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Optimization of energy charges using improved PROMETHEE method

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ABSTRACT *: In an electrical energy intensive industries the production cost is mainly affected by the cost of electrical énergy. The efficient use of electrical energy reduses the production cost. If the elecrical energyg is not managed properly, the Specific Energy Cost (SEC) i.e. cost of energy per unit output will not be optimized i.e.it is very high & some times not acceptable to the customer.This paper highlights solution to this important problem using a multiple criteria decision making method known as Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE). In this paper the PROMETHEE method is implemented to optimize the specific energy cost of the Textile Industry. This paper, deals with the energy optimization using improved PROMETHEE method which provides a complete ranking of the alternatives, from the best to the worst one, using the net flows.*
Keywords - *PROMETHEE Method, AHP, Optimization, Ranking, Energy Charges, Load Curve.*

1. INTRODUCTION

Energy management program is a systematic and scientific process to identify the potential for improvements in energy efficiency, to recommend the ways, with or without financial investment, to achieve the reduction in energy cost.

This requires collection & analysis of existing energy usage data, careful study of existing equipments, processes and then suggesting practical & economical ways for saving energy cost. There is a need for logical methods or mathematical tools to guide decision makers in considering a number of selection criteria and their interrelations.

The aim of the paper is to demonstrate the PROMETHEE method for some more decision making situations of the Electrical Energy Tariff of Textile industry. The given textile industry is the H.T. consumer. The H.T. consumer has different energy charges, i.e. M.D. (maximum demand) charges, kWh charges & TOD (time of day) charges.

H.T. consumer has maximum TOD charges in peak demand period & minimum TOD charges in off-peak demand period. With the help of energy management technique, if the load is adjusted in such a way that it provides the benefit from TOD charges. But while doing so, the load in off peak period is increased too much, it will increase the M.D., which will increase the M.D. charges.

In contrast, if it is tried to make the load curve flat with the help of load management technique, M.D. will reduce, & hence M.D. charges will reduce, but in that case benefit of TOD charges will not be achieved [3]. Hence to achieve the optimization of energy charges, the PROMETHEE method is implemented.

II. IMPROVED PROMETHEE METHOD

The PROMETHEE method was introduced by Brans et al. (1984) and belongs to the category of outranking methods. In improved PROMETHEE method more accurate results are obtained with the use of ranked value judgment on a fuzzy conversion scale for the qualitative criteria in conjunction with the analytic hierarchy process (AHP) for determining the relative importance of criteria.

- Improved PROMETHEE method is described below:

Step I :

Identify the selection criteria for the considered decision making problem and short-list the alternatives on the basis of the identified criteria satisfying the requirements.

Improved PROMETHEE method [1] proceeds to a pair wise comparison of alternatives in each single criterion in order to determine partial binary relations denoting the strength of preference of one alternative over other.

- Values of selection criterion-

Table 1. Qualitative measures of selection criterion

Qualitative measures of selection criterion	Assigned value
Exceptionally low	0.045
Extremely low	0.135
Very low	0.255
Low	0.335
Below average	0.410
Average	0.500
Above average	0.590
High	0.665
Very high	0.745
Extremely high	0.865
Exceptionally high	0.955

Step II:

1) After short-listing the alternatives, prepare a decision table including the measures or values of all criteria for the short-listed alternatives.
2) The weights of relative importance of the criteria may be assigned using 'Analytic Hierarchy Process (AHP)', method. The steps are explained below:

- Find out the relative importance of different criteria with respect to the objective. To do so, one has to construct a pair-wise comparison matrix using a scale of relative importance.
- Find the relative normalized weight (Wi) of each criterion by
  1. Calculating the geometric mean of i^{th} row
  2. Normalizing the geometric means of rows in the comparison matrix.

This can be represented as -

$$GM_i = \left\{ \prod_{i=1}^{M} r_{ij} \right\}^{1/M} \tag{1}$$

and

$$W_i = GM_i / \sum_{i=1}^{M} GM_i \tag{2}$$

The geometric mean method of AHP is used in the present work to find out the relative normalized weights of the criteria.

Step III:

After calculating the weights of the criteria using AHP method, the next step is to have the information on the decision maker preference function.

The preference function (Pi) translates the difference between the evaluations obtained by two alternatives (a1 and a2) in terms of a particular criterion, into a preference degree ranging from 0 to 1. Let $P_{i,a1a2}$ be the preference function associated to the criterion ci.

$$P_{i,a1a2} = G_i\left[ci\ (a1) - ci\ (a2)\right]$$

$$0 \le P_{i,a1a2} \le 1$$

Where, Gi is a non-decreasing function of the observed deviation (d), between two alternatives a1 and a2, over the criterion ci. Let the decision maker have specified a preference function Pi and weight wi for each criterion ci (i=1, 2, . . . , M) of the problem. The multiple criteria preference index Oa1a2 is then defined as the weighted average of the preference functions Pi:

$$\prod_{a1a2} = \sum_{i=1}^{M} W_i \, P_{i,a1a2} \tag{4}$$

$\prod_{a1a2}$ represents the intensity of preference of the decision maker of alternative a1 over alternative a2, when considering simultaneously all the criteria. Its value ranges from 0 to 1. This preference index determines a valued outranking relation on the set of actions.

For PROMETHEE outranking relations, the leaving flow, entering flow and the net flow for an alternative 'a' belonging to a set of alternatives 'A' are defined by the following equations:

$$\varnothing^{+}(a) = \sum_{x \in A} \prod_{xa} \tag{5}$$

$$\varnothing^{-}(a) = \sum_{x \in A} \prod_{ax} \tag{6}$$

$$\varnothing(a_i) = \sum \varnothing^{+}(a) - \varnothing^{-}(a) \tag{7}$$

$\varnothing^+(a)$ is called the leaving flow, $\varnothing^-(a)$ is called the entering flow and $\varnothing(a_i)$ is called the net flow. $\varnothing^+((a)$ is the measure of the outranking character of 'a' (i.e. dominance of alternative 'a' over all other alternatives) and $\varnothing^-(a)$ gives the outranked character of 'a' (i.e. degree to which alternative 'a' is dominated by all other alternatives). The net flow, $\varnothing(a_i)$ represents a value function, whereby a higher value reflects a higher attractiveness of alternative 'a'. The net flow values are used to indicate the outranking relationship between the alternatives. For example, for each alternative 'a', belonging to the set A of alternatives, $\prod_{a1a2}$ is an overall preference index of a1 over a2, taking into account all the criteria, $\varnothing^+(a)$ and $\varnothing^-(a)$. Alternative a1 outranks a2 if $\varnothing(a1) > \varnothing(a2)$ and a1 is said to be indifferent to a2 if $\varnothing(a1) = \varnothing(a2)$ As an example, the schematic calculation of the preference indices for a problem consisting of three alternatives and four criteria is given in Fig.1

- Mathematical Model of PROMETHEE method-

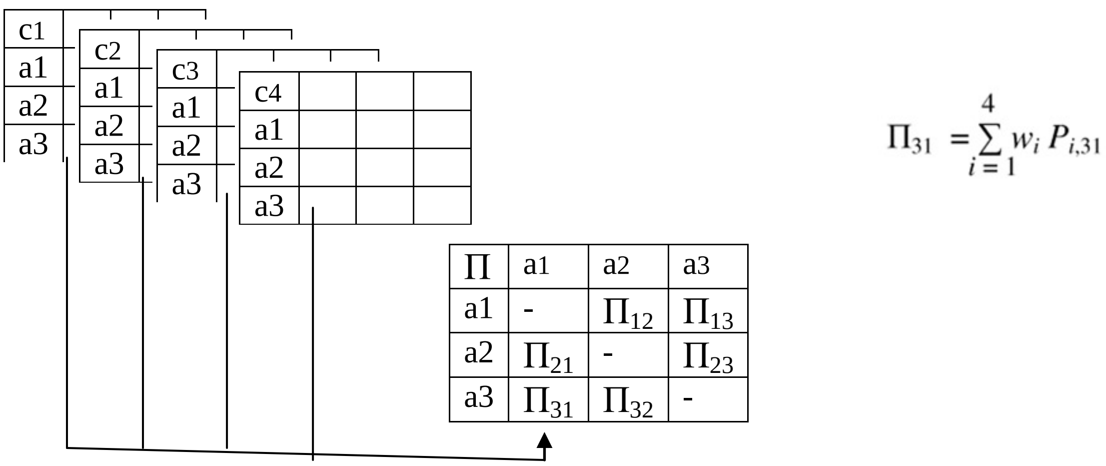

Fig.1 Mathematical Model of PROMETHEE method

The proposed decision making framework using PROMETHEE method provides a complete ranking of the alternatives. The IMPROVED PROMETHEE method is applied for the given industry for optimization of energy cost.

2. Example: Optimization of energy cost of the textile mill using PROMETHEE method.
The textile mill is the H.T. consumer. The H.T. consumer has different energy charges, i.e. M.D. charges, kWh charges & TOD charges.

H.T. consumer has maximum TOD charges in peak demand period & minimum TOD charges in off-peak demand period. With the help of energy management technique, (i.e. by shifting flexible load) if the load from peak demand period is decreased & load from off-peak demand period is increased, then it is possible to get benefit from TOD charges. But while doing so, the load in off peak period is increased too much, it will increase the M.D., which will increase the M.D. charges.

On other side, if it is tried to make the load curve flat with the help of load management technique, M.D. will reduce, & hence M.D. charges will reduce, but in that case benefit of TOD charges will not be achieved [3]. Hence to achieve the optimization of energy charges, the ‘Improved PROMETHEE method for optimization’ is implemented.

For the given industry, M.D is measured for 24 hours. The data is as given in Table .2.

Table 2. Instantaneous M.D. recorded in diff zones

Date	**Type of Zone**	**Time**	**M.D.(kVA)**
25 March 2010	B Zone (0600 To 0900 hrs)	8.00 A.M.	1275
	C Zone (0900 To 1200 hrs)	10.00	1224
	B Zone (1200 To 1800 hrs)	12.00 NOON	1350
		2.00 P.M.	1228
		4.00	1323
	D Zone (1800 To 2200 hrs)	6.00	1360
		8.00	1325
	A Zone (2200 To 0600 hrs)	10.00	1290
		12.00 MIDNIGHT	1275
		2.00 A.M.	1380
		4.00	1350
	B Zone ((0600 To 0900 hrs)	6.00	1290

Case I : As per the data collected on 25 March 2010 actual load curve of the mill is as shown in Figure.2. The values of maximum demand & TOD energy consumption are as mentioned below [2]. :
M. D. - 1380 kVA , A zone - 10590 kWh, B zone - 11596 kWh, C zone - 3924 kWh, D zone - 5230 kWh.

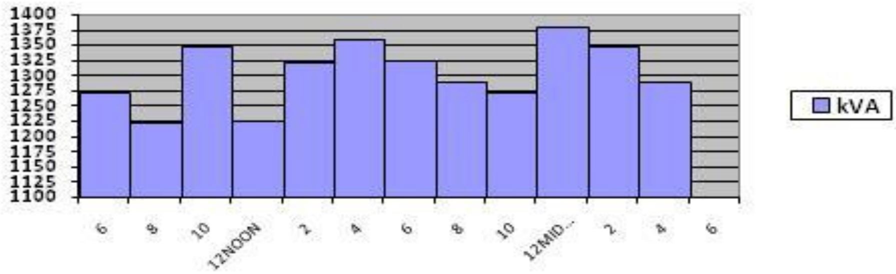

Fig.2 Actual Load curve of the mill (25 March 2010)

Case-II: In this case the load curve is flattened with the help of load management to get the benefit of M.D. charges (Fig..3). Here the load is shifted from peak demand period to off peak period by shifting of load technique. As the load curve is flattened, the contract demand can be reduced, which helps to increase the L.F. & thus it is possible to get more L.F. incentives [2].

The values of maximum demand & TOD energy consumption in this modified load curve are as mentioned below.
M. D. - 1325 kVA, A zone - 10480 kWh, B zone - 11766 kWh, C zone - 4014 kWh, D zone - 5280 kWh

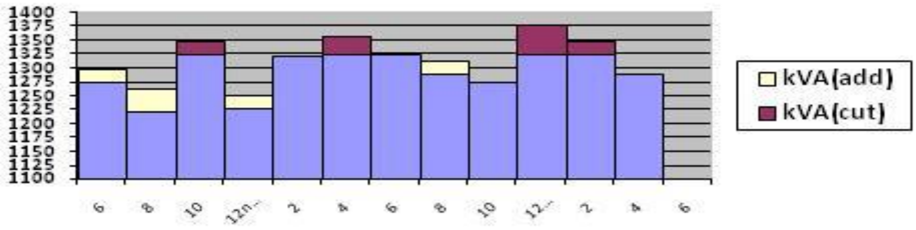

Fig.3 Modified load curve of the mill for M.D. benefit.

Case-III: In this case the flexible load is transferred with the help of load management technique, to get the benefit of TOD charges (Fig.4). Here the load is shifted from zones having higher TOD charges to the zones having lower TOD charges by strategic load growth technique.

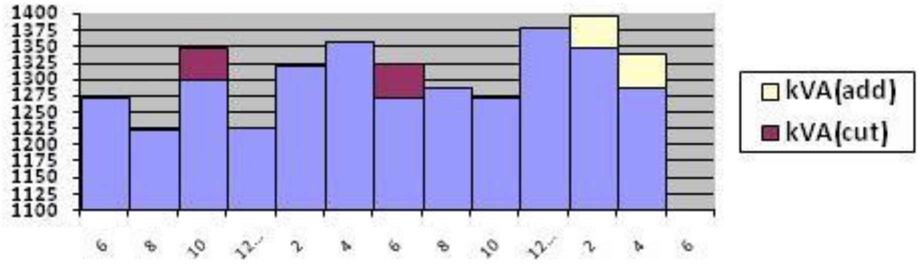

Fig.4 Modified load curve of the mill for TOD benefit.

The values of maximum demand & TOD energy consumption in this modified curve are as mentioned below

.M. D. – 1400 kVA, A zone - 10790 kWh, B zone - 11596 kWh, C zone - 3824 kWh, D zone - 5130 kWh

Table 3. Data of Optimum energy selection criteria of given example

Total Energy	M.D. kVA	A-zone kWh	B zone kWh	C zone kWh	D zone kWh
Case-I	1380	10590	11596	3924	5230
Case-II	1325	10480	11766	4014	5280
Case-III	1400	10790	11596	3824	5130

Step-I :The problem with the consideration of five criteria & three alternative cases of energy charges is as shown in Table. 3. The five criteria used to evaluate the three alternatives are M.D., A-zone kWh, B zone- kWh, C zone- kWh, D zone- kWh.

Step-II : A decision making table including the measures or values of all criteria for the short listed alternatives is prepared as shown in the Table.3. The weights of the criteria may be assigned using analytical Hierarchy Process (AHP) method as explained in step II.

- If demand is increased by 1 kVA, the M.D. charges get increased by 150 Rs/Month. If energy consumption is increased by 1 kWh in each zone for one month, TOD charges in A-zone, B-zone, C-zone & D-zone get increased by 103.5 Rs, 129 Rs, 153 Rs & 162 Rs. Respectively[3].
- The decision maker prepares the following matrix:

$$\begin{array}{c|ccccc} & \text{M. D.} & \text{A} & \text{B} & \text{C} & \text{D} \\ \hline \text{M. D.} & 1 & 150/103.5 & 150/129 & 150/153 & 150/162 \\ \text{A} & 103.5/150 & 1 & 103.5/129 & 103.5/153 & 103.5/162 \\ \text{B} & 129/150 & 129/103.5 & 1 & 129/153 & 129/162 \\ \text{C} & 153/150 & 153/103.5 & 153/129 & 1 & 153/162 \\ \text{D} & 162/150 & 162/103.5 & 162/129 & 162/153 & 1 \end{array}$$

The normalized weight of each criterion is calculated following the procedure in step II & values are as below.

M. D. - 0.2139 A zone - 0.1467 B zone - 0.1900 C zone - 0.2182 D zone - 0.2306

Step-III

After calculating the weights of the criteria using AHP method, the next step is to have the information on the decision maker preference.

Let the decision maker use the preference ‘usual function’ for all criteria. If two alternatives have a difference $d \neq 0$ in criterion c_i then a preference value ranging between 0 and 1 is assigned to the ‘better’ alternative total energy whereas the ‘worse’ alternative total energy receives a value 0. If $d = 0$, then they are indifferent which results in an assignment of 0 to both alternatives. The pair wise comparison of criterion M.D. gives the matrix as shown in the model. The total energy having a comparatively low value of M.D. is said to be 'better' than the other. Table.4 gives preference values of P resulting from the pair wise comparisons of the three alternative of total energy with respect to criterion M.D., A-zone, B-zone, C-zone, and D-zone respectively.

Mathematical Model of the given problem :

Table 4 Mathematical Model of the given problem

Π	Case-I	Case-II	Case-III	$\emptyset^+$	$\emptyset$	Ranks
Case-I	0	0.6388	0.3608	0.7296	- 0.08	2
Case-II	0.3608	0	0.3608	0.7216	- 0.556	3
Case-III	0.4488	0.6388	0	0.8176	0.096	1
$\emptyset^-$	0.8096	1.2776	0.7216	–	–	–

The leaving flow, entering flow & the net flow values for different alternatives are calculated using given equations from step III & the resulting preference indices are obtained as given in the Mathematical model shown in Table.4. The ranking of the three cases is as given in the Table .5

Table 5. Ranking of the objectives

Ranks	**Objectives**
1	case III
2	case I
3	case II

Based on the net flow values, it is clear that the total energy charges designated in case-III is the best choice among all the three cases for optimization of energy charges.

- Verification of the result[3]:-

Case - I: Total energy charges are as given below.
M.D. charges: – 150 x 1380 kVA = Rs.2, 07, 000
A zone TOD charges: – 102.9 x 10590 kWh = Rs.10, 89, 710
B zone TOD charges: – 129 x 11596 kWh = Rs.14, 95, 884
C zone TOD charges: – 153 x 3924 kWh = Rs.6, 00, 372
D zone TOD charges: – 162 x 5230 kWh = Rs.8, 47, 260
Total energy charges = Rs.42, 40, 226 ----------------------- (Rank-2)

Case - II: Total energy charges are as below.
M.D. charges: – 150 x 1325 kVA = Rs. 1, 98, 750
A zone TOD charges: – 102.9 x 10480 kWh = Rs.10, 78, 392
B zone TOD charges: – 129 x 11766 kWh = Rs.15, 17, 814
C zone TOD charges: – 153 x 4014 kWh = Rs. 6, 14,142
D zone TOD charges: – 162 x 5280 kWh = Rs. 8, 55, 360
Total energy charges = Rs.42, 64, 458 ------------------------ (Rank-3)

Case –III: - Total energy charges are as below.
M.D. charges: – 150 x 1400 kVA = Rs.2, 10, 000
A zone TOD charges: – 102.9 x 10790 kWh = Rs 11, 10, 291
B zone TOD charges: – 129 x 11596 kWh = Rs 14, 95, 884
C zone TOD charges: – 153 x 3824 kWh = Rs 5, 85, 072
D zone TOD charges: – 162 x 5130 kWh = Rs 8, 31, 060
Total energy charges = Rs 42, 32, 307 Rs------------------------ (Rank-1)

From the above calculations results obtained are as given below:
- The total energy cost saving in case III = Rs 7,919
- The total energy cost loss in case II = Rs 24,232
- Total energy cost saving in case III / annum = 7919 x 12 = Rs 95,028

When the three cases are compared from the calculations, it can be concluded that, the ranking of the three cases remains same as obtained by IMPROVED PROMETHEE method, i.e. total energy designated by case-III is the best choice among the all three cases considered for optimization of energy charges.

III. RESULT

Improved PROMETHEE method is applied on three cases of energy charges i.e. 1) Keeping load curve as it is 2) Modifying the load for M.D. benefit 3) Modifying load curve for TOD benefit.

Ranking of the alternatives from the best to the worst using the net flows remains same using both i.e. by actual calculations & by PROMETHEE method.

IV. CONCLUSIONS

1) PROMETHEE method is applicable for electrical energy intensive industries like Textile mills.
2) By using PROMETHEE method cost of the electrical energy can be saved up to 10%.
3)

V. ACKNOWLEDGEMENT

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