Chapter 6

Cross Subsidy Reduction from Tariff

6.1 Introduction

As stated in earlier chapters, Indian electricity tariffs are not in-line with the Cost-of-Service (CoS) and hence, Industrial consumers paying much higher charges (which include cross-subsidy) in comparison with the cross subsidized categories voyage towards open access which lowers the revenue collection of utility. Along with the Industrial consumers, one of the biggest consumer of electricity, the Indian railways, has also started withdrawing their huge quantum of load from the utility service and have entered into energy market [55]. Additionally, the state government is burdened with direct subsidy to the agricultural sector and there is always a delay observed or debate about reception of the said subsidy [109]. Due to these major revenue reception issues, the utilities have started facing financial scarcity. For utilities to sustain in the reforming power sector, the tariff and subsidy pattern are needed to be focused at and hence, under the functional segregation of Discom [110], cross subsidy reduction is highlighted as a necessity to have efficient electricity retail market. On this line of Cross Subsidy reduction, a basic model pertaining to Punjab state has been presented in [63] where the gap between Cost-of-Service and Average Billing Rate (ABR) is tried to bridge. The major flaw of the model is tried to overcome herein by introducing tariff constraints and the utility is also given some benefit in terms of profit at the end of every year under the policy tenure.

All Industrial and commercial consumers are charged more than their Cost-of-Service [63]. The excess amount paid is termed as cross-subsidy which compensates the lower revenue recovery due to cross-subsidized consumers like agricultural and residential.

As far as the international scenario is concerned, necessity of tariff structure rationalization is accepted by all the countries. Tariff in line with marginal cost and transparency in pricing is always desired. In the studies pertaining to China [58], Japan [59], Russia [60], Tehran [61]; it is commonly concluded that the Ramsey pricing structure is a good economical option but the hurdle pertaining to its implementation is existing policies of irrational tariff. It is mentioned to reduce industrial tariff and increase in residential tariff with subsidy abolition. But such abolition is practically impossible in the transitional economies like India where societal welfare and government policies for lifeline consumer tariffs can never go hand in hand. Hence, the only option needed to be thought at is to reduce subsidies along with utility benefit so as to have win-win situation in the existing environment. Considering the Philippine's case, in cross subsidy reduction process, rules for universal charge method are well defined in the Electric Power Industry Reform Act (EPIRA) [62]. On the same line, Forum of Regulators (FoR), India has published a report to roll out the cross subsidy component by incorporating Universal Charge (UC) in addition to tariff [63]. The said report highlights the adverse effects of cross subsidization and presents an approach to reduce cross subsidy based on the studies conducted on various state specific data & international scenario. Though, the report does not portray the bifurcation of the universal charge as defined in [62]. So much study and analysis is needed in this area if such policy is required to be suggested to the utilities.

Looking to the various studies conducted over Indian scenario, it is clear that the assistance by the government to safeguard the utility to recover from dues of banks is dangerous to economy [111]. In the developing countries, the subsidies are dominant [112]. It is narrated in [3] to charge tariff reflecting efficient Cost-of-Service to agricultural sector beyond pre-defined level of consumption and subsidy should be delivered to the identified categories directly in terms of cash or electronically. The outcome of [112] and [113] is on the same line stating that the subsidy must go directly to the targeted group. The adverse effects of cross subsidization in agricultural sector is presented in [114] and suggestion is to make the electricity consumption rationalized. The impact of Open Access which is the major trend changer reform in power sector, has not been incorporated in [112], [113] and [115]. Open Access facilitated the HT Industrial consumers having demand higher than 1 MW to opt the alternative supplier i.e. other than utility and achieve a considerable amount of saving due to lower rates payable than the rates set by utility. Hence, it is high time for the utility to move towards rationalized tariff structure. Majority of the studies present aggregate scenario of the country. But looking to the report [63], it is advisable to study the state specific scenario. Hence, as said herein above, it is tried to modify the model presented in [63] by incorporating tariff constraints on every category based on the guidelines given under [3]. The major difference between the two models is that the basic model [63] nullifies the effect of Cross Subsidy at the end of tenure considered where as the model proposed herein tries to reduce the Cross Subsidy and tries to limit tariff rise going beyond acceptable limit.

6.2 Basic Model and Recommended Modifications

In the model presented by [63], total 23 sub-categories of electricity consumers of the state of Punjab have been considered. It is tried to make the Cost-of-Service equal to the Tariff for every category. It had been evaluated with the only criterion of bringing Cost-of-Service Coverage of every category to 100%. Every year it introduces an extra charge called Universal Charge on consumers in addition to the tariff to balance out the gap created due to actual revenue recovery and expected revenue as Aggregate Revenue Requirement. The said charge as being burden on consumers is decreased every financial year and made zero for the last year of policy tenure.

The major flaw realized in the model [63] is that after Cost-of-Service Coverage adjusted to the intended value of 100%, the tariff of all the categories at and after 66 kV voltage level has increased. The tariff rise for the subsidized categories like domestic and agriculture is very high which is practically not acceptable. As per phase wise percolation of Open Access to lower consumption categories, majority of the consumers if given option will definitely voyage from utility services if such model is present. Hence, if such tariff hike is present, the model is completely non-suitable for the consumers as well as utility. The tariff and Cost-of-Service Coverage values pertaining to [63] are presented in the Table 6.1. The numerical values show that except high end industrial consumers i.e. upto 11 kV level, the Cost-of-Service Coverage has dropped down to 100% from higher value. This result is acceptable as these consumers will not be paying any extra charge along with the cost of service as cross-subsidy. For remaining consumers except Domestic consumer above 300 unit consumption i.e. category cross-subsidizing the remaining sub-categories, the Cost-of-Service Coverage has gone up. These categories are already subsidized. Resulting tariff rise is not at all acceptable for them. Table 6.2 shows final rise in Tariff at the end of model tenure.

Though for some of the categories Cost-of-Service Coverage has come down, but the tariff hike is considerable compared to high end consumers already having access to voyage from utility service to trade in energy market. Hence, results signify that the model needs to be modified where the tariff hike is needed to be restricted.

Pertaining to the above said, in the new model, considering the guidelines of tariff policy, constraints are applied on tariff rise for every category. It is also taken care that the utility gains some considerable profit so that it will be win-win situation for both the consumers as well as utility and still the goal of cross subsidy reduction can be achieved.

Some of the terms involved in the model development are as defined below.

6.2.1 Cost-of-Service

The amount involved in the process of giving a unit supply to the consumer is known as the Cost-of-Service (CoS).

Table 6.1: Tariff change after CoSC adjusted to 100% at the end of 5^{th} year

Consumer Category	**Industry-132 kV**	**Traction**	**Industrial**	**Bulk**	**Traction**
Before CoSC adjustment					
Tariff	7.16	7.7	7.16	7.13	7.7
CoSC	143%	153%	141%	143%	153%
After CoSC adjustment					
Tariff	5.02	5.02	5.07	5	5.04
CoSC	100%	100%	100%	100%	100%
Consumer Category	**Industry - 66 kV**	**Common Pool**	**Bulk**	**Industrial**	**Bulk**
Before CoSC adjustment					
Tariff	7.16	4.17	7.13	7.16	7.13
CoSC	116%	79%	124%	114%	125%
After CoSC adjustment					
Tariff	6.15	5.31	5.77	6.29	5.72
CoSC	100%	100%	100%	100%	100%
Consumer Category	**Industry LS**	**Domestic - 11 kV**	**Commercial - 11 kV**	**Bulk**	**Industry MS**
Before CoSC adjustment					
Tariff	7.16	7.42	7.7	7.13	7.16
CoSC	109%	119%	118%	113%	91%
After CoSC adjustment					
Tariff	6.55	6.25	6.5	6.3	7.87
CoSC	100%	100%	100%	100%	100%

Contd. . .

Table 6.1 . . . Contd.

Consumer Category	**Industry SP**	**Domestic (0-100)**	**Domestic (101-300)**	**Domestic (above 300)**	**Agriculture**
Before CoSC adjustment					
Tariff	6.51	5.22	7.01	7.42	5.33
CoSC	78%	74%	99%	105%	78%
After CoSC adjustment					
Tariff	8.39	7.05	7.05	7.05	6.8
CoSC	100%	100%	100%	100%	100%
Consumer Category		**Commercial**		**Public Lighting**	
Before CoSC adjustment					
Tariff		7.7		7.7	
CoSC		102%		107%	
After CoSC adjustment					
Tariff		7.56		7.17	
CoSC		100%		100%	

Table 6.2: Rise and Fall in the Tariff at the end of 5^{th} year compared to reference year

Consumer Category	**Reference Tariff, Rs/kWh**	**Final Tariff, Rs/kWh**	**% Change**	**Comment**
Industry 132kV	5.61	5.02	-12%	Fall
Traction	6.03	5.02	-20%	Fall
Industry	5.61	5.07	-11%	Fall
Bulk	5.59	5.00	-12%	Fall
Traction	6.03	5.04	-20%	Fall
Industry 66kV	5.61	6.15	9%	Rise
Common Pool	3.27	5.31	38%	Rise
Bulk	5.59	5.77	3%	Rise
Industry	5.61	6.29	11%	Rise
Bulk	5.59	5.72	2%	Rise
Industry LS	5.61	6.55	14%	Rise
Domestic 11kV	5.81	6.25	7%	Rise
Commercial 11kV	6.03	6.50	7%	Rise
Bulk	5.59	6.30	11%	Rise
Industry MS	5.61	7.87	29%	Rise
Industry SP	5.10	8.39	39%	Rise
Domestic (0-100 units)	4.09	7.05	42%	Rise
Domestic (101-300 units)	5.49	7.05	22%	Rise
Domestic (above 300 units)	5.81	7.05	18%	Rise

Table 6.2 ... Contd.

Agriculture	4.18	6.80	39%	Rise
Commercial	6.03	7.56	20%	Rise
Public Lighting	6.03	7.17	16%	Rise

6.2.2 Cost-of-Service Coverage

The ratio of Average tariff or Average Billing Rate (ABR) and CoS is known as the Cost-of-Service Coverage (CoSC) for a given category.

6.2.3 Compound Annual Growth Rate

The growth rate at which the sales are assumed to grow every year is Compound Annual Growth Rate (CAGR).

6.2.4 Aggregate Revenue Requirement

Aggregate Revenue Requirement (ARR) is the amount of revenue the utility is supposed to collect for the given financial year. Generally it comes out to be different than the actual revenue collected due to actual sale and factors like subsidy collection.

6.2.5 Universal Charge

Universal Charge (UC) is a fixed charge imposed temporarily on the consumers in addition to tariff. It is reduced every year and made zero at the end of tenure under consideration. The fund collected due to imposition of such charge is used to fill gap between the actual revenue collected and ARR.

6.2.6 Profit

The amount available with the utility after expenses are recovered for all the categories. It is defined as percentage of total revenue recovered. This will be utilized for the next year expenses and hence, it reduces the financial burden of utility.

6.3 Modified Model with Tariff Constraints

Gujarat state is selected for study purpose. The electricity consumers of Gujarat state are divided into major six consumer groups [116]. Railways and some Industries connected at & above 66 kV fall under Extra High Tension (EHT) category. The connections upto 11 kV are called High Tension (HT). Remaining consumer groups i.e. Residential, Agricultural, LTMD group including industrial & commercial categories and a common category called "Others" which include all water supply, sewerage pumps and street lighting, fall under Low Tension (LT) category. Modifications in the basic model are evaluated using two methods keeping central idea of reduction in cross-subsidy and making the utility as a profit gaining entity. To make the model more realistic and acceptable, tariff constraints are imposed on every category instead of targeting Cost-of-Service Coverage as in [63]. The cost function is considered as the utility profit which is to be maximized. The first method is based on Sequential Quadratic Programming. The second method is an Iterative Technique where the utility profit is optimized within a defined range of UC for every year.

In the following sections, both the methods are explained in detail and corresponding results are presented.

6.4 Method 1

Constraints take care that the revised tariff along with Universal Charge (UC) imposition will not be burdensome to the consumers. The basic model assumes same rate of rise for the tariff as well as the cost of supply. In this model, rate of rise of tariff is made variable and restricted by bounds. With these bounds and the constraints imposed on the final tariff, it is expected that the Distribution Company must gain profit at the end of every year considering model tenure of 5 years. The objective becomes maximization of the Distribution Company profit subject to constrained tariff by the way of bounded tariff rise rate and keeping tariff within certain percentage of Average Cost-of-Service. UC is made to decrease at a defined rate as shown in eq.(6.1).

6.4.1 The Objective Function

The objective function eq.(6.3) to be maximized is the profit of Distribution Company which is made up of difference between the total recovery eq.(6.1) and expenditure incurred eq.(6.2) considering all the category of consumers.

$$rec = \sum_{j=1}^{6} \left(T_j(1+r_j)^{(i-1)} + (UC(1-(i-1)(0.25))\right) \times \left(s_j(1+k_j)^{(i-1)}\right) \tag{6.1}$$

$$exp = \sum_{j=1}^{6} \left(((x_j(1.02)^{(i-1)})\right) \times \left(s_j(1+k_j)^{(i-1)}\right) \tag{6.2}$$

$$Profit = \max_{r} f(r) = rec - exp \tag{6.3}$$

6.4.2 Operating Constraints

The Average Cost-of-Service is considered to be same as it is not observed much variation in the value for past few years. Hence, if the increase in tariff for last year in the model is bound within Average Cost-of-Service limit, it will be within bound for all the previous years as the tariff rise is calculated having power function of the tenure number. This makes the constraint equation eq.(6.4) i.e. rate of rise of Tariff non-linear in nature due to power of 5.

$$T_j(1 + r_j)^5 \leq b_j \times ACoS \tag{6.4}$$

Where b_j is

1.2	for $j = 1$ to 4 for HT industrial and EHT, LTMD and "Others" consumer category
0.9	for $j = 5$ for Residential consumer category
0.5	for $j = 6$ for Agricultural consumer category
$ACoS$	Average cost of service
T_j	Tariff of every category
j	Consumer category
r_j	Tariff rise for every category
b_j	Factor by which tariff constraint is decided with reference to ACoS
x_j	Cost of service of every category
s_j	Consumption of every category
k	CAGR of consumption
UC	Universal charge
i	Years for which UC is applicable

6.4.3 Bounds

The rate of rise of tariff is restricted within certain lower and upper bounds.

$$lb \leq r \leq ub \tag{6.5}$$

6.5 Sequential Quadratic Programming

Looking to eq.(6.1)-(6.4) it is clear that the problem to be solved falls under the category of non-linear constrained optimization problem. There are various direct and indirect methods of problem solution instead of any unique method due to erratic behavior of the type of optimization problem herein [117]. One of the methods is Sequential Quadratic Programming (SQP). It deals with the solution of non-linear equations using Newton's iterative method and the derivation of simultaneous non-linear equations using Kuhn-Tucker conditions to the Lagrangian of the constrained optimization problem [117]. When inequality constraints are involved, it is necessary to create a quadratic sub-problem. Main advantage of SQP is non-requirement of a feasible point. It models the problem at an initial approximate solution "r" by a quadratic sub-problem. Better or newer approximate solution $r_k + 1$ is obtained using the initial solution and the sub-problem. The process is iterated to create a sequence of approximations that will converge to a solution [118].

Sub-problem Creation

The quadratic model of the objective function given by eq.(6.6) subject to constraints given in eq.(6.7) and the corresponding lagrangian function is represented by eq.(6.8) where u and v are lagrange multipliers of equality and in-equality constraints incorporating functions $h(r)$ and $g(r)$.

$$\min_{r} \nabla f(r)^t d_r + \left(\frac{1}{2}\right) r^t B r \tag{6.6}$$

Subject to

$$\nabla h(r)^t d_r + h(r) = 0 \ \ and \ \ \nabla g(r)^t d_r + g(r) \leq 0 \tag{6.7}$$

where $d_r = r_{k-1} - r_k$ is termed as the search direction for the feasible solution at k^{th} iteration.

$$L(r,u,v) = f(r) + \sum_{i=1}^{p} u_{i+m} h_i(r) + \sum_{j=1}^{m} v_j g(r) \tag{6.8}$$

B is taken as approximation of Hessian of $L(r,u,v)$. It is taken as positive definite identity matrix and updated in subsequent iterations so as to get the convergence. The solution of non-linear equations formed by Kuhn-Tucker conditions as given by eq.(6.9) is obtained by iterative process and convergence is checked.

$$\nabla f + [\nabla^2 L] d_r + [B]^t [Y] = 0 \tag{6.9}$$

Solution Procedure

One of the methods in which β_1 and β_2 are inserted into eq.(6.7) so as to ensure that the linearized constraints do not cut off the feasible space of solution. Hence, the constraints are re-written as in eq.(6.10) and β_1 and β_2 are defined in eq.(6.11).

$$\nabla h(r)^t d_r + \beta_1 h(r) = 0 \ \ and \ \ \nabla g(r)^t d_r + \beta_2 \leq 0 \tag{6.10}$$

$$\beta_1 \approx 0.9 \tag{6.11}$$

$$\beta_2 = \begin{cases} 1 & \text{if } g(r) \leq 0 \\ \beta_1 & \text{if } g(r) \geq 0 \end{cases} \tag{6.12}$$

The feasible d_r can be evaluated using (6.10), eq.(6.11) and eq.(6.12). After finding the search direction for k^{th} iteration, construction of new iterates in the new direction with step-length of α are obtained. Initially as in the case of classical Newton's method $\alpha = 1$ is taken and then modified by line search method.

$$r^{k+1} = r^k + \alpha d_r, u^{k+1} = u^k + \alpha d_u, v^{k+1} = v^k + \alpha d_v \tag{6.13}$$

Once the new iterates are obtained, the Hessian B_k is updated using dedicated formula for improving the quadratic approximation.

Convergence

Local convergence is based on Newton's method and the global convergence is based on descent method. Global convergence is measured by a merit function denoted as ϕ. By adjusting the step-length α, reduction in ϕ can be evaluated. Discussion of finding step-length, Hessian updation and local-global convergence is beyond the scope of this study.

6.5.1 Algorithm Steps

It is difficult to know whether the local or global conditions converge to a solution [118], a generic algorithm is formulated as follows.

1. Initialize $r_0, u_0, v_0, B_0, \alpha = 1$, merit function ϕ and iterate count $k = 0$.
2. Form and solve the sub-problem to obtain search directions (d_r, d_v, d_u).
3. Choose the step-length for merit function reduction i.e. $\phi(r^{k+1}) \leq \phi(r^k)$.
4. Get the new iterates as in (6.13).
5. Stop if problem is converged irrespective of global or local convergence. If not, got to next step.
6. Compute B_{k+1}.
7. Set $k = k + 1$ and go to 2.

6.6 Method 2: Iterative Technique

In this method, 100 samples are generated within a range of maximum and minimum values of UC. Profit is evaluated for each sample UC. Minimum but non-zero value of profit and corresponding UC are obtained to find Tariff and Cost-of-Service Coverage for the year under consideration. This optimized UC is considered to be the maximum UC for the next year. The minimum UC will be found by deduction of step_size from the maximum. The model is evaluated till UC becomes zero and then, for next few years evaluation continues as a test case till the profit becomes zero or negative. This is how the model or policy implementation duration is defined. Policy tenure is considered till the profit is positive. UC if becomes zero or lesser than zero, within the test duration i.e. 5 years in this case, higher value of UC is selected and the model is simulated again.

1. Initialize CAGR of sales, UC upper and lower bounds, Cost-of-Service and Tariff rise rates, reference values of X, T and S.

2. Compute the reference Cost-of-Service Coverage (CoSC).

$$Y_{i_{new}} = T_{i_{new}}/X_{i_{new}} \tag{6.14}$$

where i=1 to 6

At the starting of tenure, compute new X, T, S and expenditure Average Revenue Return (ARR) for every category i as shown below.

$$S_{i_{new}} = S_{i_{old}}(1 + \%gr) \tag{6.15}$$

$$X_{i_{new}} = X_{i_{old}}(1 + \%r) \tag{6.16}$$

$$T_{i_{new}} = T_{i_{old}}(1 + \%r) \tag{6.17}$$

$$ARR_i = S_{i_{new}} \times X_{i_{new}} \tag{6.18}$$

3. Constraint check for Tariff:

$$T_{i_{mod}} = 1.2 \times WAvg(X) \tag{6.19}$$

where i =1, 2, 3, 4

$$T_{5_{mod}} = 0.9 \times WAvg(X) \tag{6.20}$$

$$T_{6_{mod}} = 0.5 \times WAvg(X) \tag{6.21}$$

If Tariff $\geq$ constraint, set Tariff = Constraint.

4. Generate random values of UC population using formula as

$$UC_n = UC_{min} + \{rand \times (UC_{max} - UC_{min})\} \tag{6.22}$$

For all n varying form 1 to 100

5. For all 100 values of UC, compute profit of utility using Tariff, ARR and fund reserve due to UC imposition. The fund is termed as reserve available with the utility which is carried forward from last recovery at the start of next financial year and added in the profit calculation.

6. Store the minimum non-zero value of profit and corresponding UC.

$$p = [\{\sum_{i=1}^{6}(UC+T_i)\} - \{\sum_{i=1}^{6} X_i \times S_i\} + Start\_Fund] \div [\sum_{i=1}^{6}(UC+T_i) \times S_i] \tag{6.23}$$

7. If profit ≤ 0, increase UC bounds and goto step 2.

8. For comparison purpose, calculate both the Cost-of-Service Coverage i.e. with and without UC incorporated in Tariff for the same year.

9. Set new UC limits as :

$$UC_{max} = UC_{optimum}, \quad UC_{min} = UC_{optimum} - step\_size \tag{6.24}$$

10. If $UC == 0$, allow the model to run for next few years with $UC = 0$. (Perform steps 3 to 6).

11. If $profit \leq 0$, stop.

Where,

i	Index showing consumer category; varies from 1 to 6
C	Power purchase cost
L	Percentage T&D Loss component
e	Sales at last financial year
s	Sales at first financial year
t	Period for which CAGR is to be calculated
gr	CAGR of electricity sales
r	Rate of rise
S	Sales
X	Cost of Supply
T	Tariff
Y	Cost of Supply Coverage
n	Tenure in years
ARR	Aggregate Revenue Requirement
REV	Revenue
G	Gap between total Revenue and ARR
UC	Universal Charge
$Start\_fund$	Fund available due to imposing Universal Charge

6.7 Availability of Data and Assumptions

The model is developed for the consumer categories of the MGVCL, Discom of Gujarat state. HT consumers are given supply at 132 kV, 66 kV and 11 kV. After 11 kV, energy injection is done directly at 400 V [109]. The way detailed information of sales, Cost-of-Service for tariff slab specific sub-categories is made available in [119], no such detailed information for these voltage levels in Gujarat is available. The sales figures and tariff values / Average Billing Rate (ABR) herein, are obtained from the Regulatory Information Management (RIM) reports and tariff orders published by GERC. The reports publish only the Average Cost-of-Service and not the Cost-of-Service for every category. No enough data is available to compute Cost-of-Service based on embedded cost or simplified approach methods [63]. Hence, two alternative methods have been considered to compute Cost-of-Service for reference year instead of mere assumption. UC value has been considered as starting from 50 paisa/unit (0.50 Rs/unit). It is felt that further rise in the value of UC may not be practically viable as it may give shocking tariff hike to the consumers. If the UC is lower, burden on the consumer is lower and more is the acceptance to the model.

6.7.1 Initial Computations

Cost of Service Computation

Case 1: As per APTEL guidelines [63] category specific Cost-of-Service can be computed using Power Purchase Cost (PPC), % losses at various voltage levels. All the consumers connected at same voltage level are considered to have same cost of supply.

$$X_j = C_j(1 + L_j) \tag{6.25}$$

OR

Case 2: Assuming that the Cost-of-Service available [120] rises with specific rate for consecutive number of years. Considering 2% rise in the Cost-of-Service published in [62] for consecutive 5 years, base Cost-of-Service is calculated using eq. (6.26).

$$X_j = X_{j_{old}}(1 + r_c)^t \tag{6.26}$$

CAGR of consumption

The CAGR of all categories is found with the help of standard formula given in [121], [122] using the electricity sales from Financial Year-2011 to 2016 [116]. The formula is described by eq. (6.27).

$$gr = (\frac{e_j}{s_j})^{(\frac{1}{t-1})} - 1 \tag{6.27}$$

The Industrial category is divided into two sub-categories as EHT at and above 66 kV level with 4% system losses applicable and HT above 11 kV level with applicable losses of 10%. For energy injection at 11 kV, the losses are 14% for drawal at 400 V and if injection is also at 400 V, only 7% losses are applicable [109]. Hence, if the bifurcation at these three energy injection level along with the data similar to [123] are provided, case 1 can have more variation in Cost-of-Service. Hence, for time being case 2 is near to realistic scenario. Table 6.3 shows Cost-of-Service resulted using both the above mentioned methods. For the Railways falling into EHT, the CAGR is calculated based on only two years' sales i.e. after 2014 as since then Railways have started Open Access and sales from utility is reduced considerably.

6.8 Prediction of Consumption and Tariff

The electricity consumption and tariff realization of every category are available from Regulatory Information Management reports of the Distribution Company [116]. Instead of relying upon single value of any year, regression model is used to predict the consumption and category specific tariff based on available data of last 10 years. Figure.6.1 shows the regression results of the tariff for HT category in paise/unit and Figure.6.2 shows the resi-

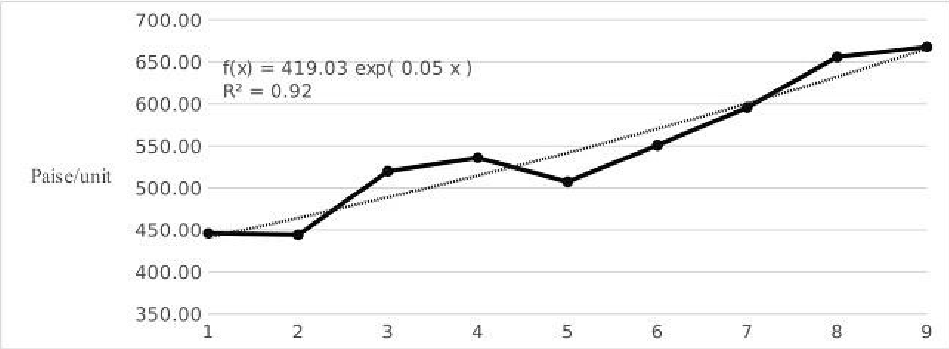

Figure 6.1: Regression curve for HT Category Tariff

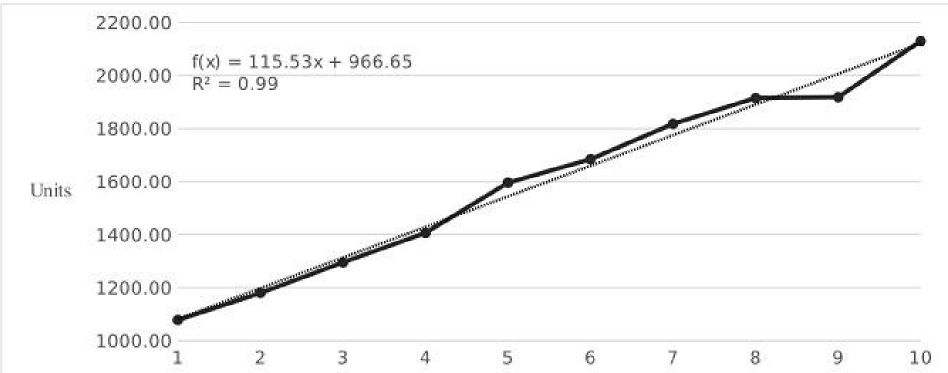

Figure 6.2: Regression curve for Residential Category Consumption

dential category consumption realization in units. Table 6.4 shows the final predicted values of consumption and tariff realized for every category.

6.9 Result and Discussion

6.9.1 Method 1: Sequential Quadratic Programming Technique

The model is analyzed for the tenure of 5 years and further 5 years of testing period. It is observed that the process converges with the tariff rise rate and

Table 6.3: Consumption and Tariff realized from Regression models

Category	**Consumption (Units)**	**Tariff Realized (Rs/kWh)**
High Tension	3000	7.0
EHT/Railways	390	6.7
Residential	2250	5.3
Industrial + Commercial (LTMD)	1300	6.9
Others	280	5.3
Agricultural	1000	2.6

Table 6.4: Cost-of-Service (CoS) resulted from case 1 and case 2

Category	Case 1, Rs/kWh	Case 2, Rs/kWh
HT Industrial	4.82	4.87
Railways	4.82	4.33
Residential	4.98	6.17
LT Industrial & Commercial (LTMD)	4.98	5.3
Others	4.98	5.03
Agricultural	4.98	5.28

Distribution Company profit as shown in Table 6.5. It is further observed that change of bounds for the variable "r" i.e. tariff rate rise, does not give any difference in the results.

The nature of the bar chart in Figure.6.3 shows that the Cost-of-Service Coverage per category is reducing except EHT consumers. Figure.6.4 shows that the tariff realized are increasing but with very lesser rate shown in Table 6.5 due to bounded rate of rise and constraints offered to all the categories. Reduction in Cost-of-Service Coverage is a good sign as this reduction is reflection of reduction in cross subsidy which is one of the prime focus. EHT category comprises of industries and railways. Since last few years these categories chose to opt Open Access and do not much rely upon Discom supply. Hence, increase in Cost-of-Service Coverage will not be burdensome to them. Looking to the Distribution Company profit shown in Table 6.5, it is negative for the 1^{st} year. But the figures of next four years show that the loss will be taken care by considerable profit margin.

6.9.2 Method 2: Iterative Technique

The model is analyzed to evaluate the most acceptable lowest UC for every year. Trials are made with variation in UC range, step-size and tenure.

The results are evaluated for various UC ranges. It is assumed that UC should not be higher than 50 paise/unit i.e. 0.5 Rs/kWh, as it is burden to the consumers addition to the tariff to be paid. The UC_{max} and UC_{min} for every Financial Year (FY) are chosen in the step of 0.1 or 0.05. The tariff and Cost-of-Service Coverage reduces from the FY1 itself due to applicable tariff constraints on all the categories except the category "Others". The tariff rises by 2% for the "Others" category which means that the tariff resulted for this category was already within the constraint limits. Hence, no Cost-of-Service Coverage change is observed on this category as equal rise of 2% is applicable on CoS and tariff both. Whereas for remaining five categories, tariff was bound by constraints and hence, the bar-chart in Figure. 6.5 shows reduction in both Cost-of-Service Coverage and tariff by the considerable amount for the first FY. Results of Discom profit and UC for every Financial Year are presented in Table 6.6.

Table 6.5: Distribution Company profit and Tariff rise rate for every category of consumers

Discom Profit	-3.54%	7.13%	12.18%	16.66%	20.90%	24.94%
Category	High Tension	Rail	Residential	Industrial+ Commercial (LTMD)	Others	Agricultural
Tariff rise rate	1.00%	2.16%	1.00%	1.00%	1.00%	1.00%

The highest billed HT category and the lowest billed agricultural category are most benefited due to tariff reduction. The maximum reduction is observed in agricultural category which is actually a highly subsidized one and HT category remains at 2^{nd} rank. Though the subsidy impact is reduced due to reduction in Cost-of-Service Coverage, the utility / Distribution company gains considerable profit for all the UC range considered. It is clear that when the profit becomes negative, the utility faces loss. Hence, the life span of the model can be treated only until the profit turns out to be

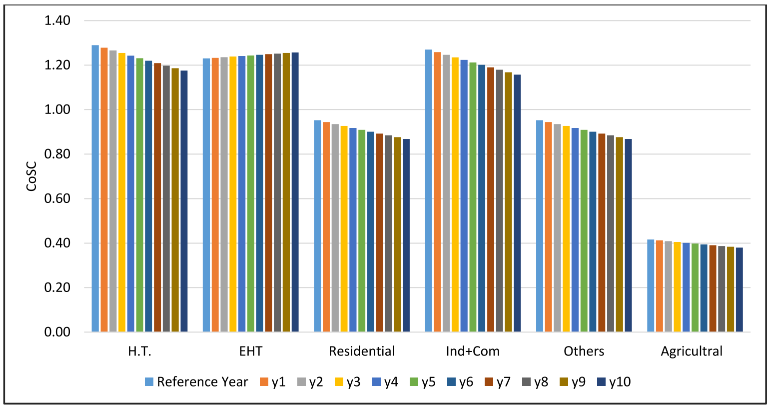

Figure 6.3: CoSC resulted for 10 years in comparison to reference value

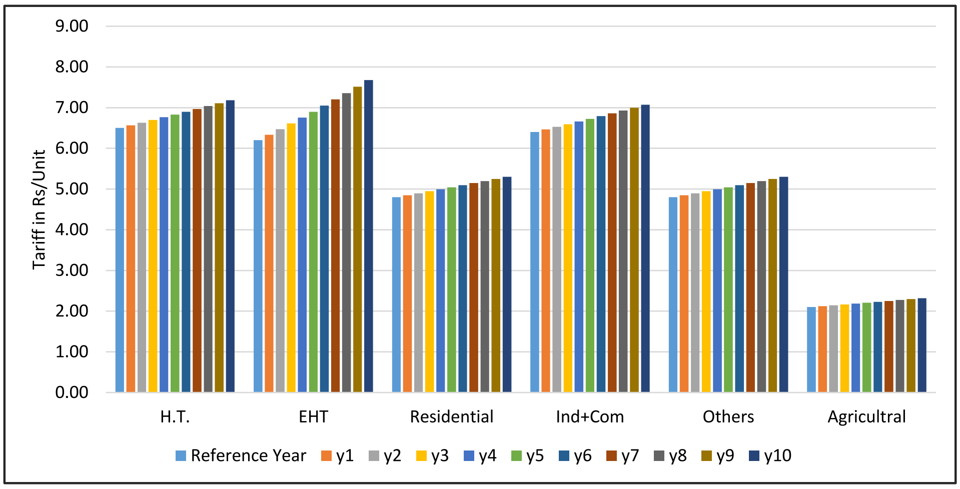

Figure 6.4: Tariff realized for 10 years in comparison to reference year

Table 6.6: Profit and *UC* resulted for FY1 to FY11

	UC start [0.4,0.35], step 0.05		**UC start [0.25,0.2], step 0.05**	
	UC value	**%Profit**	**UC value**	**%Profit**
FY1	0.35001	7.297	0.20036	4.871
FY2	0.30047	12.776	0.15052	8.009
FY3	0.25048	16.555	0.10088	9.558
FY4	0.20173	18.785	0.05198	9.674
FY5	0.15209	19.588	0.0021	8.476
FY6	0.10238	19.084	0.00001	6.832
FY7	0.05242	17.383	0.00	4.913
FY8	0.0033	14.602	0.00	2.765
FY9	0.00	11.48	0.00	0.420
FY10	0.00	8.23	0.00	-2.08
FY11	0.00	4.88	0.00	-4.74

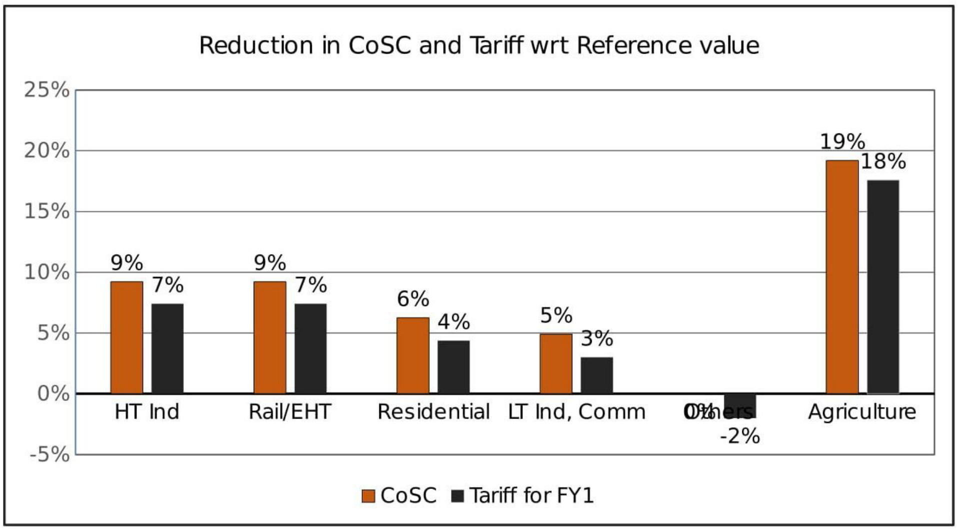

Figure 6.5: CoSC and Tariff change for FY1 due to Tariff Constraints

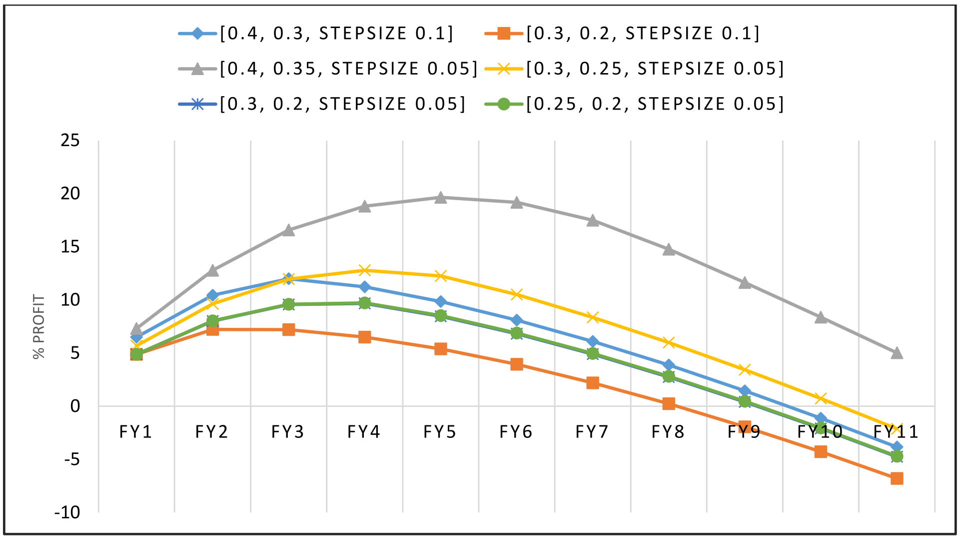

Figure 6.6: Utility profit for UC ranges and corresponding step-size

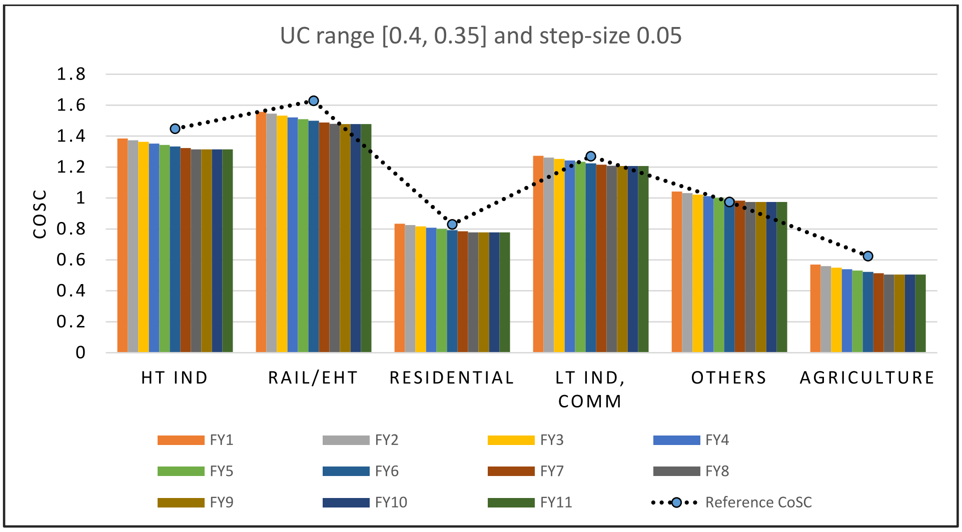

Figure 6.7: CoSC with *UC* imparted on Tariff, *UC* range [0.4, 0.35, step-size 0.05]

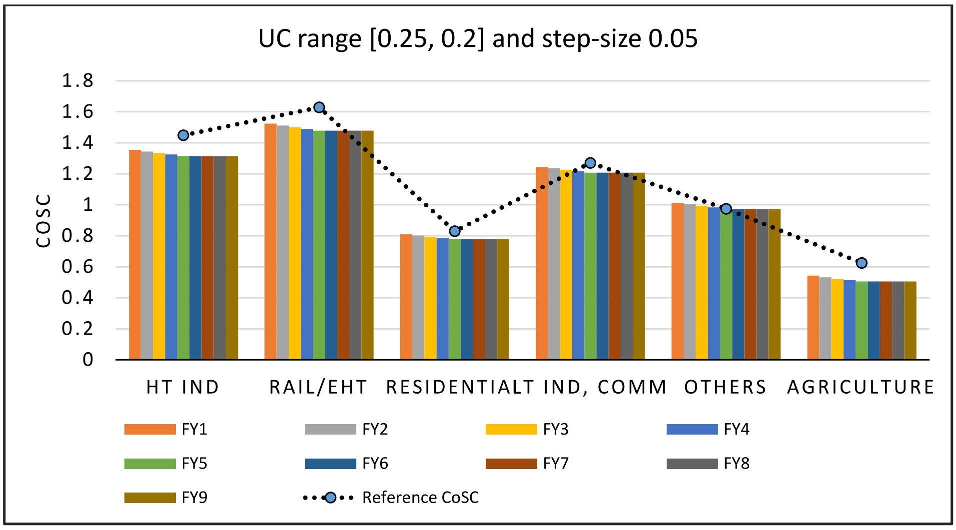

Figure 6.8: CoSC with *UC* imparted on Tariff, *UC* range [0.25, 0.2, step-size 0.05]

positive. As per the selected UC range, validity of the model can be decided from Figure.6.6 and wise-a-versa.

Figure. 6.7 and 6.8 show Cost-of-Service Coverage bar-chart for two UC beginning ranges as [0.4, 0.35] and [0.25, 0.2] with the step-size of 0.05. The total number of bars for every category show the policy tenure i.e. number of years for which policy will be active. For the case in Figure.6.7, the policy tenure is of 11 years and for the other it is of 9 years. In case of Figure.6.8, profit turns out to be negative for FY10 and FY11 which can be seen from Table 6.6. As the discom earns loss for FY10 and FY11, policy will be discontinued after FY9. The marker line over the bars shows reference Cost-of-Service Coverage. As described in earlier para, except the category "Others", remaining categories have considerable reduction in Cost-of-Service Coverage.

6.10 Conclusion

The results obtained for Tariff, Cost-of-Service Coverage and Distribution Company profit are practically acceptable as the subsidy component hidden in the tariffs has come down as the Cost-of-Service Coverage has resulted lesser than the reference for the consumers under consideration. And still, the Distribution Company gains a considerable amount of profit during the policy tenure. Hence, the model turns out to be consumer as well as Distribution Company oriented under the given scenario.

If the actual data to compute category and sub-category specific cost-of-service are made available, model will give more realistic scenario. The model can be further tested subject to varied constraints based on different scenarios in other states and if felt, can be re-modified.