Comparison of proposed electricity billing mechanism for residential clients of Maharashtra

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ABSTRACT

The comparison of three modified electricity billing mechanisms (model I, model II, and model III) for low tension (LT-I) residential consumers of Maharashtra, India, is presented in this paper. Models I and II are presented in detail along with the results in the previous version of this paper in the year 2020 and year 2022. In continuation of this work, model III is presented in this paper in the year 2023. The main components of this mechanism are traditional billing, time-of-day billing, and an optional facility to use renewable energy by implementing net metering. The combination of these elements generates three distinct billing mechanisms. These have several advantages, like the profits of the existing mechanism, renewable integration, grid stability, demand management, cost saving, environmental benefits, and customer empowerment. The projected billing mechanism is developed and implemented in MATLAB software, and a real-time application is created. The comparison between these three mechanisms helps in giving the best mechanism with respect to residential consumers. Lastly, the philosophy for the future extension to this work is presented which is based on the concept of overseas billing mechanism i.e., seasonal time of day tariff of Sacramento Municipal Utility District and Arizona Public Service.

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1. INTRODUCTION

Having reliable access to energy is crucial to a country's economic, and social development. Because of depletion and environmental concerns, the use of fossil fuels is decreasing. Green energy technology is the preferred method of meeting the ever-increasing demand for electricity. The net metering rule has been a driving force in the worldwide transition to decentralized production. It has been effectively adopted all over the world by a wide variety of nations, including America, European countries, Australia, India, Nippon, Switzerland, Lion City, the Republic of Korea, and many other countries from east, west, north, and south [1]–[9]. Most developed nations use a time-of-day (ToD) tariff structure for both low, and high tension (LT and HT) clients. With this capability, a scope can reward clients for their consumption during low-demand times, and penalize them during high-demand times. Slab-wise tariff scheme is typical for LT residential clients in India, however, the time-based tariff is approved for business clients only [4]. Both the tariffs, which may be implemented for economic/social reasons, are created to help countries achieve their primary goals. Having access to net metering encourages the adoption of renewable energy sources, which in turn reduces the demand placed on power plants that rely on fossil fuels. Solar photovoltaic (PV) plants with a capacity greater than 5 kWh have a shorter payback period [10] despite the high upfront cost of PV systems. Because of this, the domestic consumers with <5 kW load get underprivileged. The power bill must be paid according to the utility's slab-wise tariff. This is a problem in every Indian state except Kerala. This research work is carried out for Maharashtra state where the electricity billing mechanism for LT clients is slab-wise only. As a result, the current system does not provide any means by which to incentivize residential customers to use energy efficiently during peak periods.

In this paper, the Authors present three modified electricity tariff structures for LT clients of Maharashtra state, one of which employs exclusively real-time pricing based on Kerala State Electricity Board (KSEB), India, other two combine the benefits of slab-wise tariffs with those of time-of-day tariffs. In addition, people who want to build rooftop solar PV plants can reap the rewards of net metering if they do so. As a result, LT clients will be able to predict their energy needs, and cut down on their monthly payments. The first billing mechanism i.e., model I is the existing Maharashtra State Electricity Distribution Company Limited (MSEDCL) slab-wise structure, LT-II non-residential consumers' ToD pricing, and net metering which is explained in detail along with results in study [11]. The second billing mechanism i.e., model II is an expansion of model I that combines the current slab-wise structure of MSEDCL with the ToD tariff of LT consumers of KSEB, and net metering which is explained in detail along with results in the paper [12]. The third billing mechanism i.e., model III is a refinement of model II that is based only on the ToD pricing structure by the KSEB is discussed in detail in this paper in sections 3.1, and 3.2. To prove the effectiveness of the proposed electricity billing mechanism a sample case study is discussed in section 4. The comparative results of proposed billing mechanisms are presented in section 5. The conclusion is presented in section 6.

2. ENERGY TARIFF STRUCTURE IN INDIA AND OTHER COUNTRIES

In India, residential LT customers can access slab-wise pricing, whereas HT customers can get time-of-day pricing. This conventional billing is designed to help or reward low-energy consumers while penalizing heavy-energy users. However, in that situation, there is little inducement for the middle class to use electricity as efficiently as possible. Real-time tariffs are therefore crucial in these situations for residential customers as well. As a result, many industrialized nations, including Australia, United States, United Kingdom, Europe, and Japan, have begun to provide time-based pricing to all consumers. Day-ahead real-time pricing (DA-RTP) is being used by Illinois Power Company in the United States [13]; critical peak pricing has been the subject of numerous pilot projects in California, Idaho, and New Jersey [14]; and a three-level time of use (TOU) pricing tariff has been implemented in Ontario, Canada [15]. Enhance time of use (ETOU) tariff has been implemented in Malaysia [16]. The concept of on-peak electricity tariff is presented in the paper [17] for hybrid charging of electric vehicles. In Nigeria, a feed-in tariff is implemented for some of the states with the renewable energy (RE) model which includes a combination of solar, and wind energy [18]. It has been found that exposing customers to hourly real-time rates is the most effective way to encourage them to use energy more wisely, and effectively [19]. Real-time pricing (RTP) offers customers the chance to lessen their energy bills by taking advantage of times when energy prices are lower, and cutting back on power use when energy prices are high. Table 1 lists the utility in other countries that are providing a variety of electricity pricing schemes to interested customers [20]–[24].

Table 1. Availability of ToD for LT consumers in other countries

Sr.No.	Name of utilities	Electricity pricing scheme
1	Ameren Illinois	Hourly pricing
2	Commonwealth Edison (ComEd)	Day ahead and real-time pricing
3	Oklahoma Gas and Electric (OG&E)	Time of use pricing
4	Sacramento Municipal Utility and Arizona Public Service	Seasonal time-of-day pricing

In India, this issue has mainly affected the country's lower socioeconomic classes. Low-income consumers can be prioritized by maintaining the slab-based tariff structure, while those in higher income brackets can benefit from the real-time pricing. Detailed information on ToD's existence, and availability to LT customers in India can be found in the paper [11]. A summary is presented in Table 2 [25]–[53]. In Kerala, residential customers pay ToD pricing if their six-month average consumption is more than 500 units.

The client is responsible for the hundred percent ruling tariff from normal business hours, ninety percent of the ruling tariff from off-peak, and one hundred, and twenty percent of the ruling tariff from peak [26]. Customers are saving money on their monthly electricity bills because of a variable tariff structure that rewards them for using power during off-peak times. On the other side, it aids in easing peak-hour grid congestion.

Table 2. Status of ToD for LT consumers in India

Availability of ToD in India	States in India
Not Available	Maharashtra
Available	Kerala
Not Available	Karnataka
Not Available	Telangana
Not Available	Andhra Pradesh
Not Available	West Bengal
Not Available	Goa
Not Available	Gujarat
Not Available	Chhattisgarh
Not Available	Uttar Pradesh
Not Available	Madhya Pradesh
Not Available	Bihar
Not Available	Haryana
Not Available	Assam
Not Available	Tamil Nadu
Not Available	Arunachal Pradesh
Not Available	Himachal Pradesh
Not Available	Jammu and Kashmir
Not Available	Punjab
Not Available	Jharkhand
Not Available	Meghalaya
Not Available	Nagaland
Not Available	Odisha
Not Available	Sikkim
Not Available	Manipur
Not Available	Uttarakhand
Not Available	Mizoram
Not Available	Rajasthan
Not Available	Tripura

3. IDEA OF PROPOSED TARIFF FOR MAHARASHTRA'S LT CLIENTS

To avoid placing an undue financial burden on utilities, this proposal proposes the idea of real-time pricing for LT consumers. This will help people to become more conscious of the value of energy conservation, which in turn will help them to save money on their power bills. Therefore, the utility may earn more money during the high spike hours, while the customer might get savings by decreasing energy consumption during no spick’s hours. The proposed tariff structure includes estimates, but the final numbers may be different. To make an informed choice, one must have data on the various cost factors that go into setting the electricity rate. Generation costs, transmission costs, capital costs, depreciation, ongoing costs, unit consumption by all linked customers, cross-subsidy, loan kinds, land rent, and other expenses are only some of the many variables to consider. The utility companies will not provide such cost information. No one has the authority to set that data. Only the Maharashtra Electricity Regulatory Commission (MERC), and the Central Electricity Regulatory Commission (CERC), decide the price structure. Since Maharashtra State Electricity Distribution Company Limited (MSEDCL) is one of the largest energy distribution firms in Maharashtra, its price structure serves as a benchmark for this research. The recommended plan is made for the same firm. There are currently three LT client tariffs available from this service provider. Below poverty line (BPL) clients are designated as LT-I(A), low tension clients as LT-I(B), and non-residential clients as LT-II.

The proposed proposal is based on the assumption that the firm will use the additional income generated during peak hours to compensate customers who consume energy outside of those times. New tariff models are created by combining the residential tariff, the non-residential tariff, the net-metering system, and the Kerala state tariff [10]–[26]. Existing MSEDCL slab-wise structure, LT-II non-residential consumers' ToD pricing, and net metering are all brought together in the proposed tariff model I. This model was built by considering both non-PV, and PV rooftop plant clients, and the paper [11] presents the extensive analysis, assumptions, research, and simulation outcomes for the same. Model II is an expansion of model I that combines the current slab-wise structure of MSEDCL with the ToD tariff of LT consumers of KSEB, and net metering. Belge and Bodkhe [12] explains the background, assumptions, research, and simulation findings in greater depth for model II. Model III is a refinement of model II that is based only on the ToD pricing structure by the KSEB is discussed in detail in this paper. Model III, like model I and II, is a planned tariff designed to serve both types of residential clients i.e., with and without PV rooftop plants. The schedule for the ToD, however, is lifted straight from KSEB. Model III, a non-slab structure with time of day (ToD) assumes the following (Ref: KSEB, India):

- BPL customers will continue to use the same tariff plan (LT-I(A)) as before. The below-described framework is intended exclusively for LT-I(B) users.
- Every LT-I(B) class home will have a ToD meter fitted.
- ToD meters, and Net meters must be put at all locations where solar panels are placed.

3.1. Model III without PV rooftop plant

Assumption: If the number of units consumed by a residential consumer in a month is greater than some specific numbers of units; for example, 'M' units, then the ToD tariff will be applied, otherwise the existing slab-wise tariff of MSEDCL will be applicable where, $M =$ minimum no. of units consumed/month (For reference, value of M specified by KSEB is 500 units).

The ToD meter will give monthly information about the number of units consumed during the off-load period (OLP), peak load period (PLP), and base load period (BSP). Also, for each month, the ToD meter will provide the total number of OLP, PLP, and BSP units used. i.e., U_3, V_3, W_3 and T_3 as per Table 3. When determining the amount due at the end of the month, KSEB will use ToD intervals for billing its residential customers. The reference ToD Intervals are as follows:

- Off load period = OLP= (6:00 am – 6:00 pm) = 12 Hrs.
- Peak load period = PLP = (6:00 pm – 10:00 pm) = 4 Hrs.
- Base load period = BSP = (10:00 pm – 6:00 am) = 8 Hrs.

Off-peak and peak-load rebates and penalties can be used to encourage responsible use. In this model III, the electricity bill will be calculated for different ToD intervals considering the rebate and penalty imposed by the KSEB tariff for domestic consumers are shown in Table 4. Monthly consumption statistics for OLP, PLP, and BSP (U_3, V_3, and W_3) will be provided via the ToD meter. In Table 5, the author shows how to figure out monthly energy costs.

Table 3. Tariff structure for model III

OLP (12 hrs)	PLP (4 hrs)	BSP (8 hrs)	Total units
U_3	V_3	W_3	($U_3 + V_3 + W_3 = T_3$)

Table 4. ToD charges of Kerala state for non-residential clients

Period of Day	Time period	Energy Charge above base charge (₹ /kWh)	Tradeoff
OLP (12 Hrs.)	6:00 am – 6:00 pm	90 percent of the regime tariff	Rebate
PLP (4 Hrs.)	6:00 pm – 10:00 pm	120 percent of the regime tariff	Penalty
BSP (8 Hrs.)	10:00 pm – 6:00 am	100 percent of the regime tariff	Base rate

Source: KSEB.

Table 5. Bill calculation for proposed model III

Period	Calculations
Bill of OLP	$U_3 * 1.0 * R = A_3$
Bill of PLP	$V_3 * 1.2 * R = B_3$
Bill of BSP	$W_3 * 0.9 * R = C_3$
Total Energy charges = ₹. ($A_3 + B_3 + C_3$)	

3.2. Model III with rooftop plant

The model III with solar rooftop plant is based on the same assumptions that are used in model I and II in the paper [11], [12]. The ToD meter and Net meters will be installed at the consumer place and both meters will record data as mentioned below:

- ToD wise: import, export, bank, and units consumed every day.
- At the end of the month, they will provide ToD wise – bank, and units consumed for the whole month.
- Whichever ToD interval has "Units consumed" then billing will be done as per the slab-wise ToD tariff structure.

Billing will be done as per Tables 3, 4, and 5. If the unit exported is greater than the units imported, then the bank will generate ToD slots-wise. If the units imported will be greater than exported, then the actual units consumed will be recorded ToD slots-wise. Figure 1 presents an algorithm for the proposed tariff model III, used with, and without a rooftop. The MATLAB environment is used for simulation.

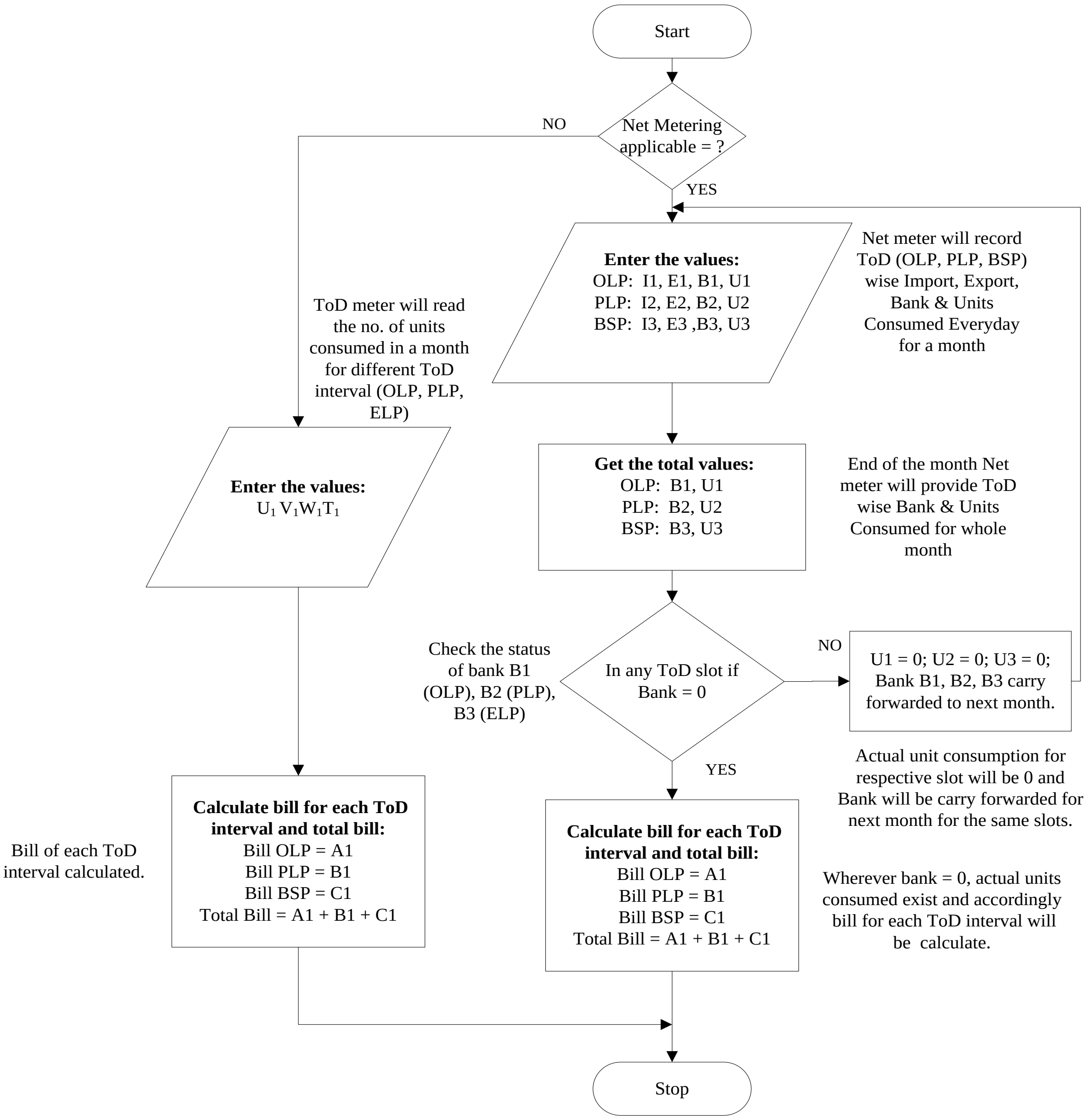
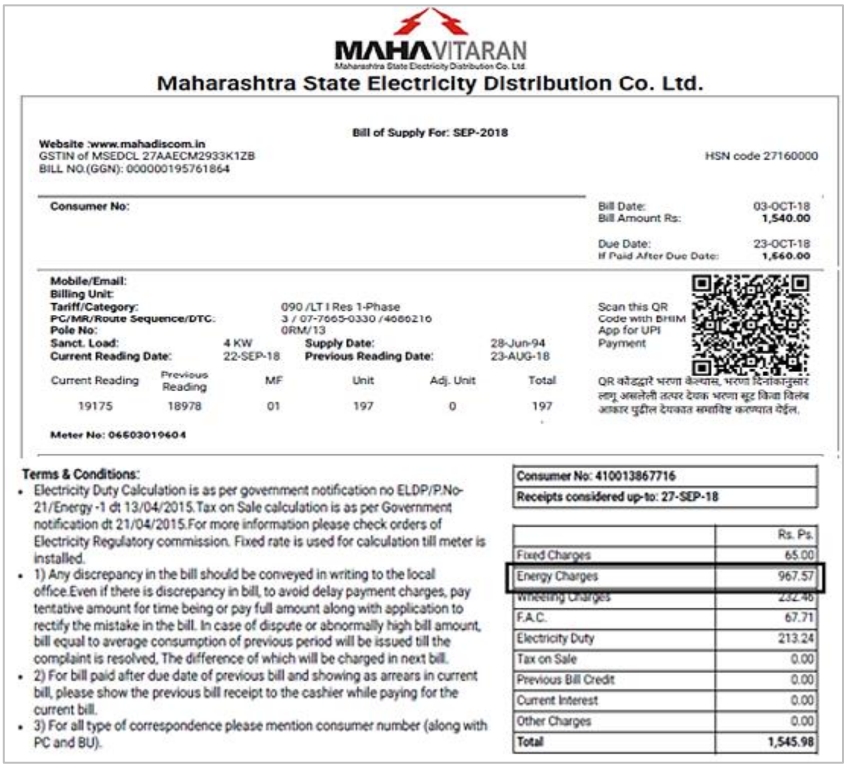


Figure 1. Flow chart for proposed electricity tariff model III

4. SAMPLE CLIENT CASE STUDY OF MAHARASHTRA STATE

The real load-feeding pattern of a residential client is analyzed, and the monthly energy charges are generated in accordance with the suggested tariff models I, II, and III, so that users may get a sense of how effective they are. The utility's monthly electricity bill is then compared to these energy costs. The electricity bill for this mentioned client, which is being supplied with power by MSEDCL, is displayed in Figure 2. Table 6 also shows the typical hourly daily consumption pattern of the load.

For the hourly feeding pattern shown in Table 6, the energy charges imposed by the power supply company are ₹ 967.57. The energy charges as per model I is ₹ 939.74 [11], and model II is ₹ 952.17 [12] whereas as per proposed model III, it is ₹ 1482.075 as shown in Table 7. The corresponding simulation results are given in Figures 3(a), 3(b), and Figure 4 respectively.


MAHAVITARAN
Maharashtra State Electricity Distribution Co. Ltd.
Maharashtra State Electricity Distribution Co. Ltd.

Bill of Supply For: SEP-2018

Website :www.mahadiscom.in
GSTIN of MSEDCL 27AAECM2933K1ZB
BILL NO.(GGN): 000000195761864
HSN code 27160000

Consumer No:

Bill Date: 03-OCT-18
Bill Amount Rs: 1,540.00
Due Date: 23-OCT-18
If Paid After Due Date: 1,560.00

Mobile/Email:
Billing Unit:
Tariff/Category: 090 /LT I Res 1-Phase
PC/MR/Route Sequence/DTC: 3 / 07-7665-0330 /4686216
Pole No: 0RM/13
Sanct. Load: 4 KW
Supply Date: 28-Jun-94
Current Reading Date: 22-SEP-18
Previous Reading Date: 23-AUG-18

Scan this QR Code with BHIM App for UPI Payment

Current Reading	Previous Reading	MF	Unit	Adj. Unit	Total
19175	18978	01	197	0	197

QR कोडद्वारे भरणा केल्यास, भरणा दिनांकानुसार लागू असलेली तत्पर देयक भरणा सूट किंवा विलंब आकार पुढील देयकात समाविष्ट करण्यात येईल.

Meter No: 06503019604

Terms & Conditions:
- Electricity Duty Calculation is as per government notification no ELDP/P.No-21/Energy -1 dt 13/04/2015.Tax on Sale calculation is as per Government notification dt 21/04/2015.For more information please check orders of Electricity Regulatory commission. Fixed rate is used for calculation till meter is installed.
- 1) Any discrepancy in the bill should be conveyed in writing to the local office.Even if there is discrepancy in bill, to avoid delay payment charges, pay tentative amount for time being or pay full amount along with application to rectify the mistake in the bill. In case of dispute or abnormally high bill amount, bill equal to average consumption of previous period will be issued till the complaint is resolved, The difference of which will be charged in next bill.
- 2) For bill paid after due date of previous bill and showing as arrears in current bill, please show the previous bill receipt to the cashier while paying for the current bill.
- 3) For all type of correspondence please mention consumer number (along with PC and BU).

Consumer No: 410013867716
Receipts considered up-to: 27-SEP-18

	Rs. Ps.
Fixed Charges	65.00
Energy Charges	967.57
Wheeling Charges	232.46
F.A.C.	67.71
Electricity Duty	213.24
Tax on Sale	0.00
Previous Bill Credit	0.00
Current Interest	0.00
Other Charges	0.00
Total	1,545.98

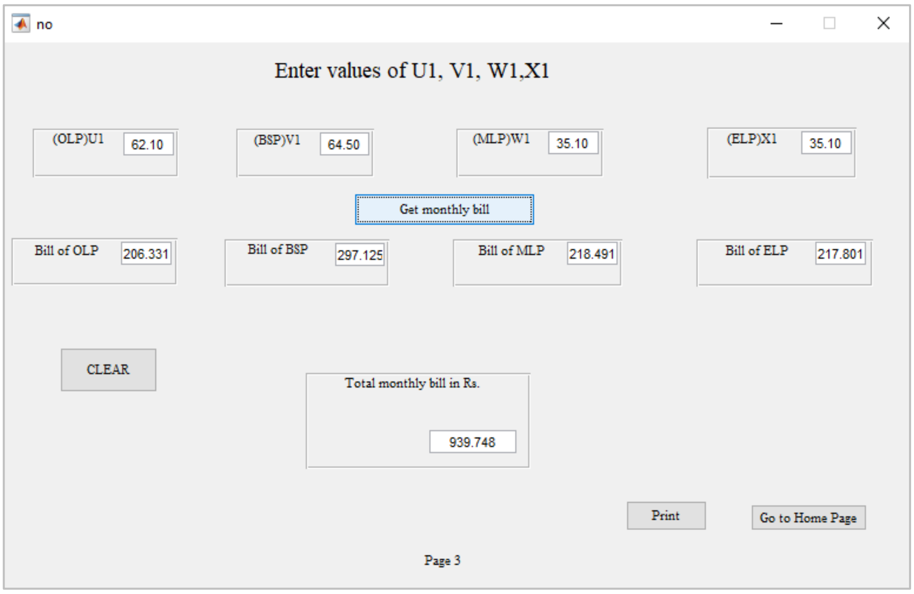
Figure 2. Sample client’s energy bill

Table 6. Hourly load feeding for identified client

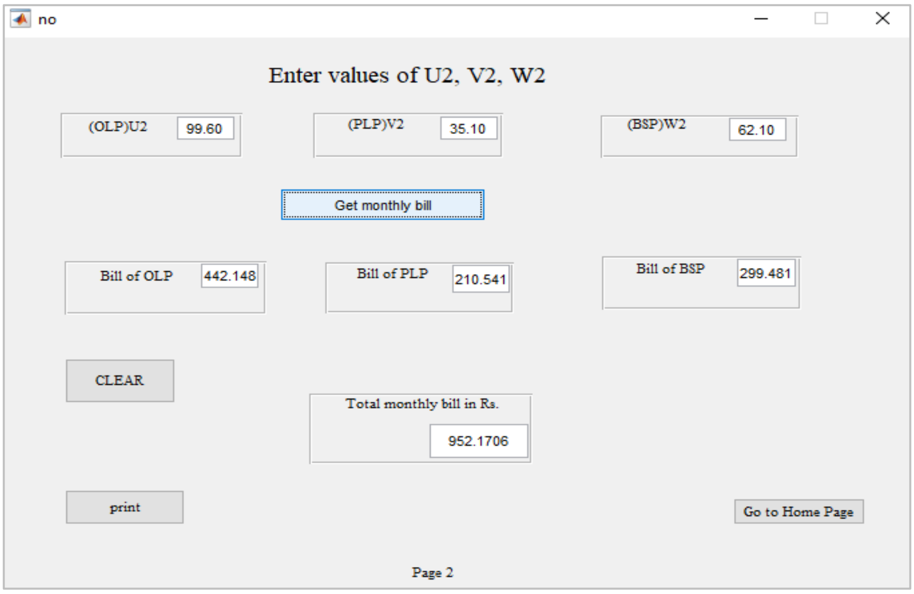
Rooms	Rating of household appliances in watts	Quantity	12 am – 1 am	1 am – 2 am	2 am – 3 am	3 am – 4 am	4 am – 5 am	5 am – 6 am	6 am – 7 am	7 am – 8 am	8 am – 9 am	9 am – 10 am	10 am – 11 am	11 am – 12 pm	12 pm – 1 pm	1 pm – 2 pm	2 pm – 3 pm	3 pm – 4 pm	4 pm – 5 pm	5 pm – 6 pm	6 pm – 7 pm	7 pm – 8 pm	8 pm – 9 pm	9 pm – 10 pm	10 pm – 11 pm	11 pm – 12 am
Bedroom-1	LED light (15)	2	■					■	■	■														■	■	■
	Fan (80)	1	■	■	■			■	■	■														■	■	■
Bedroom-2	LED light (15)	2					■	■	■																	
	Fan (80 W)	1					■	■	■																	
Hall	LED light (15)	6								■	■											■	■	■	■	■
	Fan (80)	2								■	■					■	■	■				■	■	■	■	■
	LED TV (80)	1														■	■	■				■	■	■	■	■
Kitchen	LED light (25)	1							■	■										■	■					
	Fan (80)	1									■								■							
	Exhaust fan (35)	1								■										■						
	Refrigerator (55)	1	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Oven (2450)	1																							■	
	Mixer (600)	1																		■						
Miscellaneous	Washing machine (500)	1									■															
	Geyser (3000)	1								■																
	Water pump (746)	1																							■	
Washroom	Bathroom LED (9)	1					■																			
	Exhaust fan (15)	1					■																			
	Bathroom LED (9)	1																						■		
	Exhaust fan (15)	1																						■		

Table 7. Sample clint energy charges with model III

	Proposed model III		
ToD periods	Energy feeding in a day	Energy feeding in a month	Energy cost in ₹
Off load period	3.32	99.60	747.0
Peak load period	1.17	35.10	315.9
Base load period	2.07	62.10	419.175
Total consumption		196.80	1482.075



(a)



(b)

Figure 3. Model I and II without net metering: (a) model I [11] and (b) model II [12]

Billing calculation for model III in Table 5:

$$Billof\ OLP = \{[(U_3 * 1.0 * ₹R)]\} = A_3 \quad (1)$$

99.60 units consumed during off off-load period, and the regime tariff as per KSEB is ₹7.5 [26]. Therefore, $Billof\ OLP = \{[(99.6 * 1 * ₹7.5)]\} = A_3$. Hence, the bill for OLP is ₹ 747.0.

$$Billof\ PLP = \{[(V_3 * 1.2 * ₹\,R)]\} = B_3 \quad (2)$$

35.10 units consumed during the peak load period, and the regime tariff as per KSEB is ₹7.5 [26]. Therefore, $Bill\ of\ PLP = \{[(35.10 * 1.2 * ₹\,7.5)]\} = B_3$. Hence, the bill for PLP is ₹ 315.9. Similarly, for BSP:

$$Billof\ BSP = \{[(W_3 * 0.9 * ₹\,R)]\} = C_3 \quad (3)$$

62.10 units consumed during the peak load period, and the regime tariff as per KSEB is ₹7.5 [26]. Therefore, $Bill\ of\ BSP = \{[(62.10 * 0.9 * ₹\,7.5)]\}$. Hence, the bill for BSP is ₹ 419.175. Hence, (1), (2), and (3) electricity bill with respect to the proposed electricity tariff model III is ₹ 1482.075 for the same energy consumption of 196.80 units.

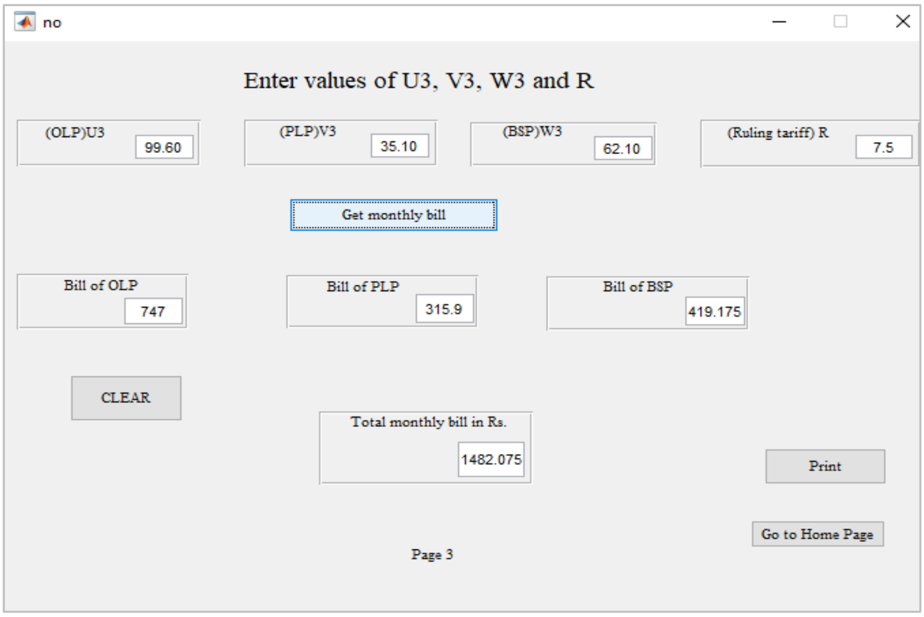


Figure 4. Output of model III without net metering

5. RESULT AND DISCUSSION

An MSEDCL sample client with a monthly usage of 197 units would see a decrease in energy charges of ₹ 27.82 i.e., ₹ 28 under the proposed tariff model I, and a decrease of ₹ 15.39 i.e., ₹ 15 under the proposed tariff model II. Whereas, in proposed tariff model III the rates of energy charges are drastically increased by ₹ 542. This shows that out of model I, II, and III, model I is the most beneficial model. The findings are highly encouraging, and they may persuade clients to consider adopting the proposed models. Table 8 shows the results.

Table 8. Energy charges of sample client with proposed models I, II, and III

Tariff model	Units consumed	Bill in ₹	Observation
Existing MSEDCL tariff	197	967.57	-
Proposed tariff model I	197	939.74	Energy charges are lower by ₹ 28
Proposed tariff model II	197	952.17	Energy charges are lower by ₹ 15
Proposed tariff model III	197	1482.075	Energy charges higher by ₹ 542

6. CONCLUSION

The comparison of three different designed models of energy tariffs for Maharashtra's residential customers is presented in this article, and the third model is discussed in detail. These models were designed to show how the three different forms (ToD, slab-wise, and net metering) can be coupled to increase the financial gain of residential consumers. Energy expenses for a real-world case study of a residential client are calculated using the proposed electricity tariff models, and compared to the energy statement supplied by the utility to verify the models' usefulness. It has been found that the client's electricity cost can be lowered while maintaining the same level of energy usage by strategic rescheduling of the electric load. Model I saves marginally more on electricity costs than model II. But in model III energy charges increase drastically with respect to model I, and II. So only a time-of-day tariff will not work to optimize the electricity bill, but a combinational tariff will give the best optimization in the bill. The suggested tariff structures incentivize clients to conserve energy during peak loads, and to install, and use solar energy through net metering. The current slab-wise tariff system is expanded by the ToD tariff. The current LT-I (A) pricing structure is meant to be preserved so as not to jeopardize the national goal of supplying cheap power to BPL subscribers. However, it is proposed to modify the LT-I (B) price structure in order to incentivize users with middle-class incomes to reduce their electricity consumption during peak load hours by, among other things, just powering on absolutely necessary loads. Obviously, utilities would benefit from such a strategy, and environmental protection would be a side effect.

In the above scenario, it is observed that model I gives the optimized results, which are based on the mixture of MSEDCL's current slab-wise tariff structure of residential Clients, and the ToD structure of non-residential clients. The future scope could be combining model I with a non-slab structure with the ToD of Sacramento Municipal Utility, and Arizona Public Service.

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