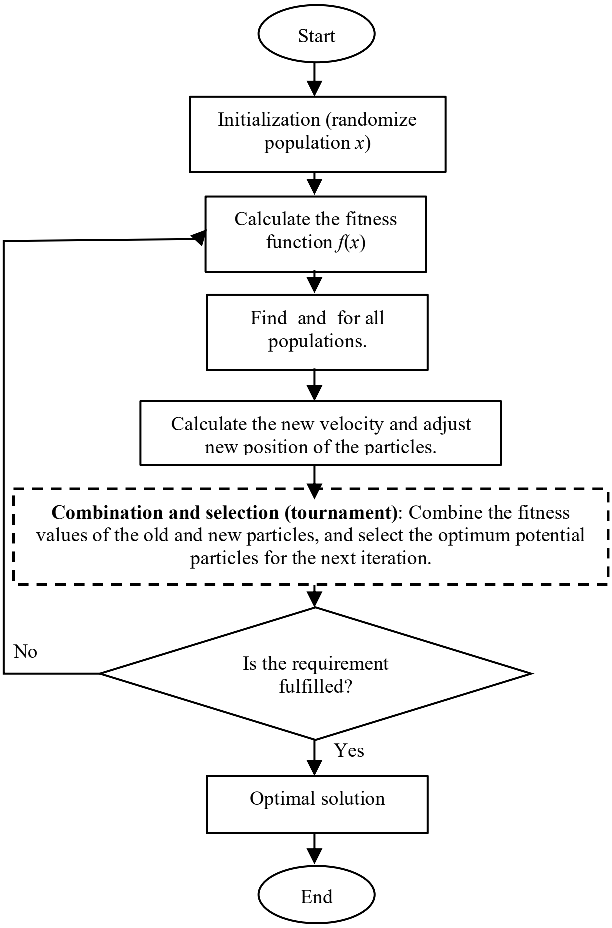

Figure 3: The flow of the EPSO process for searching for the best solution.

Case Study

Case studies were carried out to assess the effectiveness of the proposed EPSO algorithm. The EC of Malaysia provided the load profiles used for the case studies for 1 year with 30-min intervals. These load profiles were converted into 24-h load profiles with 1-h intervals. Several electronics manufacturers were chosen for the flat industrial tariff (Category E1) case studies. Category E1 consumers have the highest power demands, considering that electronics-related industries have been established in Peninsular Malaysia since 1988.

The case studies for both commercial and industrial tariffs are listed as follows:

i. Case 1: baseline load profile with flat tariff pricing
ii. Case 2: baseline load profile with TOU tariff pricing
iii. Case 3: baseline load profile with ETOU tariff pricing and without LM strategies and optimization algorithms
iv. Case 4: load profile with ETOU tariff pricing and optimization algorithms. There are two cases: (1) Case 4a: PSO algorithm and (2) Case 4b: EPSO algorithm
v. Case 5: load profile with ETOU tariff pricing, LM strategies, and optimization algorithms. There are two cases: (1) Case 5a: PSO algorithm with 50% LM weightage and (2) Case 5b: EPSO algorithm and 50% LM weightage

The tariff prices to compare and validate the results are presented in Table 1 and Table 2, which serve as the limits to set daily electricity costs in this study. For the case studies, flat and TOU costs were used as the baseline to compare the results. The time zones under the ETOU tariff were separated as in Table 3 accordingly.

Table 1: Flat and TOU tariff rates

Consumer Tariff Types	MD: MYR/kW	Peak: cents/kWh	Off-peak: cents/kWh
Industrial E1 Flat	29.60	33.60	NA
Industrial E2 TOU	32.90	33.60	19.10

Table 2: ETOU tariff rate

Tariff category	Demand charge (MYR/kW/month)		Energy charge (cents/kWh)		
	Peak	Mid-peak	Peak	Mid-peak	Off-peak
Industrial E1 MV ETOU	35.50	29.60	56.60	33.30	22.50

Table 3: ETOU time zone

Time (military)	2200-0800	0800-1100	1100-1200	1200-1400	1400-1700	1700-2200
Zone (Monday-Friday)	Off-peak	Mid-peak	Peak	Mid-peak	Peak	Mid-peak
Zone (Saturday-Sunday)	Off-peak	Off-peak	Off-peak	Off-peak	Off-peak	Off-peak

Results and Analysis

The baseline profiles were obtained from 11 electrical installations in electronics manufacturers. Based on the observations, the peak demand was less than 1,000 kW. The power consumption was static for 2 days each week because of holidays, and there was an upsurge in power consumption in regular working days. Thus, Figure 4 shows the active power consumption for 11 electrical installations in electronics manufacturing facilities with similar product types. Figure 5 shows the average weekday load profile, where the working hours were 0700–1900 and the average peak demand was 609 kW. Meanwhile, Figure 6 shows the average weekend load profile over a 24-h period. The peak demand was 356kW, while the baseline was a cover-up to 50% of the total demand.

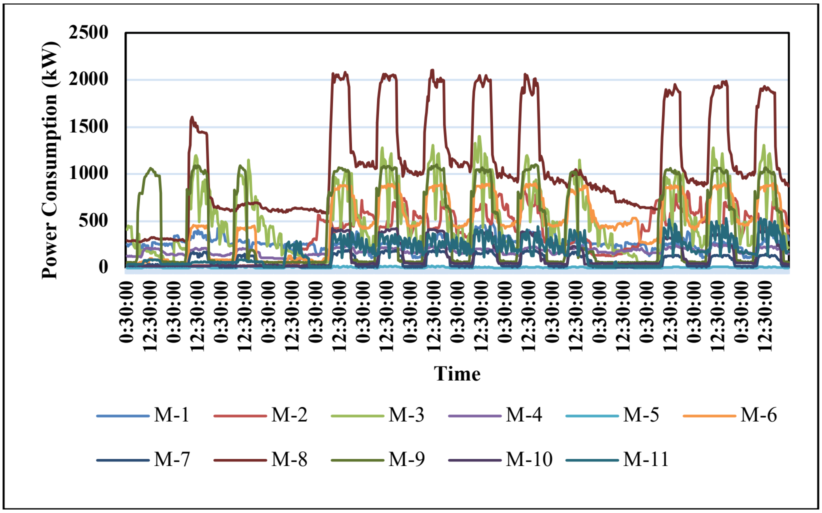

Figure 4: Average load profiles for 11 locations over 2 weeks.

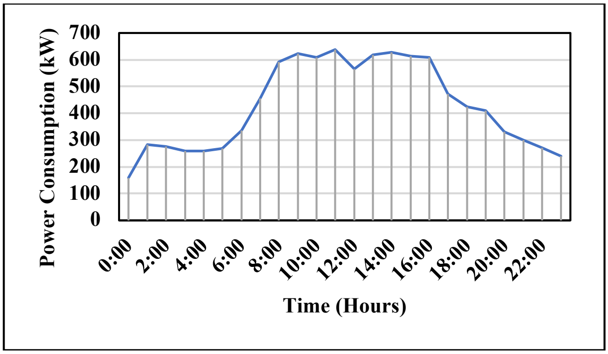

Figure 5: Average weekday load profile for electronics manufacturing facilities over a 24-h period.

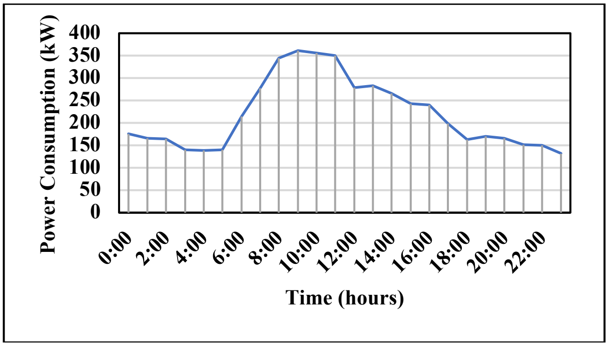

Figure 6: Average weekend load profile for electronics manufacturing facilities over a 24-h period.

Power consumption profile

Figure 7 presents the power consumption profile of all cases. Case 5b records a minimum reading of about 17 kW during the transaction of the off-peak and mid-peak zones. For both Case 5 s, the peak zones demand has been reduced by about 50%, while the off-peak zone has increased tremendously. It was observed that peak demand in the off-peak zone was 1,240 kW by Case 5a. For Case 4 s, there was a slight change in the power consumption profile compared to baseline cases. The EPSO algorithm's performance can transfer the appropriate loads from the critical high price charge to the middle and low-price rates within the convergence time.

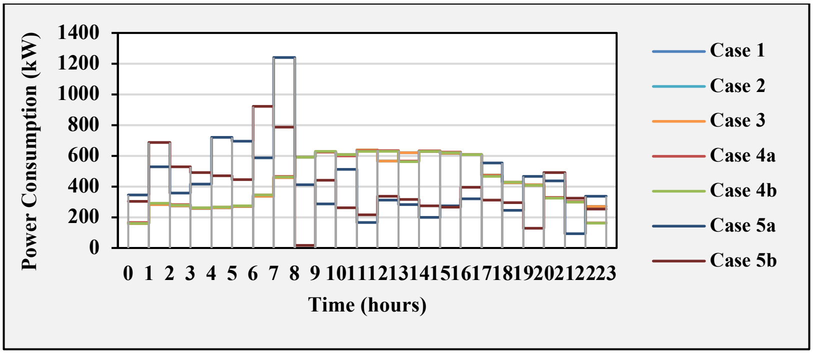

Figure 7: Tabulated power consumption profile for all cases.

Energy consumption cost minimization

Under the ETOU tariff scheme, there were two types of energy consumption cost determination: weekday and weekend, reflecting Table 3. Thus, the observation of the daily energy consumption cost for both conditions produced by all cases has been promoted by Table 4 and Table 5, respectively. Meanwhile, Table 6 presents the total calculation of the monthly energy consumption cost and represents a part of the total electricity bill for the consumers. The monthly electricity bill was calculated using the procedure in [8], where the bill was calculated for 30 days, where 8 days were weekends. For the weekdays (Monday to Friday), the average daily energy consumption cost was ~MYR 3,300.00. Case 5a recorded the minimum value.

It was observed that without any optimization algorithm and LM applied to the profile of power consumption, and the ETOU tariff scheme increases the cost by about 6.82% compared to baseline flat tariff by manufacturers. Also, there was a surge in the costs for Case 4a and Case 4b, where the PSO and EPSO algorithms have been trapped in the early stage since the LM strategy formulation with a certain percentage of the weightage factor was not applied. Hence, using the LM strategies, the results turn to achieve cost saving with the PSO, and EPSO algorithms perform the optimal solution. However, due to the fast convergence process, the application of the EPSO algorithm has recorded a slightly higher cost compared to PSO's case. This finding shows that for the small solution, such as the movement of the 24 numbers of loads, other medium-fast algorithms could be trying to achieve better results than the daily energy consumption cost.

Table 4: Cost for daily energy consumption (weekday)

Cases	Weekday Daily Energy Consumption Cost (MYR/kWh)	Saving Compared to Case 1 (%)	Saving Compared to Case 2 (%)
Case 1	3,452.90	NA	NA
Case 2	3,255.17	5.73	NA
Case 3	3,688.38	-6.82	-13.31
Case 4a	3,691.57	-6.91	-13.41
Case 4b	3,690.32	-6.88	-13.37
Case 5a	3,022.48	12.47	7.15
Case 5b	3,043.48	11.86	6.50

Apart from that, the cost for the weekends (Friday and Sunday), the ETOU tariff scheme offers a better price rate with a reduction of ~MYR 590.00/day. The idea of the ETOU scheme by the government was, consumers, handle the operation on the weekends instead of general working days. So, power generation stress could be reduced. Nevertheless, on the side of the consumers, the difficulty happened because of the increase of human resources costs due to overtime allowance and extra cost for the transportation charge during weekends. Due to that reason, in this study, the power consumption cost for the weekend was set as constant. In the ETOU tariff scheme's overall performance compared to baseline Case 1 and Case 2 as the existing tariff and optional TOU, the energy consumption cost marginally increased for ~0.5-7.0% for Case 3, Case 4a, and Case 4b. Meanwhile, cost-saving ~9.78-15.74% has been achieved by implementing the LM strategies along with optimization algorithms in Case 5a and Case 5b, respectively.

Table 5: Cost for daily energy consumption (weekend)

Baseline Cases	Weekend Daily Consumption Cost (MYR/kWh)
Case 1	1,775.74
Case 2	1,639.62
Case 3	1,185.58

Table 6: Monthly energy consumption cost

Cases	Monthly Energy Consumption Cost (MYR/kWh)	Saving Compared to Case 1 (%)	Saving Compared to Case 2 (%)
Case 1	90,169.76	NA	NA
Case 2	84,730.70	6.03	NA
Case 3	90,628.89	-0.51	-6.96
Case 4a	90,699.08	-0.59	-7.04
Case 4b	90,671.67	-0.56	-7.01
Case 5a	75,979.19	15.74	10.33
Case 5b	76,441.12	15.23	9.78

Maximum demand cost reduction

Table 7 demonstrates the findings of the MD cost for all cases. The cost has been reduced for all ETOU tariff scheme cases, with Case 5b indicating the best reduction of ~MYR 3,713.12. The power demand was reduced by about 148kW, where the maximum demand had been transferred from peak to mid-peak accordingly.

Table 7: Maximum Demand (MD) findings

Cases	MD Cost (MYR/kW)	MD (kW)	Allocation Zone
Case 1	18,884.80	638	Peak
Case 2	23,606.00	638	Peak
Case 3	18,821.00	638	Peak
Case 4a	18,715.78	634	Mid-Peak
Case 4b	18,606.21	629	Mid-Peak
Case 5a	16,307.84	552	Mid-Peak
Case 5b	15,171.68	490	Mid-Peak

On the other hand, the comparison of the MD cost mitigation percentage for the cases involved was presented in Figure 8. In the evolutionary engagement condition to the optimization process, the EPSO algorithm has produced better mitigation value for the MD. After the initial Pbest and Gbest finding, the selection and tournament process has contributed to the proper allocation for the maximum demand minimum value. The consideration of the rejection fitness function has produced additional options to provide better value [31]. Thus, in the environment of the selection for the best MD value and allocation reflecting the ETOU time zones, the EPSO algorithm would be chosen as the progressive solution. For those reasons, the importance of the MD saving was ~19-35% compared to Case 1 and Case 2, respectively.

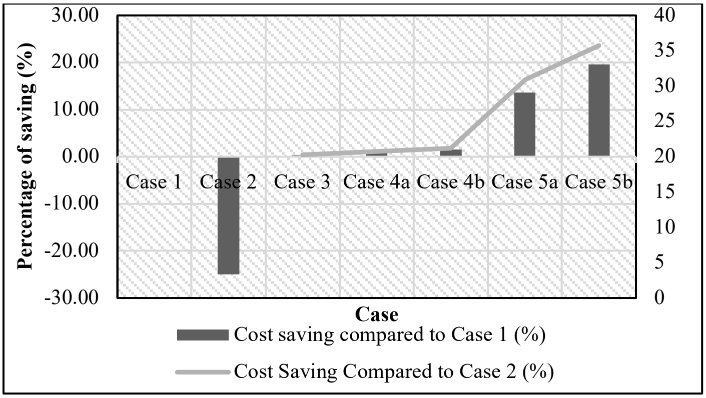

Figure 8: MD cost saving compared to baselines.

Total electricity cost

The total electricity bill for a month has involved two parts: energy consumption cost and MD cost. After considering the calculation method, as explained in the previous section, the value of the monthly electricity charge to the average electronic manufacturing facilities was demonstrated in Figure 9. Case 5b records the best reduction for approximately MYR 17,442 and MYR 16,724 compared to the existing flat tariff Case 1 and optional tariff TOU Case 2, respectively. Hence, the saving percentage of the cases have been presented in Figure 10 and Figure 11. Case 2 shows a small saving value while Case 3, Case 4a, and 4b were used ETOU price without any LM strategy has little increased the bill. The achievement of saving by both Case 5a and Case 5b was ~15.38-16% compared to Case 1 and ~14.81-15.44% compared to Case 2. The PSO and EPSO to arrange the optimal power consumption curve have contributed to these results. Thus, considering the strategic planning of load management strategies while adopting the superior optimization algorithm could help companies' management to better plan for an excellent energy policy. Meanwhile, as industrial consumers, the contribution through peak demand mitigation to the generation side would help the country sustain the power system supply congruently.

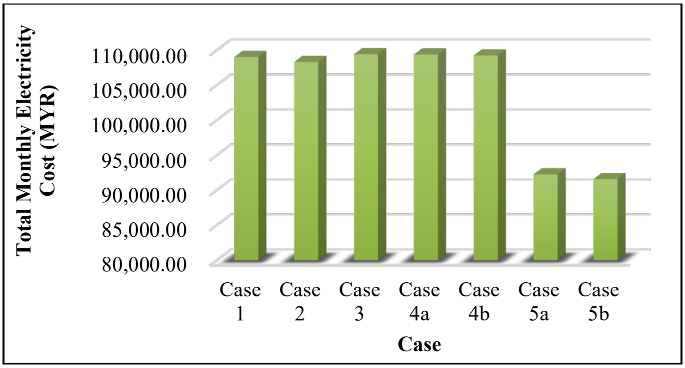

Figure 9: Total electricity cost based on monthly calculation.

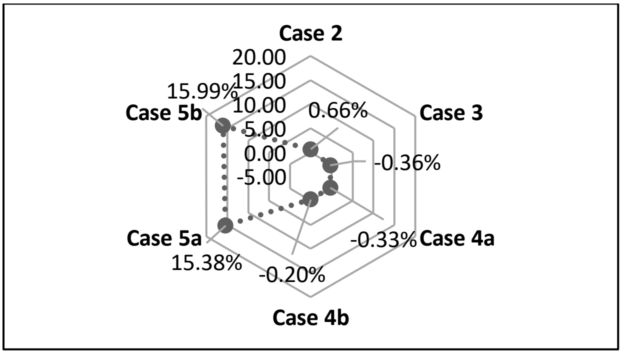

Figure 10: Monthly electricity cost saving compared to Case 1 (flat tariff).

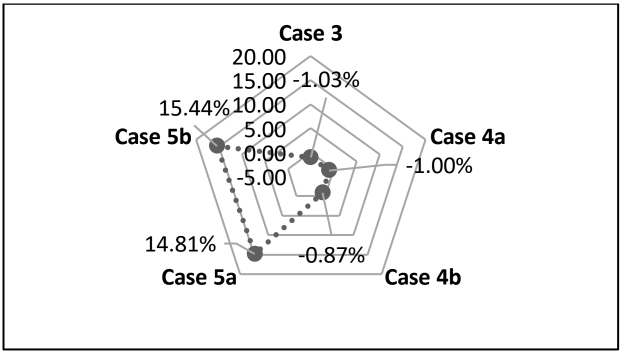

Figure 11: Monthly electricity cost saving compared to Case 2 (TOU tariff).

Conclusion

This study presents the effectiveness of the EPSO algorithm to perform in the LM strategies condition while achieving an optimal reduction of the electricity cost. The formulation of the ETOU tariff scheme has been referred to with the PBP policy introduced by the government. Meanwhile, the cost reduction objectives, which are energy consumption and MD, have been meritoriously mitigated. The additional integration of the evolutionary algorithm to the PSO brought the advantage where MD allocation was adequately located in the mid-peak zone, and the peak demand value was decreased simultaneously.

In the regulated electricity market environment, such as in Peninsular Malaysia, the study's advantage will go to the consumers. Such as developing the company’s energy policy on the demand response program. The policy could bring benefits to the company's profit but also carries benefits to the power generation side to reduce the fuel cost by reducing the peak power supply. Future works' recommendation would be to improve the EPSO algorithm to perform effectively, mainly for the mitigation of the energy consumption cost. The additional objectives would be added such as load factor and other policy indices. The effectiveness of the integration of LM strategies to the optimization algorithm has been analyzed effectively.

Acknowledgment

The authors would like to thank Universiti Teknikal Malaysia Melaka (UTeM) and Univesiti Teknologi Mara (UiTM) for all the support given.

References

[1] Q. Sun *et al.*, “Global heat stress on health, wildfires, and agricultural crops under different levels of climate warming,” *Environ. Int.*, vol. 128, pp. 125–136, 2019.
[2] W. Zhang and T. Zhou, “Increasing impacts from extreme precipitation on population over China with global warming,” *Sci. Bull.*, vol. 65, no. 3, pp. 243–252, 2019.
[3] Energy Commission (Malaysia), “Malaysia Energy Statistics Handbook 2018,” 2019.
[4] Energy Commision, “Peninsular Malaysia Electricity Supply Industry Outlook 2014,” p. 73, 2016.
[5] S. Tenaga, “Laporan Tahunan Suruhanjaya Tenaga 2016,” 2017.
[6] M. Pauzi Abdullah, M. N. Nazatul Shiema, M. Y. Hassan, and F. Hussin, “Optimizing Time of Use Electricity Pricing in Regulalted Market,” *J.*

Teknol., vol. 7, pp. 31–39, 2013.
[7] N. F. Asa, M. P. Abdullah, M. Y. Hassan, and F. Hussin, "Disaggregated electricity bill base on utilization factor and Time-of-Use (ToU) tariff," *Int. J. Electr. Comput. Eng.*, vol. 7, no. 3, pp. 1498–1505, 2017.
[8] N. A. M. Azman, M. Pauzi Abdullah, M. Y. Hassan, and D. M. Said, "Enhanced Time of Use Electricity Pricing for Industrial Customers in Malaysia," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 6, no. 1, pp. 155–160, 2017.
[9] N. A. M. Azman, M. P. Abdullah, M. Y. Hassan, D. M. Said, and F. Hussin, "Enhanced time of use electricity pricing for commercial customers in Malaysia," *Pertanika J. Sci. Technol.*, vol. 25, pp. 285–294, 2017.
[10] M. F. Sulaima, N. Y. Dahlan, M. H. Isa, M. N. Othman, Z. M. Yasin, and H. A. Kasdirin, "ETOU electricity tariff for manufacturing load shifting strategy using ACO algorithm," *Bull. Electr. Enginnering Informatics*, vol. 8, no. 1, pp. 21–29, 2019.
[11] M. F. Sulaima, N. Y. Dahlan, Z. M. Yasin, M. M. Rosli, Z. Omar, and M. Y. Hassan, "A review of electricity pricing in peninsular Malaysia: Empirical investigation about the appropriateness of Enhanced Time of Use (ETOU)electricity tariff," *Renew. Sustain. Energy Rev.*, vol. 110, pp. 348–367, 2019.
[12] J. C. Chen, J. C. Hwang, J. S. Pan, and Y. C. Huang, "PSO algorithm applications in optimal demand decision," in *2009 IEEE 6th International Power Electronics and Motion Control Conference, IPEMC '09*, 2009, vol. 3, pp. 2561–2565.
[13] T. Y. Lee and C. L. Chen, "Iteration particle swarm optimization for contract capacities selection of time-of-use rates industrial customers," *Energy Convers. Manag.*, vol. 48, no. 4, pp. 1120–1131, 2007.
[14] H. T. Yang, C. T. Yang, C. C. Tsai, G. J. Chen, and S. Y. Chen, "Improved PSO based home energy management systems integrated with demand response in a smart grid," in *2015 IEEE Congress on Evolutionary Computation, CEC 2015 - Proceedings*, 2015, pp. 275–282.
[15] A. R. S. Vidal, L. a. a. Jacobs, and L. S. Batista, "An Evolutionary Approach For The Demand Side Management Optimization In Smart Grid," in *IEEE Symposium on Computational Intelligence Applications in Smart Grid (CIASG)*, pp. 1–7, 2014
[16] T. Logenthiran, D. Srinivasan, and T. Z. Shun, "Demand side management in smart grid using heuristic optimization," *IEEE Trans. Smart Grid*, vol. 3, no. 3, pp. 1244–1252, 2012.
[17] J. Ding, S. Song, R. Zhang, R. Chiong, S. Member, and C. Wu, "Parallel Machine Scheduling Under Time-of-Use Electricity Prices: New Models and Optimization Approaches," *IEEE Trans. Autom. Sci. Eng.*, vol. 13, no. 2, pp. 1138–1154, 2016.
[18] D. Yu, H. liu, and C. Bresser, "Peak load management based on hybrid

power generation and demand response," *Energy*, vol. 163, pp. 969–985, 2018.

[19] W. Xu, M. Zhou, H. Wang, and H. Liu, "A load management optimization approach considering economic efficiency and load profile," in *International Conference on Electricity Distribution, China*, 2014, pp. 907–911.

[20] A. S. T. States, "Application of Metaheuristic Methods to Reactive Power Planning :," *IEEE Proceeding*, pp. 3755–3760, 2007.

[21] J. J. Jamian, M. W. Mustafa, and H. Mokhlis, "Optimal multiple distributed generation output through rank evolutionary particle swarm optimization," *Neurocomputing*, vol. 152, pp. 190–198, 2015.

[22] G. J. Osório, J. C. O. Matias, and J. P. S. Catalão, "Electricity prices forecasting by a hybrid evolutionary-adaptive methodology," *Energy Convers. Manag.*, vol. 80, pp. 363–373, 2014.

[23] H. Mori and K. Nakano, "An Efficient Hybrid Intelligent Method for Electricity Price Forecasting," in *Procedia Computer Science*, vol. 95, pp. 287–296, 2016.

[24] H. Mori, "EPSO-based Gaussian Process for Electricity Price Forecasting," in *IEEE Congress on Evolutionary Computation (CEC), Sendai, Japan*, pp. 291–296, 2015.

[25] M. Sulaima, N. Dahlan, and Z. Yasin, "Effective Electricity Cost Management in a Manufacturing Operation by Using Optimal ETOU Tariff Formulation," *Int. J. Electr. Electron. Syst. Res.*, vol. 15, pp. 82–93, 2019.

[26] M. F. Sulaima, N. Y. Dahlan, Z. M. Yasin, N. A. M. Asari, and Z. H. Bohari, "Optimum enhance time of use (ETOU) for demand side electricity pricing in regulated market: An implementation using evolutionary algorithm," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 8, no. 1, 2017.

[27] Y. Shi and R. Eberhart, "A modified particle swarm optimizer," in *IEEE International Conference on Evolutionary Computation Proceedings, USA*, pp. 69–73, 2002.

[28] H. T. Yang, C. T. Yang, C. C. Tsai, G. J. Chen, and S. Y. Chen, "Improved PS[1] H. T. Yang, C. T. Yang, C. C. Tsai, G. J. Chen, and S. Y. Chen, 'Improved PSO based home energy management systems integrated with demand response in a smart grid,' in 2015 IEEE Congress on Evolutionary Computation, CEC 2015 - Proceedings, ," in *2015 IEEE Congress on Evolutionary Computation, CEC 2015 - Proceedings*, pp. 275–282, 2015.

[29] M. F. Sulaima, M. K. Yunus, A. A. Rahman, Z. H. Bohari, and H. I. Jaafar, "A comparative study of hybridization methods of particle swarm optimization (PSO) family for network reconfiguration," *Int. J. Soft Comput.*, vol. 11, no. 6, 2016.

[30] P. Loganthurai, V. Rajasekaran, and K. Gnanambal, "Evolutionary algorithm based optimum scheduling of processing units in rice industry

to reduce peak demand," *Energy*, vol. 107, pp. 419–430, 2016.
[31] V. Miranda, "Evolutionary algorithms with particle swarm movements," in *International Conference on Intelligent Systems Application to Power Systems*, vol. 1, pp. 6–21, 2005.