Mathematical modelling and ANN applied to a Milk Industry through DSM

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Abstract - **The paper presents a generalized mathematical model for minimizing the total operating cost of the industry subject to the constraints. The work presented in this paper also deals with the results of application of neural network and Demand Side Management (DSM) techniques applied to a medium scale milk industrial consumer in India to achieve the improvement in load factor, reduction in Maximum Demand (MD) and also the consumer gets saving in the energy bill.**

Key words - **Demand Side Management (DSM), End Use Equipment Control (EUEC), Load Priority Technique (LPT), Maximum Demand (MD).**

I. INTRODUCTION

Among the various advancements in the power sector, Demand Side Management in power systems is the latest technology. The concept of DSM was developed in 1980s to meet the problems faced by both suppliers as well as consumer(s). DSM is broader in scope than either load management or Energy Conservation by including the alternative programs designed to build load as well as to reduce it. The main objective of the present work is to introduce the concept of DSM in an industry [1].

DSM in Power Systems involves a mutual understanding between consumer and supplier and it also announces few benefits [2]. The DSM benefits are as follows

1. Minimizing number of load shedding.
2. Reduction in energy bills
3. Smooth load shape
4. Reduces production cost
5. Reduces capital investment due to usage of more critical fuels

Daniel S. Kirschen discussed some aspects of electricity markets from the perspective of the demand-side. It argues that increasing the short-run price elasticity of the demand for electrical energy would improve the operation of these markets. It shows, however, that enhancing this elasticity is not an easy task. The DSM tools that consumers and retailers of electrical energy need to participate more actively and effectively in electricity markets are discussed. The paper also describes how consumers of electricity can take part in the provision of power system security [3].

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Mrs. Anjali Dharme, Dr. Ashok Ghatol proposed that the DSM look at side LPT is considered a new facet in Indian Power industry to solve the problems of Power shortage and Energy shortage. Load management or rather Peak power management is the only focus of DSM programs in Indian utilities. "Load shedding" is the main tool for Load management with the utility in Maharashtra state. DSM in its true sense is yet to be implemented in Indian power market. This paper defines and describes two new indices which quantify the technical and economic benefits of DSM programs. These indices would help understand the rationale for a particular DSM program for engineers, for economists and for management personnel [4].

S. Rahman and Rinaldy discussed the implementation of Demand Side Management (DSM) program in power systems is to change the Consumer and Utility's load shape that changes in the time pattern and magnitude of consumers and utility's load. Changing the load shape as a result of demand side activities could change the peak load, base load and or energy demand. Those three variables have to be explicitly modelled into the load curve for properly representing the effects of demand side management. The impact of DSM will be manifested as higher or lower reliability levels. The work presents an efficient technique to model the system load such that the impact of demand side management on the power system can be easily and accurately evaluated. The proposed technique to model the load duration curve will facilitate the representation of DSM impacts on loss-offload probability, energy not served and energy consumption. [5].

Robert Roman and Robert Wilson discussed on many methods of shedding loads during peak hours of operation have been utilized for efficient use of generation during peak periods. These methods, however, are usually non-dynamic, meaning that power for commercial, industrial, or residential appliances are simply turned on or off as needed. As load management customers increase, a variety of load shedding criteria emerges. Some commercial customers in the load management program demand dynamic or routine based power control to ensure the safety of their large equipment such as refrigeration units [6].

II. ARTIFICIAL NEURAL NETWORK

An artificial neural network (ANN) or neural network (NN) is an interconnected group of artificial neurons that uses a mathematical model or computational model for information processing based on a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network as in [1].

In a neural network model, simple nodes (called variously "neurons", "neurodes", "PEs" ("processing elements") or "units")

are connected together to form a network of nodes hence the term "neural network."
Artificial neural networks (ANNs) are essentially simple mathematical models defining a function. Each type of ANN model corresponds to a *class* of such functions.

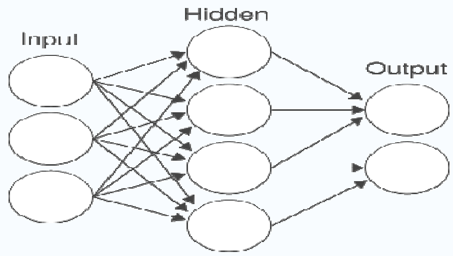

Fig -1 Neural Network

The earliest kind of neural network is a *single-layer perceptron* network, which consists of a single layer of output nodes; the inputs are fed directly to the outputs via a series of weights.
The class of networks called Multi-layer perceptrons consists of multiple layers of computational units, usually interconnected in a feed-forward way.

III. DSM TECHNIQUES ADOPTED

Selection of the most appropriate DSM technique is perhaps a crucial question for both the supplier and the consumer. The following are the DSM techniques applied to the industrial consumer as in [7]:

A) End Use Equipment Control.
B) Load Priority Technique.
C) Peak Clipping & Valley Filling.
D) Differential Tariff.

A. End Use Equipment Control

EUEC deals with the control operation of the various end use appliances for better utilization of available resources with out affecting the production schedule. This is one of the most active areas of DSM technology development. This is because some of the bulk industrial loads exhibit maximum peaks and valleys in their load curves. Due to the increased industrial activities, from most of the industrial consumption patterns it is found that the use of electrical power is exceeding beyond the permitted limits for some hours and very low for other hours of the day. So for these bulk industrial consumers here is more room for flattening these curves.

B. Load Priority Technique

In developing LPT, the loads are classified into Non-interruptible and Interruptible loads. Non-interruptible loads are the high priority loads while the interruptible loads are low priority loads. The priorities are assigned to the loads in discussion with the respective section supervisors giving immense importance to the production schedule.

The success of LPT is totally dependent upon the development of various load priorities for operation, which will not disturb the production schedule, and gives enough scope of reduction of load demand. In order to achieve this, a close interaction between the various sections of the industry is required.

C. Peak Clipping & Valley Filling

Reduction of peak demands reduces the demand charges of the consumer. Peak Clipping is achieved by direct control of equipment which are responsible for the peaks. Peak clipping is used to reduce capital investment charges, operation charges and dependence on high cost critical fuels. The main objective of Peak Clipping is to match the available generating capacity with the demand without going in for additional generation, which means cost. The principle involved in valley filling is to build up load or consume power during light load periods of the supply system. This results in a more flat load curve as seen from the supply system. Hence the supplier's equipment like generators, transformers, transmission lines, etc., are loaded to 80 to 90% of their rating instead of 15 to 20% during light loads, thus resulting in high efficiency and lower cost of operation because of improved load factor or energy efficiency of the system.

D. Differential Tariff

This technique has been introduced because of variable load on the supplier's equipment. Usually the load curve of an industrial consumer will have some peaks and valleys. Hence the supplier must install his equipment which will be capable of supplying the peak load of the consumer. With this high capacity equipment, no doubt he will be able to supply the consumer's peak but during the valley period, the equipment will be very much underutilized, thereby reducing the energy efficiency of the equipment. Hence the supplier will insist or will try by all possible means that his equipment is utilized to its rated capacity for the entire duration whenever it is in the commissioned state. He will announce incentives (say, one third of the normal load period tariff) for the consumer to consume more during his valley period. And he will announce punishment (Maybe three times the normal tariff) if the consumer utilizes energy during the peak hours. With this type of tariff, the consumer will try to avoid energy consumption during supplier's peak hours and try to consume more energy during supplier's valley periods. To achieve this, he may have to reschedule his operation schedule. This is the basic principle of differential tariff.

IV. MATHEMATICAL MODEL

A generalized mathematical Model is designed for the processing industry like, milk industry, cement industry etc. , It gives solution for minimizing the total operating cost of the industry subject to the constraints and gives the optimal response for a given production capacity under specified electricity tariff rates. The mathematical model is entirely based on discrete time representation as a representation of the continuous loads under some sufficient conditions. The

ISBN:978-988-17012-6-8

feature of this model is that it takes into account, the key characteristics of group process loads which include:

1. The group time and group capacity
2. Material input (inflow) – time periods and quantity.
3. Material Output (outflow) – Time periods and quantity.
4. Power demand and its variations with time and quantity also type/quality of material for the group.

Initially, a day is divided into 'M' intervals with equal 't' hours of time span.

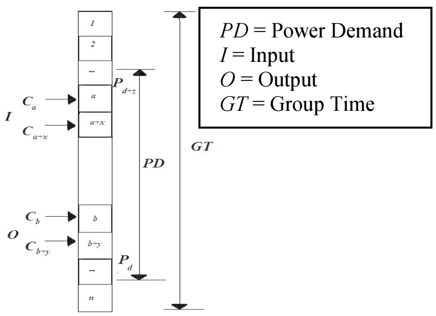

Fig-2 represents the group-time sequence.

The operating parameters and the sequences of the group-process are considered with respect to group-time sequence.

Material inflow with quantity C_a to $C_{(a+x)}$ in litres from a^{th} time to $(a+x)^{th}$ time and the outflow from b^{th} time to $(b+y)^{th}$ time with quantity C_b to $C_{(b+y)}$ respectively.

Power demand (in kW) from time'd' to (d+z) is P_d to $P_{(d+z)}$

A decision variable 'J' is taken into consideration to indicate whether the equipment has started to process a new group in the particular interval or not, in order to produce a specific product.

The conditions for the decision variable are:
$J_{nil} = 1$; the n^{th} equipment starts a group for processing the i^{th} product.
= 0; if the above condition is not satisfied.

The electrical power input (in kW) to the equipment 'n' at any interval 'l' when it is processing i^{th} product is given as follows:

$$P_{nil} = \{(X_n \times Y_{nil}) \div \eta_{nil}\} \qquad (1)$$

Where η_{nil} - Efficiency obtained from efficiency characteristics corresponding to the percentage loading

X_n - The rated capacity of the equipment (in k W)

Y_{nil} – Utilization of the n^{th} equipment at the interval 'l' when it is processing the 'i^{th} product.

Y – De-rating factor of the equipment based on 1. Loading conditions 2. Site conditions. 3. Constraints

$^{n}{}_{nil}$ - Efficiency of the equipment 'n' at the interval 'l'

The energy consumed (kWh) by the equipment 'n' in the l^{th} interval, when processing the product 'i' for the group started in the e^{th} interval is

$$E_{nil} = \sum_{e=l-(d+z)+1}^{l-d+1} P_{nil} \times J_{nie} \times t \qquad (2)$$

The industry is subjected to several constraints that are as follows:

1. Production Constraint :

Initially, a constraint called 'production constraint' is considered to keep the total production U ¡ of a product ' i'

$$\sum_{l=1}^{M} \sum_{n=1}^{N} C_{nil} \times J_{nil} \geq U_i \qquad (3)$$

Where,

N – The particular item of equipment

C_{nil} -- It is the production (outflow) in a group quantity for the machine 'n' for the product 'i'for the group started in 'l th interval.

2. The condition for the total production of the plant 'U_T 'is given by

$$\sum_{i=1}^{I} U_i \geq U_T \qquad (4)$$

Where, 'I' – total number of products

3. The condition for the availability of raw material for production is :

$$\sum_{n=1}^{N} \sum_{l=1}^{M} G_{nil} \times J_{nil} \leq G_T \qquad (5)$$

Where, 'N' – The particular item of equipment

G_{nil} - The quantity of raw material required for the 'n' th equipment for the product 'i 'and for the group started in 'l' th interval

G_T - Total raw material available

4. When a group process is going on in one equipment, the same equipment should not be allocated to any other group or product.

The condition incorporated to prevent the allocation problems is

$$\sum_{e=l}^{l+m+1} J_{nie} \leq 1 \qquad (6)$$

5. Storage condition :

Process loads with storage space are modelled with maximum capacity limitations.

Net inflow into the storage for the interval 'l' is as follows

$$S_l = [\sum_{n=1}^{N}\sum_{l=1}^{M}\sum_{e=l-(b+y)+1}^{l-b+1} C_{nil} \times J_{nie} - \sum_{g=1}^{G}\sum_{j=l}^{M}\sum_{e=l-(a+x)+1}^{l-a+1} C_{gij} \times J_{gie}] \qquad (7)$$

In the above equation,

(a) Material inflow for the entire equipment 'N' giving outflow to the storage
(b) Material outflow for the entire equipment 'G' from the storage

For both, when processing the product 'i ' for the group started at the interval 'e' is considered .

Now, Storage constraint is given by

$$S_0 + \sum_{j}^{M} S_{l-(j-1)} \leq S_n \qquad (8)$$

Where,
S_o – Initial storage level
S_m – Maximum / final storage level (maximum capacity)

6. Operating Sequence:
This is the condition for the start of the n^{th} unit at an interval 'l' after't' intervals right from the start of (n-1) th unit is as follows :

$$t \times J_{nie} \leq \sum_{e=l-t}^{l} J_{(n-1)ie} \qquad (9)$$

7. Availability of the equipment :

The unavailability of the equipment 'n' during intervals from 'e' to 'f' is as follows:

'l'= 'e' to 'f' for all products 'I'
$J_{nil} =$ 0 for all intervals

Objective function to minimize the monthly operating cost:

$$(Min\sum_{l=1}^{M}\sum_{n=1}^{N}\sum_{i=1}^{I}[(E_{nil}\times R_l)+\{R_{xl}\times J_x\}\times t])\times W+\{(R_{NT}\times MD_{CMD})+(R_{TOUT}\times MD_{ACMD})] \qquad (10)$$

The above function is subjected to production, storage and equipment constraints.

Here,
R_l – Cost of energy (charge per kWh) for the interval 'l'
W- The number of working days in a month

R_{NT} – The MD charges per kVA
N – The particular item of equipment
I- Total number of products
R_{xl} – cost of load management equipment
J_x- selection variable
J_x = 1 if additional cost occurs due to load management actions
= 0 if the above condition fails.
MD_{CMD} = Maximum demand at normal tariff
R_{TOUT} = Rate for Time Of Use Tariff
MD_{ACMD} = load above maximum demand

The main objective of Peak load management is the minimization of the total operating cost, which consists of charges for energy consumed (either a flat or TOU tariff), charges for the maximum demand (either normal M.D or TOU tariff charges) and additional operating costs due to shifting of loads .

V. CASE STUDY

The industry selected for investigation is the Kurnool District Milk Producers Cooperative Union Limited, Vijaya Milk & Milk Products, Nandyal as in [2]. Load data for a period of one month were collected from the industry. Typical load curve which recorded the maximum demand for that particular month is focused in this paper. The load curves before and after the application of DSM techniques is as shown in fig-5. The details of the tariff structure and energy billing of that particular day before and after DSM application are shown in section VI.

The energy efficiency of the system and supplier equipment has been quantified in terms of Load Factor which is defined as Average Load divided by Maximum Load in a given period.

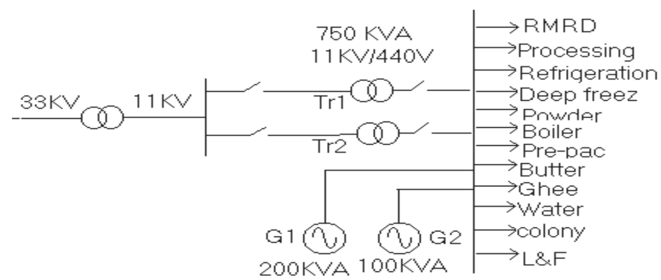

Fig-3 Electrical Layout of the industry.

The industry considered for case study exhibits poorest shapes that is peaks during the operation of powder plant and valleys when it is not in operation on seasonal days. The industry has contracted 450 kVA. During seasons, when the powder plant operates, the load exceeds nearly 550 kVA with simultaneous operation of Refrigeration Unit. The industry has to pay twice the normal MD tariff for the load demand exceeding the contracted kVA. The contracted kVA cannot be increased as during the off seasons the powder plant will not be in operation. Sometimes it will be closed for a few months. During the off season days, the load doesn't even exceed 300 kVA so it is uneconomical for the industry to increase the contracted kVA.

$$Load\ Factor = \frac{Average\ Load}{Maximum\ Load\ in\ a\ given\ period} \qquad (11)$$

The DSM technique that has been considered for study is LPT. In consultation with the section superintendents and section supervisors, 12 sections of the industry were classified into Interruptible and Non-interruptible sections. Among them RMRD, Processing, Deep Freeze, Refrigeration, Powder, Boiling, Lighting & fans, and Colony, were classified as Non-interruptible sections while the remaining Butter, Ghee, Pre-Pac, and Water sections were classified as Interruptible sections.

The working hours of the Butter, Ghee and Pre-Pac are shifted as given below:

Butter : 6AM to 9 AM and 2PM to 5PM
Ghee : 7AM to 10 AM and 3PM to 6PM
Pre-Pac: 4AM to 8 AM and 2PM to 5PM

Coming to the case of Water pumping Section, large HP motors are switched off during the peak hours and are turned on during the off-peak hours. However, this shifting of working hours is not necessary when industry is not producing Milk powder.

TABLE I
Hourly Load data before DSM application

Time (Hours)	Load in kW	Time (Hours)	Load in kW
1	341.1	13	322.8
2	322.6	14	286.7
3	327.0	15	273.3
4	371.4	16	311.4
5	363.9	17	337.0
6	319.7	18	363.4
7	411.2	19	461.2
8	381.5	20	424.3
9	431.9	21	431.9
10	410.9	22	410.9
11	398.8	23	398.8
12	410.0	24	410.0

VI. TARIFF STRUCTURE FOR ENERGY BILLING

A. MD charges

As per the rules of the Central Power Distribution Company of AP Limited (CPDCAPL), the existing Block Rate Tariff for MD charges is Rs. 195/- per KVA for the contracted 450 kVA and Rs. 525/- per kVA for the subsequent kVA consumed.

B. Differential Tariff

The DT for the load between the normal lead limits is between Rs.3.80 per kWh. For the load exceeding the normal load it is three times the normal load tariff i.e. Rs.11.40 per kWh and for the load consumed to fill the peaks, it is one third of the normal tariff, i.e. Rs.1.266 per kWh.

VII. ANN LOAD CONTROLLER

Fig-4: shows the proposed neural network structure to control the loads of an industrial consumer. Conjugate gradient back propagation algorithm is used for training the network. The network consists of one input layer, one hidden layer and ten output layers. Log sigmoid transfer function is used for hidden and output layers which trains the network by minimizing the mean square error between the desired output and the actual output as in [5].

VIII. TRAINING PATTERN CONSTRUCTION

This table II shows training data used for the ANN model, the inputs of ANN model being load in kW and output switching conditions of the interruptible loads which can be operated to increase or decrease the loads during valley or peak times respectively. From the fig-5 and numerical results shown below it is evident that the ANN model can be used as an effective tool for online controlling of loads [3], [6].
Switch 1(sw1) is indicated in table II, is controlling Ghee section, switch 2 (sw2), switch 3 (sw3), switch 4 (sw4) are controlling Butter section, switch 5 (sw5), switch 6 (sw6), switch 7 (sw7) are controlling Pre-Pac section. Switch 8 (sw8), switch 9 (sw9), switch 10 (sw10) are controlling Water section.

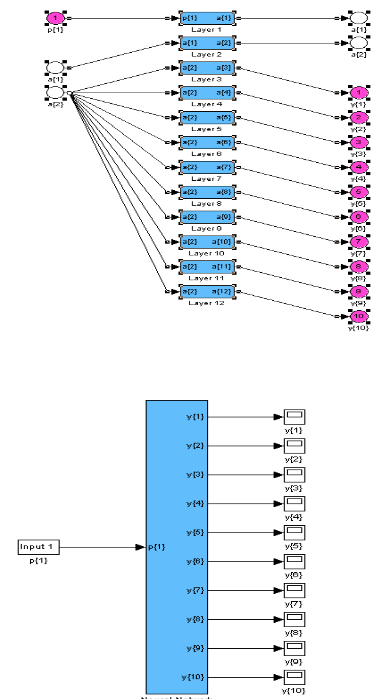

Fig-4 Neural Network for adopted case study

IX. Results and Discussion

The results of the Vijaya Milk industry before and after DSM techniques are discussed below.

The numerical calculations of case study are shown in below.

<u>Before application of DSM</u>
Maximum Demand = 518.0 kVA
MD charges = 450×195+ (518-450) ×195×3
= Rs.1, 27, 530 /-
Load Factor = 316.2/ 466.2
= 0.67824

<u>After application of DSM</u>
Maximum Demand = 470.55556 kVA
MD charges = 450×195+ (470.55556-450) ×195×3

ISBN:978-988-17012-6-8

= Rs.99, 775 /-

Load Factor = 316.2/ 423.5

= 0.75663

Net Savings for the industrial consumer for a particular month due to the lowering of MD = Rs. (1, 27, 530 – 99, 775)

= Rs.27, 755 / 578.22$

Table II
TRAINING DATA OF ANN MODEL

Load in kW	SW 1	SW 2	SW 3	SW 4	SW 5	SW 6	SW 7	SW 8	SW 9	SW 10
410	0	0	0	0	0	0	0	0	0	0
375	0	1	1	1	0	0	0	0	0	0
410	0	0	0	0	0	0	0	0	0	0
374	0	0	0	0	1	1	1	0	0	0
410	0	0	0	0	0	0	0	0	0	0
380	0	0	0	0	1	0	1	0	0	0
378	0	0	0	0	1	1	0	0	0	0
325	0	1	0	1	1	0	1	0	0	1
275	1	0	0	0	1	1	1	1	0	0
327	1	1	0	1	1	1	1	0	0	0
329	1	1	1	0	1	1	1	0	0	0
320	1	1	1	1	1	1	0	0	0	0
322	0	1	1	1	0	0	0	0	1	0
260	0	1	1	1	1	0	1	0	1	1
265	1	1	1	1	1	0	1	0	1	0
335	0	1	1	1	0	0	0	1	0	1
330	0	0	0	0	0	0	0	1	0	0
332	1	0	0	0	0	0	0	0	0	1
400	0	0	0	0	0	0	0	0	0	0
385	0	1	0	1	0	0	0	0	0	0
407	0	0	0	0	0	0	0	0	0	0
408	0	0	0	0	0	0	0	0	0	0
390	0	1	1	0	0	0	0	0	0	0
390	0	1	1	0	0	0	0	0	0	0

TABLE III
Hourly Load data after DSM application

Time (Hours)	Load in kW	Time (Hours)	Load in kW
1	412.6	13	341.1
2	410.4	14	322.6
3	422.0	15	327.0
4	382.7	16	371.4
5	421.7	17	363.9
6	383.3	18	319.7
7	382.3	19	411.2
8	359.8	20	381.5
9	332.6	21	431.9
10	382.7	22	410.9
11	386.4	23	398.8
12	360.7	24	410.0

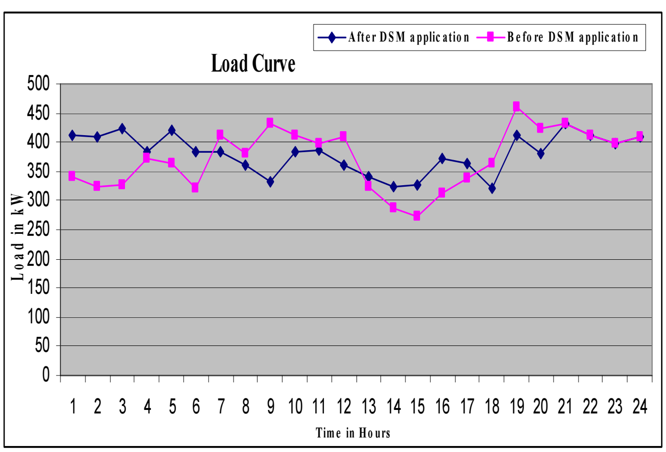

Fig-5 Average industrial load before and after DSM for a particular day

X. CONCLUSIONS

This paper has presented a mathematical model for processing industries like, milk industry to minimize the total operating cost of the industry, subjected to some constraints. The paper also presents the results of the application of neural network and a few DSM techniques applied to an industrial consumer in Nandyal town. Calculations have established that the energy efficiency of the consumer has increased by the increase in the Load Factor and the consumer also gets saving in the energy bill that is Rs. 27, 755 / 578.22$ per month.

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to the authorities of Vijaya Milk and Milk Products Industry, Nandyal, ACE College of Engineering and Sreenidhi Institute of Science and Technology, Hyderabad for their encouragement.

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