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COMPARATIVE STUDY OF OPTIMIZATION TECHNIQUES FOR HOUSEHOLD BASED DSM MODEL

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ABSTRACT

The energy crisis is being a serious matter of concern that the world demands on the limited natural resources that are used by power industrial society. These natural resources are in limited supply and due to the increased demand their availability is depleting day by day. While they do occur naturally, it can take hundreds of thousands of years to replenish the stores. Governments and environmental activists are working to prior-itize renewable resources usage, and to lessen the irresponsible use of natural supplies by implementing the modern conservation techniques.

One of such modern conservation techniques is Demand Side Management which is introduced at the consumer end . The aim of Demand Side Management (DSM) in power industry is to reduce energy consumption and improve overall electricity usage efficiency through the implementation of few simple policies and methodologies that will control consumption pattern at household levels.

In this paper, a comparative study of two optimization techniques namely, quadratic programming and steepest ascent method is presented. These mathematical models are developed to evaluate the impact of DSM on power consumption by a residential building in terms of its peak demand and cost of electricity consumed. DSM technique is modelled more accurately in steepest ascent method and in both the models the peak clipping is observed, with a noticeable reduction in both power consumed and its cost.

Keywords—Demand Side Management (DSM), Optimization, Quadratic Programming, Steepest Ascent Method.

I. INTRODUCTION

All over the world, the dynamic demand in electricity markets has increased the number of real time challenges such as the declining fuel sources, uncertainties in load growth, higher investments required for capacity addition or grid reinforcement and the cost of offsetting greenhouse gases (GHGs) emissions [1]. The large difference between peak demand and average demand results in high generation cost per unit. In developing countries like, India it is highly unimaginable to meet the targeted capacity just by installing new power plants [2].

The effective solution to the challenges mentioned above is DSM strategies that lower the peak demand and bring benefit to utilities and consumers. Greater energy efficiency helps in overcoming the challenges being faced in the energy sector and considerably improving recent trends (IEA, 2008). Here, energy efficiency improvement is defined as a reduction in the energy used for a given service (heating, lighting, etc.) or level of activity (WEC, 2008), basically without affecting the level of usage or demand [3]. Various studies in countries like China have found that cost effective DSM programs reduces the electricity usage and peak demand by approximately 20-40%. India has great opportunities for reducing energy demand using DSM in all the sectors, many are low cost that even an individual can adopt them to reduce the electricity demand and per unit generation cost, improving reliability and thus conserving environment [2].

The Indian energy sector is facing energy shortages. The planning efforts for the energy sector have been supply focused. Though the potential and cost effectiveness of energy efficiency has been recognized by planners for more than a decade, the present status is subcritical [4].

A study for the Asian Development Bank (ADB, 2003) estimated market potential of energy saving to be 54,500 Million units and peak saving of 9240 MW. This has an investment potential of 14,000 crores. Though there is some uncertainty in any aggregate estimates, it is clear that the cost-effective saving potential is at least 10% of the total generation through Demand Side Management. Presently, an estimate of the total volume of the energy efficiency consulting business (Audit, performance contract, engineering and technical assistance consultancy) is less than 1% of this potential [5].

II. DEMAND SIDE MANAGEMENT (DSM)

Demand Side Management involves co-operative action by the utility and consumer to modify the consumer load curve resulting in savings. This helps to attain the desired load shape curves of the utility along with energy efficiency and load shifting [4]. Demand Side Management (DSM) adopted to describe the planning and implementation activities of utilities, with the objective: to influence the load shape, so as to achieve peak load within proper margin, load factor as close as 1.0 and better overall system utilization [1].

A well designed DSM program has low transaction costs, should not affect the utility revenues, should have significant potential for savings and should have high consumer participation / interest. The transaction cost depends on the consumption per consumer [4]. If a DSM program has to deal with a large number of residential consumers, consuming less electricity when compared to industrial or commercial consumers, it is likely that their transaction costs will be high. DSM programs in the residential and agricultural sector would have a positive effect on the utility revenues and have significant saving potential. However it’s clear that the challenge is to generate consumer participation, since they often pay subsidized tariffs. The high transaction costs of DSM programs for these sectors could be a barrier [4].

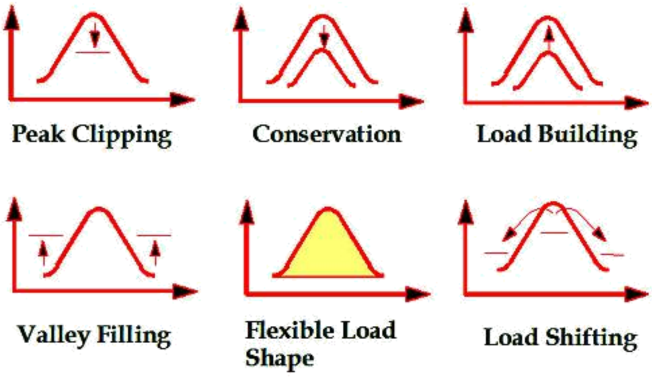

Fig. 1. Desired DSM load curves

III. METHODOLOGY

A generalized mathematical model is designed for a residential building. This model shows how the peak power demand and its cost are effectively clipped after DSM application.

3.1. PROBLEM FORMULATION

Power demand is a function of demand factor, δ and to maximize this power demand for a day, the problem can be formulated as:

$$\text{Maximize } P = f(\delta)$$
subject to:
$$0<\delta<1$$
$$P_g = f(C_x) \tag{1}$$
$$P_{\min} < P < P_{\max}$$
$$\xi_{\min} < \xi < \xi_{\max}$$

Where P_{min} and P_{max} are the power output of the minimum and maximum operation of the generating unit, is the P_g power generated and C_x is the cost of fuel, $\xi_{\min}$ and $\xi_{\max}$ are the minimum and maximum operating efficiencies of the generating unit. The cost of electricity consumed is a function of power consumed. Therefore the cost objective function can be stated as shown in equation (2). This function is dependent on demand factor δ indirectly.

$$\text{Maximize } C = f(P)$$
subject to:
$$0<\delta<1$$
$$P_g = f(C_x) \tag{2}$$
$$P_{\min} < P < P_{\max}$$
$$\xi_{\min} < \xi < \xi_{\max}$$

The peak demand and the cost of electricity are found in two different conditions, they are:

1) Without DSM
2) With DSM

3.2. WITHOUT DSM MODEL

The lighting devices present before DSM is 60W incandescent bulbs, 18W CFLs, and 27W CFLs with the demand factors i, c_1 and c_2 respectively. Thus, the equations (1) and (2) can be rewritten as:

Here, P_i, P_{c1} , and P_{c2} are power demands of 60W incandescent bulbs, 18W CFLs, and 27W CFLs respectively.

$$\text{Maximize } P = f(\delta_i, \delta_{c_1}, \delta_{c_2})$$

subject to:

$$\begin{aligned} &0<\delta_i<1 \\ &0<\delta_{c_1}<1 \\ &0<\delta_{c_2}<1 \\ &P_g = f(C_x) \\ &P_{\min} < P < P_{\max} \\ &\xi_{\min} < \xi < \xi_{\max} \end{aligned} \tag{3}$$

$$\text{Maximize } C = f(P_i, P_{c_1}, P_{c_2})$$

subject to:

$$\begin{aligned} &0<\delta_i<1 \\ &0<\delta_{c_1}<1 \\ &0<\delta_{c_2}<1 \\ &P_g = f(C_x) \\ &P_{\min} < P < P_{\max} \\ &\xi_{\min} < \xi < \xi_{\max} \end{aligned} \tag{4}$$

3.3. WITH DSM MODEL

The present lighting system is desired to be replaced by 5W LED bulbs, 14W LED bulbs, and 3W LED bulbs respectively accordingly meeting the lumens required. Their demand factors are represented by l_1, l_2 and l_3 respectively. The generalized equations of power demand and cost of electricity i.e. equations (1) and (2), can be modified as:

$$\text{Maximize } P = f(\delta_{l_1}, \delta_{l_2}, \delta_{l_3})$$

subject to:

$$0<\delta_{l_1}<1$$
$$0<\delta_{l_2}<1$$
$$0<\delta_{l_3}<1 \qquad (5)$$
$$P_g = f(C_x)$$
$$P_{\min} < P < P_{\max}$$
$$\xi_{\min} < \xi < \xi_{\max}$$

$$\text{Maximize } C = f(P_{l_1}, P_{l_2}, P_{l_3})$$

subject to:

$$0<\delta_{l_1}<1$$
$$0<\delta_{l_2}<1$$
$$0<\delta_{l_3}<1 \qquad (6)$$
$$P_g = f(C_x)$$
$$P_{\min} < P < P_{\max}$$
$$\xi_{\min} < \xi < \xi_{\max}$$

Here, P_{l1} , P_{l2} , and P_{l3} are power demands of 5W LED bulbs, 14W LED bulbs, and 3W LED bulbs respectively.

Several methods can be used to maximize these functions like quadratic programming, steepest ascent method, Newton-Raphson method etc. We have chosen two methods they are quadratic programming and steepest ascent method and compared for better results.

3.4. QUADRATIC PROGRAMMING (QP)

Quadratic programming concerns the maximization of a quadratic objective function subject to linear constraints:

$$\text{Maximize } f(x) = \sum_{j=1}^{n} c_j x_j + \frac{1}{2} \sum_{j=1}^{n} \sum_{k=1}^{n} q_{jk} x_j x_k$$

subject to: (7)

$$\sum_{j=1}^{n} a_{ij} x_j \le b_i \qquad (i = 1, 2, ...m),$$
$$x_j \ge 0 \qquad (j = 1, 2, ...n)$$

Few assumptions made are:

- c_j, a_{ij}, and b_i are known in prior.
- The symmetry condition $q_{jk} = q_{kj}$. To achieve this q_{jk} is replaced by $\frac{1}{2}\left(q_{jk} + q_{kj}\right)$.

If all $q_{jk} = 0$, then the problem reduces to a linear program.

3.5. STEEPEST ASCENT METHOD

The method of steepest ascent is a numerical method for approximating local maxima of differentiable functions:

$$\begin{aligned} &\text{Maximize } f(\mathrm{X}) : \mathbb{R}^n \to \mathbb{R} \\ &\text{where, } \mathrm{X} = (x_1, x_2, \ldots x_n) \in \mathbb{R} \end{aligned} \tag{8}$$

The basic idea of this method is to move in the gradient direction to attain its maximum until the gradient vector becomes zero. The gradient of a function is the vector of its partial derivatives:

$$\nabla f(\mathrm{X}) = \left(\frac{\partial f(\mathrm{X})}{dx_1}, \frac{\partial f(\mathrm{X})}{dx_2}, \ldots\ldots \frac{\partial f(\mathrm{X})}{dx_n} \right) \tag{9}$$

If X_0 is an initial guess then the next point X_1 is given by:

$$\mathrm{X}_1 = \mathrm{X}_0 + k\nabla f(\mathrm{X}_0) \tag{10}$$

The above equation (10) can be generalized as follows:

$$\mathrm{X}_{n+1} = \mathrm{X}_n + k\nabla f(\mathrm{X}_n) \tag{11}$$

The optimality is said to be reached once the gradient vector becomes zero and there is no possible movement in that particular direction. This is one of the basic gradient methods and simplest one to obtain the local maxima of the given function.

IV. RESULTS AND DISCUSSION

The power demand function and cost function before and after DSM are formulated with the help of curve fitting tool. The results are tabulated in TABLE I.

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TABLE I. COMPARISON OF OPTIMIZED RESULTS OBTAINED IN TWO METHODS

Parameters being optimized	Quadratic programming		Steepest ascent method	
	Without DSM	With DSM	Without DSM	With DSM
Peak power demand considered over an hour (kWh)	0.2968	0.1224	0.3014	0.1253
Maximized cost (Rs.)	1.5581	0.6425	1.6414	0.6661
Savings (Rs./day)	-	0.9156	-	0.9753
Percentage saving in power demand	-	58.76%	-	58.42%
Percentage saving in cost	-	58.76%	-	59.42%
Accuracy level	Less		More	

Based on the results tabulated it is evident that the steepest ascent method is more accurate than that of quadratic programming. Using the results obtained in this method and using the actual advantages of DSM tabulated in TABLE II the DSM Modelling is prepared. The DSM Model is tabulated in TABLE III.

TABLE II. ADVANTAGES OF DSM OVER CONVENTIONAL LIGHTING SYSTEM

Parameters	Without DSM	With DSM
Total cost of lighting devices (Rs.)	1741	4671
Lighting years	Incandescent – 1 year CFLs – 5 years	LEDs – 15 years

TABLE III. DSM MODEL

Modelling Parameters	DSM modelling
Investment for DSM (Rs.)	4671-1741=2930
Annual savings (Rs./year)	355.98
Payback period	8 years 3 months

The DSM Model hence prepared has a payback period of 8 years 3 months which is less than the life years of LED lights i.e. 15 years. Therefore, the Model is optimized and can be used for household lighting purpose.

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V. CONCLUSION

This project is to provide a better optimization technique for household based DSM model to minimize the power demand and the cost of electricity consumed on a daily basis. This can improve the energy conservation in the residential sector drastically.

The future scope of this project is that this DSM model can be solved in various upcoming algorithms for better results. This optimized DSM model can be implemented in commercial and industrial fields also.

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