Chapter 2

LITERATURE REVIEW
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2.1 Introduction

2.1.1 General

In the modern era electricity is as essential as food, clothing & shelter to mankind. Electricity has shaped the economy with a very high progress rate and has contributed to technical advances and higher standards of living of mankind. Initially, for many years, electric utilities were primarily interested in increasing the demand for electricity, and marketing activities were aimed at that. But the oil price shocks of 1970s and their repercussions caused oil-dependent utilities to adopt programmes to reduce energy consumption. By the end of the decade, the tremendous escalation in the cost of adding to capacity contributed to the widespread adoption of peak load reducing activities [1].

Many utilities have incorporated DSM concepts in their resource planning as discussed in several papers [15]. C. W. Gellings reports in 1985 that in U.S. about 300 utilities were running some 1000 projects aimed at load curve shaping and that the DSM activities were not limited to a particular kind of utility or a particular geographic region.

2.1.2 Objectives of DSM programmes

DSM programmes require participation of customers with their acceptance and willingness for the scheme. Utility and customer may have different objectives, with the common activity and common result. e.g. Direct load control during peak load hours reduces customer’s bill and achieves peak clipping for the utility [16]. Main objectives of the customers and utility defined by C. W. Gellings are presented here.
Objectives of DSM Programmes

Utility
i) Peak load management,
ii) to lower costs,
iii) to increase profits,
iv) cost-effective marketing

Customer
i) To lower bills,
ii) To get improved services, and
iii) Tailored program options

Operational objectives that can be addressed by DSM programs include the following:
- Reduce or defer capacity addition
- Satisfy regulatory constraints or rules
- Improve the image of the utility
- Reduce the need of critical fuel
- Mitigate electricity cost increase
- Increase revenue &/or profits &/or sales
- Increase reliability of service & operating flexibility
- Reduce/Remove load shedding in an area
- Improve efficiency of supply system by reducing losses
- Decrease unit cost through more efficient loading of existing & planned generating facilities

S. Rahman & Rinaldy write that (1993) the main objective of implementing DSM program in the power systems is to change the utility’s load shape i.e. changes in the time pattern and magnitude of utility’s load [17].

Utility planning framework including DSM is exhibited in Fig. 2.1.
DSM is perceived in different fashion as per the utilities need. Various definitions of DSM as per the perception of different researchers are presented in the next section.

2.2 DSM definitions

DSM provides a means to control electricity costs and shape electricity demand pattern in mutually beneficial ways for utility & for customers. C.W. Gellings who coined the term DSM defined it as “DSM is the planning, implementation and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility’s load shape; i.e. changes in the time pattern and magnitude of a utility’s load."
Utility programmes falling under the umbrella of DSM include:

i) load management,  
ii) new uses,  
iii) strategic conservation,  
iv) electrification,  
v) customer generation, and  
vi) adjustment in market share [15].

Bruce A. Smith et al define DSM as the set of activities that a utility or its customers can undertake in order to modify the shape and level of their load curve. These activities encompass load/energy decreasing and increasing programmes, which can be used to achieve various operational objectives [15].

C.W. Gellings & W.M. Smith have defined DSM in 1989 as follows; “DSM involves the planning and implementation of utility activities designed to influence the time pattern and/or amount of electricity demand in ways that will increase customer satisfaction and coincidently produce desired changes in the utility’s systems load shape” [16,18]. As per the EPRI definition “Demand side management (DSM) is the deliberate influence of customer appliance selection and energy use patterns to achieve a desired impact or load shape consistent with company goals”. Demand side management has two aspects: develop efficient utilization for electricity, (less electricity for each utilization), and take measures to encourage the customer to help flattening the load curve [19]. DSM emphasizes the need to control the demand for power rather than meeting the user’s requirements regardless of cost. DSM will many a times use financial pressure to control the demand.

Demand Side Management aims at improving energy efficiency which is reduction of kWh of energy consumption for the same service or activity, demand load management i.e. reduction of kW of Power demand or displacement of demand from peak to off peak time. Other benefits of DSM could include higher end use energy efficiency, improvement in quality and reduction in cost of power [20].

As per the initial definition of C.W. Gellings, DSM includes only those set of activities which have deliberate intervention by the utility. After a review of DSM programmes Gellings states that most of the utilities have misconcepted or misunderstood
the term DSM and do not use it beyond load management, energy conservation and energy efficiency improvement [21].

Gellings reviewed DSM in the year 2000 i.e. for a span of 20 years of DSM industry for the ‘Organisation of the Petroleum Exporting Countries (OPEC)’. He concludes that DSM is looked as energy efficiency option in developed countries, and they are moving away from the original definition of DSM. However, in developing countries, where the growth in electric energy production and delivery systems has not kept pace with population, DSM remains a viable option [22]. All types of DSM strategies are reviewed by Steven Nadel [23]. It is concluded that DSM will continue in deregulated environment but it might change its shape.

Demand-side management (DSM) has been given many different definitions reflecting the diverse range of objectives encompassed under this title. However, all definitions have as a central theme the need to modify customer end-use of electricity (and other utility supplies) to shape demand in some beneficial manner [24]. Load management was used by the suppliers to mitigate both, the rising cost of peak power and that of capacity additions in the era of 1970 to 1990. The six basic load shape objectives presented in the literature [16,17] and the same are presented in Fig. 2.2 and described in detail.

![Diagram of Load Shaping Objectives](image)

Figure 2.2: Load shaping objectives
2.2.1 Load shaping objectives

i) **Peak clipping:** Peak clipping or reduction in the peak demands, embodies one of the classic forms of load management. Direct load control by the utilities is an important tool for peak clipping or peak shaving. Direct load control of residential water heaters was very effectively used by many utilities for peak clipping in US [15,25].

Various DSM programmes and case studies are reported by researchers on direct load control of water heaters, air conditioners, space heating systems, pool pumps and similar loads [26,27]. Another common means of peak clipping was and is load reduction by Time of Use (TOU) rates for consumers [28-46]. Higher difference in peak hour rates and off-peak hour rates result into better load management [27,35,36,37]. Judgmental and statistical methods of peak electric load management are discussed in [45].

ii) **Valley filling:** Valley filling is as important as peak clipping for the end result expected is reduction in the cost. Valley filling encompasses building off-peak loads, shifting of peak loads/shoulder peak interruptible/flexible loads to valley periods, and use of electricity as alternate energy source.

Valley filling can be accomplished by adding new thermal storage devices or by time-differential tariff with off-peak hour incentives. Battery charging for electric vehicles could help valley filling in the near future all over the world. The motor rating would be in the range of 10kW to 40kW [47].

Pumped-storage plants use cheaper electricity to pump the water back to the reservoir during off-peak hours and utilize the potential energy of water to generate electricity during peak hours. Pumped storage plants also contribute to the following important functions to the electrical power systems:

i) load regulation,

ii) quick response capacity to off-set short term generation and transmission outages, and

iii) increase in overall system capacity, and reliability.

They can switch from pumping mode to generating mode and provide double the nameplate rating [37].
iii) **Load shifting:** Load shifting is the third and important classic form of load management. It is preferred to shift loads from peak and shoulder peak hours or to valley periods. It achieves peak clipping and valley filling simultaneously. Normally flexible loads are shifted so that it does not cause much inconvenience nor it affects productivity in adverse fashion. e.g. Shifting of thermal storage facility loads to off-peak hours such as i) water heaters, ii) storage space heating, and iii) coolness storage

Time of use (TOU) tariffs have a similar effect. Higher rates during peak hours and lower rates during off-peak hours motivate customers to shift their flexible, low priority loads to off-peak hours on their own [28-45].

India being a tropical country, water heating load is much less as compared to US and Europe, whereas water pumping load is a sizeable load in India and can be adjusted anywhere in the load curve, if sufficient storage capacity for water is made available. Even if storage facility is not available, agricultural water pumping load has higher flexibility and consumes about 23% energy in MSEDCL, which is just next to industrial consumption.

iv) **Strategic conservation:** Strategic conservation is the load shape change that results from utility-stimulated programmes directed at end-use consumption [15]. This might result into reduction in sales. In employing energy conservation, the utility planner must consider what conservation actions would occur “naturally” and then evaluate the cost-effectiveness of possible intended utility programmes to accelerate or stimulate those actions. Weatherization and appliance efficiency improvement are the means adopted by most utilities in developed countries like US, UK and other European countries. Strategic conservation is more of a societal issue than a utility one. Most activities are coupled to environmental goals where the main item is to prevent building of new capacity which could have a harmful impact on the environment [48-53].

An analysis has been carried out to study the effect of energy tax on the generation expansion planning and the environmental emissions from the power sector in India. It is concluded that introduction of energy tax reduces CO₂ emission along with the
reduction in the local pollutants viz. SO2 and NOx emission in all the cases. This is due to the reduction in demand as well as the coal based power plants [49].

A case study on emissions from thermal power plants in India is presented [50]. It is reported that increased oil support increases CO emission from 7.140 g/kWh of electricity to 24.49 g/kWh of electricity. Gaseous type Range of measured emission coefficient in the study for the year 2003–2004 are CO2 0.776–1.49 (g/kWh), SO2 5.210–15.99 (g/kWh), NO 1.540–3.263 (g/kWh), and CO 0.055–24.49 (g/kWh). It is also reported that CO2 emission has not changed and the 2003-04 figure matches with the 1997-98 figure. The emissions also depend upon quality of coal, quantity of oil support, age of the plant etc. It is shown in [51] that to attain environmental safety of the Thermal Power Stations and to abide by the decisions of the Kyoto Protocol lies in raising the efficiency of the heat power stations and reducing their fuel consumption by using non-conventional thermal cycles. Vitaly A. Prisyazhnii outlines the ways of reducing consumption of fuel by thermal power plants and, consequently, of reducing their discharging into the atmosphere the gases producing the greenhouse effect [52]. Thus conservation adds to societal benefits.

Strategic conservation considers only those conservation programmes which are initiated or supported by the utility and not the naturally occurring one. The word strategic indicates the difference between naturally occurring and utility driven conservation schemes [16]. This includes conservation, end use energy efficiency improvement, and loss reduction. There are three factors which affect the market penetration of any energy efficient (EE) equipment: product characteristics, potential for energy efficiency, and the acceptance for new technology. Two factors together form the formula to assess market impact:

Impact = Potential x Acceptance

The product characteristics influence the potential for efficiency. The infrastructure and the competitiveness influence the acceptance for new technology. The importance of this is easily recognizable if one considers that, however high the potential is, it will be of no use if the acceptance cannot be achieved [48].
Consumer acceptance can be increased by educating them and by giving proper information along with the appliance i.e. by providing ‘Energy label’. The Energy Policy and Conservation Act (EPCA) in 1975 provided for mandatory energy labeling of appliances, and the related Energy-Guide program took effect in May 1980. This Appliance Labeling Rule provided information to consumers about the energy efficiency of major household appliances. Labels were required on refrigerators, freezers, dishwashers, water heaters, room air conditioners, clothes washers and furnaces. Later on labels have been required on fluorescent lamp ballast, fluorescent lamps, compact fluorescent lamps (CFLs), general lighting service incandescent lamps [20].

In India, strategic conservation in Agricultural sector has large potential (up to 30%) [54]. Industrial and large commercial consumers (H.T. consumers) are somewhat aware and have already opted for efficient equipments as these measures fetch more benefits because of higher electricity tariffs in force for these sectors.

v) Strategic load growth: It is the load-shape change that refers to a general increase in sales, stimulated by the utility, beyond the valley filling [55]. In developed countries it is considered to be achieved by dual fuel heating (e.g. gas/electricity), heat pumps, and promotional rates.

vi) Flexible load shape: C. W. Gellings, the pioneer of the term DSM, explains flexible load shape as a concept related to reliability, a planning constraint [16]. Load shape can be flexible if customers are presented with options as to the variations in quality of service that they are willing to allow in exchange for various incentives. The programmes involved can be variations of interruptible or curtailable loads, concept of pooled, integrated energy management systems, or individual customer load control devices offering service constraints.

Load management technique is a method to alter or reshape the electric utility load as a function of time. The purpose of Load Management (LM) techniques is to reduce peak demands to level the daily or annual electric demand [18].

Identification and promotion of new usage include charging of vehicle batteries, use of alternate energy sources, or even the use of a new type of equipment which might be energy efficient or might demand less power e.g. a PC with LCD screen instead of usual monitor.
Strategic conservation means conservation resulting from purposeful efforts, tariff etc. and not the naturally occurring one. Electrification and load retention is for new customer generation and retaining old ones with better services. Customer generation means new addition of customers through better performance and image of the utility company. Adjustments in the market share might be for avoiding shortages or surplus of power.

2.3 DSM history and progress in various countries

Heavy price hike of oil in 1970 by OPEC countries created turbulence in the world economy. Especially the power industry was shaken by the price hike. Utility engineers started working on “energy conservation’ and other techniques to reduce costs of electricity which was necessary to maintain business.

Nuclear power plants were utilized in 1970s but were heavily criticized because of the fears concerning the safe disposal of radioactive wastes. Power companies began to look for other viable solutions to their problems and began to develop ‘load management techniques” to control electricity demand and energy consumption [18].

DSM has its origins in demand reduction programmes, aimed at reducing future generation capacity requirements in North America. As such, DSM programmes can be considered as an option in least cost planning (LCP) strategies in which the cheapest overall cost of delivering energy services is assessed. When practicing LCP, utilities must consider the question: ‘Is it cheaper to save a kWh than generate a kWh?’ [34,56].

In 1985 C. W. Gellings writes that until recently, the two forms of DSM most often referred to were “load management” and “strategic conservation”. Load management entered the scene in 1960s and 1970s. The early activities were in Europe and in USA. The load shape changes were in two areas, peak clipping and valley filling; mainly through water heater control and storage space heating respectively. Prohibitive costs of new capacity additions and vociferous opposition to capacity building from many segments of society left no option to electric utilities but to go for load management.

In USA almost all utilities instituted some or the other type of conservation programme but especially those utilities facing themselves short of critical fuels or generation capacity have pursued the option more rigorously. e.g. North-Western utilities
relying on hydro-power restored to conservation as water resources became strained. The oil pinch forced many north-eastern utilities to include conservation programmes on DSM agenda.

In India, perhaps today, utilities are going through a similar phase of capacity crunch and need to have “strategic conservation” as the main agenda in power management. EPRI, USA conducted conservation study programmes, and their 187 conservation programmes used to provide information, direct technical assistance, financial incentives, special rates, and demonstration to consumers. Perhaps Bureau of Energy Efficiency, India can perform a similar role in India.

2.4 DSM verses SSM

Till recently in power sector the concepts about demand-supply were very simple. If society demanded more power, the supply companies would simply find a way to supply users even by building more generation facilities. This concept of doing business is labeled as ‘supply-side management (SSM)’ [18]. Whereas, DSM tries to satisfy all energy needs within the available generation capacity by increasing the demand flexibility. This is a method of using the available generation capacity and resources more efficiently.

For years together utilities have responded to customer demand without questioning it. Customers, for their part, have consumed electricity and paid their bills at the end of the month without knowing exactly how their money was spent. This is analogous to going into a supermarket with no weights and no measures and no prices marked on the goods, selecting your market basket, going to the cash register, and only then knowing what you have spent and what you have gotten for it. There is a critical need for better two-way communication in developing a new partnership between the utility and its customers [18].

To be cost effective, a DSM programme must offer energy savings at less than the cost of the equivalent energy supply. An electricity company that introduces energy efficiency measures will lose some revenue, so that energy efficiency and generation cannot be considered on equal terms without some form of balancing mechanism. In many North American programmes, this balance is achieved through a regulator
approved increase in tariffs for all customers (or a customer segment), subject to certain benefit-cost measures demonstrating that the 'average' customer sees an overall reduction in energy costs. In the conservation scenario described above, DSM measures can be compared directly with supply side measures, in which construction and running costs can be associated with the avoided capacity and consumption requirements. In such comparisons, the reduction in capacity requirements associated with the DSM measure is sometimes referred to as 'negawatts'. It is important to note, however, that the avoided capacity and consumption associated with DSM measures does not by definition exist, and as such can only be predicted, or estimated, by its absence [24]. DSM programmes are viable and significant competitor to supply-side resources, and can provide economic, environmental and planning advantages [57,58,59,60].

2.4.1 DSM umbrella

DSM umbrella encompasses various activities like load management, energy conservation, improvement in energy efficiency, reactive power management, alternate energy usage, distributed generation etc. Some of the activities are utility driven, some are customer driven, and some are coordinated DSM programmes co-administered by the electric and gas utility company and government agency or its sub-grantee [21]. These coordinated programmes differ from the typical programmes run by the utility due to following features:

i) Involvement of government expenditure,

ii) The need to consider both programme and utility cost-effectiveness, and

iii) The requirement to allocate energy and capacity savings among co-administrators of the programme.

2.5 DSM and pricing

DSM and pricing has direct correlation. DSM can reduce prices and bills. Cost based pricing of electricity is used by utilities to promote DSM scheme.
2.5.1 Electricity pricing

‘Pricing of electricity’ in general means ‘retail pricing’ or the price charged to the consumer to serve the electricity at his door. In more technical terms it is called as ‘Electricity Tariff’. A fair electricity tariff is expected to have many components like target return on investment, operation and maintenance, depreciation, operating interests, taxes, and fuel costs etc. These are the components very broadly defined, which can also be the cost components of any other commodity. The hidden factors in electricity cost are ‘Time of use (TOU)’, supply voltage level, reactive power requirements of load, ‘Power Quality’ requirements of load, and also the Power Quality issues imposed (on the system) by the load, ‘marginal cost’ of the unit served, load factor of any consumer or of consumer category, interruption costs etc. These hidden factors may vary for consumers of different category, viz. residential, commercial, industrial and agricultural consumers [61]. The cost to deliver electric energy varies as a function of time, system status, and location within a power system [62].

While designing a tariff for electricity certain principles relating to fairness and equity must be satisfied, including:

i) the fair allocation of costs among consumers according to the burdens they impose on the system,

ii) the assurance of a reasonable degree of price stability and avoidance of large price fluctuations,

iii) the provision of a minimum level of service to persons who may not be able to afford the full cost,

iv) the power prices should raise sufficient revenues to meet the financial requirements of the utility,

v) the tariff structure must be simple enough to facilitate the metering and billing of customers, and

vi) other economic and political requirements must also be considered. These might include subsidized electricity supply to certain sectors [63].

Various types of tariff with long range marginal price theory in detail are presented [63]. The factors of pricing and costs in determining electricity tariffs and contracts, more specifically discussing changes in consumers’ demands and strategies for large users are
discussed in [63]. Retail and wholesale electric supply markets are studied, reviewed and recommendations are offered on appropriate regulatory policy toward retail electricity rate design and cost recovery mechanisms [65].

In developed countries three major categories of consumers are considered for electricity pricing, viz. residential, commercial and industrial. Industrial consumers are charged with lowest prices, commercial and residential consumers are charged at par or in some countries, in some utilities, residential consumers are charged higher than commercial consumers [66]. This reflects the consideration given to the load factor of consumers, TOU, flexibility of the load to get adjusted as per the GRID requirement. Some sample tariffs are depicted in Table 2.1 and 2.2.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Customer class</th>
<th>Cents / kWh</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Residential</td>
<td>8.2</td>
<td>Highest rate</td>
</tr>
<tr>
<td>2</td>
<td>Commercial</td>
<td>7.2</td>
<td>----</td>
</tr>
<tr>
<td>3</td>
<td>Industrial</td>
<td>4.4</td>
<td>Lowest rate</td>
</tr>
<tr>
<td>4</td>
<td>Others</td>
<td>6.4</td>
<td>----</td>
</tr>
</tbody>
</table>

Residential consumers cross-subsidize the industrial sector in developed countries.

<table>
<thead>
<tr>
<th>Customer class</th>
<th>Dominion Virginia Power</th>
<th>Appalachian Power</th>
<th>Allegheny Power</th>
<th>Conective Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>4.276</td>
<td>3.246</td>
<td>3.87</td>
<td>5.47</td>
</tr>
<tr>
<td>Small commercial</td>
<td>4.230</td>
<td>3.067</td>
<td>3.96</td>
<td>5.94</td>
</tr>
<tr>
<td>Large commercial</td>
<td>3.949</td>
<td>3.585</td>
<td>3.90</td>
<td>5.94</td>
</tr>
<tr>
<td>Small industrial</td>
<td>3.812</td>
<td>2.962</td>
<td>3.55</td>
<td>5.58</td>
</tr>
<tr>
<td>Large industrial</td>
<td>3.535</td>
<td>2.781</td>
<td>3.34</td>
<td>5.49</td>
</tr>
<tr>
<td>Churches</td>
<td>4.157</td>
<td>2.984</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>
The prices in different utilities are comparable, and the data reflects that the similar logic is applied for pricing. In some of the utilities residential class consumers are charged with TOU rates. This makes the consumers to shift their flexible loads like water heating load, water pumping load, space heating/cooling load from peak hours to off-peak hours of the grid. For this, special TOU metering is necessary. Detailed discussion on TOU metering and price variation during peak and off-peak hour costs is available [68].

In some utilities consumers are given incentive/rebate for putting their flexible loads on ‘direct load control (DLC)’ program, of the utility which is a DSM measure with the control of the switches resting with the supply utility. This requires sophisticated signal system, either RF signals or an additional network to carry signals or an HF signal passed through the same network supplying electricity. In a country like India, these measures for residential class consumers seem far fetched.

It is a prerequisite to study ‘electricity pricing in India’ before going into details of ‘TOU’ and ‘demand flexibility’.

2.5.2 Cost-plus method

Many a times, price of electricity paid by various consumers is the same though the ‘cost of supplying electricity’ to different consumers varies widely. At present, in India, postage stamp method is followed for pricing electricity for any particular class of consumers irrespective of the location, load density and ‘cost to serve’ to that consumer. This type of pricing hampers the cost-benefit of DSM programmes. Subsidy and cross-subsidy is another issue which makes conservation and DSM programmes unviable in subsidized sectors like agricultural and residential sector.

2.5.3 Subsidy and cross-subsidy issues in Indian electricity tariffs

Many a times the costs of supplying power to one class are recovered from some other class of consumers. ‘SUBSIDY’ and ‘CROSS-SUBSIDY’ are the major components in Indian tariffs to make the electricity prices drift away from costs to a large extent [69,70]. Most of the SEBs do not earn sufficient revenue even to meet interest and depreciation liabilities. The gap between the revenue realized and the cost of generation
can be reduced by lowering the production cost or by increasing the revenue realized or by doing both [71].

'Residential class' is charged only for energy consumption. The rates are highly subsidized for consumption less than 300 units per month, even when compared with average cost calculated by 'cost-plus method'. In reality, residential load is very costly to serve, as it is incident on the system mainly during the peak hours of the system i.e. 6 p.m. to 11p.m. The diversity, time flexibility and load factor for residential load is lowest among all the categories. If 'Time of use' (TOU) rate would be made applicable to this category, perhaps this class would have to pay the highest price per unit of electrical energy consumed. e.g. in Maharashtra state, cost of supplying energy to a residential consumer during evening peak works out to be Rs.10-12 per kWh whereas the average tariff is Rs.3.00 per kWh at any hour of the day. The ill effect of this subsidized tariff is that the consumer is unaware of the ‘actual cost of production’ and ‘cost of service’ of electrical energy. This also promotes wastage of energy and increased power demand during peak hours [70].

The industrial consumers, getting supply from high tension lines (11kV and above) and those from low tension lines are named as H.T. and L.T. consumers respectively and are charged at different rates. The ‘H.T. industrial class’ is charged for energy, kVA demand, kVAR demanded, ‘Time of Use’ and reliability. The ‘cost of service (COS)’, in electrical sector depends upon ‘voltage level’ at which electricity is supplied to the consumer. If the supply voltage is high COS is low and vice versa [61]. Some of the H.T. consumers are given supply through separate H.T. lines called “Express feeders”. Normally they are excluded from ‘load shedding’ and have to pay higher price for higher reliability [72].

On an average industrial consumers pay in the range of Rs.3.7 to Rs.5.0 per unit of energy which includes all the above costs plus ‘CROSS-SUBSIDY’. If charged on ‘COS’ basis, industrial consumers would pay the lowest rate because of their maximum load density, maximum load factor, almost constant load profile (flat load curve as compared to other class) throughout the year on a larger scale and throughout the day on a smaller one. The only peculiarity of the industrial load is their large reactive power demand. They are penalized for poor power factor and therefore take care to maintain the
power factor above the threshold value. Recently from December 2003 incentive is being
given for power factor above 0.95 by the Maharashtra State Electricity Board and many
industries try to get highest incentive by maintaining the power factor as high as 0.99
[72]. Relief to Generators and to Transmission-Distribution network is achieved through
this ‘power factor tariff’. In the new ABT regime DISCOMs will have to pay less for less
kVA (for the same useful power or kW) to TRANSCO and GENCO, as power factor will
be maintained high.

For ‘commercial class’, small consumers are L.T. consumers and are charged only
for ‘energy consumption’ similar to residential class. Slab-wise tariff structure is
applicable, but the lowest tariff for this class is higher than the average cost. H.T.
consumers are charged for kVA demand, kVAR demanded and for kWh consumption,
similar to H.T. industrial consumers. Small or L.T. commercial consumers are not
charged for reactive power demand or for power factor. One more parameter of growing
concern is also neglected at present while pricing for this class, is the “Power Quality”
issues imposed on the system by the non-linear loads like computers, fluorescent tube
lights, compact fluorescent lamps (CFL) and air conditioners [73].

At present, the tariff for commercial class is the highest amongst all the
consumers if compared with ‘average cost of supply’. Commercial consumers cross-
subsidize residential and agricultural consumers. Table 2.3 presents the summary of the
discussion.

Table 2.3: Average Electricity Tariff 99-2000 [69]

<table>
<thead>
<tr>
<th>Category</th>
<th>Tariff Rs./kWh</th>
<th>Avg.cost Rs./kWh</th>
<th>% subsidy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural</td>
<td>0.25</td>
<td>280.9</td>
<td>91.10%</td>
</tr>
<tr>
<td>Household</td>
<td>1.50</td>
<td>280.9</td>
<td>46.6%</td>
</tr>
<tr>
<td>Industrial</td>
<td>3.50</td>
<td>280.9</td>
<td>-24.59%</td>
</tr>
<tr>
<td>Commercial</td>
<td>3.60</td>
<td>280.9</td>
<td>-28.15%</td>
</tr>
</tbody>
</table>
2.5.4 Agricultural load and tariff

‘Agricultural consumers’ in India, use electricity for pumping water for irrigation. Most of the farmers use ‘flood irrigation’ method. Irrigation pumping load is typically a three phase induction motor load, which demands large amount of reactive power from the grid. The energy consumption by this load is as high as 31% and is at par with industrial consumption [6]. The lack of adequate reactive compensation has been leading to low voltage profile with 400kV voltages at some sub-stations near Indore touching 320kV during the agricultural season (October to December) [75]. Similar phenomenon is observed in Maharshtra State. In MSEDCL grid the reactive power demand increases by 2000kVAR in the month of Oct.-Nov., when the agricultural load is incident on the grid after the end of monsoon rains. The high reactive power demand is a result of the fact that the farmers remove the power factor improving capacitors provided to motors for the fear of getting shock even when the supply is off. Most of the agricultural consumers are charged for their real power demand (Rs. X/hp/month) irrespective of their energy consumption, reactive power demand and time of use. The burden of large reactive power demand from the system, results into poor voltage regulation and thereby burning of motors. Farmers get their motors rewound from local vendors, many a times for higher h.p. and lower voltage rating. The rewound motors can then run even on 340volt instead of 415volt (rated 3phase L.T. supply). The rewound motors introduce harmonics in the system and thereby the related problems like distorted voltage wave, poor power factor, increased neutral current, and increased losses in the system etc.

The fixed h.p. based tariff for agricultural load was introduced in India in 1970s [45]. This type of tariff promotes wastage of electrical power as well as wastage of ‘water’, another precious and scarce resource. It is necessary to educate farmers to operate their pump sets efficiently and save energy. Saving to the tune of 12% is expected through replacement of old foot-valves by standard low friction foot-valves [70].

The tariff for agricultural load is highly subsidized in India on social and economic grounds. ‘Agricultural sector’ is the back-bone of economy of India. So as to make agricultural products available at an affordable price to a common man, normally all inputs to agricultural sector (like fertilizers, water, electricity etc.) are subsidized. But, the hp based tariff is a mockery of the so called socialism. The ‘average price’ seems to
be subsidized for agricultural sector, but in reality a rich farmer having a cash crop like sugar cane in his field uses electricity for one and a half year period to water the crop heavily and gets electricity at about Rs.0.20 per kWh. On the other hand a poor farmer growing jowar/bajra in his field waters the crop once in a month, uses electricity sparingly and pays about Rs.5 to Rs.7 per kWh. If slab-wise ‘energy tariff’ could be made applicable for agricultural sector, SUBSIDY could be made available to those poor farmers who deserve subsidy and use less electricity for crops like bajra, jowar, wheat etc. or use efficient irrigation methods like drip irrigation. Rich farmers having large fields, cash crop like sugar cane and demand electricity on very large scale could be charged appropriately for their higher consumption [61].

2.5.5 Conclusion

In short, at present ALL residential and agricultural consumers are getting ‘subsidized tariff’ which is not affordable to Indian power industry. Commercial and industrial consumers are charged at a higher rate to cross-subsidize the above two categories. Even after cross-subsidization, the average realization is less than average cost of supply [17]. The National Tariff Policy of the Govt. of India emphasizes cost based tariff and removal of subsidy in a phased manner [7,69].

In Maharashtra state it is followed religiously, and the increase in agricultural and residential tariff is observed since the establishment of Maharashtra Electricity Regulatory Commission (MERC) in 1998 [77,78,79].

2.6 Time of use (TOU) pricing and demand elasticity

Electricity demands are time varying. Demands vary due to weather dependent energy needs or are dictated by the nature of the production processes in industrial sector. Week days and weekly holidays exhibit different load curves. Day-time energy needs differ from that of night-time needs. Variations in demand whether seasonal or daily create peaks and valleys in the load curves. Electricity costs do vary with these peaks and valleys. Costs are higher during peak hours and lower during off-peak hours as per the usual law of demand-supply economics.
TOU tariff offers options to the customer to use electricity with lower costs at off-peak hours or to use it at higher rates during peak hours. This reduces the electricity bills for the customers and operational costs at peak hours for the utility. The result is more money in both the pockets. Reliability benefits of TOU are equally important as those of economic benefits [68]. Improved voltage profile, increased frequency and thereby increased reliability are the major technical benefits of time varying tariff.

The Time-of-use (TOU) tariff based on the peak load pricing theory has been one of the most effective load management strategies. TOU pricing can either be applied as an LM program or as an incentive to drive the economics and the motivation to implement other types of LM programs. TOU pricing also can be taken as an involuntary way for consumers to adjust the electricity consumption among different time axis in accordance with the cost of electricity [28].

After studying the work carried out by various researchers [28-45] it can be concluded that the TOU rate has many benefits for the electric utility and its customers. These benefits include improvements in operating efficiency and reductions in capital investments. Application of the TOU rates to the general customers in the U. S., Japan, and other countries is expected to cope with declining load factors and to improve fairness in cost apportion. If it is possible to adjust the load in the inverse ratio of 'rates' then even with the higher prices during peak hours the incentive during off-peak hours compensates this rise and finally the total electricity bill reduces than that of the flat rate tariff.

### 2.6.1 Demand elasticity

Demand variation due to change in price is correlated by ‘demand elasticity’. It is defined as the percentage change in the quantity consumers demand in response to a one percent change in price [80,81]. One of the key concepts underpinning these issues is that customer load will migrate from one time period to another if there is a commensurate price attraction. In terms of the concept of elasticity this means that there exists not only "self-elasticity", where demand rises and falls inversely as the prevailing price, but there also exists a “cross-time elasticity”, whereby demand at one time may well depend on the prices prevailing at other times [36].
A case study on air-conditioning load in Mumbai is reported by S. Ashok and Rangan Banerjee [27]. The study shows that a reduction of 38% in peak demand is possible with air-conditioning load control if cool-storage facility is available under TOU rates. The results showed that under flat rate tariffs, the prevalent high consumer discount rates make cool storage unavailable. This provides justification for utility intervention in cool storage DSM programmes.

The problem of balancing the supply and demand side operations is addressed through ‘short range marginal cost pricing (SRMC)’ and ‘incentive term’ in [82]. Norwegian power system with static tariff and with a tariff reflecting SRMC is presented in [83].

Real-time pricing (RTP) is considered as an excellent demand management option which reflects the real cost of generating electricity to the end user, the electricity cost saving potential of RTP through demand management is presented in [32]. An analytical approach is followed to describe the potential electricity cost savings to an industrial end user under RTP. Dynamic pricing is close to ‘real-time cost of electricity’. It is necessary for the consumers to anticipate the price levels. To address this requirement several price models are developed and presented in [84]. Different types of pricing mechanisms exhibit different economic costs and benefits for the same DSM programme or prioritize the DSM programmes in different ways. This demands detailed economic analysis of DSM schemes.

Recently a frequency linked dynamic pricing structure called Availability based tariff (ABT) is introduced and implemented in India for interstate transactions. Mr. Bhanubhusan the pioneer of the concept explains this concept in [85,86]. ABT tariff depicts inverse relation between price and frequency. How ABT has brought GRID DISCIPLINE and improvement in frequency profile is studied by many researchers and presented [87-92]. The detail tariff is available online [93]. The concept and detail tariff is presented in Appendix B.
2.7 Reactive power pricing and management

Reactive power support is treated as one of the ancillary services. The North American Reliability Council (NERC) defines ancillary service as the necessary services that affect electricity transfer. The Federal Energy Regulatory Commission (FERC) specifies the following six ancillary services to maintain the integrity, quality and security of electricity service: system control, voltage control and reactive power supply, operation spinning reserve, operating supplementary reserve, and energy imbalance [94].

Transfer of real power cannot be realized without reactive power/voltage support. However, compared with real power, the idea of reactive power costing and pricing is still not well defined. John Lamont and Jian Fu have presented a detail cost analysis of reactive power support in [95]. Explicit costs as well as opportunity costs are considered in the analysis [95,96]. Researchers have elaborated on loading capability curve of generator and opportunity costs [94-101].

In olden power systems the major load on the system used to be of incandescent bulbs and heating appliances. The then utility engineers had a version that the ‘reactive power is too small to be priced’ [102]. In the present power system perhaps more than 70% load is of induction motor drives. Reactive power cannot be neglected from technical aspects nor from economic aspects. Reactive power has its own characteristics such as it can not be converted into any other form of energy like mechanical energy or so, it cannot flow over a long distance as the real power can flow, therefore, has to be generated locally where it is required to be used [101]. The basic concepts of reactive power are well explained in [103,104,105].

Reactive power when flows through the network blocks the network capacity which otherwise could be used for the real power transmission. It further blocks the real power generation capacity of the alternators. Capacitor installation is an easy, cheap and technically as well economically most effective method of Demand Side Management technique which is talked of but practically neglected in Indian rural sector [106].

The problem of reactive power support procurement by an independent system operator (ISO) in a deregulated electricity market is addressed by Jin Zhong and Kankar Bhattacharya [99,101]. A possible structure of reactive bid is proposed and discussed in the context of establishment of reactive power markets [101]. Further the authors have
presented the design of a localized competitive market for reactive power ancillary services at the level of individual voltage-control areas. The concept of electrical distance has been used to identify the different voltage-control areas within a power system [107].

2.8 Economic analysis of DSM programmes

Economic analysis of DSM programmes is necessary to know basically whether any DSM option is better than the supply side option. Comparison of DSM programmes requires cost-benefit analysis. Case studies are reported in the International referred Journals. Various terms related to “Electricity Economics” are well explained in [80].

Screening DSM programmes with value based test is presented in [108]. Department of Energy (DOE), USA, 1996 report mentions about California Standard tests which are used to determine cost to benefit ratio, net present value, levelized costs of DSM schemes per kWh, and per MW capacity [109]. Also the tests enable the decision maker to know whether the rate will increase or decrease due to a particular DSM scheme. Time value of money is the most important term in finance [80,110]. California Standard Practice Manual [111] elaborates the methodology and presents the strengths and weaknesses of the tests. Externalities like ‘cost of outage’, ‘cost of unserved energy (CUE)’ and ‘cost of pollution’ are important from societal point of view [111-114].

Cost of outage is an externality bit difficult to estimate. Due to a very few outages in developed countries many a times recent data is ten years old data. A bottom-up approach for estimating the cost of power interruptions to US electricity consumers is developed in [115]. The work considers number of electricity customers, frequency of reliability events (outages), cost of reliability events, and vulnerability of customers to reliability events.

The TERI report [114] has reported three methods available to estimate CUE:

i) Value of production loss for each unit of power outage (production loss method)
ii) Cost of alternative or back-up power generation (captive generation method)
iii) Willingness to pay (WTP) for reliable and uninterrupted electricity supply (WTP method).
The above mentioned three analytical methods gave different estimates of CUE in manufacturing industries in the two states. These estimates are based on primary data collected from 553 manufacturing industries in Haryana and 501 in Karnataka. In Haryana, the estimates of CUE are Rs 7.15/kWh (production loss method), Rs 3.38/kWh (captive generation method), and Rs 5.16/kWh (WTP method). The corresponding estimates for Karnataka are Rs 24.71/kWh, Rs 3.74/kWh, and Rs 5.22/kWh. Whereas, the average cost of service is Rs. 3.40/kWh.

An Indian case study concludes that the CUE is very high when it affects the productivity directly [112]. Figures in the TERI report makes it clear that the variation in CUE is considerable for two different cases and hence, it is difficult to incorporate the same in the economic analysis. Willingness to pay is tested for the Gujrat state [116]. It is concluded that for industrial consumers captive generation cost is comparable with the present tariff and these consumers might shift from the grid electricity to captive generation.

2.9 Programme promotion by utility

DSM is a utility financed programme for total energy savings approach to reducing peak and base loads. It introduces a new element into the planning framework by allowing for a deliberate intervention by the power utility in the market place to influence customer use of electricity in order to alter the system load shape. It encompasses the planning, evaluation, implementation and monitoring of programmes selected from a wide range of technology and marketing alternatives. The success of each alternative depends on the marketing activities to promote customer participation.

It is reported that although energy efficiency programme began in 1980, the public in Malaysia was unaware of its importance till 1993. What is required is an effective public campaign and implementation programme to educate the masses on what and, most importantly how to achieve energy efficiency. For this reason, institutional support from a well established organisation is essential [117].

Some utilities used bill inserts promoting a variety of energy-saving devices for the home. Others provided direct technical assistance such as pool pump audits and adjustment for owners of swimming pools in their service area. Very popular among
utilities promoting conservation was to offer low-interest loans to customers for weatherization. A few utilities even offered a special lower conservation rate to residential customers who meet insulation requirements [15].

Customers' acceptance of utility driven DSM programme depends upon

i) financing/economics

ii) risk aversion

iii) time preference and comfort [16].

Customer acceptance can be enhanced considerably by utility promotional practices, viz.

i) low interest financing of specific end-use technologies

ii) educational information on the costs and reliability of end-use products/services

iii) offering customers a choice of pricing options to accommodate their time preferences and comfort needs.

The success of each alternative depends on the marketing activities to promote customer participation. In US utilities DSM programme promotion was achieved by some of the preferred activities from the list presented below:

i) advertisement, communication through feedback forms,

ii) customer education,

iii) soft-loans for alternate energy use equipment
   - EE equipment
   - Subsidized weatherization equipment

iv) sending energy auditors to homes (residential consumers). Energy auditors may recommend additional insulation or thermal window panes,

v) promotion/sponsorship for R and D activities for development of Energy Efficient (EE) appliances like super efficient refrigerators, energy efficient clothes washing machine, heat-pumps, air conditioners etc. Research during 1991-93 was conducted by U. S. Department of Energy, EPRI, GRI, the National Institute of Standards and Testing, The American Council for Energy Efficient Economy in consortium and was supported by utilities. It was found that these coordinated, multi-utility programmes can help accelerate the development and market success of new high-efficiency technologies.
Advertisement, customer education and incentive or soft-loans for EE equipment proved quite useful in the utilities from US and the other developed countries. Similar promotional efforts have been started in India by the Government. DSM promotion through Ministry of Non-conventional Energy Sources (MNES), GOI and its nodal agencies like Maharashtra Energy development Agency, Pune, through Govt. policies like National Electricity policy, Energy Conservation Bill 2001, Rural Electrification policy etc. indicate Govt. support for DSM [118].

In India, BEE and utilities can perform similar experiments/R&D activities. They can involve technical institutes so that the budding engineers can have hands on experience and positive approach towards DSM and Energy Efficiency (EE) prior entering the field. Regulatory bodies in India (Electricity regulatory commissions (ERCs)) have a vital role. ERCs can advise the utilities to promote DSM activities and to pass on some incentive to customers, if the benefit to cost ratio is very high.

2.10 DSM and power system planning

In developed countries DSM is playing an important role in strategic planning process of electric utilities. As it does so, accurate forecasting of DSM programme impacts becomes essential in order to incorporate the impact of these programmes into utilities’ resource plans with confidence [1]. Load management has become a fully accepted utility corporate planning option. Its advantages in offering economic capacity relief, energy savings and financial relief are well established [119].

Marketing is the process of focusing on the customer’s wants and needs and providing products and services to meet those desires while simultaneously maintaining a healthy business. Marketing is equally applicable to encouraging conservation or load management as it is toward building load or maintaining viability in a competitive environment. Central to the concept of demand side planning is mutual utility and customer benefit—the basis of marketing [4].

The issues in the Indian power system planning are discussed in detail by Jyoti Parikh, and D. Chattopadhyay in 1996 for vertically integrated utilities namely the State Electricity Boards (SEBs) [120].
### 2.11 Benefits of DSM

DSM schemes are beneficial to utility, to consumers and to society as a whole. Reduction in the cost of electricity, increase in reliability of supply, conservation of resources, reduced pollution and improved standard of living are the benefits to name a few. Engineers are more interested in technical benefits and managements are interested in economic benefits. Some benefits are quantifiable like reduction in the number of energy units, and some are non-quantifiable, like improved image of the utility. The benefits are categorized accordingly and presented in the MATRIX in Fig. 2.3.

<table>
<thead>
<tr>
<th>Reduction in......</th>
<th>Reduction in......</th>
</tr>
</thead>
<tbody>
<tr>
<td>• kVA, kW, kVAR</td>
<td>• Temperature rise of system components</td>
</tr>
<tr>
<td>• Current and copper loss</td>
<td>• Pollution -Greenhouse effect</td>
</tr>
</tbody>
</table>

**Improved.....**
- SAIFI
- SAIDI
- Frequency profile
- Voltage profile
- Power factor

**Reduction in......**
- Capital needs,
- Overall Energy cost,
- p. u. energy cost
- Electricity bills

**Customer satisfaction**
- Improved image of the utility
- Protects global environment.
- Improved standard of living of society.

<table>
<thead>
<tr>
<th>T</th>
<th>Q</th>
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<tbody>
<tr>
<td>T</td>
<td>Q</td>
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<tr>
<td>NT</td>
<td>Q</td>
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<td>NT</td>
<td>Q</td>
</tr>
</tbody>
</table>

**T : Technical**
**Q : Quantitative**

**NT : Non-technical**
**NQ : Non-quantitative**

Figure. 2.3: DSM benefit MATRIX

43
The basic advantage of DSM is that it generates Negawatts immediately. As against, Megawatts to be added have a long gestation period of about 3-5 years.

The costs and benefits of DSM are of varied nature and are looked at in different perspective by different stakeholders. Different stakeholders might give different weightage to a particular criterion while judging the costs and benefits. There are multiple criteria and many stakeholders. To rank various DSM programmes as per their merit thus becomes a multi-criteria decision making problem.

2.12 Ranking of DSM programmes

Multi-criteria Decision Making (MCDM) approach is widely used as an effective tool in planning processes. It helps select the best plan in accord with the chosen criterion/attribute. MCDM is used for selecting the best generation resource plan, and for ranking the various plans for Distributed Generation in [121,122,123] respectively. Data envelopment analysis and analytic hierarchy process (AHP) both are used in [122] for ranking the alternative DG plans.

Analytic hierarchy process (AHP) method is widely used in decision making problems in the areas such as economics and planning. The AHP enables a decision maker to structure an MCDM problem in the form of criteria/attribute hierarchy [124]. An attribute hierarchy has minimum three levels which are normally called as layers. The final goal is at the top or at the first layer, the assessment criteria at the second layer, and the third layer comprises of alternatives or plans which compete with each other, as shown in Fig. 2.4. In the first step criteria are compared with each other and the relative importance of criteria amongst each other is found out, appropriate weights are allotted to the criteria. Then pair-wise comparison of alternatives with respect to each criterion is performed one by one for all criteria to evaluate local weights of alternative plans. The matrix of local weights of alternatives thus formed is then multiplied by the weights of criteria to get the final weights and thereby the ranking of the alternatives. AHP enables the decision maker to include tangible as well as intangible criteria in decision making.
e.g. ‘customer satisfaction’ can be a criterion for comparison between two alternatives like high reliability of supply and better voltage profile.

![Figure 2.4: AHP Model representation](image)

The AHP methodology is explained in detail by Saaty [125].

Data envelopment analysis (DEA) is an established tool used in production management for performance measurement. The goal of DEA is to determine the productive efficiency of a system of decision-making unit (DMU) by comparing how well the DMU converts inputs into outputs, while the goal of MCDM is to rank and select from a set of alternatives that have conflicting criteria. MCDM and DEA formulation coincide if inputs and outputs can be viewed as criteria for performance evaluation, with minimization of inputs and maximization of outputs as associated objectives [126]. The efficiency of the best/efficient DMU is given a score 1 and the relative efficiencies of other DMUs are obtained which get a score between zero and one. DEA is a well established tool, the details of DEA are given in [126-132] and in other referred journals paper too. Only the necessary steps used in this research work are presented here.
2.13 Summary

In nut-shell DSM is give-and-take process. The supply companies will make sacrifices by way of rate reductions or by giving soft-loans for energy efficient appliances or for specific technologies etc. Consumers will make sacrifices by exploring other options available and altering their life-style moderately. ‘Direct load control’ of residential water heaters was a popular tool for peak clipping in US utilities. When supported by TOU tariff from utility incentive for off-peak hour usage the DSM programme gained good response from the participants. Time of use adjustment from participants and sacrifice by way of incentive by the utility resulted into peak reduction and electricity bill reductions and thus created win-win situation for both.

TOU pricing is used as an effective DSM tool by many utilities in developed countries. Similar pricing structures are adopted even by Indian utilities, but at present due to high meter cost it seems possible for HT consumers only. The fallacy in the ‘TOU’ pricing lies with the word ‘Time’. In the true sense time is not the appropriate indicator of the ‘peak hour’ or ‘off-peak hour’ of the grid; ‘frequency’ can be the appropriate indicator. Using this concept a dynamic pricing mechanism called ABT is introduced in 2002-03 in the Indian power industry for interstate transactions to bring in GRID-DISCIPLINE [86].

‘Pricing of Electricity’ is a complex function having its own features. As electricity can not be stored economically on large scale, the ‘Time of use (TOU)’ makes the ‘cost function’ dynamic. There are many hidden factors like power factor, non-linearity, geographical distance and volume, time of usage which are load dependent and contribute to cost function in a dynamic fashion. These factors are not considered rationally in Indian utilities for pricing electricity. A fair pricing structure is necessary to promote energy conservation and DSM. A fair and rational pricing structure might help India to resolve the issue of present power crisis to some extent. Capacity released through DSM however small it might be, it has direct correlation with reliability of the system.

Capacity released through various DSM programmes might be different. CFL promotion programme might release only 600MW as against 2500MW through Single phasing scheme and Feeder segregation scheme. But, during the critical evening peak
period 600MW are quite precious. In the famous California blackout 300MW deficit (0.6%) in 50,000MW grid was the culprit for grid collapse. A relief of 600MW in a 10,000MW MSEDCL system during peak hours would be of great support to the system. The reliability benefits of DSM far outweigh the costs of DSM.

DSM in power sector planning reduces the need for immediate addition of capacity and/or releases capacity at present. The detailed study about Indian utilities and especially about MSEDCL is not yet reported in the literature. The Indian economy is one of the fastest growing economies in the world, which is to be supported by the power sector. This has direct implication on the living standard of the people, hence it is planned to study the Demand Side Management (DSM) and its implications in subsequent chapters.