Estimation of Price Elasticity of Electricity to evolve a methodology for implementing load management programs at Discom level, in India.

[1]Varada J. Tambe, [2]S K. Joshi

Electrical Engineering Department,
Faculty of Technology and Engineering,
The Maharaja Sayajirao University of Baroda, Vadodara, India.
[1]tambe.varada@gmail.com, [2]skjoshi@ieee.org

***Abstract*- Considering the aggregate price of electricity at a Distribution company (Discom) level, Price Elasticity (PE) estimation for various consumer categories has been presented in this paper. This facilitates the load profile management activities for enhancing Demand Side Management (DSM) in the Indian context**.

***Keywords*-Electricity, Price Elasticity, Discom, Consumer category**

I. INTRODUCTION

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 [1], [2], [3], [4], [5], [6], [7], [8]. Majority of the studies which have estimated price elasticity of electricity consumption are from the field of economics, energy and public policy [9], [10], [11], [12], [13], [14], [15], [17], [16], [18], [19]. Such estimations of demand elasticities are based on cross sectional data, time series data, panel data and time divisional market data. Except few like [6] who developed formula to get self and cross elasticity and [20] who referred annual report of Power Smart Pricing (PSP) [21], 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 e.g. 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.

The studies for estimating Price Elasticity for electricity consumption in Indian context could be listed as [10], [12], [13], [15], [22]. The study presented herein resembles with [10] in terms of consumer selection and with [15] in terms of the price selection methodology. The purpose of tariff improvisation is common to all the studies except [22] as it was based on energy projections and greenhouse gas abatement. Lagged values of variables have been considered by [15] 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 [10] 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 [12] are at national level and by [13] are at state level. Both the studies were based on the regional data provided by National Sample Survey Organization (NSSO). The studies carried out till date are based on the data which is almost a decade older. Over this period, the Indian power sector has undergone a considerable change as a result of transitional economy. In this background, revaluation / re-estimation of Price Elasticity is required. Under the subtitle "Steps for increasing penetration of Time of Dy (ToD) tariffs in existing consumer categories", the Price Elasticity is highlighted as one of the key parameters for predicting load profile modification based on tariff structure [23]. This paper attempts the estimation of Price Elasticity of electricity for the five categories of consumers using 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. This would facilitate in improving the existing tariff system and the DSM activities as rationalizing the tariff structure, reducing subsidies and bringing the tariff in line with purchase cost, modifying the load curve / consumption pattern etc have been highlighted as the existing challenges by [24].

This paper highlights the need of Price Elasticity estimation in the introduction part, defines the concept of Price Elasticity, explains the mathematical model used for the said estimation in brief, highlights the need of PE estimation at Discom level considering recent Indian power scenario, presents the estimated results and ends with concluding remarks.

II. PRICE ELASTICITY

Price Elasticity of demand is the measure of the responsiveness of the demand to its price. It is defined by percentage change in the demanded quantity with respect to the percentage change in its price [25]. Negative sign of PE 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. The Price Elasticity is formulated as,

$$PE = (\Delta Y / Y)/(\Delta X / X) = (\Delta Y / \Delta X) \times (X / Y) \quad (1)$$

OR

$$PE = (dY/dX) \times (X/Y) \quad (2)$$

Where X is the price, Y is the demand and Δ / d symbolizes change in the variable.

The PE matrix referred by the studies dealing with generation scheduling, load profiling 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. It is composed of "self elasticity" and "cross elasticity" elements. The primary diagonal elements are termed as "self elasticity" elements representing change in demand with respect to change in price at the given instance itself. 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 [26].

In general, the self elasticity of demand is considered as negative except Giffen goods and cross elasticity is considered as positive with increase in the price of a commodity. The concept of cross elasticity is little different in the case of electricity and it has been elaborated by [21] by 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.

III. MATHEMATICAL MODEL

The double log / constant elasticity model used to estimate demand elasticities for the econometric studies is represented by (3) [25], [27].

$$\ln Y = \alpha + \beta_1 . \ln X_1 + \beta_2 . \ln X_2 + \beta_3 \ln X_3 + ... + \varepsilon \quad (3)$$

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 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 explained herein as the purpose of this paper is estimation of PE using available data and no other in depth analysis. The following derivation corroborates how the 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, the relation between electricity consumption and price can be represented by (4) [27].

$$Y = \beta . X^{\beta_1} \quad (4)$$

Taking natural logarithm of the above equation, a linear relation shown in (5) is obtained which is similar to the expression in (2).

$$\ln Y = \ln \beta + \beta_1 \ln X = \alpha + \beta_1 \ln X \quad (5)$$

The functional relation between consumption and price can be represented by (6).

$$Y = f(X) \quad (6)$$

$$d(ln\, f(X))/dX = (d\, lnf(X)/d\, lnX)(d\, lnX/d\, X) \quad (7)$$

$$\left(\frac{1}{f(X)}\right)(df(X)/dX) = (d\ ln\, f(X)/d\ ln\, X)\left(\frac{1}{X}\right) \quad (8)$$

$$\left(\frac{X}{f(X)}\right)\left(\frac{df(X)}{dX}\right) = (d\, ln\, f(X)/d\, ln\, X) \quad (9)$$

Substituting (5) in (8),

$$(d\, Y/d\, X)(X/Y) = (d \ln Y/d \ln X) \quad (10)$$

It is seen that the left side term of (10) represents the formula of Price Elasticity and right side term represents the slope of the linear relation between the log values of consumption and price of electricity.

IV. NEED OF PRICE ELASTICITY ESTIMATION AT DISCOM LEVEL-INDIAN CASE

Electricity cannot 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. As stated above, 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. This has been very well explained by [15].

The consumption elasticity with respect to GDP has been less than 1 consecutively for 8th, 9th and 10th national electricity plans [28]. 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.

PE 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% [23]. 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 except for the high end consumers who avail open access. 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 tariff modification. As stated above, such possibility can be examined based on the knowledge of the Price Elasticity of electricity demand. Considering the existing Indian scenario, it is not possible to estimate PE matrix for hourly consumption due to the absence of full fledged real time electricity markets. Although there exist few intra-day transactions, they are irregular in nature [29], [30]. The open access transactions are limited to the consumers having capacity above 1MW [31]. Moreover, the frequency linked Unscheduled Interchange (UI) mechanism is to be used as the grid balancing mechanism and not as the mechanism for real time electricity transactions [32]. The ToD mechanism is present but limited to water works and High Tension (HT) consumers and hence, the analysis based on such data will be limited to the said consumer category only.

V. Data and Discussion on the Results of Price Elasticity Estimation

To estimate the Price Elasticity of major consumer categories, data are obtained from the quarterly RIM reports published by GERC for the period from 2006-07 to the first two quarters of 2012-13 for all the distribution companies [33]. Railways being the exceptional case, it is exempted from the analysis. Initial seven quarterly data for the agricultural category may 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 GERC. Rest of the Discoms have provided the consumption details keeping the same categories in their RIM 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 (11).

$$\ln Y = \alpha + \beta_1 \ln X + \beta_2 \ln Y_{pqy} \qquad (11)$$

The variable Y_{pqy} represents yearly lagged values of consumption in quarterly fashion. The intended results are listed in Table 1 to 5.

Table 1. Price Elasticity Analysis of MGVCL

Consumer Category	Price Elasticity	Coefficient of determination (r2)	Correlation coeffcient (r)	t-value*		Price Elasticity	Coefficient of determination (r2)	Correlation coeffcient (r)	t-value*
	Without lagged consumption					*With lagged consumption*			
High Tension (HT) (Industrial)	-0.14	0.00	0.03	-0.15		-0.55	0.05	0.23	-0.59
Residential	0.34	0.05	0.23	1.13		0.05	0.58	0.76	0.22
Commercial	0.40	0.01	0.10	0.44		-0.08	0.64	0.80	-0.17
Low Tension 1 (LT) (Industrial)	0.70	0.08	0.28	1.28		-0.44	0.73	0.85	-1.50
Low Tension 2 (Agriculture)	-0.28	0.18	0.42	-2.27		-0.13	0.45	0.67	-1.22

Table 2. Price Elasticity Analysis of PGVCL

Consumer Category	Price Elasticity	Coefficient of determination (r2)	Correlation coeffcient (r)	t-value*		Price Elasticity	Coefficient of determination (r2)	Correlation coeffcient (r)	t-value*
	Without lagged consumption					*With lagged consumption*			
High Tension (HT) (Industrial)	-0.30	0.19	0.43	-2.39		-0.40	0.34	0.58	-3.08
Residential	0.93	0.48	0.69	4.79		0.93	0.48	0.69	3.85
Commercial	-0.68	0.03	0.19	-0.95		-1.47	0.69	0.83	-2.91
Low Tension 1 (LT) (Industrial)	-2.29	0.35	0.59	-3.63		-2.30	0.47	0.69	-2.98

Low Tension 2 (Agriculture)	-0.39	0.16	0.40	-2.16		0.02	0.47	0.69	0.08

TABLE 3. PRICE ELASTICITY ANALYSIS OF DGVCL

Consumer Category	Price Elasticity	Coefficient of determination (r2)	Correlation coeffcient (r)	t-value*		Price Elasticity	Coefficient of determination (r2)	Correlation coeffcient (r)	t-value*
	Without lagged consumption					*With lagged consumption*			
High Tension (HT) (Industrial)	0.22	0.09	0.31	1.61		0.17	0.10	0.31	1.30
Residential	0.03	0.00	0.03	0.14		-0.10	0.43	0.65	-0.56
Commercial	0.05	0.00	0.04	0.17		-0.59	0.30	0.55	-1.83
Low Tension 1 (LT) (Industrial)	0.10	0.02	0.13	0.59		-0.28	0.17	0.41	-1.42
Low Tension 2 (Agriculture)	-0.07	0.01	0.10	-0.51		-0.09	0.73	0.86	-1.14

TABLE 4. PRICE ELASTICITY ANALYSIS OF UGVCL

Consumer Category	Price Elasticity	Coefficient of determination (r2)	Correlation coeffcient (r)	t-value*		Price Elasticity	Coefficient of determination (r2)	Correlation coeffcient (r)	t-value*
	Without lagged consumption					*With lagged consumption*			
High Tension (HT) (Industrial)	-0.17	0.02	0.15	-0.78		-0.10	0.04	0.19	-0.36
Residential	0.00	0.00	0.00	-0.01		-0.13	0.92	0.96	-1.49
Commercial	-0.24	0.03	0.17	-0.84		-0.15	0.74	0.86	-1.01
Low Tension 1 (LT) (Industrial)	-0.37	0.31	0.56	-3.28		-0.40	0.24	0.49	-1.82
Low Tension 2 (Agriculture)	-0.24	0.22	0.47	-2.64		-0.01	0.97	0.99	-0.56

TABLE 5. PRICE ELASTICITY ANALYSIS OF TORRENT POWER

Consumer Category	Price Elasticity	Coefficient of determination (r^2)	Correlation coeffcient (r)	t-value*		Price Elasticity	Coefficient of determination (r^2)	Correlation coeffcient (r)	t-value*
	Without lagged consumption					*With lagged consumption*			
High Tension (HT) (Industrial)	-2.05	0.64	0.80	-6.20		-2.32	0.74	0.86	-3.19
Residential	1.32	0.18	0.43	2.21		0.58	0.85	0.92	1.82
Commercial	-0.94	0.07	0.26	-1.25		-0.36	0.64	0.80	-0.70
Low Tension 1 (LT) (Industrial)	6.19	0.58	0.76	5.55		6.64	0.66	0.81	4.42
Low Tension 2 (Agriculture)	0.99	0.66	0.82	6.60		0.97	0.69	0.83	5.10

* estimated at 95% confidence interval

Electricity is a daily necessity and will never be considered as the "Giffen good". Hence, though some of the PE estimates are positive, they are treated as the absolute values. The coefficient of correlation "r" represents the degree of association between aggregate price and consumption. For the purpose of explaining the estimates, the values of "r" are divided in three ranges as 0 to 0.3 for no/little association, 0.4 to 0.6 for moderate association and

0.6 to 1 for considerable association between the said variables. Except the highlighted seven values falling into little and moderate association category, remaining values predict that the consumption of electricity is fairly associated with the prices offered in the case of estimates with lagged value. The degree of freedom has reduced by 5 due to consideration of lagged values. This is because the initial four quarters are dropped due to unavailability of quarterly data of previous year i.e. 2005-06 and inclusion of one more co-efficient i.e. β_2 into the model on account of the lagged consumption.

The studies by [12], [13] were limited to household consumers and based on unit values payable by the consumers. Such values introduce (an upward) bias [34] in the estimates as there is a variation between aggregate level data and individual consumer specific data. The prices considered herein are the aggregate level prices obtained from the revenue realization of Discom. 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. $(\Delta Y / \Delta X)$, the ratio of price to demand i.e. (X / Y) is higher at the consumer side i.e. 300/25 than the ratio at the Discom end i.e. 300/30. In addition to that the NSSO data are based on recall while the data used for analysis herein, are directly obtained from RIM reports of Distribution Company.

Reason mentioned for considering unit values (average price) by [12] was that the period under consideration had the single part tariff structure. Absence of fixed charges in such a case nullifies the probability of simultaneity problem occurring in the econometric estimation. The two part tariff is present in India since 1992-93. Furthermore, the estimates were presented at national level while the case presented herein is at distribution company level. The majority of the data used by earlier studies were based on the NSSO survey conducted before the restructuring of State Electricity Boards (SEBs). For the presented study, the data considered are of 6 years in a quarterly fashion for all the major categories of consumers after the restructuring of SEB of Gujarat. Depending upon the demographic and economic conditions, the estimates of Price Elasticity are resulted i.e. PGVCL has an agricultural load of about 35% of the total consumption where as DGVCL has very high industrial load of almost 75% of the total consumption (both HT and LT) [35].

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 are due to the economic and demographic conditions. As the purpose of the paper was to estimate Price Elasticity only, no econometric analysis has been conducted for the viability of the results. Such analysis may be conducted as per need at a later stage. A detailed study for estimating Price Elasticity matrix pertaining to the Time of Day tariff structure which is applicable to the High Tension consumers could be performed in future on the availability of data. This will help in developing a Price Elasticity matrix of 3×3 size as the daily load profile is divided into three parts as normal, peak and off peak demand periods.

VI. REFERENCES

[1] D. S. Kirschen, G. Strbac, P. Cumperayot, and D. de Paiva Mendes, "Factoring the elasticity of demand in electricity prices," Power Syst. IEEE Trans. On, vol. 15, no. 2, pp. 612–617, 2000.

[2] Wang, "A Demand Responsive Bidding Mechanism with Price Elasticity Matrix in Wholesale Electricity Pools," MIT, 2009.

[3] Maqbool, S.D., Ahamed, T.I., Al-Ammar, E., Malik, N.H., 2011. Demand response in Saudi Arabia, in: Electric Power and Energy Conversion Systems (EPECS), 2011 2nd International Conference On. pp. 1–6.

[4] K. Dietrich, J. M. Latorre, L. Olmos, and A. Ramos, "Demand response and its sensitivity to participation rates and elasticities," in Energy Market (EEM), 2011 8th International Conference on the European, 2011, pp. 717–716.

[5] N. Venkatesan, J. Solanki, and S. K. Solanki, "Market optimization for microgrid with Demand Response model," in North American Power Symposium (NAPS), 2011, 2011, pp. 1–6.

[6] M. P. Moghaddam, A. Abdollahi, and M. Rashidinejad, "Flexible demand response programs modeling in competitive electricity markets," Appl. Energy, vol. 88, no. 9, pp. 3257–3269, 2011.

[7] H. A. Aalami, J. Khodaei, and M. Fard, "Economical and technical evaluation of implementation mandatory demand response programs on Iranian power system," in Research and Development (SCOReD), 2011 IEEE Student Conference on, 2011, pp. 271–276.

[8] A. Abdollahi, M. P. Moghaddam, M. Rashidinejad, and M. K. Sheikh-El-Eslami, "Investigation of economic and environmental-driven demand response measures incorporating UC," Smart Grid IEEE Trans. On, vol. 3, no. 1, pp. 12–25, 2012.

[9] T. H. Stevens and G. Adams, "Testing for changes in the price elasticity of residential electricity demand," Northeast. J. Agric. Resour. Econ., vol. 15, no. 2, pp. 123–129, 1986.

[10] R. K. Bose and M. Shukla, "Elasticities of electricity demand in India," Energy Policy, vol. 27, no. 3, pp. 137–146, 1999.

[11] A. Chaudhry, "A Panel Data Analysis of Electricity Demand in Pakistan," Lahore J. Econ., vol. 15, no. Special Edition, pp. 75–106, 2001.

[12] M. Filippini and S. Pachauri, "Elasticities of electricity demand in urban Indian households," Energy Policy, vol. 32, no. 3, pp. 429–436, 2004.

[13] A. Vete, "Price elasticity of Electricity: The case of Urban Maharashtra," Energy Policy, vol. 27, pp. 2350–2356, 2005.

[14] M. A. Bernstein, J. M. Griffin, and S. Infrastructure, Regional differences in the price-elasticity of demand for energy. National Renewable Energy Laboratory, 2006.

[15] N. Bhargava and S. Gupta, "An Econometric Analysis of Demand for Electricity in Punjab," in 43rd Annual Conference of The Indian Econometric Society at Indian Institute of Technology (IIT) Bombay, 2007.
[16] M. G. Lijesen, "The real-time price elasticity of electricity," Energy Econ., vol. 29, no. 2, pp. 249–258, 2007.
[17] S. Borenstein, "To what electricity price do consumers respond? Residential demand elasticity under increasing-block pricing," Prelim. Draft April, vol. 30, 2009
[18] S. Fan and R. J. Hyndman, "The price elasticity of electricity demand in South Australia," Energy Policy, vol. 39, no. 6, pp. 3709–3719, 2011.
[19] M. Filippini, "Short-and long-run time-of-use price elasticities in Swiss residential electricity demand," Energy Policy, vol. 39, no. 10, pp. 5811–5817, 2011.
[20] N. Venkatesan, J. Solanki, and S. K. Solanki, "Demand response model and its effects on voltage profile of a distribution system," in Power and Energy Society General Meeting, 2011 IEEE, 2011, pp. 1–7.
[21] PSP, "Annual Report, April 27, 2010, Prepared by Summit Blue Consulting, Submitted to Ameren Illinois Utilities," 2009.
[22] H. Gundimeda and G. Köhlin, "Fuel demand elasticities for energy and environmental policies: Indian sample survey evidence," Energy Econ., vol. 30, no. 2, pp. 517–546, 2008.
[23] FoR, "Tariff revision assessment for financial viability of DISCOM and comparison of approaches," Forum of Regulators, India, 2010.
[24] MGVCL, 2011. BUSSINESS PLAN FOR MYT. SECOND CONTROL PERIOD FY 2011-12 TO 2015-16. Gujarat, India.
[25] Salvatore, D., 2006. Microeconomics: Theory and Applications, 4th Edition. Oxford University Press.
[26] V. J. Tambe and R. Roy, "A critical review on Demand Response scenario," in 2012 11th International Conference on Environment and Electrical Engineering (EEEIC), 2012, pp. 758–763.
[27] Gujarati, D., 2003. Basic Econometrics, 4th Edition. McGraw Hill.
[28] GoI, "Annual Report 2011-12 On the Working of State Power Utilities and Electricity Departments," Power and Energy Division, Planning Commission, India, 2011.
[29] IEX, http://www.iexindia.com (accessed, 2013)
[30] PXIL, http://www.powerexindia.com/pxil (accessed, 2013)
[31] A. Singh, "Towards a competitive market for electricity and consumer choice in the Indian power sector," Energy Policy, vol. 38, no. 8, pp. 4196–4208, 2010.
[32] CERC, "Deviation settlement mechanism," Central Electricity Regulatory Commission, India, Extraordinary Memorandum, 2013.
[33] GERC, http://www.gercin.org (accessed, 2013)
[34] J. Gibson, B. Kim, and S. Rozelle, "An Empirical Test of Methods for Estimating Price Elasticities from Household Survey Data," 2004.
[35] IIM-A, "Energy Conservation and Commercialization in Gujarat. Report on Demand Side Management (DSM) in Gujarat," India, 2009.