Optimization of Energy Consumption and Load Management In Industries

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Abstract: - Energy management embodies engineering, design, application, operation, and maintenance of electrical power systems to provide optimal use of electrical energy. This paper discusses common aspects of electrical energy management. The analyses are focused on the load management, transformer's losses, motor losses analyses and power factor management.

Key-Words:- Load Management, Tariff, Demand, Efficiency, Losses, Power Factor.

1 Introduction

Any process requires a certain minimum consumption of energy. Energy additions beyond this minimum require an evaluation of the incremental cost of more efficient equipment or techniques versus the resulting energy savings or costs. Some of the more intensive users of industrial energy, includi ng chemicals, paper, and petroleum refining, have long found it competitively advent-ageous to design for energy conservation. Two economic incentives exist for the development of an energy management program on a facility-by-facility basis: savings realized by reducing energy use, and preventing economic losses by minimizing the probability of fuel supply Curtailment. With increasing costs of energy, every facility can benefit by seeking to reduce energy consumption. [1], [2]

The aim of electrical energy management is to optimize the present operation, to promote the wise and efficient utilization of electrical energy and reduce the cost of electricity in industry.

Load management (LM) is the control of usage of electrical or other forms of energy by reducing or optimizing the amount of such usage and the rate of such usage (demand).

This method (LM) which changes the shape of the load curve so that generation by costly peaking units or capacity additions are avoided or deferred, is an effective solution to the cost problem in industries.

2 Electrical Tariffs

The electrical tariff to major industrial sector may consist of

- A charge for the total kWh consumed
- A power factor charge
- A KW maximum demand charge

There are some difference tariffs for industrial sector in countries, such low voltage, medium and high voltage tariffs.[2]

In these tariffs usually the peak period is the period between 18 hours and 22 hours while the off-peak period is between 22 hours and 06 hours. Also normal period is between 06 hours and 18 hours.

The demand charge is depended to contract demand.

Many utilities now include a power-factor adjustment clause (penalties) in their tariffs for improving the power. [1]

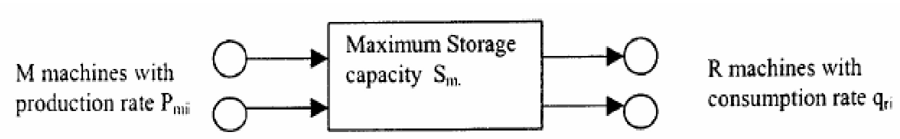

Fig. 1. Storage constraints

3 Load Management

Load management is a system's concept of modifying the pattern of electric energy use in order to improve the efficiency of the electrical energy system.

Three methods in load management to manage electrical energy use are peak clipping, valley filling and load shifting.

Most of Models used for system load forecasting are based on graphical, curve fitting and extrapolation techniques and are characterized by a high degree of aggregation limited time details and inability to consider radical changes in technology. They are not suitable for ILM applications [3].

The model proposed in this paper is based at the equipment level in continuation to the physical models proposed earlier. It includes the time dependent utilization and efficiency parameters of the machines or devices of the process and considers the storage, process, flow and production constraints. The model is coupled with an optimization framework to prescribe ILM strategies.[3]

Mathematical Formulation

Time Intervals*:* Here formulation is based on discrete time representation of the entire time horizon, of interest (e.g., one day). Events such as start or end of processes are only allowed at the interval boundaries.

Intervals are of duration t_i (e.g., 15 minutes or 1 hour) for the interval *i*.

$\sum_{i=1}^{N} t_i = H$ for the total intervals *N* in the time horizon. (1)

Decision Variable*:* The decision variable

$I_{mi} = 1 \Rightarrow$ the machine m is on in the interval *i*. (2)

$I_{mi} = 0 \Rightarrow$ the machine m is off in the interval *i* (3)

Production Constraint*:* It is required to have a specified minimum output (*Q*) of the final product in the time horizon. Then

$$\sum_{i=1}^{N}\sum_{m=1}^{M} P_{mi} * t_{mi} * I_{mi} \geq Q \qquad (4)$$

Where

M -total number of machines processing or producing the final output

P_{mi} -Production rate of machine in the interval i

Using the variable, it is possible to incorporate the changes in the production rate of machines at different intervals considering the variation of utilization and efficiency parameters.

Storage Constraint*:* Process loads with storage space with maximum capacity limitations as shown in Fig. 1 can be modeled as follows

$$\sum_{i=1}^{T}[\sum_{m=1}^{M} P_{mi} * t_{mi} * I_{mi} - \sum_{r=1}^{R} q_{ri} * t_{ri} * I_{ri}] \leq S_m$$

for T =1 to *N*. (5)

Sequential Constraint*:* It becomes necessary to keep certain operational sequence for the machines without other operating constraints The condition for the start of *m*th machine at an interval *i* after *t* intervals from the start of *(m-1)* th machine can be modeled as

$$t * I_{mi} \leq \sum_{j=i-t}^{i} I_{(m-1)j} \qquad (6)$$

Maximum Demand Constraint:Peak demand limit is an important factor to be considered in load scheduling since many industries are subjected to maximum demand restrictions. For interval i

$$\sum_{m=1}^{M}(k_{mi} / pf_{mi}) * I_{mi} \le kVA_i \qquad (7)$$

Where

kVA_i maximum demand limit;

k_{mi} electrical power input in kW;

pf_{mi} power factor of the machine for the interval.

Electrical Load Estimation*:* The electrical power input in kW to any machine *m* at any interval *i*

$$k_{mi} = \{(R_m * U_{mi}) / E_{mi}\} * I_{mi} \qquad (8)$$

Where

R_m — rated capacity of the machine/device m in kW,

U_{mi} — utilization factor of the device *m* at the interval *i*.

E_{mi} —efficiency of the machine or device at the interval *i*.

Objective Function*:* The objective function is the minimization of the electricity cost. Most industries have a two-part tariff, which consists of charges for energy consumed and charges for the registered maximum demand (MD).In the objective function used, energy cost is only considered. After obtaining the optimal schedule the MD charges is added to the energy cost. When C_i is the cost of energy for the interval, the objective function is

$$Min. \sum_{i=1}^{N} \sum_{m=1}^{M}(k_{mi} * I_{mi} * t_{mi}) * C_i \qquad (9)$$

3.1 Case Study

To illustrate the model, a case study has been used for a tire factory in Iran. The connected load of the plant is 12 MW and Contract demand 10 MVA. The plant works in 3 shifts per day. The daily maximum demand for phase 1 is 3700 kW with a total energy Consumption of 70 MWh.

While the base energy charge is 0.16$/kWh the energy charges for tariff (A) followed by Iran grid are in the ratio 1: 3.29: 0.25 for normal, peak and off peak periods and for tariff (B) are in the ratio 1: 0.7 for normal, peak periods.

3.2 Results

Table 1 shows a comparison of the existing operation with after LM.

The average power during the system peak reduces from 2850 kW to 2000 kW. If the industry use tariff (B) the electricity charges increase about 3-7%. Comparison of load curves under LM action is shown in Fig. 2.

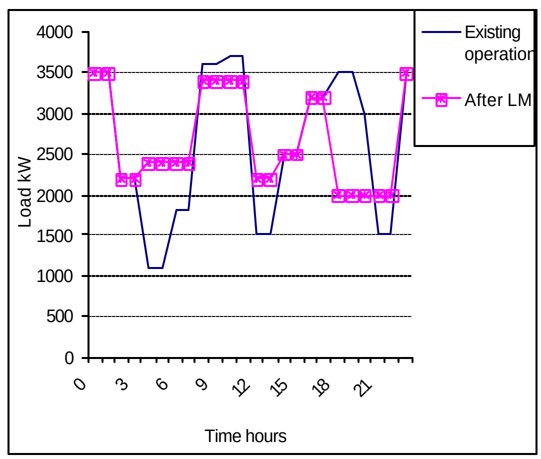

Fig. 2.Comparison of load curves under LM action

Table 1. Result of Case Study

	Average power kW				Electricity charges as % of base cost	
	Off peak 22-6	Peak 18-22	Normal 6-18	MD	With Tariff(A)	With Tariff(B)
Existing operation	2325	2850	2715	3700	100	103
After LM	2712	2000	2860	3400	89	96

Table 1 Typical Range of Efficiencies for Dry-Type Transformers: 25-100% Loading (Informative)

Rating (kVA)	100% Load		75% Load		50% Load		25% Load	
	Copper windings, 80°C rise	Aluminum windings, 150°C rise	Copper windings, 80°C rise	Aluminum windings, 150°C rise	Copper windings, 80°C rise	Aluminum windings, 150°C rise	Copper windings, 80°C rise	Aluminum windings, 150°C rise
500	98.65	97.67	98.72	98.01	98.63	98.20	97.91	97.84
100	98.86	98.01	98.92	98.29	98.85	98.43	98.27	98.05
1500	99.07	98.28	99.11	98.50	99.03	98.62	98.50	98.26
2000	99.21	98.55	99.26	98.73	99.22	98.81	98.83	98.46
2500	99.22	98.63	99.25	98.79	99.19	98.84	98.75	98.48
3000	99.20	98.72	99.24	98.86	99.18	98.94	98.75	98.64

Source: ABB Power T&D Company, Inc. Bland, VA
Note: This table considered only 60 Hz units with a high voltage Basic Insulation Level (BIL) no less than 95 kV

4 Transformer's Losses Analyses

The transformer standards do not require efficiency targets in the transformer design. The goal of the standards is safety, convenience, compatibility, security, reliability, noise control, and other engineering and environmental parameters.

Energy savings are achievable by

— Specifying and purchasing efficient transformers

— Operating the transformers efficiently

The relationship between the transformer materials and efficiently at various load is shown in Table 1.[1]

Losses in transformers occur within three distinct circuits, as follows:

a) Electric circuit losses:

1) I^2R loss due to load currents
2) I^2R loss due to no-load currents
3) Eddy current loss in conductors
4) I^2R loss due to the loss currents

b) Magnetic circuit losses:

1) Hysteresis loss in core laminations
2) Eddy current loss in core laminations
3) Stray eddy current loss in core clamps, bolts, etc.

It is a good practice to consider the load factor of the transformer before deciding to install it. The load factor must be greater than 50% to increase the efficiency of the transformer and thus to reduce the losses.

5 Motor's Losses Analyses

Most industries require industrial motors for general uses such as pumps, compressors, blowers, etc. in most industrial plant the kilowatt losses vary from 2.5% to 7.5% of the load depending upon hours of full-load and no-load plant operation. [1]

Electric motors in the U.S. are manufactured to NEMA MG 1-1993 specifications and are listed for safety by UL 1004-1994 or the UL standard for electric motors by application. Efficiency of electric motors is determined by testing in accordance with IEEE Std 112-1991, IEEE Std 113-1985, IEEE Std 114-1982, IEEE Std 115-1995,

DC motors are used in some industrial applications when adjustable speed operation is required.

The five dc motor types are as shunt-wound Compound-wound, series-wound,permanent -magnet (available to 5 hp) and brushless dc motors (0.5–10 hp)

AC motors are manufactured as single-phase and poly phase.

To properly select and apply ac motors an understanding of the efficiency definitions is essential:

$$Efficiency = \frac{\text{output}}{\text{input}} = \frac{\text{output}}{\text{output} + \text{losses}}$$

Losses in AC motors are included:

1) I^2R (Cu) losses in conductors
2) Magnetic losses in cores
3) Mechanical, eddy current, etc losses

Fig .2 shows that both the power factor and efficiency decrease as the motor becomes unloaded. The maximum of power factor and efficiency is happened in about of full load.

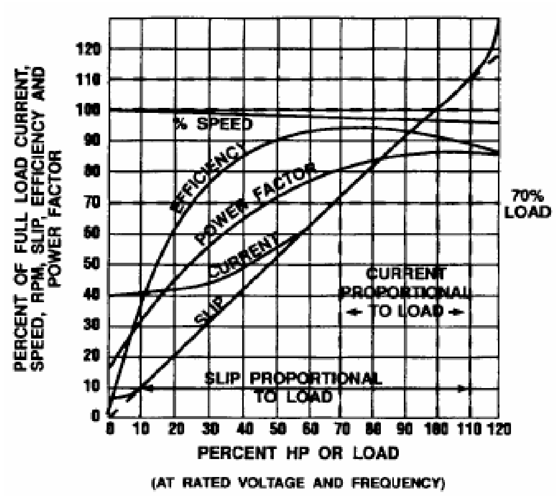

Fig2 -Typical NEMA Design B induction motor curve

6 Power Factor Management

The power factor in an industrial is normally lower than what accepted by the power supplier. When power factor is below designated level, utility often has a provision for a separate additional penalty charge. [1]
An improvement power factor can provide both economic and system advantages. Direct economic advantages are attained when monetary incentives, such as a power-factor penalty, are enforced. Operational benefits, such as improved system efficiency release of system capacity, reduction of power losses, and voltage improvement, may also be obtained.[1], [7]

6.1 Reduced power cost

Many utilities now include a power-factor adjustment clause in their rate structures to compensate for providing this component. These clauses, or penalties, provide a strong economic incentive for improving the power factor and often account for a significant portion of the total power bill.[1]
By locally furnishing reactive kVar, the consumer can often enjoy substantial savings by avoiding these penalties.

6.2 Release of system capacity

When power-factor capacitors are located at the terminals of an inductive load, they will deliver all or most of the reactive power required by the load. This means a reduction in system current will occur, permitting additional load to be connected to the system without increasing the size of transformers, and other distribution Equip ment.The percent released capacity resulting from an improvement in power factor is as follows:

$$\%\ \text{released system capacity} = 100\left(1 - \frac{pf_0}{pf}\right)$$

pfo is the original power factor
pf is the final power factor after correction

6.3 Reduced power losses

Another benefit resulting from a power-factor improvement project is the reduction of power system losses. This is especially true for older power systems where the kilowatt (I^2R) losses can account for as much as 2–5% of the total load.[1]

6.4 Voltage improvement

When capacitors are added to the power system, the voltage level will increase.[7]
The percent voltage rise associated with an improvement in power factor can be approximated as follows:

$$\%\ \text{voltage rise} \approx \frac{\text{capacitor kvar} \cdot \text{transformer \% IZ}}{\text{transformer kVA}}$$

7 Conclusions

Because of increasing in cost of burning fuels and capital costs for building new generation capacity, most factories face the problem of higher cost of production. Thay cannot reduce the cost of raw material and labor but they can reduce the cost of energy consumption by implementing energy management.
An optimization method for ILM based on physical load model has been used. This model is capable of analyzing the industry response to different tariffs, operational strategies like two or three shift operation, variation of equipment size or storage capacity and adoption of new technologies.
Energy savings can be achieved by reducing the losses in transformers and motors
By improving the power factor can provide many advantages as reduced power cost**,** release of system capacity and voltage improvement**.**

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