

Chapter 5

Time-of-Use Tariff

5.1 Introduction

Along with the Electricity Act 2003, the National Tariff Policy also highlights the necessity of Tariff rationalization [3]. As presented in chapter 2, Demand Side Management emphasizes various tariff mechanisms. They offer incentive, rebate and inflict penalty also if needed, to flatten the load profile by limiting the usage of excess electricity during peak hours. One of such proposed pricing mechanism is Time-of-Use (ToU) tariff. Topics such as scheduling of job work, effectiveness of Time-of-Use mechanism and design of Time-of-Use mechanism under various criterion had been studied in recent past. Segregating consumers by clustering technique and then designing Time-of-Use in the backdrop of Demand Response has been presented in [43]. Time-of-Use mechanism has been suggested for the consumers of low income group category in [44]. Derivation of Time-of-Use as a part of pilot study for Demand Side Management considering residential consumers has been presented in [45]. Machine or job scheduling based on Time-of-Use has been presented in [46], [101], [47]. Effectiveness of Time-of-Use has been

highlighted by [48], [50], [102], [51], [49] based on surveys or case studies. Almost a decade older Indian scenario has been presented in [50], [102], [51], [49]. A study [51] has been published by the Forum of Regulators (FoR), India to show the impact of Time-of-Use structure in India. The said report clearly mentioned that the necessary details for analysis purpose were not available from the state utilities and the study was conducted based on the limited and secondary data made available. The study was conducted with the data which is almost a decade older. The study suggested peak hours for the western region from 18 : 00 hrs to 00 : 00 hrs and the off-peak hours from 00 : 00 hrs to 06 : 00 hrs. It is recommended that every state should provide details regarding Time-of-Use consumers, their consumption pattern and effectiveness of the mechanism on monthly basis in the annual report. Phase wise progression of Time-of-Use mechanism for LT consumers has also been suggested in [51].

The Time-of-Use tariff structure is present in Gujarat state for more than a decade span i.e. from the first tariff order of FY 1999-2000 [51]. But no much information regarding Time-of-Use impact on the power system of the Gujarat state has been presented and in depth information as stated above regarding the monthly details of Time-of-Use structure is also not readily available. In April 2016, the condition of availing night rebate, for the amount of night consumption in excess of the one third of the total monthly consumption, had been waved off by Gujarat Electricity Regularity Commission and total night consumption whatever may be the amount, had been made available for seeking night rebate. Hence, it is very interesting to find effectiveness of such liberalization. This chapter portrays the effect of Time-of-Use mechanism by considering scenario of a continuous process industry falling under HT category in the state of Gujarat.

5.2 Time-of-Use in Madhya Guajrat Vij Company

As per the tariff orders of Madhya Guajrat Vij Company Ltd (MGVCL) published by Gujarat Electricity Regularity Commission and [51], it is evident that the Time-of-Use tariff structure is present in Gujarat state for more than a decade period. It is applicable to water works, sewerage pumps and HT consumers connected at 11kV and above voltage levels. Table 5.1 shows the Time-of-Use tariff for few Financial Years (FY) [87]. The HT consumers were eligible for getting night rebate only for the amount of night consumption in excess of the one third of the total monthly consumption till 2016. After that, the condition had been waved off but the rebate rate has been made almost half. It is evident that there is no change in the duration of peak and night hours for almost 18 years.

5.3 Factors Limiting the Rise in Night Consumption

As the entire night consumption is freed to have benefit of night rebate after April 2016, it is in consumers' benefit to shift the entire load at night hours and avail the maximum financial gain. But such load shifts are highly impossible due to certain logistic issues, technical constraints as stated below and working in day time is always beneficial compared to night hours as requirement of lighting load is minimum.

Major constraints or factors that limit rise in night consumption are considered herein as the contract demand, maximum demand recorded for billing and Open Access permission which compels the consumer to maintain

the granted drawal. Billing of the industrial consumers falling in HT category is done as per the recorded maximum demand and units consumed. Hence, it is recommended that the maximum demand should not be more than the contracted value. Due to the ongoing power sector reformation, majority of the consumers having demand more than 1 MW, opt for Open Access facility [53]. There is a minimum amount of drawal which is required to be maintained by such consumers as per the Open Access regime. Hence, considering the above mentioned two major criterion, only a limited amount of load shift is possible at night hours.

5.4 Problem Formulation

To find the effectiveness of Time-of-Use pricing, a continuous process industry is selected having the contract demand of 2 MVA. The billing information is presented in Table 5.2. Industry is eligible for availing Open Access facility and granted the permission of 1.8 MW power purchase from open market. After deducting the various losses, the power at the point of connection is 1.52 MW. As per the Open Access regime, it is mandatory not to cross the under drawal limit of 12%. Hence, it is compulsory to maintain drawal of 1.34 MW on continuous basis. Considering the constraints mentioned in previous section, the limiting values of monthly consumption for peak, off-peak and night block, each block of 8 hours, are listed in Table 5.3. For analysis purpose, five cases have been formulated by taking various combinations of the constraints as mentioned below.

Table 5.1: Time-of-Use Rates in MGCVCL

ToU tariff	Peak Hours: 06:00 to 11:00 hrs; 18:00 to 22:00 hrs and Night Hours: 22:00 hrs to next day 06:00 hrs	
FY	HTP Consumer	Waterworks and Sewerage pumps
2009-10	Peak charges: 75 paisa/unit and Night concession of 75 paisa/unit	Peak hour discount: 30 paisa/unit and Night concession of 75 paisa/unit
2009-10	Peak charges: 75 paisa/unit and Night concession of 75 paisa/unit	Peak hour discount: 30 paisa/unit and Night concession of 75 paisa/unit
2014-15	Peak charges: 35 paisa/unit for demand at and below 500 kVA, 75 paisa/unit for above 500 kVA and Night concession of 75 paisa/unit	Peak hour discount: 30 paisa/unit and Night concession of 75 paisa/unit
2016-17	Peak charges: 45 paisa/unit for demand at and below 500 kVA, 85 paisa/unit for above 500 kVA and Night concession of 40 paisa/unit	Peak hour discount: 40 paisa/unit and Night concession of 85 paisa/unit

5.4.1 Objective Function

Objective of the problem is to have maximum night rebate.

$$\max_r NR \quad (5.1)$$

Where,

$$NR = x_1 \times r \quad (5.2)$$

5.4.2 Constraints

$$x_1 + x_2 + x_3 \leq x_t \quad (5.3)$$

$$x_1 + x_2 + x_3 \leq x_c \quad (5.4)$$

$$x_1 \leq x_{dc} \quad (5.5)$$

$$x_1 \leq x_{md} \quad (5.6)$$

$$x_2 \leq x_{mp} \quad (5.7)$$

$$x_3 \leq x_{dc} \quad (5.8)$$

$$x_3 \leq x_{md} \quad (5.9)$$

$$x_1, x_2, x_3 \geq x_{oa} \quad (5.10)$$

$$t_n \leq t_o \quad (5.11)$$

Where,

NR	Night rebate
r	Rebate rate
x_1	Night consumption
x_2	Peak consumption
x_3	Off-peak consumption
x_t	Monthly consumption on record
t_n	New billing rate
t_o	Old billing rate
x_c	Monthly consumption due to contracted demand
x_{mp}	Monthly peak consumption on record
x_{dc}	Contract demand based consumption
x_{md}	Consumption based on maximum demand
x_{oa}	Consumption based on open access granted

The analysis is based on the assumptions that no much variation would be observed in the consumption pattern; peak, off-peak and night consumption will never go below the value equivalent to Open Access drawal amount and no maximum demand is allowed to occur during peak hours if demand crosses contracted value. The billing of May 2016 as shown in Table 5.2 of an HT industry is taken as reference. As mentioned earlier, the entire night consumption was liberalized to have night rebate in Financial Year 2016-17 with almost half rebate rate i.e. 40 paisa/unit, compared to the rebate rate of FY 2015-16. Hence, it is felt necessary to find how much would have been the financial gain to the consumers if the rate of 85 paisa/unit was continued.

Hence, both the rebate rates are considered for analysis purpose. Table 5.3 lists out the five cases under consideration.

Table 5.2: Billing Information of May 2016

Consumption		Billing in Rs.	
Total units	1346340	Total energy charge	5654628
Peak units	445080	Peak charge	378318
Night units	456480	Night rebate	182592
Off peak units	444780	Total night rebate	5472036
Actual max demand recorded, kVA	2173	pf rebate	128592.85
		Demand charge	776015
Power Factor maintained	0.997	Demand +Energy charge	6497776.2
		Fuel charge	1938729.6
		Meter rent	750
		Total bill including 15% of Electricity Duty, Rs.	9702731.6
		Per unit Bill Rate	7.21 Rs/kWh

5.5 Evolutionary Programming Technique

Due to presence of inequalities in the constraints, two algorithms were found to be suitable for solution i.e. Generalized Reduced Gradient and Evolution-

Table 5.3: Case-wise Constraints

Case	Constraint equations	Case	Constraint equations
C1	(5.3), (5.5), (5.7), (5.8), (5.9), (5.11)	C4	(5.4), (5.6), (5.7), (5.8), (5.10), (5.11)
C2	(5.3), (5.6), (5.7), (5.9), (5.10), (5.11)	C5	(5.4), (5.6), (5.7), (5.9), (5.10), (5.11)
C3	(5.3), (5.5), (5.7), (5.8), (5.10), (5.11)		

ary optimization. Evolutionary algorithm found to be best suited as it finds globally optimum solution [103]. The overview of basic algorithm by [104], [105]-[106] is briefly explained as follows.

5.5.1 Overview

Evolutionary computation programming method is a very rich class of Multi Agent Stochastic Search (MASS) algorithms based on the Neo-Darwinian paradigm of natural evolution, which can perform exhaustive searches in complex solution space [107]-[108]. Basic steps are Generate, Mutate, Evaluate and Selection.

Initially this algorithm searches a population of solutions generated stochastically. Finally stochastic variations are combined with the population parameters to develop global optimum solution. Thus, this method offers a rigorous stochastic search in the entire domain considering maximum possible interactions among them.

The basic steps of the algorithm are:

- **Initialization**

Initialize a population pool with x_{ji} as:

$$x_{ji} = [x_{1i}, x_{2i}, x_{3i} \dots x_{ji} \dots x_{ni}] \quad (5.12)$$

where,

j 1 to n where n is the number of current excitation weights

i 1 to n_p where n_p is the population size

- **Generation of off-spring by Mutation**

In Basic Evolutionary Programming, each parent vector generates an off-spring vector x'_{ji} by adding to each component of the parent trial

solution, a Gaussian random variable $N(0, \sigma(i)_j)$ of mean zero and a standard deviation $\sigma(i)_j$ which is proportional to scaled Cost Function $\sqrt{f(x_i)}$.

$$\sigma(i)_j = \frac{\sqrt{f(x_i)}}{n_p} \quad (5.13)$$

$$x'_{ji} = x_{ji} + N(0, \sigma(i)_j) \quad (5.14)$$

where $f(x_i)$ is Cost Function.

Parents as well as off-springs combinely give a population pool of $2n_p$ vectors.

- **Evaluation, Competition and Selection**

The parent trial vectors and offspring vectors of population n compete with each other within the competition pool of size $2n_p$ and get a score for evaluation. The score for j^{th} trial vector in $2n_p$ pool is calculated as:

$$\omega_j = \sum_{i=1}^{n_p} \omega_i \quad (5.15)$$

Where,

$$\omega_i = \omega_i + 1, \text{ if } (f(x_j) \leq f(x_t))$$

else $\omega_i = 0$.

Where i varies from 1 to n_p , j varies from 1 to $2n_p$ and $t = [2n_p \times (v+1)]$, v is random number ranging over $[0, 1]$.

Then the parents and the off-springs solutions are ranked in descending order according to the score obtained from eq.(5.15). The first

n_p population considering fitter than the remaining are chosen as the parental base for the next iteration. Optimum solution is obtained after completion of all epochs.

Table 5.4: Optimum results to attain maximum night rebate as per the set constraints

Constraints		Max Demand: 2173 kVA for case 1-4, 2200 kVA for case 5				
MW	Limits	case 1	case 2	case 3	case 4	case 5
Total		1346.34	1346.34	1346.34	1435.68	1435.68
Night	Min	364.8	364.8	364.8	364.8	364.8
	Max	478.56	519.95	519.95	519.95	526.41
Peak	Min	364.8	364.8	364.8	364.8	364.8
	Max	445.08	445.08	445.08	445.08	445.08
Off-peak	Min	364.8	364.8	364.8	364.8	364.8
	Max	519.95	519.95	478.56	478.56	526.41
Bill Rate		7.21	7.21	7.21	7.21	7.21
Results						
	Reference	case 1	case 2	case 3	case 4	case 5
Peak wrt ref	1	0.98	0.93	0.83	0.86	0.86
Night wrt ref	1	1.05	1.14	1.14	1.14	1.15

Table 5.4 ... Contd.

Off peak wrt ref	1	0.98	0.93	1.03	1.08	1.18
Night rebate for 40paise/kWh	182592	191424	207982.18	207982.18	207982.18	210566.4
Bill Rate, Rs/kWh	7.21	7.19	7.16	7.14	7.13	7.1
Night rebate for 85paise/kWh	182592	406776	441962.12	441962.12	441962.12	447453.6
Bill Rate, Rs/kWh	7.21	7.01	6.97	6.95	6.94	6.92

5.6 Result and Discussion

Table 5.4 shows the numerical values of all the constraints listed in Table 5.3. It also shows resulted billing rates and night rebate for every constraint case.

It is evident that the billing rates are reduced and night rebate is considerably increased. The peak consumption is reduced and night consumption is increased in all the cases where as the off-peak consumption is reduced for cases 1 & 2 and increased for cases 3 to 5. The results are represented graphically in Figure.5.1 to 5.4. Referring Figure.5.4, it is clear that if the night rebate rate is kept at 85 paise/unit as in previous Financial Year in-place-of latest revision to 40 paise/unit, considerable higher rebate can be achieved by the consumer. It is up to the consumer to select the appropriate case and gain the desired night rebate.

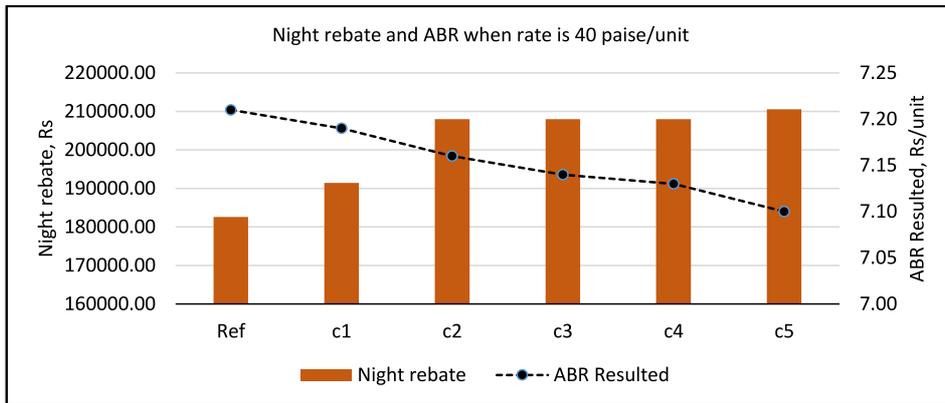


Figure 5.1: Night rebate and ABR for rebate rate of 40 paisa/unit

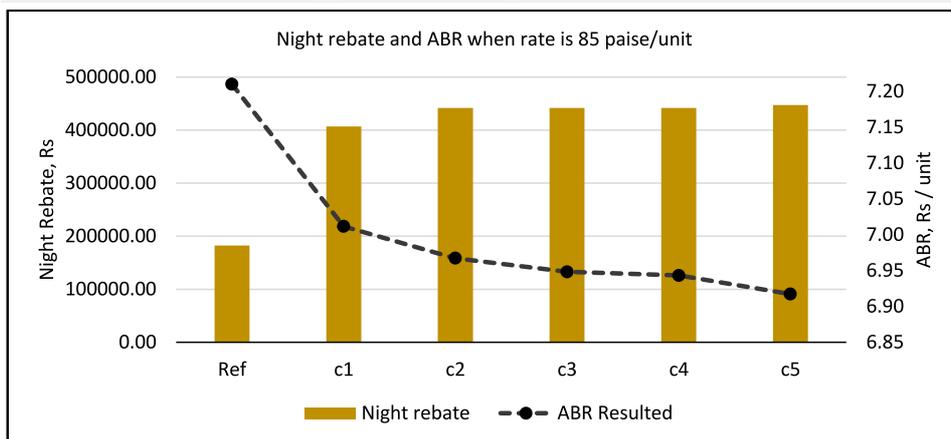
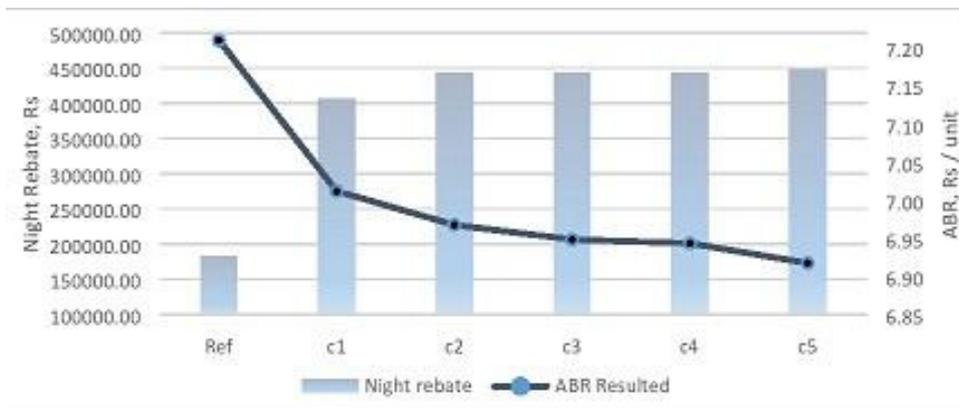


Figure 5.2: Night rebate and ABR for rebate rate of 85 paisa/unit

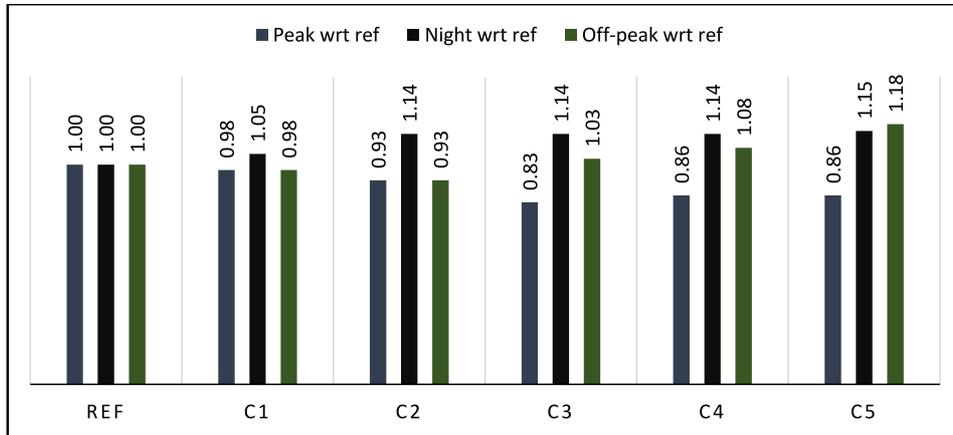


Figure 5.3: Change in consumption level

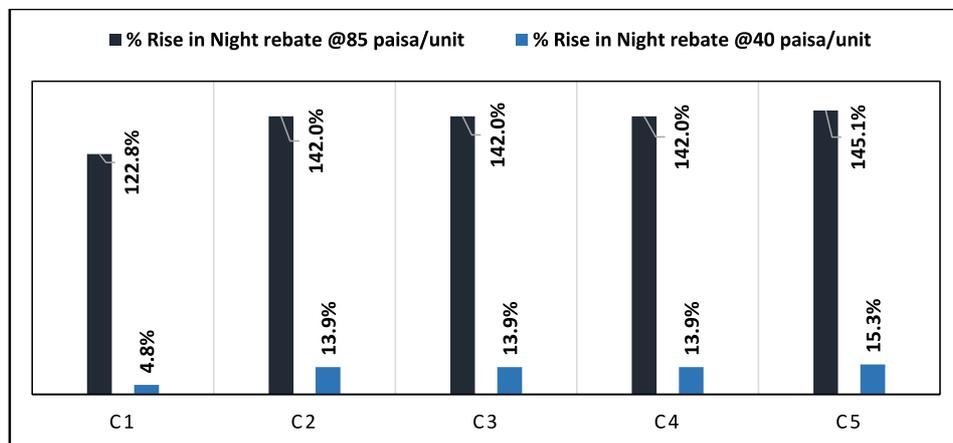


Figure 5.4: % Rise in Night rebate

5.7 Conclusion

It is evident from the comparative results that Distribution Company can take initiatives for improvement in the Time-of-Use night charges to restrict the voyage of consumers to open access if considerable savings are achieved as rebate. Moreover, load shift to night hours from peak hours will help in improving system load profile. Thus, the study pertaining to Time-of-Use tariff structure and its effectiveness has a tremendous future scope in Distribution Company load shaping. If the historical record of 24 hour consumption of EHT and HT industries is made available along with the monthly billing information; change in peak, off-peak & consumption during night hours, dominating loads on Discom profile; necessity of redefining the Time-of-Use hours can be analyzed.