MINIMIZATION OF ELECTRICITY CONSUMPTION COST OF A TYPICAL FACTORY

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ABSTRACT: The difference between the price of one Kilowatt-hour (KWh) during peak and normal hours was significantly high. The reduction in electricity consumption cost has drawn the attention towards optimal schedule. In this paper we developed a physical based optimization model that utilizes linear programming technique for minimizing electricity cost by rescheduling the specific load in such a way that all the requirements of the industry are fulfilled. The proposed model was implemented on load management problem of typical factory as a case study. The results showed that the significant reduction in peak electricity load was possible. As a result of rescheduling the load factor was improved that caused the reduction in the electricity consumption cost.

Key words: Optimization, Mathematical Modeling, Load Management, Electricity Cost, Load Curve.

INTRODUCTION

Energy resources and their availability are extremely important for every country. Energy is considered to be an essential part of community, industry, economics, and sustainable progress of any country. Among all forms of energy, electrical energy is regarded as high grade energy and has been the major driver for technological and economic development.

Pakistan is considered as one of such countries where the electrical energy sector faces many problems. The major problem in this sector is the imbalance of production and utilization of electricity. From 1970 to the early 1990s, the supply of electricity was unable to keep balance with the demand. The demand was growing regularly at 9-10% per annum while supply capacity to meet demand decreased by 15-25% per annum (Arifa, 2013). With the passage of time difference between supply and demand of electricity increased. Floods are other factor which cause electricity shortage due to damaged distribution networks. Rebuilding the system, power generation cost is significantly increasing (Pervez, 2011; Raja, 2012; Sumit, 2010). In Pakistan, the consumption of electricity in industrial sector is 26 % of the total consumption of all sectors (Shoaib, 2012). Keeping in view all the above factors, load management in this field looks quite necessary, particularly in industrial sector. Industrial load management (ILM) is an expression covering a large variety of load management alternatives applicable to industrial loads (Bjork, 1989; Vogt and Conner, 1977; Isaksen and Simons, 1981; Sheen, 1994; Cochen and Wang, 1988; Gustafsson *et. al*; 2004; Gaustafsson, 1977 and Shahzad, 2013). Industrial customers are far more diversified with respect to electrical equipment and electrical demand than either residential or commercial customers. Individual action taken by industrial customers when applying industrial load management strongly depends on the individual characteristics of every industry's electrical load composition. Load management is a strategy which is followed by the industrial customers and/or the electric utilities to change the customer's present load curve shape in order to gain from reduced total system peak loads, improve the load factor, and improve utilization of scarce and expensive resources. Load curve shows the variation of load on power station with respect to time (Alexandra, 2006). Load factor is the ratio of average load to the maximum load of power station during a given period. The increase in load factor reduces the cost of electricity per unit (Mehta, 2004).Load management approaches are applicable to both on energy demand and on supply sides. There are many methods of load management which can be followed by an industry such as peak clipping, load shifting, strategic conservation, load priority system, energy storage units, new production equipments, load shedding and restoring (Boak, 2003). The choice of an appropriate load management strategy for a specific industry depends on several factors such as the present shape of the load curve, the desired changes in the shape of load curve, the processes and the configuration of less essential loads, demand and energy charges. Load shifting is a simple method of load management and it is better option for industries. Load shifting does not decrease the overall electricity consumption, no loads are being switched off, but only shifting or rescheduling, and hence the total production is not affected. Load shifting basically means scheduling the load in such a way that loads are diverted from peak period to off-peak periods, thereby shaving the peak and filling the valley of the load curve. To encourage load shifting in industries, and thereby to reduce peak demand, many industries have already implemented time of use rates (TOU) or have plans for introducing such rates (Ashok and Banerjee, 2000).In Pakistan, the rates of peak–hours are approximately double of the off-peak hours. Therefore, it is the need of time to use the optimal schedule. To do this job the optimization technique is used which will minimize the daily cost of electricity consumed by the industry.

Methods like Particle Swarm Optimization and Genetic Algorithms are capable of solving almost all types of optimization problems, but they require constraint handling strategies like Penalty Functions to convert the constrained optimization problem into an unconstrained one (Chaudhry *et. al*; 2009). The cases where emphasis is on formulation of mathematical model rather than the problem solving approach, any optimization solver, for example, Premium Solver, LINGO, CPLEX and Optimization Toolbox of Matlab, can be used.

Formulation of optimization model: Problems that seek to maximize or minimize a mathematical function of a number of variables, subject to certain constraints, form a unique class of problems, which may be called optimization problems. Many real-world and theoretical problems can be modeled in this general framework. A common term optimize is usually used to replace the terms maximize or minimize (Rao, 1984; Gass, 1985 and Shahzad, 2013).

Mathematically, a general optimization problem is written as:

Optimize $f(\underline{x})$

Subject to

$$g_j(\underline{x}) \le 0 \qquad (j = 1, 2, 3, \ldots, J)$$

$$h_k(\underline{x}) = 0 \qquad (k = 1, 2, 3, \ldots, K)$$

$$l_r \le x_r \le u_r \qquad (r = 1, 2, 3, \ldots, n)$$

where, $\underline{x} = (x_1, x_2, x_3, \ldots, x_n)^T \in R^n$

Electrical network consists of supplier (WAPDA), distribution companies (LESCO, MEPCO, FESCO, IESCO, PESCO, GEPCO, HESCO, QESCO) and consumers (domestic, commercial, industrial). Our focus in this study paper is to build an optimization model for the load management of an industry that purchases electricity from WAPDA through distribution companies. Industrial electricity bill consists of three types of costs, (a) cost of electricity on normal period, (b) cost of maximum consumption of electricity during normal and peak hours, (c) fixed charges. There are many sections in the industry in which electric loads vary during different intervals of times. For example, the industry has $S_1, S_2, S_3, \ldots, S_m$ sections, which requires $l_1, l_2, l_3, \ldots, l_m$ electric loads on discrete time intervals respectively.

To formulate an optimization model, we make the following assumptions [19]:

A-1: The consumption of electricity is constant before and after optimization.

A-2: There is no usage of hybrid electricity.

A-3: There is no load shedding.

Notations: Decision variables and parameters that are used in our model are as under

x_t : Electricity utilization of system at time *t*.

x_{it} : Electricity utilization in ith production line at time *t*.

$x_{t,op}$: Electricity utilization in off-peak hours

$x_{t,op'}$: Electricity utilization in peak hours

α_t : Electricity utilization of lights, cooling facilities and heating in manufacturing system

M: Maximum load of electricity needed for production lines at specific time.

m: Minimum load of electricity needed for production lines at specific time.

c_t: Associated cost of electricity at time *t*

c_1: Cost of maximum electricity consumed per KWh in off – peak hour

c_2: Cost of maximum electricity consumed per KWh in peak hour

C_F: Fixed Charges

N: Number of time intervals

P: Number of production lines

According to above assumptions and notations the optimization motel of electricity consumption is formulated as:

$$\text{Minimize} \quad f(\underline{x}) = \sum_{t=1}^{N} c_t x_t + c_1 Max(x_{t,op}) + c_2\, Max(x_{t,op'}) + C_F$$

Subject to

$$\sum_{t=1}^{N} x_t = \sum_{t=1}^{N}\sum_{i=1}^{P} x_{it} + \alpha_t,$$

$$m \le x_{it} \le M$$

MATERIALS AND METHODS

Case Study: The electricity load data for this case study was taken from Amad Enterprises, Lahore-Pakistan. Load data has been collected from the industry on a normal shift day. The data was verified through the top management of the factory. There were five manufacturing sections in the factory: (i) molding section, (ii) Mechanical Work Shop, (iii) Assembly Line,

(iv) Dip Soldering, (v) Bakelite Molding. The factory is working in two shifts. The 1st shift is from 06:00 to 14:00 and 2nd shift is from 14:00 to 22:00. In other times no activity was being performed.

Numerical results and discussion: The developed model was a linear programming model of considerable size. We used Premium Solver to solve this model and the results in the form of optimal schedule are presented in Table 1.

Table 1showing: the Comparison of Electricity Consumption

Time Interval	Hour (*t*)	Electricity Consumption (KWh)		Time Interval	Hour (*t*)	Electricity Consumption (KWh)	
		Before Optimization	After Optimization			Before Optimization	After Optimization
00:00-01:00	01	6	5	12:00-13:00	13	40	35
01:00-02:00	02	6	5	13:00-14:00	14	30	20
02:00-03:00	03	6	5	14:00-15:00	15	30	30
03:00-04:00	04	6	5	15:00-16:00	16	40	35
04:00-05:00	05	6	5	16:00-17:00	17	40	35
05:00-06:00	06	6	5	17:00-18:00	18	20	25
06:00-07:00	07	10	25	18:00-19:00	19	20	15
07:00-08:00	08	15	30	19:00-20:00	20	20	15
08:00-09:00	09	20	35	20:00-21:00	21	15	11
09:00-10:00	10	30	30	21:00-22:00	22	15	11
10:00-11:00	11	30	25	22:00-23:00	23	6	5
11:00-12:00	12	35	25	23:00-24:00	24	6	5

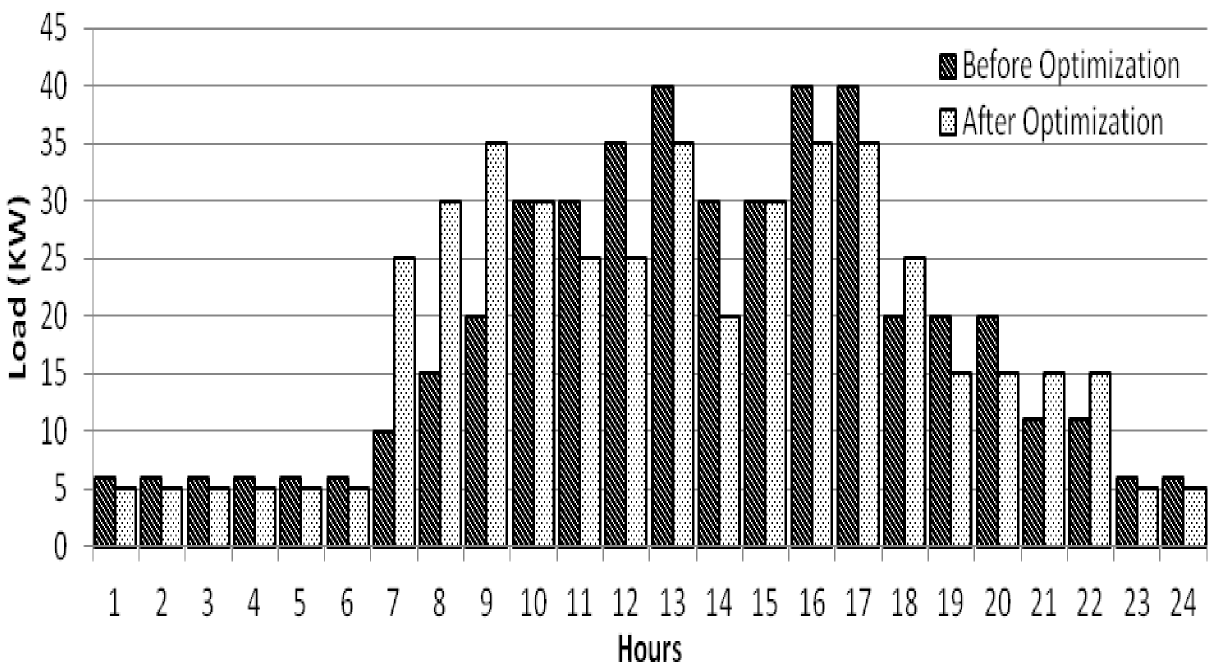

Fig.1showing: the Comparison of Hourly Electricity Consumption

Fig.1 shows the hourly comparison of consumption of electricity before and after optimization. This figure shows that, from 23:00 to mid night, and mid night to 06:00 there was a small change in consumption pattern of electricity before and after optimization. The optimized schedule suggested that more electricity should be used during 06:00-09:00 but this trend was reversed during 10:00-20:00.

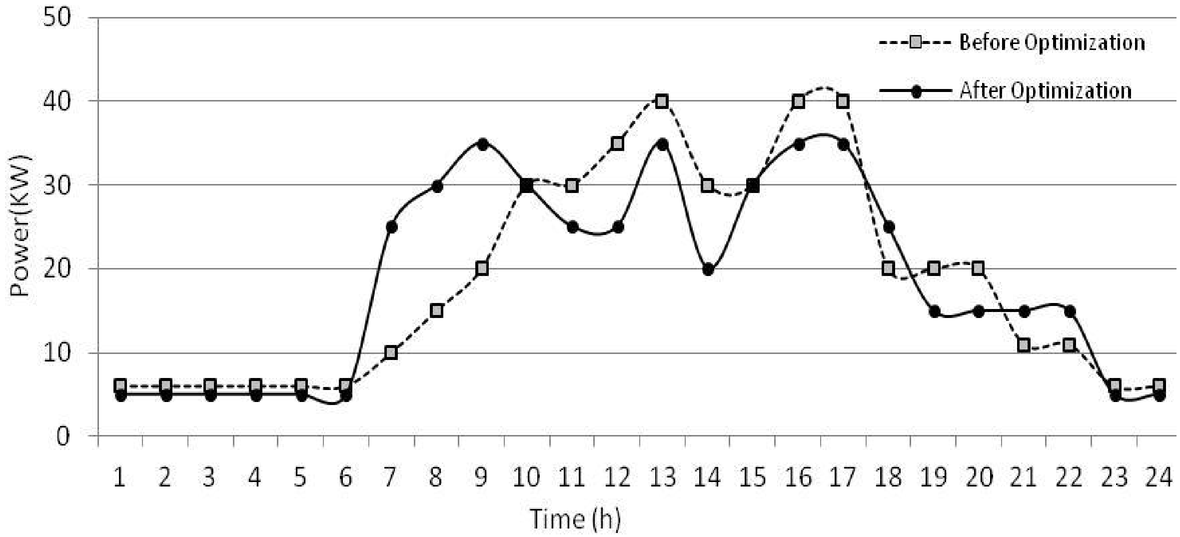

Fig.2 showing: the comparison of daily load curves

In Pakistan the electricity charges of industry are also based on maximum demand/load during a day. In the case of Amad enterprises, the maximum demand 40 KWh during a day was recorded at 13:00 and 15:00 to17:00. From figures1 and 2, the demand of industry is 5 KWh during 01:00 to 06:00 and 23:00 to 24:00. In the first working shift, from 06:00 to 14:00 the minimum and maximum demand of industry was 10KWh and 40KWh respectively. And in the second shift, from 14:00 to 22:00 the industry used the minimum 15 KWh and maximum 40KWh. It was obvious that load management reduced the peak demand, improved the load factor, and rescheduled the load in such a way that loads were shifted from peak hours to off peak hours. After optimization the maximum demand decreased from 40KWh to 35KWh during 13:00 and 15:00 to 17:00 Hrs. The total reduction in the maximum demand was 15KWh during the different hours. This 15 KWh load was shifted in off peak hours while total demand over 24 hours did not affect.

Conclusion: Load management program basically optimized the loads which reduced the peak demand of factory. Load shifting was a simple method of load management and it was better option for most industries. The model was successfully applied on load management problem of Amad Enterprises Ltd. The comparison of electricity consumption schedule before and after optimization is shown in table 1. As a result of optimal rescheduling of electricity consumption, the load factor was improved 46.25% to 52.97619 % which caused to reduce the electricity bill 16.0934% per day. Proposed optimization model for a factory presented the optimal hourly electricity consumption schedule while satisfying the factory constraints. The proposed model was capable of minimizing the peak load and daily cost of electricity.

The results carried out in this study will help to solve the industrial management problem and may saved remarkable amount of money. Furthermore, this research can also be extended to optimize the load section wise.

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