An Approach of Load Management and Cost Saving for Industrial Production Line Using Particle Swarm Optimization

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***Abstract*— The industrial revolution in Egypt and other developing countries needs a huge amount of power, while utility could not be able to provide the needed energy, where both the cost of energy and environmental issues should be also considered. In this paper a granite factory is considered as a case study, where the load shifting technique is applied in order to reduce the running cost. The applied optimization technique cost function mainly depends on three main parameters: electrical cost (which is divided into on-peak and off-peak periods), demand cost (depends on the maximum utilized power), and workers' wages (based on night or day shifts). Particle Swarm Optimization (PSO) has been introduced and simulated. By comparing the results from different operation conditions and cases, it was found that the load shifting technique can reduce the peak demand and capital cost, while increasing the running cost has been noticed. So, the shut-down period has been then suggested and studied in order to reduce both capital and running cost.**

Keywords—Particle Swarm Optimization (PSO), Cost Saving, Industrial Production Line, Demand Side management (DSM)

NOMENCLATURE

$P_{(i,j)}$	*is the load demand*
i	*is the load number.*
N	is the total number of factories; in this study case one factory is used.
j	*is the total number of time intervals*
C_T	*is the total running cost of the electrical demand and energy consumption*
$CE_{(i,j)}$	is the cost of energy for load type i at time interval number j.
$Pnew_{(i,j)}$	*is the demand of load type i at time interval j after applying load shifting technique*
$Pold_{(i,j)}$	is the demand of load type i at time interval j before applying load shifting technique
$P_{(val)}$	is an extremely limiting value given by the planner for load demand after applying the DSM program.
$Wh_{(j)}$	is the working hours of the factory during the day
NW	is the number of workers in this factory
$CW_{(i,j)}$	is the cost of workers for load type i at time interval number j.
Pmin	*minimum power for new load power (for lighting)*
Pmax	maximum power for new load power (maximum in old load profile)
v_i^k	is the vector of velocity
w	*is the inertial weight*
c_1 , c_2	are the acceleration coefficients.
s_i^k	is the current solution of individual i at iteration *k.*
$rand_1$ $rand_2$	are random numbers in the range of [0, 1].
pbest	is the local best position
w_{min} , w_{max}	are the minimum and maximum inertia parameter weights
$Iter_{max}$	is the value of maximum iterations
$Iter$	value of current iteration.

I. INTRODUCTION

Demand Side Management (DSM) is the most effective system for increasing the efficiency and saving energy for both utility and consumer. DSM concern could be divided into two main sections: load scheduling of factories and optimization techniques. A case study in a big cement factory in China used the demand side management to minimize the cost by solving the optimization problem [1]. Demand side management has studied the implementation of different industrial case studies, such as the mechanical pulp production process of paper mill site [2]. Particle Swarm Optimization (PSO) is used in Demand Side Management (DSM) to solve load shifting mathematical optimization form [3]. The results proved that using optimization techniques reduced peak load, cost and improving load factor. Using CVX in Load shaping techniques will be formulated as constrained optimization problems for direct load control purposes [4][5]. Most of the previous researches focused on decreasing peak demand cost and capital cost [6]. A crucial problem is found because of the big running cost as additional working hours are needed. DSM is a set of flexible programs, which allows customers to shift their own demand for electricity and reduce their energy consumption overall [7]. DSM has three important ends: customer, utility and society. The customer seeks two very important factors: decreasing the electrical bill and increasing the system efficiency [8]. Utility needs to reduce overall system energy, selling in peak hours, the pollution and emission. Where load management programs are: valley filling, peak clipping, load shifting, flexible reliability, strategic load growth and strategic load conservation [9]. Particle Swarm Optimization is proposed by Kennedy and Eberhart in 1995. The basic idea came from mimicking the social behavior of birds. This technique demonstrates that it is greatly successful in resolving a broad range of complicated optimization problems.

II. PROBLEM FORMULATION

A. Description of the factory line production under study

Granite factories consist of main eight sections, in this paper one section is studied. The main steps in producing a segment of granite are: cutting and polishing of each piece. The energy consumption for this section was studied, such as the number of equipment, production capacity, sequence and operation schedule. Table I shows the power consumption of each machine.

TABLE I POWER CONSUMPTION IN MACHINES

Type of Machine	Power Consumption (kW)
Cutting machine	29.4
Polishing machine	3.675
Compressor	7.35
Lighting	3

The capacity of each factory is represented by number of machines, productivity target and the operational hours. Thase are very important data for the loading profile. A sector of this factory can be presented resolved and then applied to all factories if needed. The capacity of the stuided factory sector is summerised in Table II, this data will be used to calculate the power consumption. The sequence of operation of this factory is as follow. Cutting the big single granite stone into sixteen pieces which take up to five hours to be completed, then polishing granite slabs for half an hour for one piece. This should be taken into consideration while controlling the load profile of the factory.

TABLE II CAPACITY OF GRANITE PRODUCTION FACTORY

Capacity	Section of factory
Number of granite blocks	6
Total piece production per day	96
Number of cutting machines	4
Number of polishing machines	4
Operational time of cutting machines per day	7.5
Operational time of polishing machines per day	12

The proposed load management is applied based on the load shifting technique, which shifts the load from on-peak to off-peak hours. This rescheduling of load have to be done without affecting the total production target. The objective of this case study is to reduce the peak demand of this sector, which directly affects the cost. The cost is divided into running cost of electricity consumption and the capital cost of electrical equipment such as cables, electric panels, circuit breakers. Load shifting also increases the load factor which affects the factory bill and the stability of utility. Fig. 1 shows the load profile of the granite factory before applying the proposed load management technique.

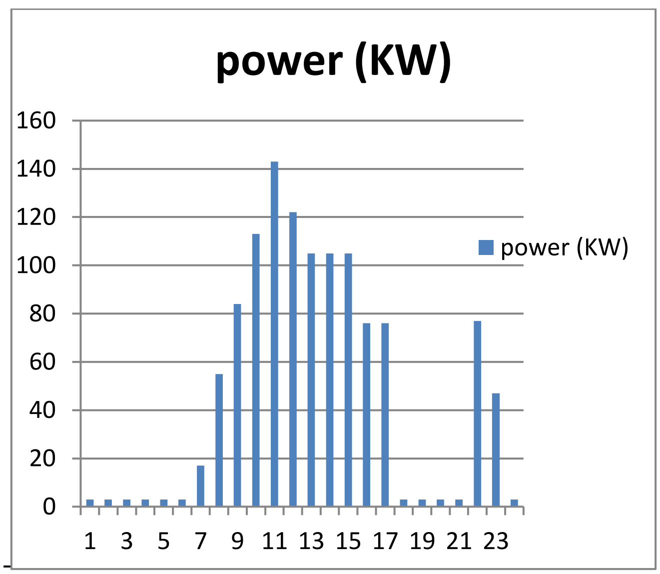

Fig 1Existing Load Profile of One Section of the Under-Study Factory[6]

B. Proposed Load shifting technique

The objective function is formulated to minimize the total running cost and improve the load curve of the industrial plant factory. The equation form is divided into three sections as follows:

$$min\ C_T = \left[\sum_{i=1}^{N}\sum_{j=1}^{24} P_{(i,j)} \times t_{(j)} \times CE_{(i,j)}\right] + [p(val) \times CD] + \left[\sum_{i=1}^{N}\sum_{j=1}^{24} Wh_{(j)} \times NW \times CW_{(i,j)}\right] \quad (1)$$

According to constraints:

$$\sum_{i=1}^{N}\sum_{j=1}^{j} P_{new(i,j)} * t_{(j)} = \sum_{i=1}^{N}\sum_{j=1}^{j} P_{old(i,j)} * t_{(j)} \quad (2)$$

$p_{new(i,j)}$= *p (val)* limitation the maximum power (3)

$p_{new(i)} \geq p_{old(i)}$ during off-peak (4)

$p_{new(i)} \leq p_{old(i)}$ during on-peak (5)

Pmin=3KW (6)

Pmax=143KW (7)

The objective function (1) aims to decrease the factory cost by applying load shaping techniques, in addition to improve the load factor, also the average and maximum power are aimed to be approximately equal. Constraint (2) ensures that energy consumption after applying a load shifting method is equal to the total energy consumption before load shifting. In peak load duration, the new power of this region cannot exceed $P_{(val)}$ as in constraint (3). $P_{(val)}$ is estimated using simulation to reduce the peak hour consumption. Constraints (4) and (5) ensure that the new power demand is reduced in peak hours, and increased during off-peak hours. Constraints (6) and (7) are the minimum and maximum limitations of new power.

C. *Proposed particle swarm technique*

PSO technique initially evaluates a population of solution, which is called a swarm. This swarm consists of particles, each particle presents the iteration solution, till finding the optimal value related to the objective function[10]. To find the optimal solution, these particles search in space and update their velocities. Through iterations position and velocity are updating to find local best and then global best according to (8) and (9).

PSO algorithm consists of 'n' particles. Each particle's case is changing according to:

- Best optimization of the position of the particle.
- Best optimization of the position of the swarm

$$v_i^{k+1} = w\, v_i^k + c_1\, rand_1\left(pbest_i - s_i^k\right) + c_2\, rand_2\left(gbest - s_i^k\right) \quad (8)$$

$$s_i^{k+1} = s_i^k + v_i^{k+1} \quad (9)$$

The best performance in getting global best value is one of the main features of the PSO algorithm. PSO technique eliminates the sinking in a local minimum value. To avoid this, the value of the weighting gain must be calculated. There are many techniques used for getting the inertia weight as adaptive inertia weight, chaotic inertia weight, and linear decreasing method. The linear decreasing technique gives a good presentation for the system, which needs to achieve a global minimum value. The inertia weight is given in equation (10).

$$w = w_{max} - \frac{w_{max} - w_{min}}{Iter_{max}} * Iter \quad (10)$$

The concept of modification of a searching point of PSO is computed the new particle (s_i), then evaluating its new location. If fitness (s_i) is better than fitness $(pbest)$, then $pbest = s_i$ in the end of iteration $gbest = pbest$[11].

III. PROPOSAL FLOW CHART

Where the flowchart illustrates the program sequence is given in Fig 2.

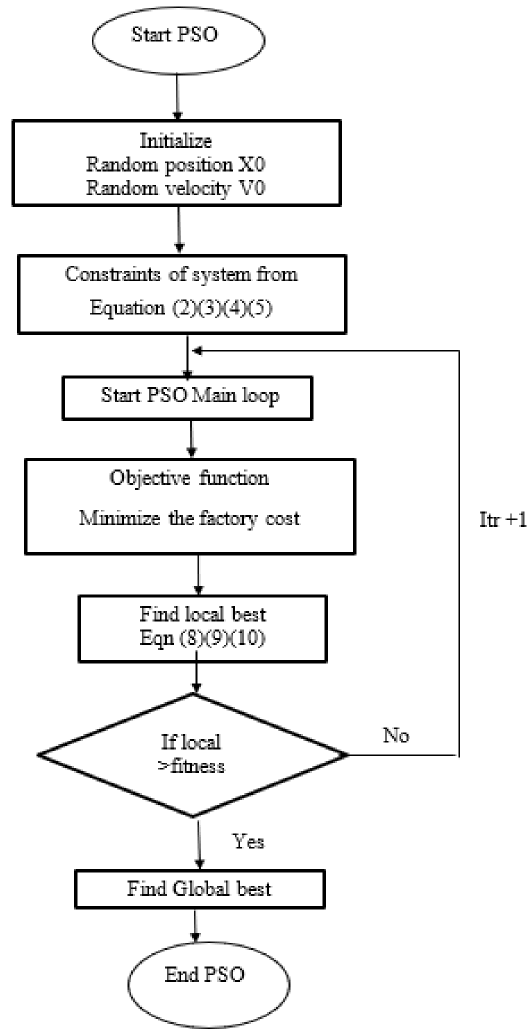

Fig. 2 PSO Flow Chart.

IV. DSM WITH RESHAPING OF FACTORY POWER LOAD CURVE

Demand Side Mangment (DSM) with reshaping of power load curve will be studied under two parts. Part A, is the effect of limitation on the cost function, which will be analysed individually. Part B, is the effect of conditioned limitation on the cost function which will be analysed by PSO

A. *Effect of Changing Limitations*

Limitation will be studied individually, where Eqn. (1) has three main parameters: the peak demand power, the workers cost and the electricity cost.

The individual effect of each parameter will be first studied in the following section, to analyse the effect before the utilization of proposed optimization techniques.

1. Maximum power

The main objective of the load shifting technique is to decrease the maximum demand power which affects the total cost by decreasing capital and demand cost. In this section the effect of changing the maximum power is studied with only one constraint that keeps the total consumed power constant. For each load profile of Fig. 3, the total cost has been calculated based on different values of maximum power (90,70 ,55 KW). And the result has been listed in Table III.

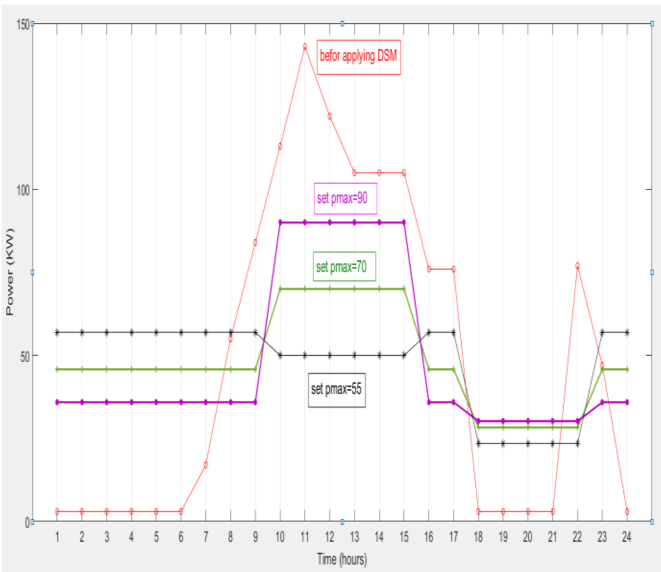

Fig. 3. Effect of changing the maximum power demand on the load curve shape.

TABLE III The TOTAL COST EFFECT OF MAXMIMUM POWER.

Pmax value	The total running cost L.E/m
After set pmax=90	81434
After set pmax=70	80176
After set pmax=55	79132

From table III, it can be noticed that the cost in three cases has increased after load shifting and this arises from increasing the total working hours particularly during peak hours of electricity cost. From comparing the three cases of load shifting together, it can be seen that Pmax = 55 provided the smallest demand cost. The total running cost is decreased with Pmax reduction by assuming the working hours are constant.

2. Effect of workers cost

The total workers' cost is affected by three parameters: the cost of workers per hour, the number of workers and the number of working hours. The working hours are divided into two shifts: day shift and night shift. This cost of workers is assumed to be changed from day to night shift to be 10 L.E/hr and 12 L.E/hr respectively. The night shift could start at 6 pm or 8 pm.

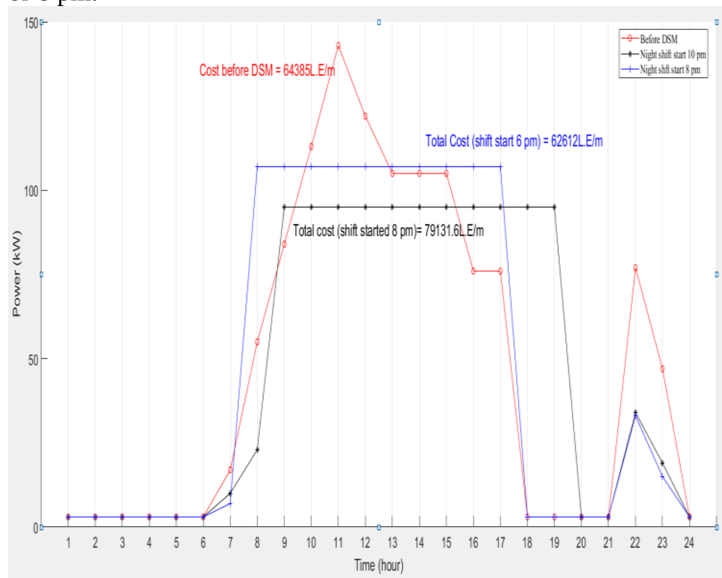

Fig 4. The new load curve after load shifting with variations of working hours.

Fig. 4 shows the different load curves when the night shift starts from 6 pm or 8 pm and both ending at 7 am. It can be seen that for the shift starts at 6 pm, more saving is achieved; since it's working hours are less than shift which starts at 8 pm. The only drawback of the 6 pm shift is that it has a higher peak demand. Table IV compares the two shifts in terms of the total running cost, peak demand, worker cost, and electricity cost.

TABLE IV THE TOTAL RUNNING COST EFFECT OF WORKERS COST .

	With night shift start at 6 pm	With night shift start at 8 pm
The total running cost (L.E/m)	67212	62612
Peak load (KW)	95	107
Worker cost (L.E/m)	23700	20700
Electricity cost (L.E/m)	38760	36562

3. Effect of electrical cost

The cost of electricity is based on an Egyptian electricity company plan 2019 [12] for industrial loads, is divided into three sections: on-peak, off-peak and average, which are during the off-peak .96 pt and during the on-peak 1.45 pt. The peak hours start from 6 pm to 10 pm, off peaks start from 2 am to 7 am otherwise is the average. The result of load shifting with only electrical cost as the limitation can be shown in Fig 7.

From Fig. 5, the output load curve is shifted to be work only in the off-peak period, causes a high increase in maximum power. The total running cost is decreased because of decreasing the working hours, but the capital cost has dramatically increased because of increasing the peak demand as shown in Table V.

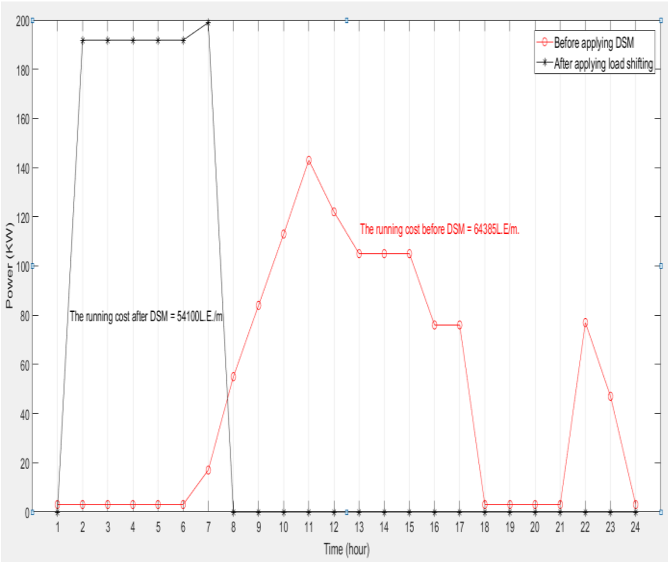

Fig. 5. New load curve with electrical cost constraint only.

TABLE V COMPARING the cost before and after load shifting with electricity cost constraints.

	Before DSM	After DSM
Total Energy (KWh)	1158	1158
Peak power (KW)	143	199
Peak demand cost (L.E/m)	7150	9950
Electricity cost (L.E/m)	36534	33351
Workers cost (L.E/m)	20700	10800
Total running cost (L.E/m)	64385	54100

From Table VI it was found that, the new load curve running cost is less than the existing one as the working hours have reduced. On the other hand, the peak demand has increased which affects the capital cost.

B. Cost optimization using PSO

In this section two different cases are studied using a Particle Swarm Optimization technique.

Case (1) a shutdown period of 6 hours at any time during the day

Case (2) a shutdown period of 10 hours at any time during the day

Case (1) : The following assumptions of the variables are given below.

The input power load curve of the granite factory as shown in Fig. 1 is represented by a matrix of twenty-four columns. The electricitycost taken from an electricity company for industrial loads as shown in Fig. 6, will be drawn by MATLAB®.The third input is the cost of employees per hour which changes from day to night shift that differs for almost 1.2%. Assuming the cost is 10 L.E/hour in day shift and 12 L.E/hour in night shift, where night shift begins from 11 pm to 6 am. The manpower in the production line factory is assumed to be five.In order to satisfy the main objective of the program to reduce the overall cost of the varying energy, the following limitations are given:

The total consumed energy of the day should be constant. The maximum power should be reduced. Increasing the power during the off-peak hours.Decreasing the power during on-peak hours. A shutdown period (minimum of six hours).

The results are can be shown in Fig. 6 and Table VI. Found that the peak demand power is decreased, but the total cost is increased by applying the load shifting technique.

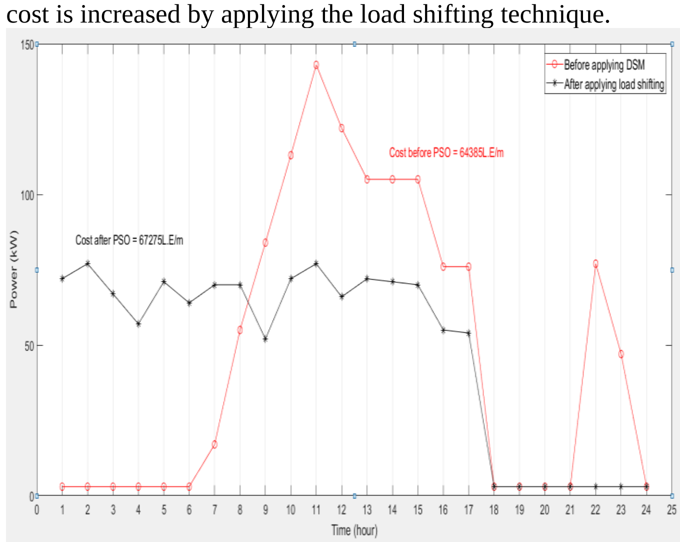

Fig. 6. Load Curve after Applying Load Shifting using PSO (Case 1).

TABLE VI THE COST RESULTS OF THE FACTORY BEFORE AND AFTER APPLYING CASE 1.

Item	Before DSM	After DSM Case (1)
Total energy (KWh)	1158	1158
Peak load (KW)	143	77
Electrical Cost (L.E/m)	36534	35525
Demand cost (L.E/m)	7150	3850
Working hours	13	17
Workers cost (L.E/m)	20700	27900
Total running cost (L.E/m)	64385	67275

In this case, shut down period is six consecutive hours which has a significant effect on the peak demand which is decreased by approximately 46%. But the running cost is increased because of the increasing working hours.

Case (2) : has the same assumption of case (1), while the shunt down period is increased to be ten hours. The results can be shown in Fig. 7 and Table VII. The peak demand is therefore decreased from 143 to 100 KW which is approximately 30%, and the running cost is decreased for approximately 6.6% which saves around 4259 L.E in a month and 51108 L.E in a year.

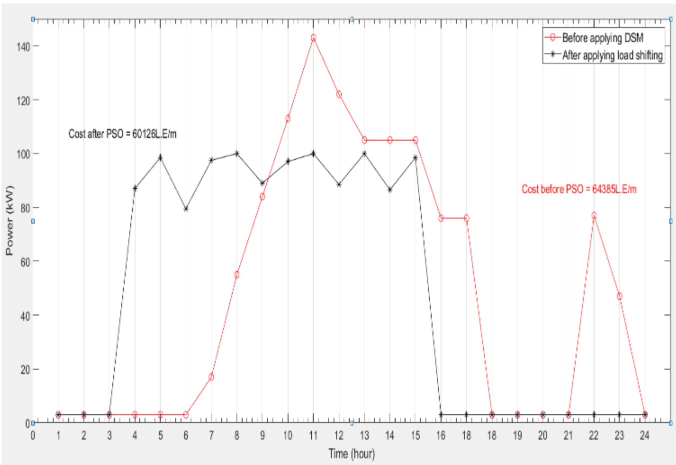

Fig 7 Load Curve after applying load shifting using PSO (Case 2).

TABLE VII THE COST RESULTS OF THE FACTORY BEFORE AND AFTER APPLYING PSO CASE 2.

Item	Before DSM	After DSM Case (2)
Total energy (KWh)	1158	1158
Peak load (KW)	143	100
Electrical Cost (L.E/m)	36534	35626
Demand cost (L.E/m)	7150	5000
Working hours	13	13
Workers cost (L.E/m)	20700	19500
Total running cost (L.E/m)	64385	60126

In this case, shut down period is increased to be ten hours, which decreases both peak demand cost and the running cost. The disadvantage of this case may be that the power value is fluctuating.

V. Conclusions

Since the load profile of industrial loads can be reshaped to save energy and hence reduce the total cost of the factories, load shifting technique as a demand-side management (DSM) strategy has been studied to reduce the peak demand and also capital cost. The optimization cost function has been formulated to calculate the total running cost within three main parameters: electricity cost, peak demand cost, and workers cost. Particle Swarm Algorithm Optimization technique has been utilized to find the optimal load patterns. Different operating conditions and cases have been studied by changing the program limitations and parameters. The obtained results showed that the load shifting technique can reduce the peak demand while the running cost could be increased as the working hours increasing. Hence the shut-down period has been suggested and taken into consideration within the optimization program. Then the final results indicated a better reduction in both capital and running costs.

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