Chapter 2

Demand Side Management And Price Elasticity Concept

2.1 Introduction

Electricity is the only commodity which can not be stored in bulk. The supply side measures of infrastructure development for additional generation being a long term process involving to overcome the cost factors, regulatory and other obstacles; obvious solution to overcome rising demand is load shedding in case of supply scarcity. Hence, the best possible measure to deal with supply shortage in short run is to implement demand side measures. Demand Side Management (DSM) is an action taken to optimize electricity consumption by means of change in electricity usage so as to have collective benefit for utility as well as consumers. So Demand Side Management program consist of the planning, implementing, and monitoring activities which were designed to encourage consumers to modify their level and pattern of electricity usage [8]. The concept of Demand Side Management percolated in India along with power sector reforms as an alternative to supply side measures. The definition of Demand Side Management as per [64] is "*Reduction in electricity usage by end consumers from their normal consumption pattern; manually or automatically, in response to high UI charges being incurred by the state due to over drawal by the state at low frequency or in response to the congestion charges being incurred by the state for creating transmission congestion or for alleviating a system contingency for which such consumers could be given a financial incentive or lower tariff*".

As stated in previous chapter, Demand Response is one of the focused activity of Demand Side Management [9]. This concept is defined and explained in the following section.

2.2 Demand Response Concept

Demand Response is [65] defined as "*the voluntary and temporary reduction in consumers' demand of electricity when the power system is stressed. It has been elaborated as a non-persistent intentional change in net electricity usage by end-use customers from normal consumptive patterns in response to a request on behalf of, or by, a power and/or distribution/transmission system operator*". This change has been driven by an agreement, potentially financial, or tariff between two or more participating parties.

To encourage consumers for re-arranging their load profile during peak load and off-peak load periods, various incentive and penalty structured tariff schemes are offered [42]. During peak demand period, if the demand on the system reduces, system can be said to have some virtual energy generation which is the available energy due to shifting of loads [66]. This energy can be supplied to the most demanding / critical loads during peak hours. This leads to optimal utilization of available generation resources. The noncritical loads those have been shifted from peak hours help the system to run stable without getting overloaded or within operating limits [67]. As consumers help the system to run smoothly during peak hours, their task is benefited by offering lower prices in other periods of the day compared to prices in the peak load period. Sometimes they are offered some proportional incentives based on amount of participation in demand response program. As the consumers show readiness to shift their consumption based on energy prices, the loads are termed as price elastic. Price Elasticity is the next term to be understood to deal with Demand Response techniques.

2.3 Benefits of Demand Response

Some of the benefits of Demand Response implementation are listed below [68] and [69].

- Cheaper and faster alternative compared to peak load power plant as dispatch capacity of Demand Response schedule is faster than peaking power plant ramp up time. Clean source of energy as no greenhouse and other toxic emissions as Demand Response is based on load reduction or load shifting.

- Reduction in outages and electricity interruption.

- Due to load redistribution, short term capacity of system increases, additional power generation requirement reduces, efficient utilization of the available infrastructure is possible and hence, the cost of infrastructure up-gradation is time being minimized.

- Due to deferred new infrastructure, better utilization of land can be an environmental benefit.

- Consumers have options in terms of prices to be paid.
- Savings in consumer's electricity bill if usage is reduced during peak hours as lower charges are offered during off-peak periods.
- Consumers receive incentives based of tariff plans.
- Improvement in system reliability.

2.4 Methods of Demand Response

Apart from classical method of Direct load control, Demand Response programs are categorized into following two groups [42].

a. Incentive based programs

b. Price based programs

Time-of-Use tariff is offered to Industrial consumers in India [70] which comes under price based Demand Response programs [42]. Under Time-of-Use scheme, different rates are offered based on average generation cost and delivery cost at peak, off-peak and night hours.

If the consumer opts any of the offered Demand Response method, the load termed as an elastic load. The measure of load reduction/ reshuffling with respect to price change/incentive offered is known as "Price Elasticity".

2.5 Price Elasticity of Demand

Price Elasticity of Demand is a microeconomics term which is defined by responsiveness of the demand to change in price [71]. Price Elasticity is represented as unit change in demand with respect ot unit change in price and formulated as eq.(2.1). When on account of price differential the demand / load shifts, it is known as Demand Response based on Price Elasticity. Customer's load reduction or redistribution is modeled by Price Elasticity Matrix of demand [72]. Negative sign of Price Elasticity indicates that consumption will reduce with the increase in the prices and positive sign indicates the reverse case. If the absolute value of elasticity is less than one, demand is said to be inelastic and if it is greater than one, demand is said to be elastic.

$$E = (\Delta Y/Y)/(\Delta X/X) = (\Delta Y/\Delta X)(X/Y) \tag{2.1}$$

Where,

X	Price of commodity
Y	Demand of the commodity
E	Price Elasticity
ΔY	Change in the commodity demand
ΔX	Change in the commodity Price

2.5.1 Price Elasticity Matrix

$$\begin{pmatrix} E_{(1,1)} & E_{(1,2)} & ... & ... & E_{(1,24)} \\ E_{(2,1)} & E_{(2,2)} & ... & ... & E_{(2,24)} \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ . & . & . & . & . \\ E_{(24,1)} & E_{(24,2)} & ... & ... & E_{(24,24)} \end{pmatrix} \tag{2.2}$$

Where,

E Price Elasticity

The 24×24 Price Elasticity Matrix shown in eq.(2.2) has been referred by the studies dealing with generation scheduling, load profiling [73]-[74]. The Price Elasticity matrix is of $n \times n$ size where n is the number of divisions of the daily load profile. Such divisions are based on either peak, off peak and valley periods; or time block wise division of load/demand profile i.e. 24 hours, 48 hours etc. It is composed of "self elasticity" and "cross elasticity" elements [25]. Each column of a Price Elasticity Matrix represents scheduling of loads throughout the day owing to the change in price at the time instance corresponding to the column number.

Self Elasticity

The primary diagonal elements are termed as "self elasticity" elements representing change in demand with respect to change in price at the same instance.

Cross Elasticity

The off-diagonal elements are termed as "cross (cross-temporal) elasticity" of demand as they represent change in demand at the given instance with respect to change in price at other time instance. The concept of cross elasticity is little different in the case of electricity and it has been elaborated by [25] considering "spill over" events. If an event is of a longer duration to fall into two different time blocks, decision to forgo the event in the first block due to the higher prices subsequently reduces consumption in the second block as well. This means that if the duration of an event is of more than an hour, the load reduction due to price increase in the i^{th} hour may reflect load reduction in the $(i+1)^{st}$ hour also. So there exists a possibility of the cross elasticity of electricity consumption turning to a negative value. The overall change in load or demand at time t_i because of change in price through-out the day can be obtained by summation of all the row elements corresponding to t_i as shown in eq.(2.3) [72].

$$\delta(t_i) = \sum_{j=1}^{24} E_{(i,j)} \left(\Delta p_j / p_0\right) \delta_0 \tag{2.3}$$

Where,

$E_{(i,j)}$	Price Elasticity of demand at i^{th} hour with reference to price change at j^{th} hour
δ	Demand of the commodity
p_j	Price of the commodity
δ_0	Demand of the commodity at 0^{th} hour
p_0	Price of the commodity at 0^{th} hour
t_i	Time stamping
i	row index of Price Elasticity matrix
j	column index of Price Elasticity matrix

If price change induces a consumer to reorganize the load without reduction in total energy demand over the entire time frame of say 24 hours, such a Price Elasticity Matrix is called lossless. The following relation shown in eq.(2.4) holds between the elements of each column of the elasticity matrix [75].

$$\sum_{j=1}^{24} E_{(i,j)} = 0, \forall i \tag{2.4}$$

On the contrary, if customer reduces the demand, the corresponding relation is as shown in eq.(2.5).

$$\sum_{j=1}^{24} E_{(i,j)} < 0, \forall i \tag{2.5}$$

Where,

E Elasticity of consumption

The value of self elasticity with increase in price is negative where as the value of cross-elasticity is positive as the reduced load from the highly priced time block gets added to other time blocks having lower prices.

2.5.2 Necessity of Estimating Price Elasticity

The Price Elasticity concept has been integrated with electricity market operation (wholesale and retail), ancillary service, consumer demand and benefit function, demand profile improvisation, reliability study and generation scheduling [72], [76]-[77]. Majority of the studies which have estimated price elasticity of electricity consumption are from the field of economics, energy and public policy [13]-[22]. Such estimations of demand elasticities are based on cross sectional data, time series data, panel data and time divisional market data. Except few like [23] who developed formula to get self and cross elasticity and [24] who referred annual report of Power Smart Pricing (PSP) [25], most of the studies dealing with load/demand profile modification have either "set / assumed" the price elasticity or "modified" the referred values. Reliability of such modifications / assumptions is limited to the simulations only as the factual estimation becomes necessary when it comes to the policy improvisation i.e. to have correction in the electricity consumption pattern by modifying the existing tariff mechanism. This is because of the fact that the load profiles of various consumer categories in different demographic areas differ due to the economic growth, tariff structure and availability of substitutes.

Electricity can't be stored in bulk like other commodities. Consumption of electricity is considerably different than the other daily necessities having an extensive scope of substitution like food, clothing and even transportation to some extent.The electricity consumption pattern has undergone a change in India and the demand of fuels like kerosene, gas and firewood as a substitute for electricity has significantly reduced [19]. The consumption elasticity with respect to Gross Domestic Product (GDP) has been less than 1 consecutively for $8^{th}, 9^{th}$ and 10^{th} national electricity plans [1]. It can be inferred that there will be a less proportional rise in electricity consumption with respect to GDP. GDP is the indicator of income and the corresponding elasticity at an aggregate level is less than 1. This indicates that electricity has become a necessity of life.

The above stated facts indicate that the estimations of income elasticity as well as the cross elasticity of substitution due to other commodities would not give an insight into changing load profiles. Thus, only the Price Elasticity remains to be estimated prior to evolving a methodology for load profile modification.

Price Elasticity estimation for electricity consumption can be done at national level, regional level, state level, distribution level and at the consumer category level based on the requirement and availability of data. Studies dealing with the modification of demand/load profile can be segregated into state specific, Discom specific and consumer category specific. If heterogeneous feeder is present, it can be considered as the representative of the consumer category which has loading share of more than 80% [27]. The reason for conducting study directly at the state level is that the state wise consumption varies based on various local factors. Discom participates in energy market based on daily fluctuations. It can sell electricity at a higher rate and purchase at lower rate so as to earn profit. To avail chances of earning more profit, it is required to have accurate load estimation with least fluctuations. To avoid chances of purchase at high prices at peak periods, strategy is required to be developed to flatten the load profile by offering flexible tariff. As stated above, such possibility can be examined based on the knowledge of the Price Elasticity of electricity demand.

The Open Access consumers trade in energy market with the criterion of maintaining the minimum and maximum drawal. The frequency linked Unscheduled Interchange mechanism is to be used as the grid balancing mechanism and not as the mechanism for real time electricity transactions [6]. The Time-of-Use mechanism giving block specific tariff is present but limited to water works and High Tension (HT) [70] with constraints to maintain consumption level as mentioned above. Hence, prediction of Price Elasticity based on time specific price change is difficult.

The studies for estimating Price Elasticity for electricity consumption in Indian context could be listed as [19], [14] - [26]. The study presented herein resembles with [14] in terms of consumer selection and with [19] in terms of the price selection methodology. The purpose of tariff improvisation is common to all the studies except [26] as it was based on energy projections and greenhouse gas abatement. Lagged values of variables have been considered by [19] to incorporate the bearing of lagged values on present aggregate consumption of Punjab state. It has also stated the justifiable reasons for not estimating the cross elasticity of substitutes. The results presented by [14] are at national level for all major consumer categories without considering the lagged effect as the estimates even with the one year lagged effect were insignificant. The seasonal Price Elasticity estimates by [16] are at national level and by [17] are at state level. Both the studies were based on the regional data provided by National Sample Survey Organization (NSSO).

The studies carried out were based on the data which is almost a decade older. Over this period, the Indian power sector has undergone a considerable change. In this background, re-evaluation / re-estimation of Price Elasticity is required. Estimation of Price Elasticity has been highlighted as one of the key parameter for load profile modification based on tariff structure and for increasing the penetration of ToU / ToD tariff into the existing consumer categories [27]. In the backdrop of the above said, using the Regulatory Information Management (RIM) reports published by Gujarat Electricity Regulatory Commission (GERC) for five distribution companies of Gujarat namely MGVCL, PGVCL, DGVCL, UGVCL and TORRENT POWER, estimation of Price Elasticity of electricity is done for the five categories of consumers considering that it may facilitate in improving the Demand Side Management activities and existing tariff structure.

2.6 Mathematical Model

The double log / constant elasticity model used to estimate demand elasticities for the econometric studies is represented by eq.(2.6) [71] and [78].

$$\ln Y = \alpha + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + ... + \epsilon \tag{2.6}$$

Y is the dependent variable, in this case it is electricity consumption; $X_1, X_2, X_3...$ are the independent variables say price of commodity (electricity herein), income, price of substitution commodity and the β_1, β_2, β_3... values are the elasticity co-efficients namely price elasticity, income elasticity and cross elasticity of substitution. The physical significance of the intercept α and the error term ϵ are not necessarily to be explained herein as the purpose of the study is estimation of Price Elasticity using available data and no other in depth analysis. The following derivation corroborates how β i.e.

slope of linear relation between dependent and independent variables, represents the demand elasticity. For ease of understanding, only two variables i.e. consumption and electricity price are taken into consideration.

Considering the general case of exponentially drooping demand curve [71], the relation between electricity consumption i.e. Y and price i.e. X can be represented by eq.(2.7).

$$Y = \beta X^{\beta_1} \tag{2.7}$$

Taking natural logarithm of the above equation, a linear relation shown in eq.(2.8) is obtained.

$$\ln Y = \ln \beta + \beta_1 \ln X \tag{2.8}$$

As β is constant, $\ln \beta$ is also a constant which is defined as α. Hence, eq.(2.8) can be re-written as (2.9).

$$\ln Y = \alpha + \beta_1 \ln X \tag{2.9}$$

The functional relation between consumption X and price Y can be represented by eq.(2.10).

$$Y = f(X) \tag{2.10}$$

Now,

$$\left(\frac{d \ln f(X)}{dX}\right) = \left(\frac{d \ln f(X)}{d \ln X}\right)\left(\frac{d \ln X}{dX}\right) \tag{2.11}$$

$$\left(\frac{1}{f(X)} \times f^{'}(X)\right) = \left(\frac{d \ln f(X)}{d \ln X}\right)\left(\frac{1}{X}\right) \tag{2.12}$$

$$\left(\frac{1}{f(X)} \times \left(\frac{df(X)}{dX}\right)\right) = \left(\frac{d \ln f(X)}{d \ln X}\right)\left(\frac{1}{X}\right) \tag{2.13}$$

$$\left(\frac{X}{f(X)}\right)\left(\frac{df(X)}{dX}\right) = \frac{d\ln f(X)}{d\ln X} \tag{2.14}$$

Substituting eq.(2.9) and eq.(2.10) in eq.(2.14), we get

$$\left(\frac{dY}{dX}\right)\left(\frac{X}{Y}\right) = \frac{d\ln Y}{d\ln X} \tag{2.15}$$

Rearranging eq.(2.15), we get

$$\left(\frac{dY}{Y}\right)/\left(\frac{dX}{X}\right) = \frac{d\ln Y}{d\ln X} \tag{2.16}$$

It is seen that the left side term of eq.(2.16) represents the formula of Price Elasticity shown in eq.(2.1) and right side term represents the slope of the linear relation between the log values of consumption and price of electricity as shown in eq.(2.6).

2.7 Data Availability

To estimate the Price Elasticity of major consumer categories, data are obtained from the quarterly Regulatory Information Management reports published by Gujarat Electricity Regulatory Commission for the period from 2006-07 to the first two quarters of 2012-13 for all the distribution companies [79]. Railways being the exceptional case (reduction of dependency on Discoms since 2014 due to granted Open Access permission [55]), it is exempted from the analysis. In few Regulatory Information Management reports, no proper bifurcation is given between Extra High Tension (EHT) and Railways. Additionally, the industrial consumers above 66kV utilize the Open Access facility and hence, dependency on Discom is again not an important aspect. The category "Others" include street lighting and water works. Option for demand reduction is not applicable for street lighting and

Time-of-Use tariff is already applicable to water works. Hence, these two categories i.e. EHT/Railways and Others, are excluded from analysis.

Initial seven quarterly data for the agricultural category are not be in line with the rest as it is indicated that the connections are metered from the fourth quarter of 2007-08. The data for commercial and industrial consumer categories are considered up to second quarter of 2011-12 for MGVCL and DGVCL as these categories were regrouped and rearranged from the next quarter as per the tariff order of Gujarat Electricity Regulatory Commission. Rest of the Discoms have provided the consumption details keeping the same categories in their Regulatory Information Management reports.

Due to consideration of quarterly data, effects of seasonality may be present in the estimations. To avoid the said effect, Price Elasticity has also been estimated considering the yearly lagged values of consumption in quarterly fashion. The modified econometric model with the inclusion of lagged consumption is represented by eq.(2.17).

$$\ln Y = \alpha + \beta_1 \ln X + \beta_2 \ln Y_y \tag{2.17}$$

The variable Y represents electricity consumption, X represents price, Y_y represents lagged values of consumption and β_1 represents the Price Elasticity.

2.7.1 Possibility of Upward Bias in Price Elasticity Estimates

When aggregate values are considered for analysis, results introduce an upward bias [80]. The reason for getting upward biased results can be explained by considering a simple example. Say consumer A has 10 units of consumption and pays Rs. 100. Consumer B consumes 15 units and pays Rs. 200. Considering the loss of 5 units, the Discom supplies 30 units and realizes Rs. 300. Considering constant slope of the demand curve i.e. the ratio of price to demand is higher at the consumer side i.e. 300/25 than the ratio at the Discom end i.e. 300/30. As the data considered in this study are aggregate values, the estimates of Price Elasticity resulted are said to have some upward bias.

2.8 Result

As per basic concept of Price Elasticity [71] and [78],

1. If estimates of Price Elasticity are poor, the demand is said to be inelastic.
2. If Price Elasticity is negative, demand decreases with increase in price.
3. If Price Elasticity is positive, demand increases with increase in price. But, for the case of Electricity, this point can be interpreted as "irrespective of the price rise, demand remains unaltered or no reduction is observed". This is because, electricity is a necessity, huge storage like other commodities for future use is not possible and hence, irrespective of prices, usage is inevitable.

The results are listed in Table 2.1. The coefficient of correlation "r" represents the degree of association between aggregate price and consumption. For the purpose of explaining the estimates of Price Elasticity, the range of correlation coefficient has been divided into subsets as 0 to 0.3 for no/little association, 0.3 to 0.6 for moderate association and 0.6 to 1 for considerable association between the variables. Out of 20 values of "r" for total 4 Discoms and 5 consumer categories, only 5 values fall in little association category, 2 values fall in moderate association range and remaining 13 values fall in considerable association range.

As per the data pertaining to GDP and urbanization of Gujarat [81]-[82], it can be emphasized that Electricity is a necessity. Hence, majority of the results portrayed in Table 2.1 having poor value of Price Elasticity are justified as per basic concept 1. For UGVCL, all Price Elasticity estimates being negative are acceptable as per basic concept 2. For MGVCL, PGVCL and DGVCL, positive Price Elasticity estimates can be acceptable stating following justifications for basic concept 3.

1. In case of Agricultural category, consumers receive very high subsidy.
2. For the residential category, as the GDP is increasing [81]-[82], possibility of positive estimates of Price Elasticity is highly acceptable.
3. For the industrial consumers, majority of high end consumers as getting diverted to Open Access, possibility of responsiveness to Discom price rise is very less.

Additionally, the un-metered consumption is burdensome on Discoms and metered consumers. Hence, chances of deviation of Price Elasticity estimates from theoretical concept are justifiable as stated above.

Table 2.1: Price Elasticity Analysis

Consumer Category	**HT Industrial**	**Residential**	**Commercial**	**LT Industrial**	**Agricultural**
			MGVCL		
Price Elasticity	-0.55	0.05	-0.08	-0.44	-0.13
Correlation co-efficient (r)	0.23	0.76	0.8	0.85	0.67
			UGVCL		
Price Elasticity	-0.1	-0.13	-0.15	-0.4	-0.01
Correlation co-efficient (r)	0.19	0.96	0.86	0.49	0.99
			DGVCL		
Price Elasticity	0.17	-0.1	-0.59	-0.28	-0.09
Correlation co-efficient (r)	0.31	0.65	0.55	0.41	0.86
			PGVCL		
Price Elasticity	-0.4	0.93	-1.47	-2.3	0.02
Correlation co-efficient (r)	0.58	0.69	0.83	0.69	0.69

2.9 Conclusion

Depending upon the data pertaining to each distribution company of Gujarat state, Price Elasticity values for major consumer categories have been estimated. The variations in the results highlight that Demand Side Management technique and tariff policy can't be decided centrally, it is needed to treat every Discom separately based on consumers' sub-categories and the demographic conditions. At this stage, a detailed study for estimating Price Elasticity Matrix pertaining to the Time-of-Use tariff structure which is applicable to the High Tension consumers could be performed in future as per the availability of historical data. Such study can be extended to Open Access consumers when deviation in consumption with real time pricing is given as an option. While doing the same, it is necessary to pay attention to the consumption pattern of every consumer category, scarcity value of electricity and subsidy provisions.

Hence, in case of the Indian power sector where flexibility in consumption with reference to real time pricing is absent and Time-of-Use structure is limited to High Tension consumers only, Price Elasticity estimates with aggregate data can not be considered as the only tool for implementing Demand Side Management.